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System and method for navigation support for a motorized mobile system

Abstract

A system and method for providing precise navigation for a motorized mobile system (MMS) in data deprived environments, the system comprising at least one camera that is operably configured to generate one or more of an image of objects in a field-of-view of the sensors, wherein the object is identified and used to enhance navigation or operation of the MMS.

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Background/Summary

RELATED APPLICATIONS (1) This application is related to and claims priority under 35 U.S.C. § 119(e) to U.S. Nonprovisional Application No. 63/344,997 filed May 23, 2022, titled "System and Method for Navigation Support for a Motorized Mobile System," and is a continuation-in-part of U.S. Nonprovisional application Ser. No. 18/106,439, entitled "Systems and Methods for Tagging Accessibility Features With a Motorized Mobile System," filed Feb. 6, 2023, which is a continuation of U.S. Nonprovisional application Ser. No. 16/877,460, entitled "Systems and Methods For Crowd Navigation In Support of Collision Avoidance For a Motorized Mobile System" filed May 18, 2020, now U.S. Pat. No. 11,604,471, which is a continuation of U.S. Nonprovisional application Ser. No. 15/880,699, entitled "System and Methods for Sensor Integration in Support of Situational Awareness for a Motorized Mobile System," filed Jan. 26, 2018, now U.S. Pat. No. 10,656,652, which claims benefit of priority under 35 U.S.C. § 119 (e) from U.S. Provisional Application No. 62/612,617 filed Dec. 31, 2017 and to U.S. Provisional Application No. 62/543,896 filed Aug. 10, 2017, all of which are hereby incorporated by reference in their entirety for all purposes. (2) The present application is related to U.S. Nonprovisional application Ser. No. 15/880,663, entitled "Secure Systems Architecture for Integrated Motorized Mobile Systems," filed Jan. 26, 2018, now U.S. Pat. No. 11,075,910, to U.S. Nonprovisional application Ser. No. 15/880,686, entitled "Federated Sensor Array for Use with a Motorized Mobile System and Method of Use," filed Jan. 26, 2018, now U.S. Pat. No. 11,154,442, to U.S. Nonprovisional application Ser. No. 16/101,152, entitled "Systems and Methods for Enhanced

Autonomous Operations of a Motorized Mobile System," filed Aug. 10, 2018, now U.S. Pat. No. 11,334,070, and to U.S. Nonprovisional application Ser. No. 16/858,704, entitled "Systems and Methods To Upgrade a Motorized Mobile Chair To a Smart Motorized Mobile Chair" filed Apr. 26, 2020, all of which are incorporated herein by reference in their entirety.

(1) TABLE-US-00001 INVENTORS Jered H. Dean US Citizen US Resident Arvada, CO Barry G. Dean US Citizen US Resident Franklin, TN Dan A. Preston US Citizen US Resident Bainbridge Island, WA Christian Prather US Citizen US Resident Golden CO Alexandra Ernst US Citizen US Resident Lakewood CO Rupak Dasgupta IN Citizen US Resident Golden CO Alien

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FIELD

(3) This disclosure relates generally to control systems and sensor systems for motorized mobile systems.

BACKGROUND

(4) Drive-by-wire (DbW), steer-by-wire, or x-by-wire technology is the use of electrical or electro-mechanical systems for performing vehicle functions traditionally achieved by mechanical linkages. This technology replaces the traditional mechanical control systems with electronic control systems using electromechanical actuators and human-machine interfaces. The technology is similar to the fly-by-wire systems used in the aviation industry. Use of these "by-wire" systems began with manned aircraft, migrated to drones, as well as marine and rail operations, and are now being used in autonomous or self-driving vehicle applications. These once expensive technologies are emerging in the market as commodity products, including products with sensors, processors, integrated mobile devices, and various communication mediums, including bandwidth increases for soon to be 5.sup.th generation (5G) wireless devices on 5G networks.

(5) This application and co-pending applications will create and achieve safe, secure independence and a richer experience for all motorized mobile system (MMS) users. As an example of the need for improved MMSs, consider that today, with the advances in robotics and systems of systems integration, as well as medical advances that allow device integration with the human nervous system, there is a widening split between MMS users with varying physiological functionality. Some mobile chair users may have significant remaining upper body mobility and cognitive function. An example of this would be a person who does not have the use of their legs and who uses a manual mobile chair for mobility, but is otherwise able to navigate day-to-day life with minimal to no assistance. Such an individual may be able to adapt to an artificial limb, such as a leg, or an exoskeleton and reasonably be able to go about their day to day life with few restrictions. However, another example would be a user with certain health issues that greatly impacts the user's mobility and/or cognition. It is unlikely that these users will benefit from the same artificial leg or exoskeleton technologies due to their physiological condition. These users may use a motorized mobile system, such as a mobile chair.

(6) Many mobile chair users report they are frequently frustrated by the general public's poor understanding of their abilities and needs. In general, the mobile chair is an extension of a user's body. People who use them have different disabilities and varying abilities. Some can use their arms and hands, while others can get out of their mobile chairs and walk for short distances. "Disability" is a general, medical term used for a functional limitation that interferes with a person's ability to walk, hear, learn, or utilize other physiological and/or cognitive functions of the body.

(7) Conditions like cerebral palsy can be a sub-set of either physiological or cognitive disabilities since there are a number of sub-types classified based on specific ailments they present, resulting in varying degrees of ability. For example, those with stiff muscles have what is medically defined as spastic cerebral palsy, those with poor coordination have ataxic cerebral palsy, and those with writhing movements have athetoid cerebral palsy, each type requiring individual mobility plans.
(8) Following are a few definitions used in this disclosure.
(9) People with disabilities: This term represents a universe of potential conditions, including physical, cognitive, and/or sensory conditions.
(10) Mobility disability: This term represents a condition for a person who uses a mobile chair or other MMS to assist in mobility.
(11) User: This term refers to an individual who uses an MMS. A “user” of a mobile chair is referred to herein as a “mobile chair user”.
(12) Operator: This term refers to an individual who operates an MMS, including manual, local, and remote operation.
(13) Caregiver: This term represents any individual that assists an MMS user. Family, friends, aides, and nurses may all be included in this category. The term “Attendant” is used synonymously with the term caregiver.
(14) Technician: This term includes one or more of those individuals who setup, service, modify, or otherwise work technically on an MMS. These individuals may be formally licensed or may include operators and caregivers who are comfortable working with the system.
(15) A mobile chair is essentially a chair with wheels used when walking is difficult or impossible due to illness, injury, or disability. Mobile chairs come in a wide variety to meet the specific needs of their users, including: Manual self-propelled mobile chairs. Manual attendant-propelled mobile chairs. Powered mobile chairs (power-chairs). Mobility scooters. Single-arm drive mobile chairs. Reclining mobile chairs. Standing mobile chairs. Combinations of the above.
(16) Mobile Chairs include specialized seating adaptions and/or individualized controls and may be specific to particular activities. The most widely recognized distinction in mobile chairs is powered and unpowered. Unpowered mobile chairs are propelled manually by the user or attendant while powered mobile chairs are propelled using electric motors.
(17) Motorized mobile chairs are useful for those unable to propel a manual mobile chair or who may need to use a mobile chair for distances or over terrain which would be fatiguing or impossible in a manual mobile chair. They may also be used not just by people with ‘traditional’ mobility impairments, but also by people with cardiovascular and fatigue-based conditions. A Motorized Mobile System (MMS) is a non-automobile motorized device which provides powered mobility to one or more users, including such systems as powered mobile chairs, mobility scooters, electronic conveyance vehicles, riding lawn mowers, grocery carts, all-terrain vehicles (ATVs), golf carts, and other recreational and/or medical mobility systems, but excludes automobiles (passenger cars, trucks, passenger buses, and other passenger or property transporting motorized vehicles intended for licensed operation on state and national highways). For the sake of clarity, a mobile chair MMS is described herein as an exemplary embodiment; however, it should be clear that the same or similar systems and methods may be applied to other MMS embodiments.
(18) A mobile chair MMS is generally four-wheeled or six-wheeled and non-folding. Four general styles of mobile chair MMS drive systems exist: front, center, rear, and all-wheel drive. Powered wheels are typically somewhat larger than the trailing/castering wheels, while castering wheels on a motorized chair are typically larger than the casters on a manual chair. Center wheel drive mobile chair MMSs have casters at both front and rear for a six-wheel layout and are often favored for their tight turning radii. Front wheel drive mobile chair MMSs are often used because of their superior curb-climbing capabilities. Power-chair chassis may also mount a specific curb-climber, a powered device to lift the front wheels over a curb of 10 cm or less.
(19) Mobile chair MMSs are most commonly controlled by arm-rest mounted joysticks which may

have additional controls to allow the user to tailor sensitivity or access multiple control modes, including modes for the seating system. For users who are unable to use a hand controller, various alternatives are available, such as sip-and-puff controllers, worked by blowing into a sensor. In some cases, a controller may be mounted for use by an aide walking behind the chair rather than by the user. Capabilities include turning one drive-wheel forward while the other goes backward, thus turning the mobile chair within its own length.

(20) The seating system on a mobile chair MMS can vary in design, including a basic sling seat and backrest, optional padding, comfortable cushions, backrest options, and headrests. Many companies produce aftermarket seat, back, leg, and head rest options which can be fitted onto mobile chair MMSs. Some seat, back, leg, and head rests are produced to aid with increased need for stability in the trunk or for those at increased risk of pressure sores from sitting. Leg rests may be integrated into the seating design and may include manual and/or powered adjustment for those users who want or need to vary their leg position. Mobile chair MMSs may also have a tilt-in-space, or reclining facility, which is particularly useful for users who are unable to maintain an upright seating position indefinitely. This function can also help with comfort by shifting pressure to different areas over time, or with positioning in a mobile chair when a user needs to get out of the chair or be hoisted.

(21) Most mobile chairs are crash tested to ISO standards 7176 and 10542. These standards mean that a mobile chair can be used facing forward in a vehicle if the vehicle has been fitted with an approved tie down or docking system for securing the mobile chair and a method of securing the occupant to the mobile chair.

(22) Rehabilitation engineering is the systematic application of engineering sciences to design, develop, adapt, test, evaluate, apply, and distribute technological solutions to problems confronted by individuals with disabilities. Current practitioners of rehabilitation engineering are often forced to work with limited information and make long term decisions about the technologies to be used by an individual on the basis of a single evaluation; a snapshot in time. Under current best-case conditions, rehabilitation engineering practitioners work closely in a long-term relationship with their clients to follow-up and readjust assistive technology systems on a regular basis. However, even in these situations, they are often working with limited information and only at periodic intervals.

(23) What is needed is an evolution of existing motorized mobile systems (MMSs) to consider the users' abilities, needs, and health, with the goal of a safe, secure, and social independence. To accomplish this, systems and methods are disclosed herein comprising: integrated software and hardware systems, sensors for situational awareness, sensors for user monitoring, communications between users and caregivers, users and other users, and users and the “cloud”, and human machine interfaces (HMIs) designed for users with a variety of physiological and cognitive conditions. The systems and methods disclosed herein are based on new underlying technologies, architectures, and network topologies that support the evolution of the MMS.

SUMMARY

(24) The application entitled “Secure Systems Architecture for Motorized Mobile Systems,” relates to systems and methods for implementing a control system onboard an MMS capable of securely communicating with and utilizing external systems. This may include integrating external devices and user health monitoring sensors with an off the shelf (OTS) or custom MMS. Integration of a smart device, such as a smart phone or tablet, with an OTS or custom MMS is another example. Today, most smart devices contain a host of applications and sensors, including one or more of image capturing devices, rate and acceleration sensors, gyroscopes, global positioning system (GPS) receivers, biometric sensors, iris scanners, fingerprint scanners, and facial recognition software. Other sensors are possible. A secure architecture for an MMS controller is disclosed in support of device integration and data security with a focus on extensibility.

(25) The application entitled “Federated Sensor Array for Use with a Motorized Mobile System and

Method of Use" discloses the integration of non-contact sensors and control logic into an MMS controller. The federated sensors have overlapping sensing fields, generally operate independently, and report certain data relevant to navigation and stability which is then used by the MMS controller. Motor, seat, and auxiliary controllers may be hosted in the MMS controller along with the federated sensor logic. The integration of these systems and applications into an MMS lays the foundation for situational awareness (SA).

(26) Situational awareness is the ability to be cognizant of oneself in a given space. It is an organized knowledge of objects and state kinematics in relation to oneself in a given space or scenario. Situational awareness also involves understanding the relationship of these objects when there is a change of position or kinematic state. The goal is to integrate this data into the MMS and use it to support a richer, safer, and more independent experience for the user.

(27) The application entitled "System and Methods for Sensor Integration in Support of Situational Awareness for a Motorized Mobile System" further discloses the integration of new sensor technologies in support of a deeper and richer situational awareness for the user. These new systems use the data generated about the user, the environment, targets in the environment, and the user's relationship to them. This information may be generated from one or more sources and include data from non-contact sensors, like radar, optical, laser, and ultrasonic sensors. These non-contact sensors can generate data about the environment, including range measurements, bearing measurements, target classification, and target kinematics. The new sensors provide a much richer set of data about the environment.

(28) The federated system uses a single type of sensor that generates a single report (i.e. a communication with or identifying data sensed by the sensor) with what is called a single mode variance, where each sensor has distinct capabilities and one or more fixed errors inherent to the sensor. Ultra-sonic sensors have better range determination than cross range position determination, for instance. In an example, using data from a different type of sensor, a good cross range report can be generated, but with poor down range determination. In this evolving system, the best of two (or more) separate reports may be combined. This is referred to as a dual mode variance.

(29) The application entitled "System and Methods for Enhanced Autonomous Operations of a Motorized Mobile System" discloses the implementation of advanced filtering techniques and sensor fusion in support of situational awareness and autonomy. Adding more sensors to a federation of sensors increases expense, weight, and power consumption. Integration and use of sensor fusion (e.g., using different types of sensors in one system) and advanced filtering techniques improves the information the MMS controller uses to track the user and environment, while reducing complexity and cost when compared to a federated approach. Decision logic consisting of data association techniques, track and target management, handling out of sequence measurements, and sensor frame management are all building blocks for this leap in system capability.

(30) In this enhanced system, raw data is received and "filtered", or as is known in the art fused, with other data related to the MMS user and their activities while navigating in the environment. The other data may include certain biometric data, user inputs, and user activities. Filtering and state estimation are some of the most pervasive tools of engineering. In some embodiments, a model may be used to form a prediction of a state into the future, followed by an observation of the state or actual measurement of the expectation. A comparison of the predicted state and the measured state is then made. If the observations made are within the predicted measurements, the model may be adjusted by reducing the covariance of the next measurement, thereby increasing system confidence. If the observations are outside of the predicted measurements, the model may be adjusted to increase the covariance of the next measurement, thereby decreasing system confidence.

(31) In this enhanced system, the MMS is fully aware of its environment and can travel safely wherever the user wishes to go, within reason. Moreover, the MMS may learn to anticipate the

needs of the user. The result is a user experience that is safe, secure, and independent, based on the user's base abilities and current condition.

(32) Other systems may be integrated to improve user experience. As a non-limiting example, augmented reality (AR) may be included. Augmented reality is a live direct or indirect view of a physical, real-world environment where the elements are augmented (or supplemented) by computer-generated sensory input. The input can be sound, smell, or graphics. It is related to a more general concept called computer-mediated reality, in which a view of reality is modified, possibly even diminished rather than augmented, by a computer. As a result, the technology functions by enhancing one's current perception of reality. Virtual Reality (VR) is another technology that may be integrated to improve user experience. By contrast, VR replaces the real world with a simulated one. Augmentation is conventionally in real time and in semantic context with environmental elements, such as sports scores on TV during a match. However, VR refers to computer technologies that use VR headsets, sometimes in combination with physical spaces or multi-projected environments, to generate realistic images, sounds, and other sensations that simulate a user's physical presence in a virtual or imaginary environment.

(33) In one aspect, a motorized mobile system (MMS) comprises a first sensor, a second sensor, and a processor. The first sensor generates first sensor data about an object, the first sensor data about the object comprising a first range measurement to the object and a first bearing measurement to the object, the first range measurement having an associated first uncertainty, and the first bearing measurement having an associated second uncertainty. The second sensor generates second sensor data about the object, the second sensor data about the object comprising a second range measurement to the object and a second bearing measurement to the object, the second range measurement having an associated third uncertainty, and the second bearing measurement having an associated fourth uncertainty. The processor receives the first sensor data about the object, receives the second sensor data about the object, selects a lower range uncertainty between the first uncertainty and the third uncertainty, selects a lower bearing uncertainty between the second uncertainty and the fourth uncertainty, and combines the bearing measurement associated with the selected lower bearing uncertainty and the range measurement associated with the selected lower range uncertainty as a location of the object within a reduced area of uncertainty.

(34) In another aspect, a motorized mobile system (MMS) comprises a first sensor, a second sensor, and a processor. The first sensor generates first sensor data about an object, the object located proximate to the motorized mobile system, wherein the first sensor data about the object comprises a first range measurement to the object and a first bearing measurement to the object, the first range measurement has an associated first uncertainty, and the first bearing measurement has an associated second uncertainty. The second sensor generates second sensor data about the object, the object located proximate to the motorized mobile system, wherein the second sensor data about the object comprises a second range measurement to the object and a second bearing measurement to the object, the second range measurement has an associated third uncertainty, and the second bearing measurement has an associated fourth uncertainty. The processor receives the first sensor data about the object, receives the second sensor data about the object, selects a lower range uncertainty between the first uncertainty and the third uncertainty, selects a lower bearing uncertainty between the second uncertainty and the fourth uncertainty, and combines the bearing measurement associated with the selected lower bearing uncertainty and the range measurement associated with the selected lower range uncertainty as a location of the object within a reduced area of uncertainty.

(35) In another aspect, a method for a motorized mobile system (MMS) comprises generating first sensor data about an object from a first sensor, wherein the first sensor data about the object comprises a first range measurement to the object and a first bearing measurement to the object, the first range measurement has an associated first uncertainty, and the first bearing measurement has an associated second uncertainty. The method further comprises generating second sensor data

about the object from a second sensor, wherein the second sensor data about the object comprises a second range measurement to the object and a second bearing measurement to the object, the second range measurement has an associated third uncertainty, and the second bearing measurement has an associated fourth uncertainty. A lower range uncertainty between the first uncertainty and the third uncertainty is selected by a processor. A lower bearing uncertainty between the second uncertainty and the fourth uncertainty is selected by the processor. The bearing measurement associated with the selected lower bearing uncertainty and the range measurement associated with the selected lower range uncertainty are combined by the processor as a location of the object within a reduced area of uncertainty.

(36) In another aspect, a method for a motorized mobile system (MMS) comprises generating first sensor data about an object from a first sensor, the object located proximate to the motorized mobile system, wherein the first sensor data about the object comprises a first range measurement to the object and a first bearing measurement to the object, the first range measurement has an associated first uncertainty, and the first bearing measurement has an associated second uncertainty. The method further comprises generating second sensor data about the object from a second sensor, the object located proximate to the motorized mobile system, wherein the second sensor data about the object comprises a second range measurement to the object and a second bearing measurement to the object, the second range measurement has an associated third uncertainty, and the second bearing measurement has an associated fourth uncertainty. A lower range uncertainty between the first uncertainty and the third uncertainty is selected by a processor. A lower bearing uncertainty between the second uncertainty and the fourth uncertainty is selected by the processor. The bearing measurement associated with the selected lower bearing uncertainty and the range measurement associated with the selected lower range uncertainty are combined by the processor as a location of the object within a reduced area of uncertainty.

(37) In another aspect, a motorized mobile system (MMS) comprises a camera sensor, operably configured to generate first data about a fiducial located proximate to the motorized mobile system and in a field of view of the first sensor. A processor receives the first generated data from the camera and identifies a fiducial identity in the first generated data, and changes one or more operating mode of the system in response to the fiducial identity.

(38) Applicant(s) herein expressly incorporate(s) by reference all of the following materials identified in each paragraph below. The incorporated materials are not necessarily "prior art". ISO/IEC 15408-1:2009, 3rd Edition: "Information technology—Security techniques—Evaluation criteria for IT security—Part 1: Introduction and general model". ISO/IEC 15408-2:2008, 3rd Edition: "Information technology—Security techniques—Evaluation criteria for IT security—Part 2: Security functional components". ISO/IEC 15408-3:2008, 3rd Edition: "Information technology—Security techniques—Evaluation criteria for IT security—Part 3: Security assurance components". 802.11-2016: "IEEE Standard for Information technology—Telecommunications and information exchange between systems Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications". 1609.0-2013: "IEEE Guide for Wireless Access in Vehicular Environments (WAVE)—Architecture". 1609.2-2016: "IEEE Standard for Wireless Access in Vehicular Environments—Security Services for Applications and Management Messages". 1609.4-2016: "IEEE Standard for Wireless Access in Vehicular Environments (WAVE)—Multi-Channel Operation". 1609.11-2010: "IEEE Standard for Wireless Access in Vehicular Environments (WAVE)—Over-the-Air Electronic Payment Data Exchange Protocol for Intelligent Transportation Systems (ITS)". 1609.12-2016: "IEEE Standard for Wireless Access in Vehicular Environments (WAVE)—Identifier Allocations". ETSI EN 302 663 (V1.2.1): "Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band." ETSI EN 302 571 (V1.2.1): "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band;

Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive”. ETSI TS 102 792 (V1.2.1): “Intelligent Transport Systems (ITS); Mitigation techniques to avoid interference between European CEN Dedicated Short Range Communication (CEN DSRC) equipment and Intelligent Transport Systems (ITS) operating in the 5 GHz frequency range”. IEEE 802-2014: “IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture”. ANSI/IEEE Std 802.2 (1998): “IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 2: Logical Link Control”. ISO/IEC 7498-1:1994: “Information technology—Open Systems Interconnection—Basic Reference Model: The Basic Model”. ITU-T Recommendation X.691 (2015): “Information technology—ASN.1 encoding rules: Specification of Packed Encoding Rules (PER)”. ETSI TS 102 687 (V1.1.1): “Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part”. IEEE 1003.1-2008: “IEEE Standard for Information Technology—Portable Operating System Interface (POSIX(R))”. IEEE 802.15.1-2005: “Wireless medium access control (MAC) and physical layer (PHY) specifications for wireless personal area networks (WPANs)”. IEEE 802.15.4-2015: “IEEE Standard for Low-Rate Wireless Networks”. ISO/IEC 18092:2013: “Information technology—Telecommunications and information exchange between systems—Near Field Communication—Interface and Protocol (NFCIP-1)”. IEEE 802.16-2012: “IEEE Standard for Air Interface for Broadband Wireless Access Systems”. ISO/IEEE 11073-20601-2014: “IEEE Health informatics—Personal health device communication—Part 20601: Application profile—Optimized Exchange Protocol”. Bluetooth SIG: “Bluetooth Core Specification”, v5.0.

(39) If it is believed that any of the above-incorporated material constitutes “essential material” within the meaning of 37 CFR 1.57(d)(1)-(3), applicant(s) reserve the right to amend the specification to expressly recite the essential material that is incorporated by reference as allowed by the applicable rules.

(40) Aspects and applications presented here are described below in the drawings and detailed description. Unless specifically noted, it is intended that the words and phrases in the specification and the claims be given their plain and ordinary meaning to those of ordinary skill in the applicable arts. The inventors are aware that they can be their own lexicographers if desired. The inventors expressly elect, as their own lexicographers, to use only the plain and ordinary meaning of terms in the specification and claims unless they clearly state otherwise and expressly set forth the “special” definition of that term. Absent such clear statements of intent to apply a “special” definition, it is the inventors' intent and desire that the plain and ordinary meaning to the terms be applied to the interpretation of the specification and claims.

(41) Further, the inventors are informed of the standards and application of the special provisions of 35 U.S.C. § 112(f). Thus, the use of the words “function,” “means” or “step” in the Detailed Description or Description of the Drawings or claims is not intended to somehow indicate a desire to invoke the special provisions of 35 U.S.C. § 112(f) to define the systems, methods, processes, and/or apparatuses disclosed herein. To the contrary, if the provisions of 35 U.S.C. § 112(f) are sought to be invoked to define the embodiments, the claims will specifically and expressly state the exact phrases “means for” or “step for” and will also recite the word “function” (i.e., will state “means for performing the function of . . . ”), without also reciting in such phrases any structure, material, or act in support of the function. Thus, even when the claims recite a “means for performing the function of . . . ” or “step for performing the function of . . . ”, if the claims also recite any structure, material, or acts in support of that means or step then it is the clear intention of the inventors not to invoke the provisions of 35 U.S.C. § 112(f). Moreover, even if the provisions of 35 U.S.C. § 112(f) are invoked to define the claimed embodiments, it is intended that the embodiments not be limited only to the specific structures, materials, or acts that are described in the preferred embodiments, but in addition, include any and all structures, materials, or acts that

perform the claimed function as described in alternative embodiments or forms, or that are well known present or later-developed equivalent structures, materials, or acts for performing the claimed function.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) A more complete understanding of the systems, methods, processes, and/or apparatuses disclosed herein may be derived by referring to the detailed description when considered in connection with the following illustrative figures. In the figures, like-reference numbers refer to like-elements or acts throughout the figures.
(2) FIG. **1** depicts a control system architecture with hardware and software components for an S-MMS.
(3) FIG. **2** depicts an embodiment of an S-MMS hardware architecture.
(4) FIG. **3** depicts an embodiment of a control system architecture for an S-MMS hosting an integrated situational awareness controller.
(5) FIG. **4** depicts an embodiment of a control system architecture for an S-MMS with a situational awareness controller.
(6) FIG. **5** depicts an embodiment of a situational awareness controller.
(7) FIG. **6** depicts an embodiment of a sensor system.
(8) FIG. **7** depicts an example embodiment of 360-degree situational awareness.
(9) FIG. **8** depicts reference frames of typical sensors.
(10) FIG. **9** depicts an S-MMS frame of reference.
(11) FIG. **10**A depicts a navigation frame of reference.
(12) FIG. **10**B depicts another view of the navigation frame of reference of FIG. **10**A.
(13) FIG. **10**C depicts an actual navigation frame of reference and a perceived navigation frame of reference.
(14) FIG. **11** depicts an embodiment of an actual navigation frame of reference that deviates from a perceived navigation frame of reference.
(15) FIG. **12** depicts two sensors operating with different fields of view.
(16) FIG. **13** depicts a standard conversion of error (variance).
(17) FIG. **14** depicts two S-MMS users approaching a blind intersection of two pathways.
(18) FIG. **15** depicts an embodiment of an S-MMS system securely connected to a remote server.
(19) FIG. **16**A depicts an embodiment of an S-MMS communicating with GPS satellites.
(20) FIG. **16**B depicts an embodiment of an S-MMS navigating an indoor environment based on one or more sensors without GPS information.
(21) FIG. **17** depicts one or more S-MMSs connected to a remote server.
(22) FIG. **18** depicts multiple S-MMS users combining map data.
(23) FIG. **19** depicts multiple users uploading accessibility information to a shared map repository.
(24) FIG. **20** depicts an embodiment wherein an S-MMS uses onboard sensors to sense and model an object.
(25) FIG. **21** depicts an S-MMS paired to an augmented reality (AR) device via a wireless link.
(26) FIG. **22** depicts a typical path and motions required to successfully park a mobile chair MMS inside an accessible van.
(27) FIG. **23** depicts use of targets to assist in S-MMS positioning.
(28) FIG. **24** depicts a common S-MMS transfer situation.
(29) FIG. **25** depicts an embodiment of approach mode on an S-MMS.
(30) FIG. **26**A depicts an exemplary placement of sensors to measure forces on an arm rest.
(31) FIG. **26**B depicts an exemplary placement of sensors to measure forces on a foot rest.

(32) FIG. **27**A depicts an embodiment of a self-retracting control unit when extended.
(33) FIG. **27**B depicts an embodiment of a self-retracting control unit when retracted.
(34) FIG. **28**A depicts an S-MMS traveling to its charging station.
(35) FIG. **28**B depicts an S-MMS returning to the user.
(36) FIG. **29** depicts an embodiment in which a wearable device with an embedded transceiver communicates with an S-MMS.
(37) FIG. **30** depicts an example of a service animal "nudging" an S-MMS and redirecting it.
(38) FIG. **31**A depicts an S-MMS orienting a user to face individuals with whom the user is engaged.
(39) FIG. **31**B depicts an S-MMS orienting a user to face individuals with whom the user is engaged.
(40) FIG. **32**A depicts an example of crowd interaction with an S-MMS sensor system.
(41) FIG. **32**B depicts an example of crowd interaction with an S-MMS sensor system.
(42) FIG. **33** depicts crowd navigation enhanced by integration of a navigation system.
(43) FIG. **34** depicts an embodiment of auto-queuing functionality.
(44) FIG. **35** depicts non-limiting examples of graphical tags or fiducials.
(45) FIG. **36** depicts a camera of an S-MMS where a fiducial is within the field-of-view of the camera.
(46) FIG. **37** depicts a feature extraction process.
(47) FIG. **38** depicts an S-MMS traveling towards an accessible van ramp.
(48) FIG. **39** depicts multiple fiducials installed on a ramp.
(49) FIG. **40** depicts a flow chart of a driver assist process.
(50) FIG. **41** depicts an embodiment of a human machine interface.
(51) FIG. **42** depicts a user interface for ramp assist on a paired mobile device.
(52) FIG. **43** depicts an S-MMS near a ramp, preparing to run approach.
(53) FIG. **44** depicts a logic diagram of an approach function.
(54) FIG. **45** depicts an example geometry for the approach process to calculate the distance to the goal.
(55) FIGS. **46**A-C depict three drive states of the approach function.
(56) FIG. **47** depicts an S-MMS ready to navigate a ramp, preparing to run adjust.
(57) FIG. **48** depicts a logic diagram depicting a ramp assist adjust function.
(58) FIG. **49** depicts a S-MMS approaching an accessible vehicle and traveling through positions A-C.
(59) FIG. **50** depicts an S-MMS automatically following a moving fiducial.
(60) FIG. **51** depicts fiducial-based localization allowing automated transit between defined waypoints.
(61) Elements and acts in the figures are illustrated for simplicity and have not necessarily been rendered according to any particular sequence or embodiment.

DETAILED DESCRIPTION

(62) In the following description, and for the purposes of explanation, numerous specific details, process durations, and/or specific formula values are set forth in order to provide a thorough understanding of the various aspects of exemplary embodiments. However, it will be understood by those skilled in the relevant arts that the apparatus, systems, and methods herein may be practiced without all of these specific details, process durations, and/or specific formula values. Other embodiments may be utilized and structural and functional changes may be made without departing from the scope of the apparatus, systems, and methods herein. It should be noted that there are different and alternative configurations, devices, and technologies to which the disclosed embodiments may be applied. The full scope of the embodiments is not limited to the examples that are described below.
(63) In the following examples of the illustrated embodiments, references are made to the

accompanying drawings which form a part hereof, and in which is shown by way of illustration various embodiments in which the systems, methods, processes, and/or apparatuses disclosed herein may be practiced. It is to be understood that other embodiments may be utilized and structural and functional changes may be made without departing from the scope.

(64) Systems and methods are disclosed for use of multiple sensors and their associated data on a smart motorized mobile system (S-MMS). Referring generally to FIGS. **1-34**, systems, methods, and apparatuses for providing safety and independence for S-MMS users are illustrated. The systems and methods disclosed support non-automobile motorized mobile systems, such as powered mobile chairs, mobility scooters, electronic conveyance vehicles, riding lawn mowers, grocery carts, ATVs, golf carts, off-road vehicles, and other recreational and/or medical mobility systems, but excludes automobiles. For the purposes of this disclosure, automobiles are defined as passenger cars, trucks, passenger buses, and other passenger or property transporting motorized vehicles intended for licensed operation on state and national highways. A non-limiting, illustrative example of a motorized mobile chair is used throughout the disclosure. In various embodiments, a placement or location of at least one sensor may be determined based at least in part upon unique S-MMS dynamic characteristics, user seating position, wheel or track location associated with the S-MMS, or other characteristics relevant to the disclosed systems and methods.

(65) Some embodiments of the systems disclosed may be referred to as separate generations based on level of capability. While these generations are discussed as separate embodiments, it should be clear that any one or more aspects of any one or more generations may be combined to form other systems not explicitly disclosed herein (or in the related co-pending applications). The generations are as follows: Generation 0 (Gen 0), Generation I (Gen I), Generation II (Gen II), and Generation III (Gen III).

(66) The motorized mobile systems in existence today may be referred to herein as Generation 0. Generation 0 is an MMS with a user interface and a control system. Generation 0 is hosted in a controller with a Human Machine Interface (HMI) typically consisting of a joystick, tactile surface array, sip and puff type array, or similar interface. The joystick receives input indicating “move forward”, the command is generated, and control instructions are sent to a motor controller, which responds with a preconfigured response. The control instructions may include a change in state or an adjustment of an operating parameter. The state of the art for a Generation 0 system is to provide extremely simple control instructions and open loop limits on the MMS. Open loop systems lack the ability for self-correcting actions. An example of an open loop limit currently in use on MMSs is to cut the maximum MMS speed to a predetermined set point if the user raises the seat position above a certain threshold. The motor controller responds directly to the user input regardless of the environment proximate to the MMS. A new user may have a learning curve to master before they can confidently maneuver close to people, objects, or in confined environments.

(67) A Smart Motorized Mobile System (S-MMS) of the present disclosure is an evolution of MMS technology, and includes embodiments of a new controller and control architecture, some of which include secure methods for collecting and transmitting data across one or more networks.

(68) The present application and one or more related applications disclose improved generations of S-MMS architectures, including Generations I-Ill architectures. Generation I is an embodiment for a group of sensors reporting to a controller for the S-MMS. Generation II embodiments further include consideration for scanning and/or image sensors operating in overlapping regions. Using a sensor with good down range error, and a second sensor with good cross range error, a Generation II system embodiment can coordinate reports in real-time, associate them, and take the best measurements in an ability to make the situational awareness picture more accurate. This use of more than one sensor is typically referred to as dual mode variance.

(69) Generation II S-MMSs may take advantage of their ability to exchange data with other like equipped systems about their environment. In addition to other like equipped systems, the S-MMS may be configured to receive data from traffic through Dedicated Short-Range Communications

(DSRC) across an IEEE 802.11P link. This data may help the user to better navigate next to a road way, or along paths that are shared by automobiles and other MMSs. For an S-MMS user, the ability to announce one's presence and the ability to control traffic could be lifesaving.
(70) Generation II systems are based on historical data or on observations of state at a finite time, in this case time T.sub.1. In one example, an event is measured at time T.sub.1, the event is processed at time T.sub.2, data for the processed event is transmitted at time T.sub.3, the data for the processed event is related to other data at time T.sub.4, and any other actions that need to be carried out are done at time T.sub.5. This can be done very quickly, e.g. from tenths of a second to even seconds. Regardless of delay, it is all historic.
(71) Generation III is an embodiment for a multi-generation controller architecture and logic. In some embodiments, a Generation III system may host one or more of the previous generations or combinations thereof. Generation III systems go beyond dual mode variance to true sensor fusion.
(72) The S-MMS controller may be one or more processors (hardware), application-specific integrated circuits, or field-programmable gate arrays that host the disclosed architecture. Control signals may be via wired or wireless communications, and comprised of digital and/or analog signals.
(73) Control System Embodiment
(74) FIG. **1** depicts an embodiment of an S-MMS **18** control system composed of hardware and software components. An S-MMS controller **110** lies between two secure abstraction layers **135** and **145**. Abstraction layers are used as a way of hiding the implementation details of a particular set of functionalities, allowing the separation of concerns to facilitate interoperability and platform independence. The upper abstraction layer **135** abstracts through an Application Programmers Interface (API) to a hosted application space **125** and a complex application space **130**. The API is a set of subroutine definitions, protocols, and tools for building applications. An API allows for communication between the various components. The complex application space **130** may include hosted control logic for an S-MMS **18**. Below the S-MMS controller **110** and its secure abstraction **145** is a breakout of the operating system **150**, one or more processors **160** (which are hardware), and a communications layer **170**, which may include a hardware communications interface. Memory **120**, which is hardware, cross cuts all of the layers in the depicted embodiment and may include volatile and non-volatile non-transitory computer storage media for storing information. The S-MMS controller **110** is software that executes on one or more processors **160** on the S-MMS **18** and is stored in memory **120**.
(75) With a focus now on the one or more hardware processors that the S-MMS controller **110** is executed on and interacts with, FIG. **2** depicts a hardware embodiment of an S-MMS **18**A architecture. The depicted electrical architecture comprises an S-MMS processor **202** between two security processors **204** and **212**, each of which is hardware. The S-MMS processor **202** may be paired with a lock-step processor (not depicted) for critical life, health, and safety applications, in some embodiments. The security processors **204** and **212** may host (i.e. execute) modules and other software, such as the previously disclosed secure abstraction APIs **135** and **145**. Additionally or alternatively, the security processors may host services, such as watch-dog and data source authentication services. The S-MMS controller **110**A is hosted on an S-MMS processor **202**. The processors may comprise one or more of a processor, multiple processors, an application-specific integrated circuit, or a field-programmable gate array.
(76) The S-MMS controller **110**A utilizes computer readable storage media **220**, which includes the memory **120**, for data storage and retrieval during operation. Executable program instructions for the S-MMS controller **210**D also may be stored in the memory **120**. The memory **120** is one or more of a volatile and non-volatile non-transitory computer storage medium for storing information and may be located onboard the S-MMS **18**A, may be remote storage available on a smart device or server, or some combination of the foregoing. One or more secure, encrypted memory partitions are used to store electronic protected health information (ePHI) and other secure health data. The

data stored on the secure memory is only made available to one or more pre-authorized systems, wherein the pre-authorized system comprises a device or service associated with an individual user. This may include a mobile motorized system, a smart device, a computer, a data terminal, or a device or service associated with an approved third party.

(77) The S-MMS **18**A hardware system may comprise multiple additional processors beyond the core S-MMS processor **202**. In the case of a power wheelchair S-MMS, these additional hardware processors may include one or more caregiver processors **206**, one or more HMI processors **208**, one or more application processors **210**, one or more sensor processors **214**, one or more communication processors **216**, and one or more drive processors **218**, each of which is hardware. Each processor executes software and may produce control signals wherein the control signal is a wired or wireless signal, and wherein the control signal comprises one or more of a digital or an analog signal, and generally comprises or indicates data, instructions, and/or a state. A brief description of each of the additional processors for the depicted embodiment is provided below.

(78) A caregiver processor **206** may be physically attached to the S-MMS or may be part of a remote device. In one embodiment, a caregiver processor **206** is a duplicate HMI and associated processor for the S-MMS that allows a caregiver to physically drive or otherwise maneuver or control the S-MMS or its components.

(79) An HMI processor **208** may accept one or more user inputs from one or more HMI devices, such as a joystick or touch screen, and convert them into one or more control signals with data and/or instructions which are transmitted in response to the one or more user inputs at the HMI. Control instructions may comprise one or more of a calculation, a logical comparison, a state, a change in state, an instruction, a request, data, a sensor reading or record, an adjustment of an operating parameter, a limitation of a feature or capability, or an enablement of a feature or capability.

(80) An application processor **210** may include one or more processors embedded in ancillary products, such as a seat controller, lighting controller, or 3rd party device. Typically, these processors receive one or more control signals that causes them to respond with a preconfigured response, wherein the preconfigured response may include moving, measuring, changing a state, transmitting data, or taking operational control of the associated hardware (e.g., raising, lowering, or angling a seat or increasing or decreasing a light brightness or turning a light on or off). An application processor **210** may additionally or alternatively supply data about the S-MMS or use data generated from one or more sensors.

(81) A sensor processor **214** receives data generated from one or more sensors used by the S-MMS or otherwise associated with one or more characteristics of the mobile system or a user of the mobile system. The received data may be stored in a memory and/or transmitted. Multiple sensors may use a single sensor processor **214** or multiple processors. Additionally or alternatively, individual sensors may have their own (e.g., dedicated) processors.

(82) A communication processor **216** is used to establish one or more connections with one or more devices and transmits communications to, and receives communications from, one or more devices through associated devices of the S-MMS (e.g., one or more transceivers). Devices may communicate with the processor via wired or wireless means. These devices may be located on the S-MMS **18**A or may be remote to the S-MMS **18**A. A communication processor **216** may be part of a communication system for a mobile system for secure transmission and/or secure reception of data. In some embodiments, the S-MMS processor **202** may have an integrated communication processor or the S-MMS processor performs the functions of the communication processor

(83) In an exemplary embodiment, a communication processor **216** on the S-MMS **18**A is configured to establish secure connections between the S-MMS **18**A and one or more other wireless devices over which data is transmitted and received by the communication processor and the one or more wireless devices. Responsive to a secure connection being established by the communication processor **216** with a wireless device, the communication processor retrieves from

a secure memory **220** one or more of stored first data or stored second data; wherein first data is data generated from one or more sensors associated with one or more characteristics of the mobile system (e.g., sensors on or used by the S-MMS **18**A for measurement of distances, angles, or planes at which the S-MMS is operating, drive speed or direction, angular momentum, or other operational characteristics of the S-MMS itself) and second data is data generated from one or more sensors associated with a user of the mobile system (e.g., user presence in the seat, heart rate, seat moisture, or other characteristics of the user of the S-MMS). One or more of the first data and second data is then communicated to the wireless device via the secure connection for storage in a secure second memory of the wireless device. The wireless device associated and the communication processor **216** may communicate using one or more of cellular, 802.11, Wi-Fi, 802.15, Bluetooth, Bluetooth Low Energy, 802.20, and WiMAX.

(84) A drive processor **218** receives one or more control signals, for example from the S-MMS controller **110**A, that cause the drive processor to respond with a preconfigured response to the steering system and/or drive motor(s) of the S-MMS, wherein the preconfigured response includes one or more of taking operational control of the steering system or drive motor(s), steering the S-MMS, or starting and/or stopping one or more drive motors to move the S-MMS in one or more directions. A drive processor **218** may additionally or alternatively supply data generated from one or more sensors associated with one or more characteristics of the mobile system to the S-MMS controller **110**A.

(85) In some embodiments, one or more sensors may be mounted to different physical locations on an S-MMS **18**A. In some embodiments, the sensing area/view/field of one or more sensors may overlap the sensing area/view/field of one or more other sensors or a contiguous sensing field may exist between sensors to obtain a complete 360-degree sensing area view around the S-MMS **18**A, which is referred to herein as a federation of sensors. In some embodiments, the one or more sensors are non-cooperating independent sensors that generate a detection response to objects with some confidence (e.g., generate a control signal that indicates one or more objects were detected and a distance to the one or more objects or other measurement data relative to the one or more objects). In such an embodiment, the kinematic states of detection that can be determined include position and time of detection. In some embodiments, control logic may be deployed in an S-MMS controller **110**A to create an integrated system of systems within the S-MMS **18**A.

(86) Situational Awareness System

(87) Situational awareness (SA) is the perception of environmental elements, objects, conditions, and events with respect to the observer, in terms of time and space. Situational awareness involves being aware of what is happening in the vicinity of the user to understand how information, events, and one's own actions will impact objectives, both immediately and in the near future. More importantly, situational awareness involves the comprehension of information's meaning, and the projection of an object's status after some variable has changed or occurred, such as time, or some other variable has changed or occurred, such as a predetermined event. Situational awareness is also the field of study concerned with understanding the environment critical to a decision-making process in a complex dynamic system. Dynamic situations may include ordinary, but nevertheless complex, tasks such as maneuvering an S-MMS in an environment safely.

(88) A federation of sensors may be oriented proximate to an S-MMS **18** in such a way to ensure 360-degree sensor coverage. These sensors may report to an S-MMS controller **110** that is tasked with receiving information from one or more sensors, interpreting information from one or more sensors, and taking action based on information provided by the one or more sensors. The S-MMS controller **110** may attempt to assign meaning to the information and create a projection of one or more statuses or states of the S-MMS **18**, including after some variable has changed or occurred. When one or more sensors report data identifying an object, the S-MMS controller **110** may respond based on those reports, either automatically or with user input.

(89) FIG. **3** depicts an embodiment in which the S-MMS controller **110B** is deployed on an S-

MMS. The depicted embodiment comprises a situational awareness controller **302** within the S-MMS controller **1108**. The S-MMS situational awareness controller **302** communicates with a motor controller **351** and a Human Machine Interface (HMI) **352**. In some embodiments, one or more of the motor controller **351** and HMI **352** may be integrated into the S-MMS controller **1108**. The depicted S-MMS controller **1108** further comprises real-time operating system (RTOS) services **362** and navigation **363**.

(90) An arbitration Information Assurity Manager (IAM) **370** manages sensor reports from one or more sensors on or used by the S-MMS **18** and may include communication, navigation, and identification (CNI) **371** processing capabilities. Communications received from a sensor are termed sensor reports. In some embodiments, the arbitration IAM **370** resides on a security or arbitration processor **212** (FIG. **2**). Additionally or alternatively, functions of the CNI **371** may be performed by a dedicated communication processor **216** (FIG. **2**). Sensor reports received and managed by the arbitration IAM **370** may include non-contact sensor reports **372**, search and track sensor reports **373**, image sensor reports **374**, and user sensor reports **375**. Sensor reports (**372-375**) may be composed of data stored in one or more of long-term or short-term system memory **120** or read from an input port on an S-MMS **18**A processor (e.g., processors **212**, **216** or **214**). A report (**371-376**) may include additional data beyond a simple measurement, including sensor status, confidence levels, or other information.

(91) Non-contact sensors are devices used to take a measurement, often a distance, without coming in contact with the detected object. There are many types of non-contact sensors, including optical (e.g., LIDAR), acoustic (e.g., RADAR or ultrasonic), and magnetic (e.g., hall effect sensor). Microphones may additionally be included as a non-contact sensor. Search and track sensors may include image and non-contact sensor types but are sensors that often have larger fields of view and may scan within these fields of view. Image sensors detect and convey information that constitutes an image or series of images/video, wherein the image(s)/video may contain light or electromagnetic radiation information on an area. These sensor reports interface to the specific sensor types in the system to identify measurements, detections, number, efficiency, health, degraded performance, states, statuses, and/or other data of each sensor in the sensing system.

(92) The depicted arbitration IAM **370** further comprises a global positioning system (GPS) and inertial manager **376**. In the depicted embodiment, the situational awareness controller **302** communicates with the CNI **371**, sensor reports **372**, **373**, **374**, and **375** and navigation **363**. Navigation **363** communicates with the GPS and inertial manager **376** in the arbitration IAM **370**. The depicted embodiment of the situational awareness controller **302** includes logic to manage the sensors, including one or more of on and off, sweep rate, sensor volume, regional interrogation, and/or other operations.

(93) The CNI **371** manages communications through system links and off board links to enable vehicle to device, intra-vehicle, and inter-vehicle communication and coordination, including cooperative navigation among vehicles and using other devices and identification of devices and vehicles. In some embodiments, the CNI **371** identifies other data sources and retrieves data from other data sources, including for threats detected and kinematic states of sensors, vehicles, and devices. The CNI **371** is also responsible for GPS corrected system-wide time and processor time sync across the system in conjunction with the operating system. For example, the CNI **371** receives an accurate time via the GPS and inertial manager **376** and transmits that accurate time to all hardware processors along with an instruction to sync their internal clocks to that accurate time. This time coordination function is important in some embodiments since errors in time coordination can introduce as much error in system performance as a bad sensor reading in those embodiments. Propagating a sensor measurement to the wrong point in time can induce significant confusion to filters, such as a Kalman filter, especially if time goes backward due to sync errors.

(94) The CNI **371**, in some embodiments, may be configured to receive data from one or more different sources, including other like-equipped S-MMSs, vehicles and traffic devices, among

others, through a Dedicated Short-Range Transceiver (DSRC), for instance, across an IEEE 802.11P link, which may be formatted in an IEEE 1609 format. This data may help the user to better navigate next to a roadway or along paths that are shared by automobiles. Some embodiments may allow for traffic lights, speed signs, and traffic routing to be dynamically altered. For an S-MMS user, the ability to announce one's presence and thereby enable a traffic control device to effect a change in traffic, such as by changing a stop light to red, could be lifesaving.
(95) A search and track function **373** may be used to maintain sensor health, detect sensor failures, monitor sensor zones of coverage (sensor zones), and notify the situational awareness controller **302** or other component of the S-MMS controller **110**B of sensor system degradation or other states. The search and track function **373** may also manage the transition of sensors from online and off-line states (including plug and play future options).
(96) The user sensor reports **375**, in some embodiments, may be configured to receive data from one or more sensors used to monitor user condition, user position, and/or user status. This data may allow for assistive behaviors to be triggered and/or tuned by the situational awareness controller **302** to the human in the loop of the S-MMS **18**.
(97) The GPS and inertial manager **376** includes one or more inertial measurement unit (IMU) data services that receives one or more reports from an attitude and heading reference system (AHRS) that includes an IMU. An IMU of an AHRS consists of one or more sensors on three axes that provide attitude information of the S-MMS **18** to the GPS and inertial manager **376**, including yaw, pitch, and roll of the S-MMS and deviations to each. As an example, an x-axis may typically be lateral across the S-MMS **18** coaxial with the axles of the front wheels of the S-MMS, extending 90-degrees left and 90-degrees right, a y-axis may extend forward and rearward of the S-MMS, and a z-axis may extend vertically through the S-MMS, 90-degrees to the x and y axes. An IMU typically comprises acceleration and rate determining sensors on each axis. In the case of x, y, and z measurements, the IMU is referred to as a 6-Degree of Freedom (DOF) sensor. Some IM Us also have a small hall device on each axis to measure the magnetic line of flux of the earth's magnetic poles, similar to a compass, that allows for the calculation of true, earth referenced orientation. These IMU embodiments are referred to as a 9-DOF sensor and are more accurate than a 6-DOF sensor. However, some systems may interpolate the z-axis by detecting gravity on either the x or y axes, which may be less accurate. The IMU is fixed to the S-MMS **18** in some embodiments and provides reports to the GPS and inertial manager **376**.
(98) The GPS and inertial manager **376** also receives GPS signals from a GPS receiver. The GPS receiver may be mounted to the S-MMS **18**, be part of a smart device paired or otherwise linked to the S-MMS, or be another receiver that transmits signals to the S-MMS or a smart device linked to the S-MMS.
(99) Navigation **363**, in the depicted embodiment, is an inertial reference system, including an inertial navigation system (INS), for navigating using dead reckoning (DR). Dead reckoning is the process of calculating the S-MMS **18** current position by using a previously determined position, or fix, and advancing that position based upon known or estimated speeds and steering over elapsed time and heading. In one embodiment, DR uses GPS location data (e.g., via GPS and inertial manager **376**) to update the INS DR fix. Speed, heading, and elapsed time data are then provided by the INS function of navigation **363** to the situational awareness controller **302**. S-MMS speed (e.g., velocity and/or acceleration) may be received directly from one or more motor controllers **351**. Additionally, speed and heading may be received or calculated from one or more GPS and inertial manager **376** reports. Elapsed time is provided by RTOS services **362**. The navigation **363** allows the S-MMS **18** to navigate inside a building without GPS or otherwise (e.g., outside of GPS coverage) to a similar degree of accuracy as navigating outside with continuous GPS data or otherwise. Speed, heading, and elapsed time for navigation **363**, in some other embodiments, is calculated onboard the processors of internal and/or external sensors, including one or more GPS receivers and one or more solid state inertial measurement units (IMUs). In some embodiments, the

S-MMS processor **202** calculates speed, heading, and elapsed time and generates steering and drive signals, including optionally based on one or more non-contact sensor reports and/or GPS and inertial manager reports.
(100) FIG. **4** illustrates an embodiment of a system in which logic **402** for one or more architectures, including one or more generations referenced above, is deployed on the control system architecture depicted in FIG. **3**. The logic **402** may take full advantage of the entire suite of sensors available in the depicted control system embodiment and/or other sensors not depicted. The logic **402** processes reports and other data from smart sensors, including smart non-contact sensors **372**, search and track sensors **373**, and image sensors **374**. These sensors often have larger fields of view and may scan within these fields of view. These sensors may be able to characterize reports, i.e. generate both quantitative and qualitative attributes to sensor reports and coordinate sensor reports in time. These capabilities may be used to support data association techniques that can eventually be used in predictive systems.
(101) The complexity and capability of the situational awareness controller **302** may dictate the types of applications it will support. In one example, the logic **402** supports simple applications, like tip detection, drop off detection, and/or function override for safety. In another example, the logic **402** supports user assistance systems that will result in a workload reduction for both the user and/or caregiver. In another example, the logic **402** supports increased user independence due to increased confidence in system actions.
(102) FIG. **5** depicts an embodiment of a situational awareness controller **302**B that may be deployed in the architecture described by FIG. **4**. The embodiment comprises a sensor track fusion **500**, a user health manager **510**, a sensor tasker **520**, a stability manager **525**, a collision manager **526**, a tactical manager **527**, a threat assessor **528**, a drive path manager **529**, a feature extraction **530**, and an alert manager **540**. These processes interact with the CNI **371**, non-contact sensor reports **372**, S&T sensor reports **373**, image sensor reports **374**, user sensor reports **375**, and navigation **363**.
(103) Sensor track fusion (STF) **500** is responsible for processing, filtering, and reporting detections of one or more areas around an S-MMS **18** (e.g., between 0 and 360 degrees from a point or location on the S-MMS **18**, 360 degrees around an S-MMS **18**, and/or one or more overlapping areas from or around the S-MMS **18**). This is accomplished by processing reports from the available sensors **371-375** and/or feature extraction **530**. Next, recursive filtering (e.g., in one embodiment a Kalman filter) is used to estimate the state of each track based on the processed reports (e.g., **371-375**, **530**) in combination with one or more kinematic models (e.g., algorithms or mathematic equations) of possible track motion, for example, to determine if the track is in motion or stationary relative to the S-MMS. The estimate is compared to the state of each previously identified track maintained by the tactical manager **527** of the SAC **302**B. If the STF **500** determines there is a high-quality match, the state of that track is updated in the tactical manager **527**. If not, a new track is generated and communicated to the tactical manager **527**. Upon track generation, a priority may be established based on time to impact by the threat assessor **528**, and additional sensor data may be requested by transmitting a tasking request to sensor tasking **520**.
(104) Sensor fusion is the combining data from two or more sensors for the purpose of improving data quality and/or performance. In the embodiment depicted in FIG. **5**, the boxes around the sensor track fusion **500** and user health manager **510** are dashed to indicate that all processes are historically based. These processes are focused on the creation of tracks and associating current sensor readings in ways that increase the confidence in the parameters (e.g., such as range and bearing) of those tracks.
(105) The systems herein are predictive systems, wherein the sensor track fusion **500** and user health manager **510** processes may be enhanced based on one or more of: a prior knowledge of state, a prediction step based on a physical model, where measurements are made and compared to the measurements, and, an update step is performed that is either: recursively used as a state

transition model becoming the next prior knowledge of state, or an output estimate of state for the next step.

(106) This approach allows the S-MMS **18** to predict ahead of measurements an amount of time such that when an output estimate of state is generated, the system acts at T.sub.0 or T.sub.k from T.sub.k−1. Essentially, the estimate of state at time step k before the k.sup.th measurement has been taken into account along with the difference between the state transition step and the predicted step in uncertainty. Uncertainty, for the purpose of this disclosure, may be a parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurement. In lay terms, the prediction of state is at some probability of accuracy surrounded by some uncertainty. At some point, the predictions are within the estimates and actions may be taken, essentially at time T.sub.0.

(107) The sensors used with the disclosed control system may operate with large fields of view (FOV). These FOVs may typically be in the 30 to 120-degree range, in some embodiments. Larger FOVs reduce the number of sensors needed to achieve situational awareness of the S-MMS **18**. In some embodiments, two or more sensors operate in overlapping zones of coverage. This overlap allows sensor reports for a single track, condition, or object to be generated by more than one sensor and/or sensors of different types.

(108) A user health manager (UHM) **510** is responsible for processing, filtering, and reporting changes in user behavior and/or health that may be relevant to the situational awareness controller **302**B of the S-MMS. Data from user sensor reports **375**, CNI **371**, and/or HMI inputs **352** (FIG. **4**) are used by the UHM **510** to monitor individual and combined health metrics. The UHM **510** then determines the appropriate timeline for any S-MMS controller **1108** intervention or adjustments to SAC **302**B behavior. The UHM **510** may further access a user profile and log user data to secure memory linked to the user profile.

(109) A sensor tasker (ST) **520** responds to sensor information requests from sensor track fusion **500** and sensor information prioritizations from the threat assessor **528**. These priorities are used by the sensor tasker **520** to change sensor update rates for possible unsafe conditions (e.g., such as collisions or tipping danger) and to manage sensor front-end resources to maintain the highest quality tracks on the closest detections. A track is a threat to the S-MMS **18** that has been identified by the SAC **302**B and given a unique identifier for use in future calculations and processes. The sensor tasker **520** may act as a filter and utilizes the S-MMS system kinematic and identity information for decision making based on predefined decision boundaries to control the amount of sensor data provided to the SAC **302**B at a given instant.

(110) A stability manager **525** determines the stability of the S-MMS **18** and whether the upcoming ground is likely to cause instability (e.g., tipping) based on one or more inputs from navigation **363**, sensor track fusion **500**, and/or threat assessor **528**. The stability of the S-MMS **18** is calculated based on orientation readings (e.g., pitch and/or roll) received from navigation **363** (e.g., from one or more inertial measurement units fixed to the S-MMS) in combination with a mathematical tipping model for the S-MMS **18** stored in memory and executed by the stability manager **525**. The stability manager **525** also determines the suitability of upcoming terrain based on factors, such as topographic profile and/or surface composition as measured by one or more sensors **371-374** in relation to current S-MMS **18** operation characteristics, such as orientation and S-MMS kinematics (e.g., rate of travel, direction of travel, and S-MMS configuration settings). In an example, an S-MMS **18** may have known limits for pitch and roll where tilting beyond the known limits causes the S-MMS to tip. Based on the current orientation (e.g., pitch and/or roll) of the S-MMS, the stability manager **525** may use readings of the ground slope around the S-MMS to estimate the future pitch/roll of the S-MMS if it travels further forward. If the pitch/roll is below a threshold, the action is allowable. If not, then the action is not allowable. A list of stability conditions and their location relative to the S-MMS **18** are provided to the tactical manager **527** for integration into the master threat assessment map. The appropriate timeline for any necessary

steering actions and any future coupled steering maneuvers to minimize instability accidents may be computed by the stability manager **525**. System cutoffs, emergency braking, and/or motor controller disengagement functions may be performed by this stability manager **525**. The stability manager **525** may further include crash event data recording and logging for use in S-MMS system diagnostics, in some embodiments.

(111) A collision manager **526** computes the Time to Impact (TTI) function based on one or more inputs from threat assessor **528** and sensor fusion **500**. The TTI function uses received sensor data associated with one or more objects located around the S-MMS **18** in combination with the current state of the S-MMS **18** (e.g., heading, velocity, and/or acceleration) to estimate the time until a collision with those objects is anticipated. The collision manager **526** then determines the appropriate timeline for any necessary steering actions and any future coupled steering maneuvers to minimize collision accidents. Any system cutoffs, emergency braking, and/or motor controller disengagement functions may be performed by the collision manager **526**. The collision manager **526** may further include crash event data recording and logging for use in S-MMS system diagnostics, in some embodiments.

(112) A tactical manager **527** uses inputs from one or more of a stability manager **525**, collision manager **526**, drive path manager **529**, navigation **363**, threat assessor **528**, and/or sensor track fusion **500** to maintain a master, 360-degree map of known objects and conditions in relation to the S-MMS **18**. The tactical manager **527** combines the outputs of the stability manager **525** (e.g., a map of the ground surrounding the S-MMS) and collision manager **526** into a single, integrated map of known tracks. Each track may be assigned a threat level by the threat assessor **528**. The current direction and speed of travel (e.g., from navigation **363**) and/or desired future direction and speed of travel (e.g., drive path manager **529**) can then be overlaid on the threat assessment map maintained by the tactical manager **527**.

(113) A threat assessor **528** function evaluates the multiple tracks and/or objects detected by the SAC **302**B processes, including the stability manager **525**, collision manager **526**, tactical manager **527**, and feature extraction **530**, and prioritizes them. Prioritization may be based on a rules engine. The rules engine executes one or more predefined rules as part of threat assessor **528**. In one example, the rules engine uses a statistical assessment of the threat posed by each track and/or object based on the estimated time to impact to each track provided by the collision manager **526** in combination with the safe speed determined in the direction of travel provided by the stability manager **525** and/or drive path manager **529**. If an identified track presents a statistical risk above a predefined threshold, the threat assessor **528** will prioritize that track above other tracks with lower calculated risk numbers. The prioritized list of tracks from the threat assessor **528** is sent to the sensor tasker **520** which may take additional readings or otherwise focus sensor resources on the highest threat tracks. Additionally, the prioritized list of tracks from the threat assessor **528** may be sent to the tactical manager **527** so that areas with a high concentration of high threat tracks may be flagged as keep-out zones.

(114) A drive path manager (DM) **529** is responsible for route determination, interpretation of external map data (e.g., received from external sources such as a remote server or smart device via CNI **371**) for future advanced routing functions, and generation of steering actions for autonomous by wire speed sensitive steering support. External map data, when received, must be oriented to match the S-MMS **18** reference frame by the DM **529** so that it can be used with the threat assessment map maintained by the tactical manager **527**. The DM **529** combines one or more inputs from the tactical manager **527**, senor track fusion **500**, threat assessor **528**, and/or navigation **363** in order to determine where the S-MMS **18** should drive. The DM **529** contains a complex 6-DOF S-MMS **18** model that may be used in predictive applications to support stop and go functions, in some embodiments.

(115) Feature extraction **530** performs angle resolution, object detection, edge detection, and bore sight correction for the S-MMS **18**. Angle resolution is the process of determining the location and

error of the orientation of a feature (e.g., object, edge, surface, or plane) around the S-MMS **18**. Bore sight correction is the process of correcting downrange measurements for sensor misalignment. The sensor tasker **520** receives raw data of one or more image sensors via the image sensor reports **374**, uses pixel masks from the sensor tasker **520**, produces a detection report by applying one or more pixel masks to one or more image sensor reports, and assigns a unique identifier (identity) and kinematic data to each track identified in a detection report for sensor track fusion **500** consumption. Pixel masks are used to filter out or obscure areas of an image that are not of current concern to the SAC **302**B process in order to decrease compute time and resources required for the process. In some embodiments, feature extraction **530** may be used in a similar way by the user health manager **510** to measure user health metrics.

(116) In some embodiments, an alert manager **540** may be hosted on (e.g., executed by) the SAC **302**B, one of the SAC processors (FIG. **2**), and/or hosted in one or more of the application spaces **125** and/or **130** (FIG. **1**).

(117) In an embodiment, the alert manager **540** responds to inputs from stability manager **525**, collision manager **526**, drive path manager **529**, and/or STF **500** to alert the user to possible dangers, enabling a warning, caution, or advisory to actually come from the direction of the problem. For example, the alert manager **540** of the SAC **302**B generates one or more signals to one or more speakers on or around the S-MMS **18** causing the one or more speakers to produce one or more sounds that are either generic or particular to the particular speakers (e.g., one sound for a right lateral speaker to notify the user of an alert on the right lateral side of the S-MMS, another sound for a left lateral speaker to notify the user of an alert on the left lateral side of the S-MMS **18**, another sound for a forward speaker to notify the user of an alert in front of the S-MMS, and another sound for a rear speaker to notify the user of an alert behind the S-MMS). This alert manager **540** may receive and process data from the collision manager **526**, the stability manager **525**, and/or the UHM **510**, such as timing for predicted collision, instability, or user health issues, and coordinate one or more alerts with the time for the predicted collision, instability, or user health issue for crash mitigation or condition avoidance. This timing may be based on expected user reaction times and user health considerations. In some embodiments, an audio alerting function or 3D audio is implemented. When an obstacle or dangerous condition is detected, one or more sounds are produced from the direction of the threat by one or more speakers installed on or around an S-MMS **18**.

(118) In one embodiment, the necessary speakers are integrated as part of the HMI and controlled by the HMI processor **208** (FIG. **2**). Other embodiments may alternatively or additionally include visual, haptic, or biofeedback mechanisms to provide a corresponding feedback.

(119) The alert manager **540** may also alert the user to degraded systems that require maintenance to keep systems operational. One example of this is integration of LED lights on each sensor or associated with each sensor processor **214** (FIG. **2**). In this example, the alert manager **540** monitors the status of the sensors (e.g., by receiving a status signal from each sensor) and transmits a signal to each sensor LED when that sensor fails causing the LED to turn on and notify users and technicians of a failed sensor. In one example, the sensor status signal is either an on state (positive voltage signal) or an off state (no voltage). The alert manager **540** may receive multiple types of status signals from the sensors and/or other devices of the S-MMS **18** and transmit one or more signals to one or more status indicators (e.g., single or multicolored LED or other visual, audio, or signal indicator) to cause to indicator to alert the user, technician, or other person as to the status of the sensor or other device. These “Clean Lights” or other indicators may also be clustered in a central display as part of the HMI **352**.

(120) FIG. **6** depicts a front-wheel drive S-MMS **18**B equipped with an embodiment of sensor arrays to cover three main types of sensor coverage zones, including zones **610** (zones with solid lines), zones **620** (zones with dashed lines), and zones **630** (zones with dash-dot lines). The depicted sensor coverage zones **610**, **620**, **630** are covered using three main sensor arrays, including

five forward sensors, five rearward sensors, and six side sensors (three for each side) generally aimed to cover the range of motion of the S-MMS **18**B and toward the blind spots of a user. The sensors may be arranged to take readings on the area proximate to the S-MMS **18**. Additionally or alternatively, the sensors may be arranged to take readings on the terrain (e.g., ground) proximate to the S-MMS **18**. The depicted sensor arrays are composed of a mix of (a) short-range sensors such as short-range LIDAR, SONAR, and RADAR sensors for zones **610** with solid lines, (b) long-range sensors such as long-range LI DAR and RADAR sensors for zones **620** with dashed lines, and (c) image capturing sensors (including still images and/or video, referred to generally as imagers) such as cameras for zones **630** with dash-dot lines. Generally, short-range sensors have wider fields of view (FOV), while long-range sensors have narrower fields of view. The sensor array of FIG. **6** may be characterized as an overlapping, large FOV (with both narrow and wide FOVs), sensor array. The sensor placement, number of sensors used, and types of reports expected in the depicted embodiment are used as a non-limiting example. It should be clear that more or fewer sensors of varying types may be used.

(121) One or more single sensor units may have the ability to act in both short and long-range modes. One or more single sensor units may have the ability to measure objects and measure or map the terrain proximate to the S-MMS **18**. One or more sensors and sensor types may be selected for a desired S-MMS **18** architecture and user. As an example, if the user is a quadriplegic and spends most of their time indoors in a relatively slow-moving S-MMS, the sensor arrays may be comprised of all short-range sensors, with multiple overlapping FOVs, where the time to impact on a close-in maneuvering object is much more critical than a vehicle on the horizon. Alternatively or additionally, the sensor array would be adjusted if fitted to alternative drive configurations such as a center or rear-wheel drive S-MMS.

(122) When working with an overlapping, large FOV, sensor array, Multiple Object Tracking (MOT), or Multiple Target Tracking (MTT), techniques may be used. For example, a threat assessor (TA) function **528** (FIG. **5**) of the SAC **302**B is responsible for locating multiple objects, maintaining their identities, and calculating their individual trajectories given sensor input data (e.g., sensor reports **372-374**). Objects to track can be, for example, pedestrians on the street, vehicles in the road, sport players on the court, obstacles or features of the ground, surface conditions of upcoming terrain, or animals. Further, multiple "objects" could also be viewed as different parts of a single object. This is the situational awareness map or tactical awareness map (e.g., a map and/or an identification of the ground, conditions, surfaces, and/or objects surrounding the S-MMS) maintained by the tactical manager **527**.

(123) FIG. **7** depicts an example of 360-degree situational awareness. Multiple objects may be present at any given time, arranged around the S-MMS **18**B at varying distances from the user. These objects may include features such as a curb or drop **751** in the ground that could be dangerous to stability, moving objects such as a person **752** or bicycle **753**, and stationary objects such as a lamp post **754**. The S-MMS **18**B may become aware of objects in the distance **720**, yet not be able to confidently identify the objects until they are in range or more information can be gathered. For instance, the S-MMS **18**B may not be able to confidently differentiate a bicycle **753** from a motorcycle when it is a long distance **720** away. Objects in midrange **730** may be more easily recognizable, and object identity may be qualified and quantified. "Quantify" refers to the determination of aspects such as range, bearing, location, velocity, and acceleration, i.e. the kinematic state of an object. In close proximity **740**, the SAC **302** (FIG. **3**) may generate threat/collision data/information. "Close" may be assessed in terms of time to impact, distance, and/or general threat.

(124) In practice, the zones depicted in FIG. **7** extend 360-degrees around the S-MMS **18**B. Each side may have varying degrees of need for the size and placement of the zones dependent on several factors, including S-MMS dynamics, which in turn may dictate the number and type of sensors required, in some embodiments. The depicted zones are for example purposes only and

may vary between embodiments depending on sensor types, number of sensors, sensor ranges, characterization data, historical data, and other related systems, devices, and information/data.
(125) Uniform Cartesian Grid
(126) The SAC **302**B, in some embodiments, is a tactical manager that operates in a uniform way at a systems level with all of the sensors, data, time, etc. coordinated into a unified system. Some difficulties in uniform operations include that target reports from the sensors are typically in polar coordinates (e.g., range and bearing) to a target from the center of the sensor aperture or receptor, that the sensors are mounted at distributed points on and around the S-MMS **18** to achieve the best fields of view, and that processing time, sweep rate, communications time, and other sensor operating parameters may vary with each sensor. The frames of reference for each sensor can be identified and described in terms of their relationship to each other and their functional roles. These difficulties may be overcome using the following methods.
(127) There are five frames of reference in an S-MMS **18** sensor system, where the S-MMS **18** is designed to navigate the real world. These frames of reference are: 1. Sensor Frame. 2. MMS Frame. 3. Navigation Frame. 4. Earth Frame. 5. Geo Frame.
(128) A sensor frame extends from the center of an aperture or receptor (e.g., lens, antenna, etc.) of the sensor. FIG. **8** depicts typical sensors **802**, **804**. In the depicted embodiment, the x-axis of each sensor extends orthogonal to the direction of travel and indicates roll attitude, the y-axis of the sensor extends in the direction of travel and indicates the pitch axis, and the z-axis of the sensor extends vertically through the center of the sensor and indicates the yaw.
(129) FIG. **9** depicts an exemplary mobile chair S-MMS **18**C frame of reference. In the depicted embodiment, the x-axis extends from left to right of the mobile chair S-MMS **18**C and is parallel to the front of the mobile chair S-MMS, the y-axis is perpendicular to the x-axis extending forward in the direction of travel, and the z-axis is orthogonal to the x and y-axis and vertical through the intersection of the x and y axes. As with the sensor reference frames, x, y, and z-axes represent roll, pitch, and yaw measurements.
(130) In some embodiments, an S-MMS **18**C may have multiple frames of reference, one of which may be considered the master frame of reference. As an illustrative example, the S-MMS **18**C may have suspended assemblies (such as wheel cowlings) that move relative to the S-MMS frame itself. If a sensor were mounted on a suspended assembly, then the motion of the suspension would need to be accounted for when translating a sensor frame of reference to the master frame of reference.
(131) FIGS. **10**A-**10**C depict an exemplary navigation frame of reference overlaid on a mobile chair S-MMS **18**C. The navigation frame of reference relates to how an S-MMS **18**C is traveling in its environment. FIGS. **10**A and **10**B depict an exemplary navigation frame of reference. FIG. **10**C depicts a situation in which the actual navigation frame of reference and the sensor frame of reference do not align due to error. In this scenario, the S-MMS **18**C sees the world as x′ and y′-axes, but in reality, the S-MMS travels in x and y-axes. In this example, x and y-axes are the actual navigation frame, regardless of what the sensors detect. As an analogy, FIG. **11** depicts an airplane **1110** traveling through the air. The pilot of the airplane **1110** thinks it is traveling along a y-path when in reality it is traveling along a y′-path. Regardless of the sensor reports along the y-path, the plane **1110** is traveling along the y′-path. If an object like a small plane **1120** is in the true navigation frame of the plane **1110**, there will be a collision. An understanding of this principle is important to safety and object avoidance. The reported data from sensors reporting along a y-axis of an S-MMS **18**C frame, and/or other sensor frames, will be different in the navigation frame as described. The SAC **302**B tactical manager **527** properly associates objects and conditions reported by sensors (**371-376**) with the true navigation frame of the S-MMS **18**C. Below, further systems and methods are disclosed for detecting and managing these frames.
(132) The next two frames of reference are the earth frame and geo frame. The earth frame is in terms of latitude, longitude, and altitude as represented on a map. The geo frame is earth centered and earth fixed in terms of direction cosines. The intersection of these curved lines from the center

of the earth represent where an object is located three dimensionally above or below the surface of the earth, as when traveling in an airplane or submarine. These two terms are sometimes referred to as the geoid and spheroid. Use of the geo frame and earth frame may be useful for navigating between floors on a multi-story building.

(133) Altitude changes of the surface of the earth frame (e.g., terrain) are particularly important for safe and effective navigation of S-MMSs to avoid tipping and/or instability. The need of an S-MMS **18**C to map and characterize terrain at a high accuracy is unique to S-MMSs compared to other types of vehicles.

(134) Establishing the UCG

(135) With focus on the first four frames of reference, a uniform way of receiving, using, and sharing information needs to be established. Sensor reports (**372-375**, FIG. **3**) and external data (**371**, FIG. **3**) may be received by the situational awareness controller **302**B relative to different frames of reference. A method for managing this is to establish a uniform Cartesian coordinate system extending from the S-MMS **18**C reference frame depicted in FIG. **9**. All data received by the SAC **302**B may be translated to the S-MMS **18**C reference frame, where the earth reference frame is also referenced to the S-MMS **18**C reference frame by navigation **363**. Sensor reports received in polar coordinates (i.e., range and bearing to objects) are first translated into Cartesian coordinates by the SAC **302**B through what is called a standard conversion, disclosed below. Then, those converted sensor reports may be translated by the SAC **302**B into the S-MMS **18**C reference frame and related to the earth frame.

(136) Motorized mobile systems enable their users to navigate the world. They navigate and move in a distinct way, at a different speed, and occupy a very different footprint from the people or animals walking around them. This unique behavior, combined with the power and weight of the MMS, make awareness and avoidance of people, animals, and other things that move important to the safety of both the MMS user and those moving around it. As opposed to simply avoiding collisions like an autonomous vehicle, these systems need to watch for and avoid toes and tails. S-MMS **18** collision avoidance and navigation systems must be much more accurate than existing automobile systems and must take into consideration unique situations.

(137) The uniform Cartesian grid (UCG) lays the foundation for creating a virtual situational awareness (SA), or tactical, map. The situational awareness map comprises objects, the kinematic states of these objects, and state propagation with respect to the user's S-MMS **18** and the objects in their environment. The threat map is constantly updating with data reported by onboard sensors (see FIG. **6**), data reported by remote sensors via CNI **371**, and data received via the internet or other external sources using one or more onboard communication processors **216**, FIG. **2**. The SA map may be maintained by the tactical manager **527** of the SAC **302**B and allows the S-MMS **18** to calculate time to impact on proximate objects. The UCG becomes the single corrected frame of reference for all calculations on the SAC **302**.

(138) The S-MMS **18**, as disclosed, uses sensors capable of making measurements with the lowest possible amount of error, or variance. Variance may be defined in terms of plus or minus in seconds, milliseconds, feet, inches, yards, degrees, radians, etc. Sensor measurements are used in support of a logic based S-MMS controller **1108** system that may be inferenced by some form of adaptive learning that operates like intuition, as discussed further below. Two or more sensor reports on the same object that are different and can be associated in time may be combined to generate a better report, with the goal of improving confidence in the tactical map.

(139) Referring back to FIG. **6**, object **640**, is covered by four sensors: two short-range LIDAR as designated by zone **610**, one forward imager as designated by zone **630** and one long-range radar as designated by zone **620**. A process is necessary for reconciling these multiple sensor reports (**372**, **373**, and **374**) on the single object **640** received by the SAC **302**B. Preferably, this method would materially improve confidence in the accuracy of the system tactical map maintained by the tactical manager **527**, thus improving situational awareness. As discussed above, the SAC **302**B may

implement a probability based system with an estimator.

(140) Dual Mode Variance

(141) Dual mode variance is a method for improving confidence in the situational awareness map of the SAC **302**. Dual-mode variance may be used to decrease uncertainty of any S-MMS **18** functions disclosed wherein two or more sensor reports (**371-376**), or readings from multiple modes on a single sensor, can be combined to decrease uncertainty. An approach is depicted in FIG. **12** and comprises a first object **1202**, located proximate to a motorized mobile system **18**, wherein the first object **1202** is in the field of view **1204**, **1206** of at least two sensors **1208**, **1210** associated with the motorized mobile system **18**. In some embodiments, a first sensor **1208** generates data about the first object **1202**, wherein the first object data is represented by one or more of a first range measurement and a first bearing measurement to the first object. A range, or down range, measurement is the distance of something to be located from some point of operation, typically defined by the sensor frame of reference. A cross range or bearing measurement is a direction expressed in degrees offset from an arbitrary true baseline direction, typically defined by the sensor frame of reference. The first range measurement may have an associated first uncertainty with the first range measurement, and wherein the first bearing measurement has an associated second uncertainty with the first bearing measurement. As a non-limiting example, the first sensor **1208**, an imager for example, may provide good cross range or bearing measurements but poor down range measurements such that the first uncertainty is larger than the second uncertainty as depicted by zone **1212**. A second sensor **1210** may generate data about the first object **1202**, wherein the first object data is represented by one or more of a second range measurement and a second bearing measurement to the first object. The second sensor **1210**, a radar for example, may provide good down range measurements but poor cross range measurements such that the second range measurement has an associated third uncertainty with the second range measurement, and wherein the second bearing measurement has an associated fourth uncertainty with the second bearing measurement, wherein the fourth uncertainty is larger than the third uncertainty as depicted by zone **1214**.

(142) These overlapping sensor reports may be coordinated in time and associated with a single object (a.k.a. track) by sensor track fusion **520** on the SAC **302**B. The most accurate measurement from each sensor report (cross range from the imager and down range from the radar, in the example) may be combined to make the situational awareness map more accurate. This use of more than one sensor is referred to as dual mode variance. In order to accomplish this, a processor (e.g., S-MMS processor **202**), may host one or more programs such as the SAC **302**B of the S-MMS controller **1108** to: receive from the first sensor data about the first object **1202**, receive the second sensor data about the first object **1202**, retrieve from memory **120** the range and bearing uncertainties associated with the data generated from the first sensor, retrieve from memory **120** the range and bearing uncertainties associated with the data generated from the second sensor, identify the lower bearing uncertainty from the second and fourth bearing uncertainty, identify the lower range uncertainty from the first and third range uncertainty, combine the measurements associated with the lower bearing uncertainty and lower range uncertainty to generate a new reduced area of uncertainty (e.g., **1216** as compared to **1218**), wherein uncertainty refers to errors in physical measurements that are already made.

(143) As an example, FIG. **12** depicts an embodiment comprising two sensors **1208**, **1210** operating with different fields of view. Imager **1210** has a field of view of 120-degrees **1206**, and is based on a 1920×1080 resolution camera. This equates to an accuracy of 16 pixels per degree (1920-pixels/120-degrees=16 pixels per degree). If the detection software (e.g., running on the sensor processor **214**) has a cross range resolution of ±2 pixels for object detection, there is a cross range error of ±0.125-degrees on the image sensor reports **374** from the imager **1210** received by the SAC **302**B. The down range error for the imager **1210** is reported by the camera manufacturer as half the distance to the target. If the detection software on the imager **1210** estimated the target at

100-meters, the down range error is ±50-meters. This results in a variance, or error envelope, that looks like **1212**. If the second sensor is a radar **1208** with an associated field of view **1204** of 30-degrees and that is reported to have down range errors in the ±10-cm range, but cross range errors of ±3-degrees its error envelope is depicted as **1214**.

(144) If, for example, these two sensor reports **374** and **372** are received by the SAC **302**B, associated with a single object (a.k.a. track) by sensor track fusion **520**, and unchanging over the last 30-seconds, the confidence is high that both sensors **1208**, **1210** are targeting the same object. In one embodiment, the tactical manager **527** places the reports on the situational awareness map, and the object's location is marked as somewhere in the field of uncertainty depicted by **1218**. Alternatively, if dual mode variance is employed, the best (e.g., lowest variance) elements of each sensor **1208**, **1210** readings are combined, and the object's location is marked as somewhere in the field of uncertainty depicted by **1216**. This is a significant reduction in uncertainty of object parameters. Without application of the disclosed approach, the uncertainty of object parameters would be the combination of the maximum errors or variances **1218**. This improvement is termed dual-mode variance, and any single sensor reports are termed single-mode variance (e.g., **1212** or **1214**).

(145) As another non-limiting example, a single radar using a dual-mode synthetic aperture may be used, where the fields of view have two operating modes, a short range wide mode and a long-range narrow mode. The sensor report in short range wide mode may have similar characteristics to the imager **1210** discussed in the first example (i.e. good cross range accuracy, but poor down range accuracy). The sensor report in long range narrow mode may have similar characteristics to the traditional radar **1208** discussed in the first example (i.e. poor cross range accuracy, but good down range accuracy). If two measurements are taken from the single dual-mode synthetic aperture sensor, one in each mode, the measurements can be combined by the SAC **302**B using dual-mode variance to increase confidence in the properties of a given object.

(146) The previous examples are presented for clarity and are not intended to limit the types of objects, sensors, or scenarios where dual mode variance may be utilized. The first and second sensors may be one or more of an optical sensor, a sound sensor, a hall effect sensor, a proximity sensor, and a time of flight sensor, including radar, sonar, ultrasonic, LIDAR, or a distance camera. An object may include one or more of a thing, person, animal, ground feature, and surface condition. Additionally or alternatively, applications may include combinations of bio-medical sensors to track user health **375**, ground or terrain tracking sensors to monitor system stability **372-374**, and/or S-MMS status sensors included as part of the motor controller **351** or HMI **352**, among others. Additionally or alternatively, one or more of the sensors generating data about an object may be received from a second S-MMS **18** or remote sensor associated with the S-MMS **18**.

(147) Polar to Cartesian Conversion

(148) Another method of improving situational awareness and increasing confidence in the situational awareness map is application of polar to Cartesian conversion techniques. An inertial measurement unit (IMU) may be attached to the frame of an S-MMS **18** so that it reports the absolute orientation, attitude, and heading of the S-MMS **18** to the S-MMS controller **1108** via the GPS and inertial manager **376**. These reports may then be used to support the navigation **363** function of the S-MMS controller **1108**. Additionally, the IMU sensor reports may also be used by the S-MMS controller **1108** and SAC **302**B to establish a vehicle reference frame extending along the S-MMS axes, as illustrated in FIG. **9**.

(149) Having a vehicle reference frame is necessary in the move to smart sensors that generate target sensor reports in a polar coordinate system, where the sensor reports are not in terms of x, y, and z, but in terms of range and bearing. Moreover, these sensor reports are received based on one or more sensor reference frames (FIG. **8**). Navigation **363** (FIG. **3**) is responsible for maintaining the vehicle reference frame. The SAC **302**B then translates data from sensor reports representing targets in the environment and other data into a uniform Cartesian coordinate system allowing a

higher confidence in the determination of threats.

(150) As the sensor system evolves from single sensor reports to an integrated system of sensors, new issues arise, such as the capture and management of system error. In the example of axis translation as sited above, the polar translation may be completed in a standard conversion, as described in Equation 1:

x.sub.m=r.sub.m cos θ.sub.m and y.sub.m=r.sub.m sin θ.sub.m, Eq. 1 where r.sub.m and θ.sub.m are the range and bearing, respectively, of the sensor target in the polar reference frame, and x.sub.m and y.sub.m are the down range and cross range coordinates, respectively, in the converted Cartesian reference frame. As an example, for a target at 10-meters, with a bearing of 1-degree, Equation lyields a Cartesian location of (9.99-meters, 0.17-meter) for (x,y). This conversion leads to some error. However, for the scenarios disclosed, the errors induced will be negligible. Additionally or alternatively, the SAC **302**B may de-bias the variances of the polar reports when they are translated to Cartesian coordinates. A debiasing term may be used in the case that the standard Equation 1 cannot be used because they induce significant error. FIG. **13** depicts the standard conversion as well as the use of a debiased conversion correction term.

Cooperative Targeting

(151) Cooperative targeting is another way of improving the situational awareness of the S-MMS **18**. As stated earlier, the communication, navigation, identification (CNI) **371** (FIG. **3**) function of the arbitration IAM **370** manages off-board communication for the S-MMS **18** through system links and off-board links to enable S-MMS **18** coordination. CNI **371** is also responsible for system wide time and processor time synchronization across the system in conjunction with the operating system of the S-MMS controller **110**B.

(152) Communication standards have been developed to support and enhance automobile communications known as vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I). The standards define an architecture and a complementary set of services and interfaces that collectively enable V2V and V2I wireless communications. Together, these standards provide the foundation for a broad range of applications in the automobile transportation environment, including automobile safety, automated tolling, enhanced navigation, traffic management, and many others. One standard was adopted as IEEE 1609 for Wireless Access in Vehicular Environments (WAVE) in the United States. The European Telecommunications Standards Institute (ETSI) Technical Committee Intelligent Transport System (ITS) developed and adopted a related set of standards, collectively called the ITS-G5. The WAVE and ITS-G5 standards are herein incorporated by reference in their entirety.

(153) V2X communication is based on WLAN technology and works directly between vehicles or infrastructure, which form a vehicular ad-hoc network, as two V2X transceivers come within each other's range. Hence, V2X communication does not require any infrastructure to communicate, which helps to increase safety in remote or little developed areas. V2X is particularly well-suited for S-MMS **18** communication, due to its low latency and the ability to communicate instantly with no surrounding infrastructure. V2X transmits messages known as Common Awareness Messages (CAM), Decentralized Notification Messages (DENM), or Basic Safety Messages (BSM). Messages may contain a range of content, including the identity, type, and kinematic states of the entity containing each V2X transceiver.

(154) FIG. **14** depicts two mobile chair S-MMSs **18**D and **18**E in communication with each other via an ad hoc network **1404**. In an embodiment, the two S-MMS **18**D and **18**E may be configured to communicate with each other over a V2X network connection. The S-MMS **18**D, **18**E may be equipped with an 802.11P transceiver of the S-MMS **18** in communication with the communications processor **216** and the CNI **371** configured to manage 802.11P communications. In this way, the two S-MMSs **18**D, **18**E form a communication system comprising a vehicular ad hoc network for exchanging messages. The vehicular ad hoc system comprises a first security manager located in a portable first transceiver, wherein the portable first transceiver is one or more

of proximate to the S-MMS **18**D and physically coupled to the S-MMS **18**D, linking data for transmission off-board to a second processor and second security manager associated with a second S-MMS **18**E connected to the vehicular ad hoc network.

(155) As a non-limiting example of improving situational awareness using cooperative targeting, FIG. **14** depicts a first S-MMS **18**D and a second S-MMS **18**E approaching a blind intersection of two pathways. The onboard sensors **1402** of the first S-MMS **18**D do not detect the second S-MMS **18**E, nor do the onboard sensors of the second S-MMS detect the first S-MMS. However, both S-MMSs **18**D, **18**E are equipped with an 802.11p architecture (including software and hardware as described above, including an 802.11P transceiver, to effect the 802.11p architecture), transmit their kinematic states, and receive signals from the other S-MMS containing information on the kinematic states of the other S-MMS via a vehicular ad hoc network **1404**. In this example, the 802.11P transceiver on the first S-MMS **18**D picks up the signals from the second S-MMS **18**E. The CNI **371** of the first S-MMS **18**D receives the signals from the second S-MMS **18**E via the 802.11P transceiver of the first S-MMS and transmits the contents of the received signals (including the kinematic state information therein) to the S-MMS controller **1108** of the first S-MMS via the arbitration IAM **370**. Additionally or alternatively, the signal contents may be stored in one or more onboard memory locations **120** of the first S-MMS **18**D for consumption by the S-MMS controller **1108** of the first S-MMS. The signal contents from the second S-MMS **18**E may include the identification information, kinematic state information (e.g., current location, heading, and velocity of the S-MMS **18**E), and estimated error in the kinematic state information.

(156) The SAC **302**B on the S-MMS controller **1108** of the first S-MMS **18**D may use the information from the signals received from the second S-MMS **18**E in one of many ways. In one embodiment, the SAC **302**B of the first S-MMS **18**D may identify a track for the second S-MMS **18**E based on the information from the signals and directly place the newly identified track for the second S-MMS on the situational awareness map via the tactical manager **527**. The threat assessor **528** of the first S-MMS **18**D may then assign a perceived threat level to the second S-MMS **18**E based on the newly identified track or based directly on the information from the signals. Other SAC **302**B functions of the first S-MMS **18**D may then act on the information from the signals of the second S-MMS **18**E as if the onboard sensors of the first S-MMS had detected the second S-MMS, when in reality the second S-MMS was not in view. At the same time that these actions are occurring on first S-MMS **18**D, the second S-MMS **18**E may also be taking these actions. This is referred to as cooperative targeting.

(157) In some embodiments, data provided by the second S-MMS **18**E to the first S-MMS **18**D over the ad-hoc **1404** network may be combined with sensor reports **1402** received by the first S-MMS **18**D in such a way that the confidence of additional tracks on the situational awareness map maintained by the tactical manager **527** may be improved. For example, the confidence of a location of a particular object as determined by the SAC **302**B of the first S-MMS **18**D may be enhanced by combining information (e.g., using dual mode variance for example) from one or more sensor reports **1402** from the first S-MMS **18**D with data about the same object (e.g., track data) provided by one or more sensors onboard the second S-MMS **18**E via one or more signals from the second S-MMS that include sensor data from the second S-MMS.

(158) In some embodiments, the S-MMS controllers **1108** on each S-MMS **18**D, **18**E may automatically coordinate the right of way or other behavior when they meet (e.g., at the intersection depicted in FIG. **14**). Each S-MMS **18**D, **18**E may process one or more received signals and determine a message should be sent over the ad-hoc network **1404** indicating the direction the S-MMS is traveling and the anticipated crossing time of the two S-MMSs. In each S-MMS **18**D, **18**E, the CNI **371** receives a message from its S-MMS controller **1108** and transmits the message via its 802.11P transceiver. Based on this message, the S-MMS controller **1108** on one of the two S-MMSs may request permission from the S-MMS controller on the other S-MMS for right-of-way. If the request is approved by the S-MMS controller **110**B of the other S-MMS, then the SAC **302**B

of the other S-MMS determines it is to stop and may alert its drive path manager **529** via its threat assessor **528** to block its forward motion at a specific location and/or time. Additionally or alternatively, the two S-MMS **18**D, **18**E may simply coordinate a slight increase or decrease in velocity or direction that ensures the two S-MMSs **18**D, **18**E do not collide at the intersection. In other embodiments, a second message will be transmitted by the S-MMSs **18**D, **18**E (via their respective components described above) when the intersection has been successfully traversed.

(159) Cloud Integration

(160) FIG. **15** depicts an embodiment of an S-MMS system **1506** securely connected to a remote server **1510**. In the depicted embodiment, a wireless processor either onboard the S-MMS **18**F or associated with the S-MMS as a paired or connected wireless smart device **1502** is operably coupled to a second wireless processor (e.g., via a secure wireless connection), wherein the second wireless processor is configured to operate on a public packet network. The connection **1508** to the public packet network from the S-MMS system **1506** allows access to one or more servers, or remote services, **1510** configured to receive data from a secure memory on the S-MMS **18**F and/or the secure memory on the associated smart device **1502** of the S-MMS system **1506**. The received data may then be stored in a secure memory on the remote server **1510** wherein the secured, stored data is accessible to pre-authorized systems or pre-authorized persons.

(161) In an embodiment, a pre-authorized system may be a web interface **1542** accessed through an internet connected device, wherein a pre-authorized user **1544** logs in using security credentials and may view a history of events or other data associated with a particular S-MMS user or the S-MMS of that user. In another embodiment, the web interface **1542** may be used to communicate with the S-MMS user or modify or add data to the S-MMS users' unique data file. Data transmitted to the web interface **1540** may be delivered via a secure connection, such as a secure sockets layer (SSL) connection.

(162) In one embodiment, the remote server **1510** may be configured to accept, process, store, and complete specific actions based on messages from an S-MMS system **1506**. FIG. **15** depicts a remote server **1510** configured to receive incoming messages from an S-MMS system **1506** via a secure connection **1508**. Messages may be sent from the S-MMS system **1506** when a particular event takes place (e.g., on a tipping event), at state events (e.g., at startup of the device), and/or at pre-scheduled times (e.g., at midnight each night). These incoming messages are received by an input queue **1512** hosted on the remote server **1510**. Messages from the input queue may then be sent to one or more of a compute engine **1514**, a database or data storage system **1516**, and an output queue **1518**. The compute engine **1514** may compare data included in incoming messages from the input queue **1512** to predefined rules. Additionally or alternatively, the compute engine **1514** may work as a filter to associate individual messages with unique user accounts prior to storing data in a database **1516**. The compute engine **1514** may also, based on the content of a received message, push alerts or action requests to an output queue **1518**. The output queue **1518** may be a subscription/publication service that, when activated, sends alerts to internet connected devices **1532**, such as an S-MMS users' caregiver's smart device. Alerts may be sent as text messages, voice messages, voice calls, or video over a cellular and/or Internet Protocol (IP) network **1530**, including the internet. Additionally or alternatively, outbound messages may be sent via the cellular and/or Internet Protocol (IP) network **1530**. In some embodiments, the services **1512-1518** on the remote server **1510** may be executed on one or many individual server instances that work together to complete tasks as a single unit on one or more hardware processors. Additionally or alternatively, multiple other remote server architectures are possible to accomplish the intended functionality. As a non-limiting example dashed-dot lines have been included to show alternative connections that may be enabled in some embodiments. Additionally, the compute engine **1514** may include more advanced machine learning logic, such as a neural network, in some embodiments. Diagnostics and other basic server components have been left off of the diagram for the purpose of clarity.

(163) Each of the exemplary embodiments disclosed illustrate how the combined features of the S-MMS system enable various capabilities for S-MMSs. While each exemplary embodiment is discussed separately it should be clear that any one or more aspect of each exemplary embodiment may be combined with any one or more aspects of one or more of the other exemplary embodiments.

(164) Precision Navigation

(165) S-MMS navigation requires accuracy and a unique set of technologies. Navigation for automobile use relies primarily on GPS for location. FIG. **16**A depicts an S-MMS **18**G configured with one or more communication processors **216** which provide data to the S-MMS controller **110**B based on data received from Global Positioning System (GPS) signals **1602**. However, unlike automobiles, S-MMS users may spend much of their time indoors and in other locations where GPS does not work. GPS-assisted devices require signal strength for accuracy. When signals weaken (in areas like downtowns or the interiors of buildings), the accuracy lags, potentially causing inaccuracies in navigation that can have a detrimental impact on those who rely on driver assistance or autonomous operation with high accuracy. FIG. **16**B depicts an S-MMS **18**G in an indoor environment where GPS signals **1602** are weakened or completely blocked.

(166) Moreover, currently available GPS technologies struggle to provide the positional accuracy required for S-MMS navigation along sidewalks, paths, and other rights of way which are typically much narrower than roadways. Indoor navigation of multi-story buildings is another challenge that is not currently addressed by vehicle navigation systems for obvious reasons. These issues mean that S-MMS **18** navigation requires a unique set of technologies and methods. The S-MMS **18** situational awareness controller **302**B with tactical manager **527** (FIG. **5**), and drive path manager **529** lay the foundation for precision navigation. The tactical manager **527** maintains a situational awareness map of the surroundings (e.g., a map and/or an identification of the ground, conditions, surfaces, and/or objects surrounding the S-MMS) based on data provided to the SAC **302**B. The drive path manager **529** references the situational awareness map when assisting a user or for autonomous navigation. The combination of sensors available to the S-MMS controller **110**B via the arbitration IAM **370** includes GPS and inertial manager **376**, multiple onboard sensors previously disclosed **372-374**, information available from remote services **1510** and third-party information available via the CNI **371** which, together, may support creation of a precise S-MMS situational awareness map at a level of detail not otherwise available.

(167) Navigation **363**, in an embodiment, may rely at least partially on an inertial reference system (IRS), including an inertial navigation system (INS) for navigating using dead reckoning (DR). Dead reckoning is the process of calculating the S-MMS **18**G (FIG. **16**) current position by using a previously determined position, or fix, and advancing that position based upon known or estimated speeds and/or steering over elapsed time and heading. In one embodiment, depicted in FIG. **16**B, an S-MMS **18**G enters a building and loses a GPS signal **1602**. The DR function in navigation **363** uses location data from the GPS and inertial manager **376** to update the INS DR fix **1604** by setting a stable earth frame of reference. Speed, heading, and elapsed time data is then provided by GPS and inertial manager **376**. Navigation **363** uses this information to track the movements **1608** of the S-MMS **18**G (or more precisely it's vehicle frame of reference) relative to the fix **1604** and estimate its location. This allows the S-MMS **18**G to navigate inside a building with GPS or otherwise (e.g., otherwise outside of GPS coverage) to a similar degree of accuracy as navigating outside of buildings with continuous GPS data or otherwise. The approach may also be utilized when GPS coverage is available to increase locational accuracy by cross-checking the DR value with GPS data.

(168) Navigation assistance and autonomy may be strengthened further and smoothed by combining DR, as previously disclosed, with the SAC **302**B situational awareness map maintained by the tactical manager **527** (FIG. **5**). This map is maintained with information from the collision manager **526** and stability manager **525** and their associated sensors. While GPS and DR provide

an estimate of absolute location, the situational awareness map provides information on safe directions of travel and distances to surrounding objects. For example, when traveling down a hallway, navigation **363** may know the current location and target end location of the S-MMS **18**G, and the SAC **302**B is aware that the S-MMS must stay between the two walls to get to that location. The drive path manager **529** of the SAC **302**B references the situational awareness map when assisting user or autonomous navigation. This added awareness allows navigation of tight spaces that would not otherwise be possible with DR alone. Increased accuracy of the situational awareness map improves navigation capabilities and, therefore, use of dual mode variance improves S-MMS **18**G precision navigation capabilities.

(169) With reference to FIG. **16**, in an embodiment, the CNI function **371** (FIG. **5**) is provisioned such that at least one wireless system is available to transmit and receive (transceive) data relevant to navigation of an S-MMS **18**G. In some embodiments, the S-MMS **18**G may be compatible with cellular, Bluetooth, Bluetooth Low Power, Wi-Fi, and other signals which can be used for navigation assistance. These signals may be used in addition to, or as an alternative to, GPS signals. Additionally or alternatively, the S-MMS **18**G may use Bluetooth, Bluetooth Low Power, Wi-Fi, and other signals, such as light frequency navigation as sensed by a paired smart device, for instance, being deployed for indoor tracking and navigation by several companies. In one embodiment, a wireless beacon **1610**, communicates **1612** with the S-MMS **18**G via a communication processor **216** (FIG. **2**) of the S-MMS **18**G through one of 802.11, Bluetooth, Bluetooth Low Energy (BLE), Near Field Communication (NFC), and/or Zigbee™, among others. These communications **1612** are typically predicated on a "just works" model, one that requires little interface with the device **1610**, **18**G and the underlying technology. As beacon and indoor navigation systems grow in use, S-MMS **18**G precision navigation may take advantage of them to more accurately determine the location of the S-MMS **18**G with respect to the earth reference frame. Additionally or alternatively, the S-MMS **18**G SAC **302**B may use this information to improve mapping of objects and conditions on the situational awareness map as maintained by the tactical manager **527**.

(170) As previously disclosed (FIG. **14**), two S-MMSs **18**G, **18**H may communicate with each other via an ad hoc network. In an embodiment, the S-MMSs **18**G, **18**H may be equipped with an 802.11P transceiver in communication with their respective communications processors **216**, and their CNIs **371** are configured to manage 802.11P communications. In this way, the two S-MMSs **18**G, **18**H form a communication system comprising an ad hoc network for exchanging messages. The contents of messages transmitted from the two S-MMSs **18**G, **18**H may include information relevant to navigation. In one implementation, the messages may contain information on the current location and kinematic state of the respective S-MMS **18**G, **18**H. Additionally or alternatively, the messages transmitted from the two S-MMS **18**G, **18**H may share location and kinematic state of tracks each S-MMS is tracking. These tracks may then be translated by the receiving S-MMS **18**G, **18**H from a vehicle frame of reference to an earth frame of reference and added to or combined with existing tracks on the SAC **302**B situational awareness map maintained by the tactical manager **527**. In this way, two S-MMSs **18**G, **18**H can benefit from enhanced situational awareness though cooperative targeting of objects, conditions, and events proximate to each.

(171) In some embodiments, the S-MMS **18**G may be equipped with one or more sensors intended to determine the altitude (earth reference frame) or one or more earth centered direction cosines (geoid reference frame). These sensors may include an onboard barometer or altimeter. In one embodiment, an onboard altimeter reports earth-referenced altitude to the SAC **302**B via GPS and inertial manager **376** and/or navigation **363**. This information may allow the S-MMS **18**G to determine its location in a multistory building for improved navigation and coordinate with the S-MMS **18**H by transmitting that information to the s-MMS **18**H in one or more messages, thereby working cooperatively in the same multi-story building. Additionally or alternatively, altitude data

may be received by an S-MMS **18**G or **18**H from one or more messages transmitted from a paired smart device **1502** and/or off board beacon **1610**, in either case based on sensor readings from one or more sensors on the smart device and/or off board beacon that are included in the one or more transmitted messages.

(172) Best Route

(173) Precision navigation capabilities are strengthened when combined with the availability of high quality maps. Moving through new environments in an MMS can often be very challenging. Often ramps and elevators are out of the way, and if MMS users don't know which direction to go, they may end up getting lost or having to backtrack. For power chair MMS systems, oftentimes the handicap parking space is located across the parking lot from an accessible ramp. New buildings, let alone new cities, may be a daunting challenge in the unknown for an MMS user. Lack of familiarity makes navigation in new areas difficult, and often is very time-consuming. Without pre-existing knowledge of a route and accessibility in an area, an MMS user could easily be overwhelmed and ultimately lost or stranded. When an MMS user is moving through an outdoor environment, something as common as a gap in the sidewalk may be a complete roadblock, as some MMSs may tip if they encounter drop-offs as little as two-inches. Currently available maps do not provide the level of detail or information required for MMS users to plot accessible routes.

(174) The same sensors and advanced navigation and safety systems in the S-MMS **18** that allow it to avoid dangerous drop-offs and collisions may be additionally used to capture valuable data regarding accessibility, terrain, and preferred paths as users navigate through the environment. This data may be used both to create maps of areas that have not yet been mapped with the level of detail required for MMS users and to update areas that have already been mapped. Sensor data on sidewalks, interiors of public spaces, and parking lot hazards may be collected and stored by the S-MMS **18** and associated with one or more maps. The increased accuracy of dual mode variance readings, as previously disclosed (FIG. **12**), may aid in producing high quality maps. In some embodiments, the combination of camera data (e.g., via image sensor reports **374**) and distance data (e.g., via non-contact sensor and S&T sensor reports **372** or **373**) may allow the SAC **302**B to create extremely detailed 3D digital re-creations of locations and features based on the S-MMS **18** situational awareness map. The completeness and detail of these maps may vary based on the sensors available on the S-MMS **18**, the path of the S-MMS through the location, the amount of processing power assigned to the SAC **302**B, and the amount of memory **120** partitioned for use by the tactical manager **527**. Additionally or alternatively, a separate mapping function may be added to the S-MMS controller **1108** to manage mapping of locations. This may be incorporated as part of the SAC **302**B or separate from the SAC.

(175) In some embodiments, data associated with one or more S-MMS **18** sensors and part or all of the situational awareness map maintained by the SAC **302**B may be shared with remote services and servers **1510** (FIG. **15**). Additionally or alternatively, the data may be shared with a paired smart device **1502** as previously disclosed.

(176) FIG. **17** depicts an embodiment of an S-MMS **18**I wirelessly connected with a remote server **1510**B. The remote server **1510**B may be configured to accept information related to mapping and navigation from the S-MMS **18**I over a public packet network, such as the internet. Additionally or alternatively, the information related to mapping and navigation may be separated by a rules engine **1706** so that any personally identifiable information is stored as private data **1702**, and non-identifiable information is added to or merged with public mapping data **1704**. In an embodiment, received data may be further anonymized using published best practices for data anonymization by scrubbing data based on predefined rules **1708** or a program that modifies or mixes information (**1514**, FIG. **15**) prior to being placed in public data **1704**. In an alternative embodiment, data may be sorted and/or anonymized onboard the S-MMS **18**I prior to being transmitted to the remote server **1510**B. In some embodiments, public data relevant to navigation can be overlaid on, or included in, existing map programs, such as Google® maps or WAZE™′ adding significantly to the

resolution of the data available for a given location. In this embodiment, the S-MMS **18**I may connect directly to a service over a public packet network, or public data **1704** from a remote server **1510**B may be fed to a service or location for use by a 3rd party.
(177) As illustrated in FIG. **18**, as more S-MMSs **18**I-X navigate an area and upload their data, map(s) **1802** become more accurate and stay up to date. In some embodiments, users, S-MMSs **18**I, **18**X, and others may insert pins **1804**, much like on the current WAZE™ application, to alert others of new construction and other potential hazards that may affect accessibility of MMS users in an area (i.e. broken power-assist doors or elevators, cracks in the sidewalk, closed ramps, closed trails etc.). In some embodiments, the S-MMSs **18**I, **18**X may add such pins **1804** to a map automatically by detecting areas that S-MMS users must consistently avoid, areas that S-MMS users must consistently travel through, and/or by using feature recognition. In one embodiment, a machine learning engine **1710** on the remote server **1510**B by be configured to recognize and mark these features based on public data **1704** compiled from many users. Rules **1708**, such as a confidence level, may be established and enforced by a rules engine **1706** before public data **1704** is modified to include these new features. Whether an S-MMS **18**I automatically uploads map data and/or adds pins to map data (including uploaded data) or requires user input may be dependent on user preferences and/or settings. In some embodiments, an S-MMS **18**I may automatically and upload (optionally anonymously) map data to a remote server or service with or without added pins or alternately only upload pinned locations to the remote server or service.
(178) Smart MMSs **18**I may allow a user to find the most accessible route to their destination based on a combination of the onboard situational awareness map maintained by the situational awareness controller (**302**B, FIG. **5**), paired sensors or beacons **1610** (FIG. **16**B), and cloud based map data **1802** (FIG. **18**) as previously disclosed. In some embodiments, map data **1802** from one or more sources may be loaded in the S-MMS **18** system memory **120** and/or into the memory of a paired device **1502** such that a user may navigate an area using local map data even when they have no internet connection. In some embodiments, the S-MMS **18**I may utilize map information **1802** as an input to the drive path manager **529** (FIG. **5**) of the SAC **302**B to automatically direct an S-MMS **18** user to a location using the most accessible route. In some embodiments, the best route may be determined by the SAC **302**B (by the drive path manager **529** or otherwise) using one or more of time, accessibility confidence, elevation change, and safety as weighting factors. In some embodiments, users may adjust preferences and/or settings affecting how a best route may be determined. In some embodiments, an S-MMS may be capable of learning from trial and error and/or user input/data to shift weighting factors to provide better best route suggestions. The machine learning or rules engine required for this task may reside on the S-MMS controller **110**B or may be hosted on a remote server **1510**.
(179) S-MMS Mapping
(180) Whether an S-MMS **18** is connected to the cloud or not, it is capable of gathering data relevant to mapping and navigation. Many of the disclosed sensors used to avoid collisions and manage the stability of the S-MMS **18** (e.g., via reports **372-376**, FIG. **3**) create detailed profiles of the surroundings and ground around an S-MMS **18**. In some embodiments, other sensors may be incorporated to specifically improve mapping data acquisition. If the remote server **1510** is offline, mapping data may be saved to secure local memory **120** until such time as the S-MMS **18** reestablishes a network connection **1508** with the remote server. When mapping areas offline, the data gathered by the S-MMS **18** may be mapped with respect to the nearest or most recently known location to improve accuracy when the information is uploaded. While the mapping system is described as essentially cloud-based in some embodiments, it should be clear that the same principles may be applied to mapping applications that may never, or rarely, share information via the Internet.
(181) S-MMSs **18** equipped to continuously measure and evaluate their surroundings can create highly accurate maps of the accessibility of each location they traverse, as illustrated in FIG. **19**. As

multiple S-MMSs **18**I-K upload information, often mapped with respect to different known locations, a remote mapping system (e.g., hosted on a remote server **1510**) is able to receive the multiple streams of data (e.g., **1512**), overlay and fuse the information to eliminate outliers (e.g., via a computation engine **1514** and/or rules engine **1706**), and create a unified publicly available map **1902**, stored in a public data repository **1704**, for use by S-MMS systems **1506**, general caregivers **1544**, or smart devices **1532**. The map **1802**B then provides accurate up-to-date navigation information to users using the S-MMS **18** accurate frame of reference tracking previously disclosed.

(182) As a non-limiting example, mobile chair S-MMS **18** users navigate the world in a way that requires a wholly unique set of accommodations which can vary greatly between locations. In addition, each accommodation is likely used in sequence (e.g., from an accessible parking spot, to a sidewalk ramp, to a different ramp, to a power-assisted door). As mobile chair S-MMS users navigate the world, each link in each sequence is a potential roadblock, unknown to them until they or an assistant arrives at the next step. Detailed, continuous mapping and logging of these accommodations is important to relieving this uncertainty. In some embodiments, S-MMSs **18**I-K may be configured to automatically detect and catalogue any accessibility features **1904**, **1906**, and **1908** encountered while they are traveling. Automatic detection of accessibility features may be accomplished using one or more techniques currently used for facial recognition, including geometric, photometric, or 3D recognition. In some embodiments, feature extraction **530** on the SAC **302**B may utilize algorithms, including principal component analysis using eigenfaces, linear discriminant analysis, elastic bunch graph matching using the Fisherface algorithm, and the hidden Markov model to identify accessibility features. In an embodiment, sensor track fusion **500** may combine feature extraction **530** outputs with information from one or more non-contact sensor reports **372** and S&T sensor reports **373** for 3D recognition of accessibility features. In an embodiment, one or more machine learning engines (e.g., **1710**, FIG. **17**) may be used to identify accessibility features using published approaches, such as multilinear subspace learning or dynamic link matching. The totality of these measurements from S-MMSs **18**I-K, when combined as previously disclosed, creates a detailed map of not only the accessibility of a specific location, but of the sequence of locations through which a user must pass to their destination, which may be used by other S-MMSs **18**I-K navigating the same location. As an analogy, the sequence of these events to enter a building may be equivalent to road information provided for automobile navigation. In some embodiments, other systems and devices, such as wearable devices (wearables) or smart device applications, either associated with an S-MMS **18** or not, may contribute information to mapping **1802**B by transmitting their data to one or more S-MMSs or the remote server **1510**, and processed and/or stored as described above, and/or may host the mapping application(s).

(183) Indoor locations are a challenge to accurately map because they often change, are often densely populated with objects, and may require repeated scans in order to be mapped and kept up-to-date. S-MMSs **18** equipped to continuously sense and document their surroundings, as previously disclosed, can overcome these issues to create highly accurate and regularly updated maps of indoor locations. Not only can these maps be used to enable accessible S-MMS **18** indoor navigation, they can also be used by services like Apple's MapKit™ to create very accurate indoor navigation and wayfinding for everyone.

(184) In some embodiments, this mapping process may also be linked to 3D models of common objects such as chairs, tables, and doors that can be placed and associated on a map by either an S-MMS **18** user, a third party, or in an automated fashion to further refine indoor maps. Objects may be automatically created based on S-MMS **18** sensor data, custom modeled using a tool such as SketchUp™, or they may be retrieved from model databases such as GrabCAD™. FIG. **20** depicts an embodiment wherein the S-MMS controller **1108** of S-MMS **18**I uses one or more sensor reports (e.g., sensor reports **373** from a LIDAR and sensor reports **374** from a camera) to sense an

object **2050**. The object **2050** is assigned a track by the SAC **302**B and may be characterized as a chair by sensor track fusion **500** or by a machine learning engine **1710** (either onboard the S-MMS **18**I or on a remote server **1510**B) configured for object detection. Based on the characterization, the S-MMS **18**I then downloads a 3D chair model from a remote service or server **1510**C. The tactical manager may then associate this new data with the chair track, scale **2030** the 3D chair model to match the proportions of the measured object **2020** so that it takes up the same space as the physical object, and then place the object on the situational awareness map of the SAC **302**B. This process may result in the 3D chair model, scaled and placed on the situational awareness map, effectively filling in gaps **2050** in the S-MMSs **18**I awareness. In some embodiments, these objects may then be treated by an S-MMS **18**I as if they were physically present in the world and properly handled by the situational awareness control **302**B of an S-MMS **18**I. This data may be stored in local memory **120** and shared with the previously disclosed remote server or service used for public mapping **1510**.

(185) Socialization can be a challenge for MMS users, regardless of abilities or impairments. The act of mapping locations could be gamified to achieve both the complete mapping of locations more quickly and to encourage social interaction for S-MMS **18**I users. Most locations have high- and low-trafficked areas, and, motivated by gameplay, the completeness of mapping could be encouraged and rewarded. In one embodiment, a remote server **1510**B configured to generate public map data **1704** may enact rules **1708** in a rules engine **1706** which flag areas of low map **1802** quality. These areas may then be displayed to S-MMS **18** users via a paired smart device **1502**, to users or caregivers via a web interface **1542**, and to others via smart devices **1532** in order to encourage mapping of those areas. In an embodiment, players may earn points/experience/status/achievements/rewards based on where they map, how much total area they map, if they are the first to map an area, if they identify a new obstacle or accessibility feature, etc. Additionally or alternatively, the areas flagged by the remote server **1510**B may be communicated to S-MMSs **18**I proximate to the area of the flag. This information may be received via one or more wireless transceiver **216** onboard the S-MMS **18**I and communicated to the S-MMS controller **1108** via CNI **371**. In some embodiments, this may cause the S-MMS **18**I to alert the user via the HMI **352** or a paired smart device **1502** that a mapping opportunity is nearby. Additionally or alternatively, the sensor tasker **520** function of the SAC **302**B may cause the S-MMS **18**I to take additional sensor readings when passing through a flagged area and communicate that data back to the remote server **1510**.

(186) A remote server **1502** may be configured to transmit messages/data and receive messages/data to cause the games to be played on a receiving smart device **1502**, including for a user interface to be displayed on the smart device to display data for the game and allow inputs to the smart device for the game (such as the inputs described above) that are transmitted to the remote server for processing and response so the game can be played. Alternately, the games may be hosted in the hosted **125** or complex application space **130** of the S-MMS **18** (FIG. **1**), and the S-MMS controller **110**B then would be configured to transmit messages/data and receive messages/data to cause the games to be played on a receiving smart device **1502**, including for a user interface to be displayed on the smart device to display data for the game and allow inputs to the smart device for the game (such as the inputs described above) that are transmitted to the remote server for processing and response so the game can be played.

(187) Augmented reality (AR) may enhance gameplay to offer 3D games, such as Pacman, chasing aliens, or playing hide-and-seek with animals, in locations that need to be mapped. This ability may encourage movement into certain flagged areas for mapping, or may just enhance the enjoyment of the activity itself. FIG. **21** depicts an S-MMS **18**M paired to an AR device **2102** via a wireless link **2104**. In one embodiment, the CNI function **371** (FIG. **3**) is provisioned such that at least one wireless system is available to transmit and receive (transceive) data relevant to a desired operation of a mobile chair S-MMS **18**M. In one embodiment, an AR device **2102**, such as a smart device

running an AR application or a wearable such as MicroSoft HoloLens, communicates **2104** with the S-MMS **18**M via a communication processor **216** (FIG. **2**) of the S-MMS **18**M through one of 802.11, Bluetooth, Bluetooth Low Energy (BLE), Near Field Communication (NFC), and/or Zigbee™, among others. These communications **2104** are typically predicated on a “just works” model, one that requires little interface with the device **2102** and S-MMS **18**M and the underlying technology. The levels of security and privacy are device **2102**, OS, and wireless service dependent. In some embodiments, the AR device **2102** may communicate **2104** with the S-MMS **18**M via a wired interface. In some embodiments, the communications **2104** may be wireless and accomplished via a secure Bluetooth connection based on the HDP and MCAP standards included in the Bluetooth Core Specification herein incorporated by reference.

(188) Other activities may also, or alternatively, be gamified. For instance, completing regular exercises/physical therapy sessions or improvements in such activities could be rewarded in a game or game-like fashion. These game applications may be hosted in the hosted **125** or complex application space **130** of the S-MMS **18** (FIG. **1**) and communicate with the S-MMS controller **1108** via an API **135**. Activities that may normally be tedious or monotonous may be gamified to encourage the users to perform and to motivate them to excel with various points/experience/status/achievements/rewards. In some embodiments, the rewards may be one or more of based on the particular gaming environment (for the activity or chosen by the user), picked by the user from an assortment of different rewards, and personalized to motivate a particular user. Feedback, prompts, and input for the games may be provided via the HMI **352** or via a paired smart device **1502**.

(189) S-MMS user data may be characterized as HIPAA medical data or may be characterized as non-medical data. By default, all user data associated with a user account may be characterized as private and secure, including gaming and mapping data. However, this data may be shared in multiple ways. In some embodiments, a user may elect to share collected map data with a third party such as a mapping service or S-MMS manufacturer. This data may be disassociated from the user when shared. In some embodiments, the user may choose to share only certain mapping data on a transactional basis with third parties. For conditional or transactional data sharing, technologies such as block chain may allow for secure sharing and/or payment for data services provided. In some embodiments, the user and/or caregiver may set privacy settings and preferences globally in the system and/or per use, per application or application type. In these embodiments, the S-MMS controller **110**B and/or smart device **1502**, as the case may be, would implement the above-referenced technology in the messages/signals/communications/data it sends.

(190) Location Memory and Auto Return

(191) MMS users often frequent the same locations inside and outside the home. The effort and time of navigation to these frequent locations increases greatly for mobile chair MMS users and can increase more for those with cognitive or mobility impairments that impact the motor functions needed for steering. Simple navigation to frequent locations in one's own home can become both time-consuming and taxing for some MMS users, which directly impacts quality of life.

(192) The best route system, previously discussed, can assist users with autonomous navigation to frequent locations within a home, facility, or other frequently visited place. In some embodiments, the S-MMS **18** situational awareness controller **302**B has an awareness of predetermined locations or a history of recently visited locations. The S-MMS controller **1108** uses the SAC **302**B and navigation **363** to assist the user and speed their travel to a selected location. Users may select a destination using the S-MMS HMI **352** and/or the HMI of an associated smart device **1502**. HMI selection mechanisms may include a control button or input on the HMI, a voice command, or the selection of a destination from a list of predetermined locations. Additionally or alternatively, the S-MMS navigation **363** or drive path manager **529** of the S-MMS controller **1108** may make a rules based determination based on current location, direction, and possible destinations of possible locations to offer the user. Once a selection is made, the S-MMS **18** assists safe navigation to the

selected destination, helping speed up the trip and lowering the burden of driving on the user. Autonomous navigation is managed by the drive path manager **529** of the SAC **302**B based on information received from navigation **363** and other S-MMS systems previously disclosed. The motor controller **351** responds to commands from the SAC **302**B to drive motors and actuators.

(193) The S-MMS **18**I may learn from the user's behavioral history and may begin to anticipate the user. In some embodiments, S-MMS **18**I navigation history may be sent to a remote server **1510**B where one or more of a rules engine **1706** or machine learning engine **1710** may identify and flag frequently visited locations. This information may be stored as private data **1702** on the remote server, or it may be transferred to S-MMS **18**I onboard memory **120**. In an embodiment, the rules engine **1706** or machine learning engine **1710** may be hosted on the S-MMS controller **1108**. In an embodiment, the drive-path-manager may look for flagged locations in the private data **1702** proximate to the current path. Those locations may then be offered to the user for selection via the HMI **352** or a paired smart device **1502**. In some embodiments, the rules engine **1706** may look for correlations between locations and other factors, such as time of day. For instance, if a user regularly travels to the kitchen for lunch at 12 PM, the S-MMS controller **110**B may guide them there when the user turns in that direction around that time period. In some embodiments, the user may be presented with the suggestion by the S-MMS controller **110**B and choose yes or no to activate the automatic guidance or not. Based on the previously disclosed approach, the S-MMS controller **1108** may be capable of determining when the user is differing from their usual behavior, such as if the S-MMS controller detects the location as other than home at 12 PM, and the S-MMS controller will not suggest travel to the kitchen at that time.

(194) Motion Memory and Parking Assistant

(195) Motorized mobile systems can be difficult to repeatably navigate due to the imprecision of the steering mechanism (e.g., a joystick or steering bar) and the lack of an ability (for some systems) to move directly sideways. In addition, frequent locations for parking often have a relationship to another object and/or activity, including parking next to a toilet to allow toileting, parking in a van or truck in order to be tethered to anchor points, and parking next to a bed, among others. These frequent parking locations can require precise position and maneuvering to provide the appropriate proximity for access or the exact location for tethering in the vehicle scenario. Precision is required for access for the desired location, but the proximity often requires careful maneuvering. This precision movement and alignment is important and time-consuming.

(196) An S-MMS **18** may aid with parking at common locations by assisting with speed and alignment. Assistance, in some embodiments, may include full autonomous positioning and in other embodiments may simply constrain user inputs to within a predefined error term of an ideal track established by the drive path manager **529** of the SAC **302**B. In an embodiment, an S-MMS controller **1108** may utilize an SAC **302**B (FIG. **5**) along with one or more of the previously disclosed precision navigation techniques, location memory and precision map data to navigate to a predefined parking location. This embodiment requires that the S-MMS controller **1108** stores the required parking orientation at that location. This data may be stored either onboard S-MMS **18** memory **120** or on a remote server **1510**. By combining the previously disclosed techniques, a parking assistant implemented by the S-MMS controller **1108** may eliminate the need for the user to precisely maneuver by automating tasks. The S-MMS **18** prevents misalignment through its understanding of the correct positioning at that destination, and speeds parking by recognizing the safe path to, and any obstacles near, the desired parking location. In some cases, the S S-MMS controller **1108** may enter an automated parking mode where the S-MMS controller takes over and controls the S-MMS **18** to park more quickly and precisely and reduce strain on the user. The automated parking mode may store information about common parking areas and/or it may be able to perform common actions in known and/or new locations using sensor data.

(197) FIG. **22** illustrates a typical path and the motions required to successfully park a mobile chair S-MMS **18**N inside an accessible van **2220**. In an embodiment, a parking assistant implemented by

the S-MMS controller **1108** may respond to external, wireless signals and may transmit one or more wireless signals via one or more communications processors or transceivers **216**. Using the parking assistant, a user may take advantage of many of the capabilities of the disclosed S-MMS **18** in a fluid process. As the user approaches the van **2220** they may be prompted via the HMI **352** or a paired smart device **1502** to confirm that they are heading to the van **2220**. The SAC **302**B of the S-MMS controller **1108** may recognize the van **2220** based on user input, image recognition, location, patterns of use, and/or wireless ad hoc communication (e.g., such as WAVE™ as previously disclosed). If parking mode is confirmed, the S-MMS controller **1108** may transmit one or more wireless communications **2230** to a control system of the van **2220** to cause one or more of automatically unlock the van if the user is authorized, open the door, and lower the automatic ramp **2240**. Wireless communication may include an ad hoc network or RF signals. As the ramp **2240** touches down, the S-MMS **18**N user may confirm that they wish to use the parking assistant and the S-MMS controller **1108** may cause the S-MMS **18**N to automatically drive up the ramp **2240** and follow the path and motions **2250** depicted to position itself relative to attachment point(s) **2260** in the vehicle. The path and motions may be calculated and executed uniquely each time by the drive path manager **529** of the SAC **302**B to position the S-MMS **18**N relative to one or more objects or references available at the location. As a non-limiting example, one or more of the image sensors may be tasked by the sensor tasker to monitor for the attachment point(s) **2260** (e.g., tie down straps) using feature extraction **530**. These “landmarks” may then be used to develop the drive path **2250** to be used by the -MMS controller **1108**. Additionally or alternatively, the SAC **302**B may be configured so that once the S-MM **18**N is positioned in a location proximate to the target, the S-MMS controller **1108**, in coordination with the motor controller **351**, executes a predefined series of motions retrieved from memory **120**.

(198) FIG. **23** illustrates the use of one or more optical or retro-reflective targets **2330** to assist in S-MMS **18**N positioning. Placing targets **2330** allows the S-MMS **18**N to position itself quickly and with high precision in a wide variety of settings. As an added benefit, targets **2330** may be used as an approximate reference point for positioning for non-MMS users. As a non-limiting example, a vinyl sticker **2330** with a predefined pattern may be placed at particular coordinates relative to a handicap accessible toilet **2320**. Data may be associated with the particular pattern or pattern and location combination. The unique pattern may be associated with a location, a function, a message, or set of desired S-MMS **18**N actions that may assist in positioning the S-MMS **18**N in relation to the target **2330**. This information may be stored onboard S-MMS memory **120**, may be uniquely associated to an individual user and stored as private data **1702**, or maybe accessible public data **1704** retrieved by the SAC **302**B from a remote server **1510**.

(199) The MMS controller **1108** is capable of recognizing the positioning target **2330**. In one embodiment, one or more onboard image sensor reports **374**, received by the SAC **302**B, are processed in feature extraction **530**, and the target pattern is recognized by one or more of the pattern recognition processes previously disclosed (FIG. **19**). Positioning may still be assisted by use of other onboard sensor reports **372-376** (FIG. **4**) as well as data referenced or provided by the target **2330**. In an embodiment, SAC **302**B sensor fusion **500** associates the target **2330** identified by feature extraction **530** as part of the object track, in this case a toilet **2320**. This association of the target and the object data serves as an alternative approach to dual mode variance, wherein a positioning target proximate to the object is used as an extension of the object to provide information on the location or a track to the SAC **302**B and increase the accuracy of the situational awareness map maintained by the tactical manager **527**.

(200) Targets **2330** may take many forms and include standardized targets that are used in public settings to increase accessibility for S-MMS **18**N users. Additionally or alternatively, custom targets **2330** may be used that users may purchase or print and place at locations of their choosing to assist with positioning tasks of their choosing. In some embodiments, the targets **2330** may be recognized objects in the surroundings, such as a particular piece of furniture or decoration in a

home rather than a sticker. In some embodiments, targets **2330** may take any form that is recognizable by the S-MMS controller **1108** of the S-MMS **18**N, including certain objects, artwork, stickers, decals, and patterns such that the targets may blend with the overall aesthetic of the location they are in.

(201) In some embodiments, targets **2330** may incorporate or be replaced by RFID chips, Bluetooth beacons, or other computer readable chips, such that they may be recognized by, and transmit their coordinates to, the S-MMS controller **1108** wirelessly as previously disclosed for general, precision indoor navigation.

(202) Transfer Assistance

(203) Transfers to and from an MMS are common and critical for users. As a non-limiting example, therapists spend months with new mobile chair MMS users breaking down transfers, moving into a car, moving to a toilet, and/or switching to a couch or chair. Each piece of that journey becomes part of a routine that, when improperly done, can lead to serious injury. If an MMS user's seat is positioned slightly wrong for a transfer, it changes distances and balance points that they have practiced and rely on. These changes often lead to falls. But even if the user doesn't fall, they may strain or pull muscles in the attempt to correct for an initial positioning error.

(204) A transfer mode allows S-MMS **18**N users to have more control and confidence when transferring to and from their S-MMS. FIG. **24** illustrates a common transfer situation. As a non-limiting example, consider a user positioning their S-MMS **18**N next to a chair **2420** that they plan to transfer to. This situation is unique from tables and desks, because rather than pulling forward, toward the interface, users often approach from the side and then transfer sideways to the chair **2420**. The user must position the S-MMS **18**N seat **2440** both vertically (h) and horizontally (d) in relation to the target chair **2420** with high accuracy. The parking assistant, as previously disclosed, may assist the S-MMS **18**N user in accurately achieving the desired horizontal distance (d). Using the transfer mode, the S-MMS controller **1108** may automatically adjust the seat position (e.g., by sending control signals to the motor controller **351** after determining the height from sensor reports **371-374**) to match the vertical height of the adjacent seating surface **2430** or maintain a predefined vertical height difference (h) per the user's settings for easier transfer. Seat height of the adjacent seating surface may be determined using one or more onboard, non-contact sensors **372**.

(205) In an embodiment, as the S-MMS **18**N approaches the chair **2420**, or other target transfer surface, the user may select transfer mode via the S-MMS HMI **352** or a paired smart device **1502** and indicate the transfer target **2420**. With this information, the S-MMS controller **1108** SAC **320**B may send control signals/commands to the motor controller **351** causing the S-MMS **18**N to autonomously pull within a maximum preferred transfer gap (d) of the transfer target **2420**. This gap (d) may be unique to each user and stored in memory **120** as part of a unique user profile. In addition, the S-MMS controller **1108** may position the S-MMS **18**N per settings in relation to the transfer target **2420** front to back. The S-MMS controller **1108** may then adjust the seat **2440** height in relation to the height of the adjacent seating surface **2430** for easier transfer. In one example, the S-MMS controller **1108** repeatedly receives and processes sensor reports to determine a current distance away from the transfer target **2420** and transmit control signals/commands to the motor controller **351** causing the S-MMS **18**N to autonomously pull within the maximum preferred transfer gap (d) of the transfer target **2420**. Similarly, the S-MMS controller **1108** repeatedly receives and processes sensor reports to determine a current height of the seating surface **2430** of the transfer target **2420** and transmit control signals/commands to the motor controller **351** causing the seat **2440** height to be moved to the correct height relative to the adjacent seating surface **2430**. In one embodiment, additional non-contact sensors **2450**, such as an infrared or ultrasonic sensor, is mounted in a location such as the armrest of the chair so that the height of a transfer seating surface **2430** may be measured relative to the S-MMS **18**N seat **2440**. Most S-MMS users prefer to transfer from a higher to a lower seating surface, so the user may preprogram a preferred height differential (h) so that the S-MMS controller **1108** of the S-MMS **18**N provides a personalized optimal transfer

when the mode is activated. Similar to the previously disclosed approach mode, the S-MMS controller **1108** of the S-MMS **18**E may also be programmed and the settings for common transfer locations can be saved in local **120** or remote **1510** memory, in some embodiments.
(206) Additionally or alternatively, the transfer mode may be configured to automatically modify other seat settings and/or deploy transfer aides. In order to ease the transfer process, transfer mode on the S-MMS controller **1108** may be configured to automatically control any powered systems available on the S-MMS or via the motor controller **351**. For example, for S-MMSs **18** that have powered, self-lifting arm rests, activation of the transfer mode may automatically raise the armrest that is directly adjacent to the selected transfer target. S-MMS **18** with active suspension systems may be configured to have the S-MMS controller **1108** automatically lower or stiffen the suspension of the S-MMS **18** to assist in stability during the transfer. In some embodiments, S-MMSs **18** may include transfer assistance devices, such as extra grab bars or sliding support rails. When available, use of such features may be linked to the transfer mode being engaged, and their activation may be controlled by control signals sent from the S-MMS controller **1108**.
(207) Once a transfer is complete, the transfer mode may automatically reconfigure the seat to settings selected for transfer back into the S-MMS **18**N. The S-MMS controller **1108** may confirm that the transfer is complete by ensuring there is no user present. This may be accomplished by confirming that no weight or force is sensed on the S-MMS **18**N based on user sensor reports **375** received by the SAC **302**B, by tracking proximity of a paired wearable sensor in communication with the CNI **371**, or any other means. A user may set the S-MMS **18**N via the S-MMS controller **1108** to lower the height of the seat to just below the height of the surface they are transferring from for ease of transferring back to the S-MMS **18**N at a later time.
(208) Approaching-Objects and Furniture
(209) For many MMS users, collision is a way of life. Tables, desks, chairs, and most of the objects in their daily life have been designed without them in mind. Even good drivers run into things, often damaging their MMS and their surroundings. What isn't often considered is the toll that this takes on users physically as they smash toes, knees, and fingers on the objects they run into.
(210) It is not always enough for an S-MMS **18** safety system to behave in accordance with the spatial requirements of the S-MMS **18** itself and avoid hard collisions. In some embodiments, the S-MMS **18** may also take the user into consideration. As an example, positioning a mobile chair S-MMS **18** in front of a table requires the user to pull up to the right location (front-back) with high precision. This is often difficult with existing steering HMIs **352** like joysticks. In addition, since table heights differ, the user may have to position the S-MMS **18** seat vertically (up-down) to the right level as they approach the table. Often switching between positional control (front-back, left-right) and seat height control (up-down) requires multiple user button presses and actions via the HMI **352**. If any of these directions are inaccurate, then the user's hands, fingers, or knees may run into the table. Even worse, often times they will get pinched between the table and the S-MMS **18**. This is a simple example of existing conditions for many MMS users, and it ignores other user preference settings like seat back positioning which may be different for setting at a desk versus at a dinner table.
(211) An approach mode on an S-MMS **18** allows the user to get close enough to use or interact with common objects (e.g., desks, tables) as needed, but prevents injury of the user or damage to the object by preventing contact on both approach and exit of the S-MMS. This feature is illustrated in FIG. **25**. As the mobile chair S-MMS **18**N approaches a table, desk, bar, or other object with an overhang **2520**, the situational awareness controller **302**B of the S-MMS controller **1108** detects the object **2520** based on one or more sensor reports **371-374** and positions the seat height to match the object height (generally per user history, general recommendations, and/or user preferences associated with a user profile stored in memory **120**). This is unique from a typical collision avoidance system that would simply stop the S-MMS **18**N user from approaching the table or other object **2520**. For this reason, the user may need to activate the approach mode

behavior either as an always on feature or per event via a voice command, gesture, or other HMI **352** input. This feature frees the user to focus on positioning the mobile chair S-MMS **18**N close enough to the table or desk **2520** without worrying about injury.

(212) For convenience, and because users will tend to use the same tables and desks or other objects **2520** often, the positioning system can be set to remember specific locations or types of objects as previously disclosed. As the S-MMS **18**N approaches a known location or object type, the S-MMS controller **1108** may auto adjust based on memory **120** without user intervention. The S-MMS controller **1108** can remember both preferred seat settings and preferred front-back position to the object **2520** so that the S-MMS controller may automatically stop at the preferred spacing and adjust for comfort of the user. Approach mode may rely on a combination of sensors previously disclosed. Additionally or alternatively, additional sensors **2502** or **2504** may be utilized. In some embodiments, one or more sensor reports (e.g., **2502**) may be provided to the S-MMS controller **110**B by one or more sensors embedded in a pair smart device **1502**.

(213) In some embodiments, the S-MMS controller **110**B may take into consideration both the extents of the S-MMS **18**N and the location of the driver's knees, fingers, elbows, and other leading features (e.g., via data of those locations stored in memory and retrieved by the S-MMS controller, by sensors on the S-MMS placed at or focused on those locations as described herein and transmitting sensor reports of those locations to be used as inputs in the processes of the S-MMS controller, or otherwise). If a problem is detected by the user at any point, they can take over control of the S-MMS **18**N. In some embodiments, a verbal command such as "stop" may halt the automated activity at any point in the process. To further safeguard the user, additional safety checks may be activated during approach maneuvers that are intended to sense and avoid soft impacts. Sensors on the seating system, or other locations, may sense if a force is detected in a place where force is not expected during a maneuver and pause the maneuver.

(214) FIGS. **26**A and **26**B illustrate a non-limiting example placement of such sensors **2630** and **2660** to measure forces on the arm rest **2610** and footrest **2640** of a mobile chair S-MMS **18**N. In the event that a soft impact force F is detected, the S-MMS **18**N may halt or slowly back away from the object being approached, which may impact one or more of those areas, and await further instructions from the user. Users may set preferences for how the S-MMS **18**N should react in such situations. This functionality can also be linked to user health systems, such as electrodermal activity tracking devices or heart rate devices capable of sensing user pain if available and paired with the S-MMS **18**N.

(215) The approach mode may be further enhanced on S-MMSs **18** equipped with motorized accessories. As a non-limiting example, FIGS. **27**A and **27**B depict a self-retracting control unit **2710**. The depicted example self-retracting unit **2710** moves out of the way automatically when the approach mode is engaged. In this example, a sensor on the self-retracting unit **2710** or a device attached to the self-retracting unit transmits one or more sensor reports to the S-MMS controller **110**B. The S-MMS controller receives and processes the sensor reports from the self-retracting control unit **2710** to determine the self-retracting control unit will impact an object **2720** and transmits a control signal/command to the self-retracting control unit instructing the self-retracting control unit to retract. The self-retracting unit **2710** receives and processes the control signal/command from the S-MMS controller **110**B and, in response thereto, retracts an arm or other member of the self-retracting unit. This keeps the user from having to manually reposition the unit in order to pull in close to a table or desk **2720**. It also provides a clear indicator that the autonomous approach mode has been engaged. As a further benefit, the actuators used to move the unit may also be used to sense any unexpected forces that might indicate pinching or soft impacts enhancing the previously disclosed safety checks for approach mode.

(216) Call and Send to Charge

(217) An S-MMS **18** may be its user's access point for their entire world, both inside and outside the home. As a non-limiting example, a user of a mobile chair S-MMS requires their S-MMS to be

within a certain proximity to transfer off and onto the S-MMS. Whenever the user is not on their S-MMS, it must be close by when the user wants to change locations, or the S-MMS must be brought to them by someone else. Not being in proximity to their S-MMS puts the user at risk if mobility is needed for safety reasons and degrades the quality of life and independence of the user if they cannot attend to their personal needs or desires because the location of the S-MMS does not allow transfer.

(218) Due to the importance and frequency of transfers, a mobile chair S-MMS **18**N may be programmed with the needed proximity to the user for a successful transfer (e.g., using the previously disclosed transfer mode functionality), which would allow the S-MMS to safely gain this proximity to a previously visited or preprogramed location based on the previously disclosed auto-return functionality combined with precision navigation capabilities of the S-MMS controller **1108**. Combining these functions, a user currently not in their S-MMS **18** may command their S-MMS to come to their location and park within the proximity required for transfer. These commands may come in many different ways, including voice, direct input, hand signal, or other methods of input through the HMI **352** or a paired smart device **1502**.

(219) The location of the user may be determined by the S-MMS **18** in a number of manners. The simplest manner being data stored in a memory **120** of the last time that the user was detected on the S-MMS **18** by the SAC **302**B, e.g., based on user sensor reports **375**. As a non-limiting example, weight sensors embedded in the seating system may add a waypoint to the S-MMS situational awareness map at the location that user weight is no longer detected in the seat. Additionally or alternatively, a location of the user may be determined based on the location of a wearable device or other device configured to transmit a beacon signal for detection by one or more communication processors **216** on the S-MMS **18**. In an embodiment, the S-MMS controller **110** may use signal strength of the beacon to detect the user.

(220) Managing the charge of battery powered S-MMSs **18** is critically important. The safety of the user relies on a fully functional S-MMS **18**, which must be sufficiently charged to function as designed. FIG. **28**A depicts a charging station **2802** located across a room from a bed **2804**. In this example, the location of a charging station **2802** may not be within a safe proximity for the user to transfer to another location (e.g., the bed **2804**) while the S-MMS **18**N charges. In one embodiment, the location of the charge station **2802** has been marked by the user on their private map data **1702** stored on a remote server **1510** or onboard **120**. Based on one or more of the navigation and location determination techniques previously disclosed, the S-MMS controller **110**B navigation **363** function is aware of the S-MMS **18**N current location and its proximity to the charging station **2802** and may control the S-MMS to travel to the charging station from the bed **2402** and/or to the bed from the charging station at a preset speed or an optional speed determined by input to the HMI **352** (e.g., by causing one or more commands to be sent from the S-MMS controller to the motor controller **351**).

(221) As illustrated in FIGS. **28**A and **28**B, the user may transfer to their bed **2804** at the end of the day and then command the S-MMS **18**N to go to its charging station **2802** from its current location. In the morning, the user may command the S-MMS **18**N to return to the bed **2804** within a proximity required to transfer back onto the S-MMS **18**N. When paired with a wireless or robotic charging system, this functionality allows significant freedom and confidence for the user. These commands may be input using any one or more different methods, including voice, hand signal, or other methods of input through the HMI **352**, paired smart device, wearable, and/or application **1502**.

(222) Avoiding People and Animals

(223) The disclosed systems and methods allow an S-MMS **18** to avoid people and animals. Consider that motorized mobile systems often navigate and move in a distinct way, at a different speed, and occupy a very different footprint from the people or animals around them. This unique behavior, combined with the power and weight of a typical MMS, make awareness and avoidance

of people, animals, and other things that move on their own important to the safety of both the S-MMS **18**O user and those moving around it. As opposed to simply avoiding collisions with other automobiles in generally open environments like an automobile, the S-MMS **18**O needs to watch for and avoid toes and tails, sometimes in tightly constrained spaces. S-MMS collision avoidance systems may be much more accurate than existing automobile systems. The disclosed SAC **302**B (FIG. **5**) combined with the dual mode variance techniques disclosed (FIG. **12**) and careful attention to frames of reference and conversion error (FIG. **13**) lay the foundation for collision avoidance with the required accuracy for an S-MMS **18**.
(224) S-MMSs **18** are often used in environments where people are in extremely close proximity. People can walk erratically and, when moving around an S-MMS, can be positioned where the user cannot see them or their toes. Depending on the abilities of the user, they may not have an awareness of those around them as they navigate their S-MMS **18** because of many factors, like a person who is moving quickly to pass them, is sitting, is short, is a child, or has moved from one side of the S-MMS to another. The disclosed SAC **302**B with tactical manager **527** and threat assessor processes **528** (FIG. **5**) enhance situational awareness of the user by creating and maintaining a situational awareness map that can then be used by the drive path manager **529** and alert manager **540**.
(225) In some embodiments, the S-MMS controller **1108** is aware of people and animals (unique tracks) positioned or moving close by. The SAC **302**B on the S-MMS controller **1108** may recognize movement, and cause the motor controller **351** to react to that movement in the safest way possible, including slowing, stopping, or changing direction of the S-MMS **18**. Additionally or alternatively, the user may be alerted via the HMI **352** of the location of people, animals, and objects positioned close by. As a non-limiting example, the SAC **302**B on the S-MMS controller **1108** may slow down the S-MMS **18** to protect individuals in the vicinity. Additionally or alternatively, the alert manager **540** of the SAC **302**B may emit audible or visual warnings, using HMI **352** provisions such as lights and speakers, to those around the S-MMS **18** to make them aware that the device is within close proximity.
(226) Wireless Identification
(227) FIG. **29** illustrates an embodiment of an S-MMS **18**O in which a non-user (e.g., caregiver, service animal, technician, or other partner) may wear a wearable device **2904**, such as a wrist band, necklace, ring or other accessory, with an embedded transceiver configured to communicate wirelessly **2902** with the S-MMS controller **1108**. Additionally or alternatively, a caregiver or other individual may use their smart device (e.g., watch or smart phone) as the “accessory” if equipped with the proper transceiver and application. The wearable device **2904** transceiver may be configured to use one or more of the following means of communication **2902**: Active or passive RF, Bluetooth, IEEE 802.11 based Wi-Fi communication, multiple low-rate wireless personal area networks (LR-WPANS) based on IEEE 802.15.4 including ZigBee, MiWi, and Wireless HART, or, near field communications (NFC) protocol based on ISO/IEC 18092.
(228) The applicable standards are herein incorporated by reference in their entirety.
(229) As a non-limiting example, a caregiver, may wear a wrist band wearable **2904** with an embedded RF transceiver. The transceiver may be passive or active, with active transceivers allowing longer-range communication but requiring a power source, such as a battery. When the wrist band wearable **2904** comes within range of the S-MMS **18**O, the signals **2902** from the wrist band are received by a communications processor **216** onboard the S-MMS **18**O and the contents of the signal may be routed to the S-MMS controller **1108** via a security processor or arbitrator **212**. The detected presence of the wrist band wearable **2904** may cause the SAC **302**B to operate uniquely.
(230) Animal Partner Example
(231) An S-MMS **18**O may respond uniquely to individual people or animals and at a level of refinement not typically needed by existing autonomous systems. This may be accomplished by

marking their tracks on the situational awareness map maintained by the SAC **302**B and associating their track with unique threat assessor **528**, drive path manager **529**, or collision manager **526** behaviors on the SAC **302**B (FIG. **5**). As a non-limiting example, service animals are common companions to S-MMS **18** users. Socialization, interaction, and finding community can be challenging for those with limited mobility, and service animals many times provide companionship to those who use an S-MMSs. There are special training programs to prepare service animals to safely work around mobile chair MMSs. However, an S-MMS **18**O may also be trained to work as a team with a service animal. In some embodiments, the S-MMS **18**O recognizes its service animal partner and treats them differently than other animals or people. One example of this behavior may include the ability to for the S-MMS **18**O to follow the service animal on command.

(232) An example, illustrated in FIG. **30**, is for the service animal **3010** to have the ability to "nudge" the mobile chair S-MMS **18**O and redirect it by taking specific positions (say getting close to one side of the S-MMS **18**O) while the user is driving. This behavior is unique and may only be engaged when a known service animal is recognized. Service animal control mode may be turned on or off by the user via the HMI **352**, in some embodiments. In some embodiments, it is engaged automatically when the animal **3010** is in range. The S-MMS **18**O may recognize the service animal by a special smart collar or addition to the service animals' vest **3030**. The collar or vest **3030** may include a transponder or transceiver which uses one or more of the wireless protocols previously disclosed to transmit a signal to the S-MMS **18**O. S-The MMS controller **1108** receives and processes the signal to determine one or more actions are to be taken (e.g., move the S-MMS forward, backward, left, or right, or generate an alert for example) and transmits one or more control signals/commands to the motor controller **351**, HMI **352**, and/or other S-MMS **18**O component as described herein to cause the one or more actions to be taken. Additionally or alternatively, the S-MMS controller **110**B may use onboard cameras to recognize people and animals visually using on or more of the previously disclosed feature recognition approaches including use of badges or tags **2330** worn by the animal or individual **3010**. In one embodiment, an S-MMS **18**O receives a signal from an active RF transmitter embedded in a dog vest **3030** worn by the service animal **3010** via one or more communication processors **216** on the S-MMS **18**O. The presence of the service animal signal is communicated to the SAC **302**B via CNI **371** which causes the SAC **302**B to task image sensors **520** on the S-MMS **18**O to take 360-degree data. Feature extraction **530** is used to recognize a unique pattern (e.g., a QR code) on the animal's vest which has been pre-associated with that animal. When recognized, sensor track fusion **500** may associate the bearing location of the animal **3010** with range data received from other sensors (e.g., **371-373**) and associate the track with the animal's unique identity code or flag. The tactical manager **527** may then place the identified track on the situational awareness map and the unique identity code may notify other functions (e.g., collision manager **536**, drive path manager **529**, threat assessor **528**) to react to the individual track of the service animal **3010** using a unique, preconfigured, set of control instructions or rules. This same concept of unique behavior for unique individuals may extend to the way the S-MMS controller **110**B reacts to specific caregivers, coworkers, trainers service animals, or other individuals. Unique behaviors may include, but are not limited to, allowing individuals to get closer to the S-MMS **18**O before taking evasive action, following the individual, allowing the individual to nudge the direction of travel of the S-MMS **18**O, or modification of any behavior of the motor controller **351** or HMI **352**.

(233) Turn and Look

(234) For MMS users, social norms like maintaining eye contact and facing the speaker during conversations may not currently be possible without assistance or manually maneuvering their MMS. This not only distracts from engagement in the conversation, but may be a challenge for users who have diminished motor function or cognitive impairments that delay reactions. As illustrated in FIGS. **31**A and **31**B, the S-MMS controller **110**B of an S-MMS **18**O may assist user

engagement when conversing and interacting by automatically orienting the user to face individuals with whom the user is engaged. The drive path manager **529** of the SAC **302**B allows the S-MMS **18**O to safely orient itself when in close proximity to people or objects. Moreover, in some embodiments (FIG. **5**) the SAC **302**B may have an accurate situational awareness map of those in the immediate vicinity, their location, and their relative position to where the S-MMS **18**O (i.e. user) is facing. Turn and look functionality allows the S-MMS **18**O to be directed to face different individuals with minimal or no effort on the part of the user.

(235) When turn and look is enabled on the S-MMS controller **1108**, the SAC **302**B may use onboard cameras (e.g., image sensor reports **374**) and microphones (e.g., non-contact sensor reports **373**) to add information to the tracks of individual people, determining whether they are speaking, if they say any key words, and to locate their faces. In an embodiment, microphones associated with one or more onboard sonic sensors may be temporarily retasked to sample ambient noise. Additionally or alternatively, one or more dedicated microphone sensors may be added to the S-MMS **18**O for use with this system. For example, the MMS controller **1108** may receive and process a sensor report from a microphone to determine one or more actions are to be taken (e.g., move the S-MMS in a direction to face the front of the S-MMS toward the detected sound, for example) and transmit one or more control signals/commands to the motor controller **351** as described herein to cause the one or more actions to be taken. When combined with proximity and location information already identified with each individual's track on the situational awareness map maintained by the tactical manager **527**, this allows enhancement of the existing situational awareness map of nearby individuals with information on their direction of interaction (which way they are facing).

(236) In some embodiments, in its most basic form, the user may simply flick their HMI **352** input device (for example, a joystick) in the direction of an individual they wish to speak with and the S-MMS controller **1108** will receive and process a signal from the HMI indicating the direction and reorient the S-MMS **18**O to face the nearest individual in the chosen direction. HMI **352** input devices may include a series of buttons or a joystick that is used to select individuals to direct the user towards. Another type of user interface is a map of the recognized individuals to be displayed on the screen of a paired smart device **1502** so that the user can simply select the person they would like to speak with.

(237) Turn to look mode may alternatively or additionally have an automatic setting, which with minimal or no input from the user automatically faces the S-MMS **18**O towards an individual based on one or more predetermined criteria stored in memory **120**. The S-MMS **18**O may allow the use of onboard microphones to detect a person's name and automatically turn the user to face that person, in some embodiments. For example, the MMS controller **1108** may receive and process a sensor report from a microphone to determine one or more actions are to be taken (e.g., move the S-MMS in a direction toward the detected name, for example) and transmit one or more control signals/commands to the motor controller **351** as described herein to cause the one or more actions to be taken. This behavior may be filtered by voice code so that, for example, the S-MMS controller **1108** will react when a mother or father calls the name of a child in an S-MMS **18**O but will not react similarly for anyone else.

(238) Additionally or alternatively, the turn of turn and look functionality may be triggered by other signal sources such as light, sound, or wireless signals received from a certain direction. For any of these signal sources the signal may be recognized based on one or more of presence of the signal, signal frequency, sequence or pattern, or intensity.

(239) Crowd Navigation

(240) Navigating in a crowd is often particularly difficult in an MMS. Driving an MMS effectively lowers a user's field of view, making it difficult to see a destination past the crowd. This works both ways, so that the crowd perceives the MMS location as a hole in the crowd. Adding to the challenge of visibility as the crowd presses in, it can become extremely difficult to maneuver the

MMS without colliding with or injuring nearby individuals. For MMS users, crowds can be both dangerous and intimidating. What is needed are novel methods to allow MMS users to confidently and safely visit crowded environments like sporting events, community events, and amusement parks.

(241) The situational awareness controller **302**B of the S-MMS controller **1108** may assist in crowd navigation. The increased confidence in situational awareness provided by dual mode variance accuracy (FIG. **12**) and the other navigation approaches disclosed herein are critical to the ability to operate and avoid collisions (e.g., collision manager **526**) in a tightly constrained crowd situation. By providing real-time ground mapping and dynamic anti-tip features, the stability manager **525** allows S-MMS **18** users to focus on avoiding and following the crowd rather than worrying about safety. This somewhat reduces the cognitive load on the user. Furthermore, the stability manager **525** of the SAC **302**B may allow users of S-MMSs **18** with significant seat lift or stand capability to drive confidently within bounds defined by the drive path manager **529** and enforced by the S-MMS controller **1108** while elevated.

(242) These things significantly aid the user, but do not fully solve the problem. At a certain crowd density, the S-MMS tactical manager **527** and or threat assessor **528** processes may become overwhelmed by the number of objects, or tracks, in the environment or the number of unique objects identified may be so close together as to effectively form one object. Additionally or alternatively, even in less dense crowds, an S-MMS user may want to simply follow along with the general flow of the crowd. For those reasons, a crowd following mode may be included in the S-MMS controller **1108**. While this and other modes or functions disclosed are embodied as included on the S-MMS controller **1108**, it is clear that these modes and functions may alternatively or additionally be deployed via an API **135** which communicates with the S-MMS controller and is hosted in one or more application spaces **125**, **130**.

(243) FIGS. **32**A and **32**B illustrate an example of crowd interaction with an S-MMS **18**P. Crowd following mode, when enabled, may cause the tactical manager **527** of the SAC **302**B to group multiple detected threats, or tracks, into zone reports with associated kinematic properties on the situational awareness map and create a map of “free space” **3202** around the S-MMS **18**P. This map of free space **3202** may be incorporated as part of the situational awareness map or may be maintained as a separate entity. Crowd following mode may then cause the drive path manager **529** to engage an alternative set of flock based rules stored in memory **120**. These rules may include one or more published flocking algorithms. Rather than trying to navigate to a specific location, the S-MMS controller **110**B may use onboard sensors to follow the flow of people and keep the S-MMS **18**P moving.

(244) In one embodiment of flock based rules, the SAC **302**B may establish and hold some basic rules. These may include matching the speed of the zone movement in front of the S-MMS **18**P, maximize/equalize space between the S-MMS **18**P and the free space on either side, or other published flocking algorithms. This mode may be triggered manually via the HMI **352** or a paired smart device **1502** or offered to the user when the tactical manager **527** or threat assessor **528** has determined that a significant number of tracks are being detected. An operator may choose to manually override the autonomous operations by the S-MMS controller **110**B at any time, in some embodiments.

(245) FIG. **33** illustrates crowd navigation enhanced by integration of the previously disclosed best route system. Users may select both crowd following and location based navigation systems at the same time (e.g., via the HMI **352** or a paired smart device **1502**) so that the S-MMS **18**P may move towards a selected target location, along an accessible route, while navigating the flow of traffic in a crowd. As a non-limiting example, an S-MMS user may select a target end location for the S-MMS **18**P to navigate to autonomously from a map on their paired smart device **1502** while the S-MMS **18**P is surrounded by a moving crowd of people. This selection is communicated to the S-MMS controller **110**B at which point the SAC **302**B drive path manager **529**, in coordination with

navigation **363**, determines the optimal accessible route (as illustrated in FIG. **33**). Additionally, the tactical manager **527** recognizes that the user is surrounded by a moving crowd and alerts the drive path manager **529** and threat assessor **528** to switch to crowd navigation mode. Based on this, the drive path manager **529** may adjust its navigation approach. Rather than taking the ideal accessible route or following the direction of travel of the crowd (Traffic D.sub.TRAVEL in FIG. **33**), the drive path manager **529** may cause motion across the main flow of traffic in a crowd by adjusting standard flocking rules. In an embodiment, the drive path manager **529** may cause one or more signals/commands to be transmitted to the motor controller **351** to cause the motor controller to engage the steering and drive of the S-MMS to drive on the edge of the detected free space **3202**A in the direction of desired travel in order to create space in the crowd. In some embodiments, this edge following behavior may also be activated when the user inputs manual steering inputs into the HMI **352** while in crowd mode.

(246) As a way to enhance the user experience, an amusement park or stadium may integrate their navigation, mapping, and crowd management systems with the S-MMS **18**P through an API. This both enhances the user experience via a more accurate and easy way of finding information for destinations and enhances the facilities management by using S-MMSs **18**P to provide real time crowd density and flow information.

(247) Auto Queueing

(248) Queuing can be another tedious task for MMS users. Parks, stadiums, and other facilities can simplify this process by providing auto-queuing guidance to S-MMSs **18**, for example, through an application loaded in memory **120** and accessing the S-MMS controller **1108** via an API **135**. In some embodiments, the park may install special symbols such as a machine readable QR code, floor or wall markings, or a coded sequence of lights that instructs S-MMSs **18** as to how they should behave in a queue. In one embodiment, an S-MMS **18** equipped with one or more cameras may use feature extraction **530** on the SAC **302**B to evaluate image sensor reports **374** for special symbols. When recognized by feature extraction **530**, sensor track fusion **500** may alert the drive path manager **529** and cause the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS and/or cause the HMI to provide feedback or take another action. Additionally or alternatively, auto-queuing information may be transmitted wirelessly to the S-MMS using one or more of the previously disclosed methods, such as Bluetooth. This allows a user to cease manual operation while queuing and have the S-MMS controller **1108** simply and automatically guide the S-MMS **18** through the queue (e.g., onto a ride or into a stadium). In some embodiments, S-MMSs **18** may be guided through queues by other wireless means, such as those disclosed for wireless ID of individuals and animals and or turn and look functions.

(249) For locations where auto-queuing as previously disclosed might not be available, the user may pull into a queue and then select a feature to follow a queue autonomously. FIG. **34** illustrates an embodiment of this functionality. In an example, many queues are separated by fabric lines **3420**. In an embodiment, an S-MMS **18**P user may select queuing mode via the HMI **352** or on a paired smart device **1502** when entering a queue. Via one or more of the input methods (for example using a touch screen on a paired smart device) the user may select the fabric line **3420** from an image. Based on their selection, the drive path manager **529** of the SAC **302**B may combine a wall-following algorithm based on the selected reference with collision avoidance functionality (e.g., collision manager **526**) which maintains a distance to d **1** to the next person in the queue **3410** and a distance d **2** to the divider **3420** to provide hands-free operation in a queue. The selected reference may be recognized by feature extraction **530** from image sensor reports **374** using one or more of published edge detection, feature recognition, and/or color recognition techniques.

(250) In some embodiments, S-MMS users may be guided through a facility, queue, ride or other activity by augmented reality overlays (FIG. **21**) provided by a facility so that navigation may still

be partially or completely manually controlled by the user within one or more parameters.

(251) Augmented, Situationally Aware Reality

(252) The mobility MMSs enable freedom for their users. This freedom of choice, and the independence it enables, comes with a requirement of new skills and responsibilities. As an example, new users of an MMS now have control of a device that can cause injury to others, and they must develop new skills to operate the MMS safely. Users who struggle to develop the necessary control of their device may find it taken away or their freedom limited. New MMS users need training and encouragement to safely operate their systems.

(253) In some embodiments, one or more cameras may be located on the S-MMS **18**. These cameras may be used to provide the user with a view of the areas around and behind them (e.g., via a display that is also mounted on the S-MMS **18**). In this example, image data is communicated to the S-MMS controller **1108**, such as via a communication interface of the CNI **371**, and the S-MMS controller **1108** generates an image display via video or still images to the display. Alternately, one or more displays may be connected directly to one or more cameras. Moreover, based on ambient conditions, the image display may be filtered or otherwise modified by the S-MMS controller **1108** for purposes of enhancing user situational awareness. Examples of such modification by the S-MMS controller **1108** include filters that highlight contrasts, transitions in the image, and/or filters such as infrared filters to assist with night driving.

(254) As previously disclosed (FIG. **21**), the S-MMS **18** may be configured to pair with virtual reality (VR) or augmented reality (AR) systems. In one embodiment, this capability is used to provide safe, secure training. Training scenarios or programs may be either pre-programmed (e.g., included in memory **120** of the S-MMS **18**) or downloaded to the device from one or more remote servers **1510** as desired. In some embodiments, these scenarios may utilize specific features and capabilities of the S-MMS controller **1108**, motor controller **351** and/or HMI **352** accessed via an API **135**. Data related to the training plan, progress, and level of the user may be stored in a secure memory **120** on the S-MMS **18** and on a secure memory on a remote server **1510** in some embodiments. Additionally, data associated with the user may be associated with a unique individual user profile. The training programs may allow unique behavior of S-MMS **18** controls while still maintaining and being subservient to the critical safety systems (e.g., collision avoidance **526** and stability management **525**) of the SAC **302**B.

(255) A training simulation may involve working the controls (e.g., HMI **352**) of the S-MMS **18** to complete exercises. In an embodiment, the game application may consist of game logic hosted on a complex application space **130** which is set up by a parent, or otherwise configured based on a desired goal. The S-MMS **18**, in some scenarios in concert with an application running on a smart device **1502** and/or sensory device(s,) such as a headset **2102**, is guided by the user through an augmented or virtual world to achieve a desired outcome, training, or encouragement. In some embodiments, with an AR device **2102**, a user could drive a course and collect virtual coins that they see in AR, or navigate to avoid virtual obstacles like cones, puddles, alligators, chairs, etc. that are projected on the real environment inside the AR device **2102**. The S-MMS controller **110** may respond to virtual objects like it would those objects in the real world, allowing the user to learn safe proximity to objects in all directions. The training could progress in difficulty, allow users to achieve different levels, or encourage repeating exercises or training levels that are not successfully completed. In some embodiments, the achievement of levels or tasks in an augmented or virtual training simulation may unlock new real features, settings, or performance levels on the user's S-MMS. As a non-limiting example, the S-MMS **18** maximum speed may increase after completing a predefined number of levels.

(256) In some embodiments, these or similar AR and VR programs may be used to periodically test a user's capabilities over time to analyze for any changes in their overall skill level, reaction time, and other metrics. This data may be very useful in analyzing changes in a user's overall health and ability especially, for instance, if the results of the tests degrade regularly over time. User result

data may be stored and associated with an individual user profile and may be treated as ePHI.
(257) AR may additionally or alternatively be used as a behavioral incentive system. S-MMS **18** users may be encouraged to navigate to locations by having a target set by another person or system. As a non-limiting example, if a parent **1544** wanted their child to drive an S-MMS **18** toward their van so they could go to school, the parent could set the van as the target either via a web interface **1542** or smart device **1532**, and the user would see (via AR) a path to the van. The user could navigate, with the S-MMS controller **1108** correcting back to the path determined by the drive path manager **529** of the SAC **302**B with a predetermined amount of assistance, or no assistance, depending on settings and preferences. A score may be kept and rewards or feedback given during the trip or at the destination for levels of achievement based on how well the user controlled the S-MMS **18** compared to an ideal path as determined by the drive path manager **529**.
(258) These same or similar AR and VR capabilities may be utilized for general gaming. Socialization may be a challenge for MMS users. Inclusion, contribution, and community all derive from, or are reliant on, socialization of some kind. Games like Pokémon Go show that gaming outside the home is a real, powerful, communal activity. Gaming with an S-MMS **18** offers opportunities for S-MMS users and non-users to share in common activities in the same environment. However, location-based gaming relies on the accessibility of the location to the player. The SAC's **302**B real-time understanding of the accessibility of the S-MMS gamer's surroundings allows a game hosted on the S-MMS **18** to modify gameplay so all game elements are available to the player within the accessible area proximate to the S-MMS. Accessibility awareness opens up the game to all users equally, ensuring complete inclusion in the game community.
(259) While the safety systems of the disclosed S-MMS controller **1108** maintain situational awareness of the surroundings, the user may have limited access to this awareness until a S-MMS controller action is triggered. Providing enhanced user awareness of potential accessibility or safety issues provides them with more information about their surroundings sooner.
(260) Early awareness of potential stability, collision, and/or health issues helps the user grow in independence by relying less on the S-MMS controller **1108** to intervene. In addition, it may allow users to create safer plans and more efficient manual navigation routes and maneuvers. Awareness may be delivered to the user in many ways via the HMI **352**, including through voice assistants like Siri™, or as visual cues overlaid on the real world through AR. Paired AR equipment (FIG. **21**) allows the display of visual warnings overlaid on the real environment. These warnings may take many forms, including highlighting or spotlighting dangerous conditions, displaying preferred paths, or displaying navigation instructions to a predetermined location. In one embodiment, paired AR glasses are used to display an overlay of the situational awareness map, maintained by the tactical manager **527** of the SAC **302**B, onto the view directly in front of the user. Additionally or alternatively, one or more routes determined by the drive path manager **529** may be displayed on the AR glasses. A critical use is to provide information about unsafe conditions before the actual danger or condition is imminent. In some embodiments, only data deemed critical to the user (e.g., by threat assessor **528**) is displayed. This may include the ability to reduce (rather than add) the amount of visibility and information available to the user. Additionally or alternatively, by accelerating the display of concerns, users who are driving fast S-MMSs **18** or those with cognitive impairments that delay reaction time would be able to better navigate.
(261) In an embodiment, in concert with turn and look mode, connected wearables may be utilized to assist with navigation tasks. An example of this is the pairing of smart glasses such as Google Glass **2102** with an S-MMS **18**M. When the user turns their head, the S-MMS controller **1108** may automatically pivot the S-MMS **18**M to match where the user is looking. While eventually items such as Google Glass may be common, many individuals may want a less conspicuous solution. For those users, the disclosed system may be configured work with “Navigation Accessories”. These accessories may include things like baseball caps, hair ribbons, or other accessories with embedded IMU sensors and wireless transceivers that allow similar navigation functionality with

discrete, stylish concealment.

(262) Navigation Support

(263) The autonomous or semi-autonomous parking assistance implementation described in FIG. **22** may be further enhanced using one or more optical or retro-reflective targets **2330** to assist in S-MMS **18**N positioning. In an exemplary embodiment the target is a graphical tag or fiducial where a fiducial is a marker used as a reference in measurement, navigation, or alignment. A fiducial may also include encoded information about its function or properties in some embodiments. In computer vision and image processing, fiducial markers or landmarks are special features or patterns used for object tracking, camera calibration, and/or image alignment. Graphical fiducials may also be called tags or boards.

(264) FIG. **35** depicts non-limiting examples of graphical tags or fiducials that may be included on an optical target, such as an ArUco marker **3505**, a collection of multiple ArUco markers **3510**, concentric circles **3515**, or parallel bars **3520**. In an example, a fiducial is comprised of six, unique ArUco markers that are arranged into a grid to form a single fiducial **3510**. The addition of multiple unique markers is not required, but it may be useful to provide one or more of additional information about the fiducial function or properties during feature extraction, increased confidence of positive identification of the fiducial if one or more of the markers is covered by debris or obscured by light conditions or otherwise obscured, and/or more precision or confidence in parameters calculated from the fiducial by combining multiple measurements from individual unique markers.

(265) FIG. **36** depicts a camera **3605** of an S-MMS **18**N where a fiducial **3510** is within the field-of-view of the camera. In this example, the fiducial **3510** represents the target, however, the target may be any suitable optical target or combination of targets in various possible examples. The camera **3605** may be a camera of the S-MMS **18**N sensor system as previously disclosed (e.g., **610**, **1210**) or may be a dedicated camera tasked for the purpose of fiducial recognition. When a fiducial **3510** enters the field of view of a camera **3605**, one or more image sensor reports **374** are received by the SAC **302**B, processed by the feature extraction **530**, and the fiducial pattern may be recognized by one or more pattern recognition processes of the feature extraction.

(266) The pattern recognition processes of feature extraction **530** involve identifying and classifying patterns in images using algorithms and/or machine learning techniques. The general process for recognizing patterns in the image involves preprocessing, extraction, classification, and may involve post processing, in some embodiments. The raw image data is preprocessed to remove noise, enhance contrast, and normalize illumination to make it easier for the algorithms to recognize patterns. The image is then analyzed to extract relevant features or characteristics that can distinguish different patterns or objects, such as edges, corners, textures, colors, or shapes. This is done using some combination of convolution, Fourier transforms, or wavelets. The one or more extracted features are then classified or labeled using machine learning algorithms such as neural networks, support vector machines, or decision trees. In some instances, these classification models may use training data to learn the patterns and relationships between features or characteristics and the class and then apply this knowledge to new images to make predictions. Finally, the output of the classification model may then be post processed to refine the results, remove false positives, or combine the results of multiple classifiers or other sources of information. Post processing may involve clustering, filtering, or smoothing.

(267) Feature extraction **530** may output one or more of the presence or lack of presence of a fiducial (e.g. **3510**), a unique identifier of a recognized fiducial, and/or other key parameters of the fiducial. The key parameters of the fiducial include the size, skew, location, or any combination thereof of one or more elements of the fiducial. FIG. **37** depicts an exemplary feature extraction **530** process. On a received image sensor report, a whole, or part of the received image may be searched to detect the presence of a potential fiducial **3710** within the image. The search for the presence of fiducial function may not run on every sensor report received and may be idle for

periods of time. In one embodiment, the search function **3710** runs every second on a sample frame from one or more cameras. Computer vision corner detection techniques may be used to detect the corners of the one or more features or markers of the fiducial with a Harris corner detector, Shi-Tomasi corner detector, or other detection algorithm. If no fiducial is detected, then the process restarts with a new sensor report. If the corners of a fiducial have been detected **3720**, the homography between the image and fiducial is estimated using a Direct Linear Transform (DLT) or RANSAC algorithm to determine if the detected fiducial matches a valid or expected fiducial **3730** based on one or more parameters of the fiducial matching the parameters of an expected fiducial retrieved from memory. This step may additionally include filtering to remove false positives. If the fiducial is a valid fiducial **3740**, then feature extraction **530** additionally uses one or more parameters of the fiducial (e.g., size and skew determined as part of the homography) to calculate the pose of the fiducial **3750**. The pose is the 2D or 3D position and orientation of the fiducial relative to the sensor (e.g., FIG. **8**) or vehicle (e.g., FIG. **9**) frame of reference. The homography estimate is used to calculate the pose of the fiducial in the correct frame of reference via several mathematical transforms.

(268) The output of feature extraction (e.g., the presence or lack of presence of a fiducial, a unique identifier for the fiducial, one or more parameters of the fiducial, a pose of the fiducial, or combinations thereof) may be sent to STF **500** for combination with one or more other sensor reports, may be provided to navigation **363** for localization, may be sent directly to the tactical manager **527** or alert manager **540** for processing, calculation, and use by the SAC **302**B, or any combination thereof in various possible examples. Additionally or alternatively, one or more or the outputs of feature extraction may be used to set one or more states or modes of operation **3760** of the S-MMS.

(269) FIG. **38** depicts an overheard view of an S-MMS **18**N traveling towards an accessible van ramp **3805** with a fiducial **3810** that is placed at the bottom, right corner of the ramp. The parameters of the fiducial **3810** are stored in memory **120** of the S-MMS and the unique identifier of the fiducial is associated with a bottom-right-corner of a ramp, although the unique identifier may be located at any location on or near the ramp with associated parameters stored accordingly. The fiducial is within the field of view of one or more cameras (e.g., **630** of FIG. **6**) of the S-MMS **18**N. An image sensor report **374** is generated and/or received and feature extraction **530** of the SAC **302**B identifies the presence of the fiducial, determines the unique ID of the fiducial based on one or more features of the fiducial, and/or uses one or more parameters of the fiducial to calculate the pose of the fiducial. The presence of a fiducial with a unique ID **3710** and its pose may then be used to develop a drive path **2250** to be used by the S-MMS controller **1108**. Additionally or alternatively, the presence, or lack of presence, and/or pose of a fiducial may be communicated to the tactical manager **527** of the SAC **302**B to change the drive behavior of the S-MMS by adding, removing or modifying tracks. Additionally or alternatively, the presence or lack of presence, and/or pose of a fiducial may be communicated to the threat assessor **528** of the SAC **302**B to change the drive behavior of the S-MMS by changing the priority of one or more tracks or transmitting one or more request to the sensor tasker **520**. Additionally or alternatively, the SAC **302**B may be configured so that once the S-MMS **18**N is positioned in a location proximate to the fiducial, the S-MMS controller **1108**, in coordination with the motor controller **351**, executes a predefined series of motions retrieved from memory **120**. Additionally or alternatively, the presence of a fiducial with a unique ID **3710** may be received from feature extraction **530** as an input to the alert manager **540** of the SAC to generate one or more signals to one or more speakers, lights, other HMI **352** elements, or combinations of the same which cause them to generate sounds, lights, haptic feedback or other user notifications based on a rules engine or other calculation of the alert manager.

(270) In one embodiment, a Ramp Assist feature of the S-MMS Controller **110**A uses one or more sensors of the S-MMS (e.g., **630**) and one or more processors (e.g., **202**) of the S-MMS to identify

and assist users in navigating ramps **3705** marked with one or more fiducial **3710**. The ramp described in this example is a ramp into an accessible van, but the ramp may be any accessible ramp including indoor and outdoor ramps, curb cuts, and/or those in accessible vans, busses, homes, and facilities. Ramps are hard to navigate in a wheelchair and many ramps are about the same width as the user's wheelchair. A single caster-flip can be enough to knock a chair off-center of the ramp. That makes it hard for users to confidently drive-up narrow ramps. Ramp Assist uses the one or more fiducials on the ramp to trigger automated assistance and extra positioning accuracy to automatically drive users up a properly marked ramp.

(271) FIG. **39** depicts multiple fiducials **3910-3920** installed on a ramp **3930** to be navigated by the S-MMS. In an embodiment, the ramp assist function uses fiducials (e.g., **3910-3920**) to recognize the ramp as a ramp, to identify the edge of the ramp, and to automatically engage and disengage S-MMS behavior. In this embodiment, fiducials are installed in a manner to be correctly interpreted. For example: Install all fiducials on the right-hand edge of the ramp (or some standardized position on the ramp) so that the right edge of the fiducial is aligned with the far-right edge of the ramp when viewed from the bottom of the ramp. The fiducial closest to the ground **3910**, (i.e., the first fiducial on the ramp) is a unique fiducial (e.g., identifier #1 as shown). Place one fiducial at the bottom, right corner of the ramp **3910** and another fiducial at the top, right corner of the ramp **3920**. The spacing between fiducials is less than D (e.g., 2.5 feet) of maximum fiducial spacing. If the bottom and top corner fiducials are more than D apart, add more fiducials along the right edge of the ramp, approximately equally spaced so there is a fiducial at least every D feet.

(272) In the example of FIG. **39**, the presence of one or more fiducials may cause sensor track fusion **500** to alert the drive path manager **529** and cause the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS and/or cause the HMI to provide feedback or take another action. The detected presence of a first fiducial **3910** may cause the S-MMS controller to begin sending one or more control messages. The detected presence of a second fiducial may cause the S-MMS controller to stop sending one or more control messages. The lack of presence of one or more fiducial may additionally or alternatively cause the S-MMS controller to start or stop sending one or more control messages. Additional fiducials in between a start and stop fiducial may be used to confirm feature and/or provide additional positioning accuracy while in specific feature mode.

(273) Ramp Assist may also provide auto-driving of the S-MMSs **18**, for example, through an application loaded in memory **120** and accessing the S-MMS controller **1108** (e.g., via an API **135**). The user may install fiducials or images of fiducials, such as a machine readable QR codes, floor or wall markings, a coded sequence of lights, or combinations thereof that instructs S-MMSs **18** as to how the S-MMS should behave on a ramp. In one embodiment, an S-MMS **18** equipped with one or more cameras may use feature extraction **530** on the SAC **302**B to evaluate image sensor reports **374** for symbols or fiducials. When recognized by feature extraction **530**, sensor track fusion **500** may alert the drive path manager **529** and cause the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS and/or cause the HMI to provide feedback or take another action.

(274) Ramp Assist is a function of a motorized mobile system (MMS) comprising a camera to detect a fiducial, where the fiducial is an optical or retro-reflective target within the field of view of the camera. The camera provides one or more image sensor reports to a processor. The processor receives the one or more image sensor reports and uses one or more feature extraction techniques to identify the presence or lack of presence of a fiducial. Responsive to determining the presence of a fiducial, the processor uses one or more feature extraction techniques to identify a unique identifier for the fiducial, one or more parameters of the fiducial, a pose of the fiducial, or combinations thereof. FIG. **40** depicts a flow chart of an exemplary driver assist process where operating modes

and functions are determined by one or more properties of a detected fiducial. In this example, a fiducial associated with a ramp is detected and the drive assist state **4010** is selected based on one or more properties of the detected fiducial (e.g., at step **3760** of FIG. **37**). The last state **4015** of the system, one or more properties of the fiducial and its pose **4020**, and any relevant user inputs **4025** may be used by one or more calculations and processes of the drive assist state. On entering the state for the first time **4030**, one or more operating parameters of the S-MMS may be set **4035** based on the unique identifier, one or more parameters, and/or pose of the fiducial. Additionally or alternatively, one or more actions may be taken by the S-MMS where an action may be to enable or disable one or more features of the S-MMS (e.g., change the operating parameters of one or more sensor, turn lights no or off, enable or disable sensors, mov). Additionally or alternatively, a mode of operation may be selected for one or more system of the S-MMS or a function may be executed. In an example, the driver profile and speed may be automatically set, the headlines turned on, one or more operating parameters of a camera may be adjusted, and/or the seating assembly of the S-MMS may be modified when entering the ramp assist state for the first time. The presence or lack of presence of a fiducial may cause the processor of the S-MMS to trigger enable, disable, or modify runtime settings in memory.

(275) Once the operating parameters for the ramp assist state are set **4035**, the correct operating mode for ramp assist is determined **4040**. In this step, one or more calculation or rules-based determination is made to select the proper mode of operation of the ramp assist feature. In an embodiment, the potential modes of operation may include approach **4045**, adjust **4050**, and exit **4055**. To determine which ramp assist mode to set **4040**, the drive path manager **529** (or other process of the SAC) calculates the location of the S-MMS relative to the pose of the fiducial **4020** or calculates, using one or more parameters and/or pose of the fiducial, a vector or distance to a set point or location. If the distance to the set point and/or location is in an acceptable range (e.g., retrieved from memory **120**), but the S-MMS is not yet aligned with the ramp, then the approach mode of operation is selected **4045**. If the distance to the set point and/or location is within an acceptable range and the S-MMS is aligned with the ramp, the adjust **4050** mode of operation is selected. If the distance to the set point and/or location is not in an acceptable range, the ramp assist state is exited **4055**. Each mode of operation may include one or more process which cause the processor to send one or more signals (e.g., to the motor controller) which cause the S-MMS to move from its current location towards the calculated set point or location.

(276) Ramp Assist HMI

(277) FIG. **41** depicts an embodiment of a human machine interface which provides one or more indications to the user of the S-MMS based on a detected fiducial. The user interface may comprise a speaker **4105** to play audio indications, series of lights to display state **4110-4125**, and a button **4130** for user input. In some embodiments, a microphone to sense, process, and respond to voice commands and/or a screen for more detailed visual feedback may be included. When drive assist state **4010** is active, one more processes of the SAC causes the processor to send one or more signals which cause the HMI of the S-MMS to provide one or more indication to the user of the S-MMS. In an exemplary embodiment, when drive assist state **4010** is entered, an audible warning of “Ramp Detected” is played through the speaker **4105**, and the lights indicating state **4110-4125** begin to play a repeating, chasing pattern to indicate that ramp assist is active. In this embodiment, if at any time while ramp assist is active, the user presses the button **4130**, then ramp assist state may be exited **4055**.

(278) FIG. **42** depicts a user interface for ramp assist on a paired mobile device or local user interface. Referencing FIG. **15**, in an embodiment, a processor of the S-MMS **18**F may be coupled wirelessly or via a wire with a smart device **1502**, for example, via Bluetooth or serial over USB. The connection to the S-MMS allows access to one or more APIs of the S-MMS which provides data to an interface application on the connected device. The interface application is stored on memory of a smart device communicatively coupled to the S-MMS controller **110** and executed by

the processor of the smart device. For this example, the application receives data and/or control information to the S-MMS controller **110** and may send data and/or control information to the S-MMS controller to change settings and/or cause actions of the S-MMS via the API. The depicted interface application comprises a representation of the S-MMS **18**Q, the possible zones of motion of the S-MMS **4205**, the ramp **4210**, an indication of the user **4215** and/or computer **4220** inputs to the system, a visualization of obstacles in the environment **4225**, and one or more button or zone used to activate, deactivate, or modify one or more operations of the S-MMS **4230**. This user interface may only become available when ramp assist is active in some embodiments.

(279) Approach Function

(280) FIG. **43** depicts an S-MMS **18**N near a ramp **3805**, preparing to run the approach operation **4045** of drive assist **4010**. The goal of the approach operation or algorithm is to align the user's S-MMS parallel with the base of the ramp and near a center line of the ramp. The S-MMS may then begin traversing the ramp while substantially aligned with the ramp following the approach operation. In the embodiment shown, the ramp **3805** has a fiducial **3810**A placed at the bottom right corner. The fiducial has an associated origin **4305**, while the S-MMS **18**N also has an associated origin **4310**. The goal of the approach operation is to move the S-MMS **18**N from its current location to a new location at which the S-MMS origin **4310** aligns up with a target **4315**. In an embodiment, the target or goal location **4315** is determined as an offset of the fiducial origin **4305**, where the offset is determined such that the S-MMS **18**N will be approximately centered with the centerline of the ramp and the front edge of the S-MMS will be lined up with the bottom edge of the ramp when aligned. In this way, the offset may be directly related to the length and width (track) of the S-MMS. One or more calculations or processes of the approach algorithm may therefore cause the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS and/or cause the HMI to provide feedback or take another action.

(281) FIG. **44** depicts a logic diagram depicting a ramp assist approach function. This example provides for the S-MMS to navigate to a center point of the ramp autonomously from any position near the ramp. A key feature of the system and method described is the flexibility to operate even as the ramp moves from place to place relative to an earth centric frame of reference. In this example, the approach function **4045**A uses one or more of the target or goal location **4315**, fiducial data and pose **4020**, user inputs **4025**, and navigation inputs **4405** to cause the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and/or drive of the S-MMS and/or cause the HMI to provide feedback or take another action. The first step of the function is to calculate the distance to the goal **4410** and the angle to the goal **4420** from the current position of the S-MMS, such as with the example of the goal is shown on FIG. **43**. The results of these calculations may then be checked against one or more rules to determine if they are acceptable goals **4430** for approach **4045**A. If the distance or angle are not accepted or otherwise feasible, then the operation may 1) exit ramp assist or 2) enter adjust **4050**. If the distance and angle are accepted, then the approach operation begins a three-step process that includes calculating and executing an initial turn from the ramp **4440**, calculating and executing a linear drive **4450**, and calculating and executing a turn back to the ramp **4460**. After these steps are completed, the process starts over again until the system either exits ramp assist or enters the adjust **4050** mode of operation. The set point logic is meant to allow navigation to a ramp even if the S-MMS start position is relatively close or even behind the ramp. There are multiple alternative methods to accomplish the approach operation to the ramp.

(282) FIG. **45** depicts an example geometry for the approach process to calculate the distance to the goal **4410** and the calculated angle to the goal **4420** based on the pose **4020** determined from one or more data or parameters of the fiducial or tag **3810**B (i.e. by Feature Extraction **530**) and the target **4315** set by the approach function **4045**A based on one more rules, offsets, or calculations

completed based one or more data or parameter of the fiducial. To calculate the distance to goal **4410**, the coordinates of the goal **4351**A and S-MMS **18**O relative to the fiducial **3810**B are used. To get distance to goal, the Pythagorean theorem may be used. Calculating the angle to goal **4420** function is accomplished in two steps, in one embodiment. For example, the perpendicular angle from the S-MMS **18**O origin to the center line of the ramp may be determined. Angle theta may be calculated based on the distance to get the S-MMS **18**O perpendicular with the ramp **3805**A. This calculation may consider both positive and negative Euler readings based on the pose of the tag **3810**B, which may change sign based on a turn direction of the S-MMS. The difference from 90 degrees (perpendicular) is calculated and output from the calculate angle to goal **4420** function. The second step of the angle to goal function is to find the angle to the set point **3515**A (e.g., omega plus theta). Angle omega is calculated by the inverse tangent of the remaining Y distance to set point divided by the chair x distance. Omega and theta are then summed together (with sign) to get the resulting angle needed to travel to be oriented with set point. The calculated distances and angles are then checked against acceptable limits and combinations to see if they are acceptable goals **4430** for approach **4045**A. Examples of acceptable goal checks may include limits to the distance to goal (both maximum and minimum), limits to theta, limits to omega, or the combination of any of the above to avoid excessive turning in a non-ideal direction, and or exclusion of areas around the ramp from feature engagement based on reference to the fiducial location **3810**B.

(283) FIGS. **46**A-C depict the three drive states of the approach function if the calculated approach goals are accepted **4430**. In one embodiment, once the approach operation is engaged, the system becomes a state driven sequence, operating through the three-step sequence of: turning from ramp **4440** in FIG. **46**A, driving towards goal **4450** in FIG. **46**B, and turning back **4060** to the ramp in FIG. **46**C. The initial turn from the ramp is designed to get the S-MMS **18**N facing the goal **4315**. In this example, one or more calculated angles are used to calculate a desired motion (A) where the desired motion is used (e.g. by a PID controller of the drive path manager **529**) to cause the S-MMS controller **110**B to send one or more control messages to the motor controller **351** to cause the motor controller to engage the steering and turn the S-MMS until it has turned to the position depicted in FIG. **46**B. The next step is to drive forward which is used to get the S-MMS origin **4310** on the center axis of the ramp. To accomplish these one or more calculated angles and/or distances, a calculated desired motion (B) is determined where the desired motion is used (e.g. by a PID controller of the drive path manager **529**) to cause the S-MMS controller **110**B to send one or more control messages to the motor controller **351** to cause the motor controller to engage the steering and drive the S-MMS until it has moved to the position depicted in FIG. **46**C. After the S-MMS has successfully driven forward, the S-MMS turns back to face the ramp. In this example, one or more calculated angles are used to calculate a desired motion (C) where the desired motion is used (e.g. by a PID controller of the drive path manager **529**) to cause the S-MMS controller **110**B to send one or more control messages to the motor controller **351** to cause the motor controller to engage the steering and turn the S-MMS until it has turned so that the S-MMS origin **4310** is properly aligned with the goal **4315** and the S-MMS is ready to drive up the ramp. If there is a successful alignment, then one or more rules of the approach function **4045**A are executed to accept goal **4430** to check if the S-MMS can exit the approach operation so that other functions (e.g., adjust **4050**) can take over. One or more of the calculations and processes previously described above may additionally or alternatively use one or more outputs from navigation **363** such as S-MMS orientation, velocity, and/or position **4405** to assist in the calculation of desired motions and execution of the desired motions by the S-MMS controller **1108**. At any given stage of the processes described, the system may use pose data from one or more fiducial **4020** and/or navigation data **4405** (e.g., from an IMU). The determination to use fiducial data or navigation data may be determined if a fiducial is in frame as managed by the controller. However, the system may navigate without a fiducial in frame during one or more operations of the process. This blind navigation may be accomplished with input from encoders, visual or point-cloud based localization

techniques (i.e., SLAM), IMU tracking, and/or dead reckoning provided by navigation **363**. Additionally or alternatively, outputs from navigation **363** may be combined with localization data derived from one or more fiducials (e.g. outputs from calculate pose **3750**) to enhance S-MMS localization and precision driving capabilities. While the previously described processes involve navigation to a single target location or goal, other embodiments may use the processes described to navigate to two or more target locations in succession in some embodiments. Approach (e.g., **4045**A) may additionally or alternatively be used in part or in whole to accomplish other automated tasks for the S-MMS user, such as navigating to a marked parking position (reference FIG. **23**), navigating to an ideal transfer position (reference FIG. **24**), parking under a table at a goal position (reference FIG. **25**), for automated navigation to a charging position (reference FIG. **28**), and/or navigation to a known location in a queue (reference FIG. **34**) in some embodiments.

(284) Referencing FIG. **23**, the approach operation may be used to navigate to any marked position where a fiducial, optical, or retro-reflective target **2330** is within the field of view of one or more onboard image sensors. The sensor report **374** may be received by the SAC **302**B and processed by feature extraction **530**, which outputs fiducial data and pose **4020**. An approach function **4045**A uses one or more of the target or goal locations **4315**, fiducial data and pose **4020**, user inputs **4025**, and/or navigation inputs **4405** to cause the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS and/or cause the HMI to provide feedback or take another action. The one or more control messages may be unique to the specific fiducial, as identified in fiducial data and pose **4020**, where the unique behavior and pattern of behavior may be stored onboard S-MMS memory **210**, may be uniquely associated to an individual user and stored as private data **1702**, or may be accessible public data **1704** retrieved by the SAC **302**B from a remote server **1510**.

(285) Referencing FIGS. **24** and **25**, approach may additionally include automated adjustment of one or more attributes of the S-MMS. In an example, a fiducial, optical, or retro-reflective target **2330** may be within the field of view of one or more onboard image sensors. The sensor report **374** is received by the SAC **302**B and processed by feature extraction **530** which outputs fiducial data and pose **4020**. The unique identity or location of the fiducial (e.g., retrieved from fiducial data and pose **4020**) may be associated with a specific expected action by the SAC **320**B and may automatically adjust the seat position by sending control signals to the motor controller **351** to match the angle of a ramp or maintain a predefined vertical height difference per the user settings (in memory **120**) for easier navigation or other purposes. The amount of seat movement may, in some embodiments, be determined using one or more onboard non-contact sensors **372** of the S-MMS. In an example, the user may need to activate or allow the automated adjustment feature per event via a voice command, gesture, or other user input **4025**.

(286) Adjust Function

(287) FIG. **47** depicts an S-MMS **18**N ready to navigate a ramp **3805** by preparing to run the adjust operation **4050** of drive assist **4010**. The goal of the adjust operation is to drive the S-MMS along a calculated path, determined by the drive path manager **529** of the SAC **302**B. In the embodiment shown, the ramp **3805** has a fiducial **3810**A placed at the bottom right corner. The fiducial has an origin **4305**, the S-MMS **18**N has an origin **4310**A, and the goal is to move the S-MMS from its current location along a defined drive path **4710**. In one embodiment, the drive path **4710** is an offset of the fiducial origin **4305** where the offset is determined so that the origin of the S-MMS will travel along the centerline of the ramp. The drive path **4710** may be calculated in part or in whole based on the length and width (track) of the S-MMS (e.g. from memory **120**), one or more parameters or poses of the fiducial **4020**, a user input **4025**, navigation information **4405**, the environmental threats reported by the threat assessor **528**, and/or one or more sensor reports of onboard non-contact sensors **372** of the S-MMS. One or more calculations or processes of the adjust operation may therefore cause the S-MMS controller **1108** to send one or more control

messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS and/or cause the HMI to provide feedback or take another action.
(288) FIG. **48** depicts a logic diagram of a ramp assist adjust function. The adjust algorithm is the process to maintain a relatively parallel rotation between the edge of the ramp and the S-MMS as it drives along a path. In this example, the adjust function **4050**A uses one or more of fiducial data and pose **4020**, user inputs **4025**, and navigation inputs **4405** to cause the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS and/or cause the HMI to provide feedback or take another action. The first step of the function is to calculate the ideal drive path **4810**, where an example of an ideal drive path is shown in FIG. **47**. The ideal drive path may be linear or any other path that can be navigated by the S-MMS and may be calculated by the drive path manager **529** of the SAC **302**B based on the length and width (track) of the S-MMS (e.g., from memory **120**), one or more parameter or pose of the fiducial **4020**, a user input **4025**, navigation information **4405**, the environmental threats reported by the threat assessor **528**, and/or one or more sensor reports of onboard non-contact sensors **372** of the S-MMS.
(289) An offset of the ideal drive path **4810** from the fiducial origin **4305** may be determined based on the width of the ramp **3805** calculated by a function of the SAC **302**B where the ramp width is found using visual edge detection or depth frame ground plane detection. Visual edge detection takes advantage of the fact that ramps may be offset from the ground or floor height which allows one or more algorithms to identify and extract the boundaries between the ramp and the surrounding scene. Edge detection algorithms may apply a series of filters to image data (e.g., image sensor reports **374** received by feature extraction **530** for analysis). The filters are designed to identify areas of change in contrast or color with commonly used algorithms being the Sobel, Prewitt, and Canny algorithms which use different techniques to find the edges of a feature in an image. By identifying the nearest identified edge to the left of the fiducial, the ramp width may be estimated and the ideal drive path **4710** plotted.
(290) In an alternative embodiment, one or more non-contact sensors, such as a stereo vision pairs that report back non-contact sensor reports **372** as a point cloud, are received and used to find the edges of the ramp. In this example, the stability manager **525** may first establish a ground plane from the point cloud data to provide the reference when looking for inclining ramps and their edges. When looking at the point cloud, if there are multiple points with consistent deltas in their z height (vertical height) that fall on a single additional axis (e.g., are in a line and inclined or declined), then the edge of a ramp can be extracted to be the line of best fit for these points. If this is done for both sides of the ramp, then the ideal travel path may be the distinct distance between the two parallel lines.
(291) In another embodiment, using visual imagery (e.g., color, IR, black and white images) from one or more image sensor, the process may be much the same. The ramp may be identified in numerous ways, including but not limited to, haar cascades, segmentation models, or a combination of image detection and object classification. One particular method may train an image classifier (e.g., of feature extraction **530**) to continuously look for ramps in frames and, once a ramp is seen in a frame, apply a segmentation or object detection model to get the edges. This would allow for a low overhead model, the image classifier, to run continuously and only activate the more computationally intensive models (segmentation) once a ramp is known to be in frame.
(292) Once the ideal drive path is determined, the current speed and location of the S-MMS (e.g., from navigation input **4405**) is checked against the ideal drive path. If the current speed and location of the S-MMS is within the ideal operating range (e.g., as defined and retrieved from memory **120**) then a cross track function **4830** drives the S-MMS along the ideal path. If the current speed and/or location of the S-MMS is outside of the ideal range, then a rotation correction function **4840** will attempt to correct the error. If the current speed and/or location of the S-MMS is outside of a range determined as safe, beyond the limits of the rotation correction function, the

adjust will exit and ramp assist mode may enter other states such as approach **4045** or exit **4055**. There are multiple alternative methods to accomplish adjust. The example method described is robust based on testing.

(293) In an exemplary embodiment, a cross track **4830** function uses a cross track error (XTE) based calculation and a PID loop to determine an output that cause the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS and/or cause the HMI to provide feedback or take another action. The cross-track algorithm takes the current position of the S-MMS (e.g., the current location of the origin **4310**A) and the coordinate of the nearest point on the ideal drive path **3805** to calculate the perpendicular distance between the two. This distance is called the cross-track error. The cross-track function **4830** then uses this error to determine the direction in which the S-MMS needs to turn to correct its course as it travels forward at a target speed to stay on the ideal path. In this example, the cross-track error is fed into a PID and is run when S-MMS center is a certain distance away from ideal route. The goal of the PID is to get the S-MMS back to the center of the drive path in the case it has drifted away from the path. Additionally or alternatively, a tracking function may be included, where tracking corrects for caster interference with the drive of the S-MMS using IMU and/or encoder data (e.g. from navigation **363**) compared to expected drive behavior.

(294) In an exemplary embodiment, a rotation correction **4840** function is a simple rotation PID loop that determines an output that cause the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS and/or cause the HMI to provide feedback or take another action. In this example, forward motion of the S-MMS is stopped, and a calculated yaw rotation correction of the S-MMS is fed into the PID to correct error. The rotation correction function is only run when the S-MMS center is within a certain distance from ramp center.

(295) In some embodiments, the distance or vector to the fiducial is used for relative positioning to enhance or replace the one or more outputs of navigation **363** of the S-MMS. As a non-limiting example, the change in distance to the fiducial (based on pose) over time may be used to calculate a linear or angular velocity which may be used by one or more processes of the SAC **302**B. This calculated velocity may then be combined with IM U or encoder-based velocities reported to navigation **363** to calculate a more accurate fused velocity. Alternatively, the fiducial based velocity may be used instead of one or more other sources of velocity data by navigation **363** for use in ramp assist or globally for all calculations of the SAC.

(296) While the previously described process involves navigation with a single fiducial, other embodiments may use additional fiducials (e.g., **4720** FIG. **47**) to determine the ideal path **4710**, to start and stop the adjustment process, or to provide additional information for behavior or navigation purposes. In an example, a fiducial is placed on either side of a door threshold such that when the fiducial on one side of the door enters the field of view of one or more image sensor (e.g. **610**) of the S-MMS, an image sensor report **374** is received and processed by feature extraction **530** of the SAC **302**B which searches for the presence of a fiducial **3710**, identifies the fiducial **3730**, calculates the pose of the fiducial **3750**, and provides fiducial data to other processes of the SAC. Additionally, a “door” state is set **3760** that triggers one or more calculation or process of the SAC to send one or more output that cause the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS through the door using adjust **4050**A and causes the HMI to provide feedback to the user. When the second fiducial (on the other side of the door) is recognized (e.g., by feature extraction), the “door” state is exited, the S-MMS controller stops sending control messages (or alternatively sends a cancellation message) and the user may take over manual control of the S-MMS. Additionally or alternatively, multiple fiducials may be used to provide additional navigation information and/or to confirm the continued operation of a state. Adjust (e.g., **4050**A)

may additionally or alternatively be used in part or in whole to accomplish other automated tasks for the S-MMS user such as for automated navigation to a charging position (reference FIG. **28**), for following a path set by a caregiver (reference FIG. **29**), driving a predetermined accessible route (reference FIG. **33**), and/or navigation to a known location in a queue (reference FIG. **34**) in some embodiments.

(297) Adjust may additionally or alternatively be used to navigate paths independent of a fiducial. Referencing FIG. **33**, adjust may be used to navigate any drive path determined by the drive path manager **529** of the SAC **302**B. In an embodiment, the drive path manager **529** may use adjust to calculate one or more signals/commands to be transmitted to the motor controller **351** to cause the motor controller to engage the steering and drive the S-MMS along a calculated accessible path.

(298) For all automated driving functions of the S-MMS, safety is important. In an embodiment, all desired autonomous drive actions calculated by ramp assist or other functions of the SAC **502**B are combined with one or more inputs from the tactical manager **527**, the threat assessor **528**, and navigation **363** by the drive path manager **529** to determine where the S-MMS should drive. In this way, the safety features such as collision avoidance, stability management, and tip protection are active while ramp assist and other autonomous drive features are active. In a situation in which automated driving (e.g., navigating up ramps with drop-off protection enabled can be difficult because the edges are so close and that triggers step points) is overly limited by other features of the S-MMS (e.g., threat assessor **528**) one or more operating parameters or rules of the drive path manager may be modified based on the presence or lack of presence of a fiducial. In an example, ramp assist may reduce the influence or priority of step obstacles received by the drive path manager while ramp assist is active to be safe while also allowing traversal of ramps. This effectively changes a run-time parameter of a function based on the presence of a detected fiducial.

(299) In addition to safety, the user may want to actively give permission or remove permission for automated functions. In an exemplary embodiment, the user may exit (deactivate) ramp assist using the HMI (e.g., **4130** to send a user input **4025**), including using buttons, voice commands, other indications, and combination of the same at any time. Additionally or alternatively, ramp assist or other automated driving behaviors of the SAC **302**B may be canceled due to error, safety check, user interaction, or combinations of the same.

(300) The presence of a fiducial (e.g., **3810**) may cause one or more wired or wireless communications (data and alerts) to be sent via CNI **371** to an external device or service (e.g., a remote server **1510**). In an example, a ramp assist fiducial **3810** may trigger one or more images to be captured, processed, compressed, and uploaded to a remote server **1510**. The detection of a fiducial with a unique identifier may cause the camera of the S-MMS to take a picture or video, store it on the S-MMS in memory and/or transmit the stored picture or video to a remote server **1510** or pair device **1502**. The picture or video may then: a. Be used by remote compute resources **1514** to train a machine learning or AI algorithm to recognize the object marked with the fiducial, b. Be viewed by remote customer support or development team members for product improvement, to determine success metrics, or any other development activities, and/or, c. To provide guidance to a user or caregiver via visual cues on a paired device **1502**.

(301) This approach allows automated data collection which enables training of machine learning and AI models when there are not readily available data sets of training images. Images that have been uploaded to cloud storage from one or more S-MMS with Ramp Assist functionality are used for supervised learning, unsupervised learning and/or reinforcement learning to develop or improve regression, classification, clustering, decision tree or neural network AI. In an example, images uploaded from multiple devices running the ramp assist function are used to develop a classification engine that can recognize a ramp without the use of fiducials. This new classification engine may then be deployed as part of feature extraction for use by the ramp assist function instead of the use of fiducial recognition. In another example, a neural network is trained with images captured as previously disclosed that can both recognize the ramp without the use of

fiducials and calculate one or more parameters of the ramp, such as the location of the edges of the ramp or the slope of the ramp, which can then be output to the Ramp Assist function.

(302) Ramp Assist Summary

(303) Fiducials may be used to identify zones of behavior, trigger actions and/or engage modes of the S-MMS or other wirelessly connected devices. FIG. **49** depicts a S-MMS **18**N approaching an accessible vehicle **4905** and traveling through positions A-C. As the S-MMS approaches the accessible vehicle (at position A) one or more wireless signals **4910** may be transmitted via one or more communications processors or transceivers **216**. In an embodiment, the user may be prompted (e.g., through the HMI **352** or a paired smart device **1502**) to confirm that they want to enter the accessible vehicle **4605**. When they confirm that they want to enter the accessible vehicle **4605**, via a voice command, physical action, or gesture, then the S-MMS controller **1108** may transmit one or more wireless communications (e.g. via ultra-wide band, Bluetooth or WIFI) to the control system of the vehicle **4905** which causes on or more of automated unlocking the accessible vehicle if the user is authorized, opening the door, lowering an automatic ramp **4915**, and or setting one or more custom user settings of the van such as music or temperature preferences. Alternatively, the S-MMS controller **1108** may instead transmit one or more wireless communications to a paired smart device **1502** which has authorization to control one or more features of the accessible vehicle (e.g., through a manufacturer's app, Apple Car Key, or similar API or service) and causes the one or more actions of the accessible vehicle. The one or more wireless signals **4910** may be transmitted based on a user request via the HMI **352** or paired smart device **1502**, in response to a known, remembered location retrieved from memory **120** of the S-MMS and confirmed based on current GPS location (e.g., from navigation **363**) on a process of the SAC **302**B, graphical/image based recognition of the license plate, fiducial, or other attribute of the accessible vehicle **4905** as recognized by feature extraction **530** and reported to a function of the SAC, or based on proximity to a recognized (e.g., from memory **120**) wireless transponder signal received by one or more transceiver of the S-MMS, processed by CNI **371** and reported to a function of the SAC in different embodiments. Additionally, in response to a recognized accessible vehicle the S-MMS controller **1108** may send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS and/or cause the HMI to provide feedback or take another action. In an example, motion of the S-MMS **18**N may be stopped at position A until the accessible vehicle **4905** has unlocked, lowered the ramp **4915** and sent one or more wireless signals confirming that the ramp is ready to be driven on where the wireless signals are received by one or more transceiver of the S-MMS and reported through CNI **371** to the drive path manager **529** of the SAC **302**B that driving can continue. In this example the HMI **352** may provide audio, visual, and/or haptic feedback indicating to the user that they should wait for the loading process to continue. Alternatively, motion is allowed and is automatically triggered by the visibility (or lack of visibility) of the ramp fiducial **4920** by the one or more cameras of the S-MMS.

(304) As the ramp **4915** touches down, a camera of the S-MMS **18**N may see one or more fiducial on the ramp **4920**. The presence of the one or more fiducial **4920** enables the ramp assist function. In an embodiment, the user may confirm that they wish to use ramp assist via the HMI. The S-MMS controller **1108** may cause the S-MMS **18**N to automatically drive up the ramp **4915** from position A to position B using the previously described approach and adjust. In this exemplary embodiment, with the S-MMS **18**N at position A and the ramp **4915** fully deployed, the one or more camera of the S-MMS will have one or more fiducial or ramp tag **4920** within their field of view. In an example, the ramp into the accessible vehicle may be marked with two or more fiducials where one fiducial is located at the bottom right corner of the ramp **4920** and another unique fiducial is located at the top right corner of the ramp **4925**. When feature extraction **530**, the SAC **302**B, identifies the fiducial **4920** associated (e.g., from memory) with drive assist **4010** the first time **4030** then a speaker of the HMI (e.g., **4105**) announces “Ramp Detected” to the user and

one or more indicator of the HMI (e.g., **4110-4125**) visually indicate that ramp assist has begun. Based on the fiducial data and pose **4020** of one or more ramp fiducial, the correct ramp mode is determined **4040**. In this example, at position A, approach **4045** is selected to line the S-MMS up with the ramp **4915**. Ramp assist calculates the location of the ramp edge relative to the wheelchair based on a unique fiducial placed at the bottom right corner of the ramp as previously described and drive path manager **529** determines the one or more required drive commands needed to drive the S-MMS to the bottom of the ramp. In an embodiment, the SAC of the S-MMS will only autonomously move if the user provides a confirmation input (i.e., user input **4025**) of the desire to move via the HMI for example by pressing a button or holding a joystick or switch forward. While the user provides confirmation input **4025** ramp assist will send permission to move by holding forward on the joystick, S-MMS controller **1108** will send one or more control messages to the motor controller **351** to cause the motor controller to engage the steering and drive of the S-MMS toward the bottom of the ramp and turn toward the ramp to align the S-MMS. This may turn the S-MMS completely away from the ramp for an amount of time in some scenarios so that the S-MMS must navigate without a fiducial based on one or more input from navigation **363**. However, the S-MMS will come back to a position for entering the ramp with one or more fiducial **4920-4925** in the field of view of one or more camera of the S-MMS **18**N.

(305) In an exemplary embodiment, when the S-MMS **18**N reaches the bottom of the ramp, ramp assist (as it completes approach **4045**A and transitions to adjust **4050**A) may set one or more operating parameters **4035** such as the S-MMS controller **1108** may send one or more control messages to the motor controller **351** to cause the motor controller to adjust the position of the seating assembly of the S-MMS. As a non-limiting example raising, lowering, tilting, or reclining the seating assembly of the S-MMS so that the user can fit through the door of the accessible vehicle at the top of the ramp **4915**. The one or more seating adjustments may be retrieved from memory **120** or may be calculated by one or more process of the SAC **302**B based on one or more user sensor reports **375**, CNI reports **371**, non-contact sensor reports **372**, S-MMS orientation from navigation **363**, and/or image sensor reports **374**. In an embodiment, one or more sensor reports from non-contact sensors of the S-MMS **18**N are used to measure the height of the opening in the accessible vehicle **4905** at the top of the ramp **4915**. Based on this calculated height, one or more control messages are sent to the motor controller **351** to cause the seating actuators to adjust the elevation and tilt of the seating assembly so that the user's head will not hit the top of vehicle. This may additionally or alternatively be accomplished by feature extraction **530** based on one or more image sensor reports **374** received by the SAC of the accessible vehicle opening. In another embodiment, sensor reports from one or more image sensor of the of the S-MMS and/or the pitch (orientation) of the S-MMS as reported by navigation **363** are used to calculate a seating assembly tilt that will keep the user level to their current position while the S-MMS transitions up the ramp **4915**. In another embodiment, the one or more control messages to the motor controller **351** may simply cause the seating assembly to move to a memory position of the seating assembly (e.g., as stored on the motor controller).

(306) With the S-MMS **18**N parked at the bottom of the ramp (between positions A and B) will now navigate up the ramp **4915** to position B. Based on the fiducial data and pose **4020** of one or more ramp fiducial, the correct ramp mode is determined **4040**. In this example, at position adjust **4050**A is selected drive the S-MMS up with the ramp **4915**. Ramp assist calculates the ideal drive path up the center of the ramp based on one or more unique fiducial placed on the ramp as previously described and drive path manager **529** determines the one or more required drive commands needed to drive the S-MMS to the top of the ramp making corrections as needed until the camera can no longer see any ramp fiducials. In this example, by driving past fiducial **4925**. During this entire process depicted in FIG. **49**, the user may continue to give ramp assist permission to drive by providing user input **4025** such as by holding forward on the joystick in some embodiments. If the user wants the S-MMS to stop, the user may let go of the joystick. At

any point during the automated driving process the user may have the ability to cancel automated driving via a user input **4025**. For example, a user might push an override button (e.g., **4130**) to exit **4055** the function.

(307) Continuing with the example of FIG. **49**, at S-MMS position B the ramp fiducials are no longer in the field of view of the forward-facing cameras of the S-MMS and ramp assist is complete. At position B, the camera of the S-MMS can no longer see the ramp fiducials **4920-4925** but can now see a different fiducial with a different unique ID **4930** and different associated drive behavior. In an embodiment, this fiducial **4930** is placed on the ceiling of the accessible vehicle at a specific location. The presence of this unique fiducial, when in the field of view of one or more camera of the S-MMS **18**N, causes the S-MMS to position itself directly under the fiducial and then turn 90-degrees to the right by triggering one or more calculation or process of the SAC to send one or more output that cause the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS using approach **4045**A and causing the HMI to provide feedback to the user. Additionally, in an embodiment, one or more operating parameter of the S-MMS may be uniquely set based on the recognized ID of the fiducial **4930** so that, for example the headlights of the S-MMS are turned on when the fiducial is detected by feature extraction **530**.

(308) Once the maneuver under fiducial **4930** is completed, the S-MMS **18**N will be facing towards a third, unique fiducial **4940** which, in this example, is placed horizontally on the dashboard. The presence of the third, unique fiducial **4940** causes the drive path manager **529** to use a combination of the approach **4045**A and/or adjust **4050**A functions to calculate one or more output which causes the S-MMS controller **1108** to send one or more control messages to the motor controller **351** and/or HMI **352** to cause the motor controller to engage the steering and drive of the S-MMS forward until the front of the S-MMS is parked a set distance (retrieved from memory **120** or encoded as fiducial data **4020** and provided from feature extraction **530**) from the edge of the fiducial **5130**. This final position, position C, is the desired driving position for the user. The path and motions may be calculated and executed uniquely each time by the drive path manager **529** of the SAC **302**B to position the S-MMS **18**N relative to one or more objects, such as a fiducial, or references available at the location. As a non-limiting example, one or more of the image sensors may be tasked by the sensor tasker to monitor for the fiducial(s) **2260** using feature extraction **530**. These “landmarks” may then be used to develop the drive path to be used by the S-MMS controller **1108**. Additionally or alternatively, the SAC **302**B may be configured so that once the S-MM **18**N is positioned in a location proximate to the target, the S-MMS controller **1108**, in coordination with the motor controller **351**, executes a predefined series of motions retrieved from memory **120**. Additionally, the presence or lack of presence of a fiducial (e.g. the presence of fiducial **4940**) may change one or more runtime parameters of the SAC **302**B. For example, disabling the collision manager **526** of the SAC **302**B while the S-MMS **18**N pulls into position C because the S-MMS may purposefully touch the dashboard during the maneuver. When the S-MMS reaches location C, the S-MMS controller **1108** may transmit one or more wireless signals via one or more communications processors or transceivers **216** to one or more communications processors or transceivers of the accessible vehicle **4905** or a tie-down, locking or positioning system of the accessible van. In an exemplary embodiment, when the S-MMS of FIG. **49** reaches position C successfully, one or more wireless signals is sent from the S-MMS to the accessible van which causes an auto locking mechanism of the accessible van to clamp or lock onto the base of the S-MMS so that it is properly restrained in the vehicle for travel. In a similar way, wireless signals may be used as an alternative or a complement to the activities completed due to the presence of a fiducial. Other examples include integration of automated start functions of the vehicle, changing environmental controls or settings of the vehicle, ramp raising or lowering, door opening, closing, locking, or unlocking, or other functions of the vehicle.

(309) While the example of FIG. **49** was depicted on an accessible vehicle, the methods described

may be used to assist in loading, unloading, and navigating many other situations with an S-MMS. Alternate embodiments of the ramp assist functionality previously explained, fiducials and the approach and adjustment functions of the ramp assist function can be used to help users navigate many common situations including but not limited to trains, automated people movers, shuttles, autonomous vehicles, elevators, classrooms, bathrooms, and other public and private facilities.

(310) Follow Me

(311) FIG. **50** depicts an S-MMS **18** automatically following a moving fiducial **5010**. In an embodiment, a caregiver **5020**, or another MMS, has a fiducial **5010** which they are carrying or is attached to them. One or more camera of the S-MMS sees the fiducial **5010** when it is in the field of view **5030** of the camera and follows the fiducial. When a fiducial **5010** associated (e.g., in memory **120**) with follow me is identified by feature extraction **530** from one or more image sensor reports **374** the location of the fiducial (determined by the pose) is set as a navigation target **4315** for the drive assist **4010** function of the drive path manager **529**. This causes the drive path manager **529** to use a combination of the approach **4045**A and/or adjust **4050**A functions to calculate one or more output which causes the S-MMS controller **1108** to send one or more control messages to the motor controller **351** to cause the motor controller to engage the steering and drive of the S-MMS toward the fiducial **5010** until the S-MMS is parked a set distance (retrieved from memory **120** or encoded as fiducial data **4020** and provided from feature extraction **530**) from the fiducial. Additionally or alternatively, the SAC may send one or more output that cause the S-MMS controller **1108** to send one or more control messages to the HMI **352** that causes the HMI to provide feedback to the user. In some embodiments, the fiducial **5010** may be printed on clothing, affixed as a sticker to the back of a vehicle, wheelchair, bed, cart or other moving article (like a walker), may be a Velcro patch on a backpack or other piece of clothing, or may be a symbol projected with a projector or laser light source.

(312) The use of fiducials may, enhance the use of RF localization and following in some embodiments. In an example, referencing FIG. **29**, a fiducial placed on the wearable transceiver **2904** may also include a unique fiducial that, when held in front of one or more of the image sensors of the S-MMS may be recognized by feature extraction an cause the SAC **302**B to enter or exit a follow-me state that may use the one or more attribute of the received RF transmissions from the wearable transceiver **2904** (e.g., angle of arrival, time of flight, or signal strength from CNI) to calculate one or more output that causes the drive path manager **529** to use a combination of the approach **4045**A and/or adjust **4050**A functions to calculate one or more output which causes the S-MMS controller **1108** to send one or more control messages to the motor controller **351** to cause the motor controller to engage the steering and drive of the S-MMS toward the wrist band wearable **2904**. In another example, referencing FIG. **30**, the S-MMS **18**O may unique behavior of the S-MMS may be engaged and/or disengaged based on the presence of a unique fiducial on the animal's collar or vest **3030** recognized by feature extraction **530**. In this example, the pose of the fiducial may additionally or alternatively be used to enhance localization and drive behaviors as previously described for drive assist **4010**.

(313) Enhanced SLAM

(314) FIG. **51** depicts fiducial-based localization allowing automated transit between defined waypoints marked with one or more fiducial. In an embodiment, a home or care facility has multiple unique fiducials (1-4) that are stationary, fixed to the ground, wall, or other non-moving object. Each of these unique fiducials are associated (e.g., in memory **120**) with specific locations in the home or care facility. Placing the fiducials or targets allows the S-MMS to quickly determine its location in a large, complex, or GPS deprived environments without the use of other computationally intensive localization techniques. The unique fiducial may be associated with a location, a function, a message, or set of desired S-MMS **18**N actions that may assist the S-MMS user. This information may be stored onboard S-MMS memory **120**, may be uniquely associated to an individual user and stored as private data **1702**, or maybe accessible public data **1704** retrieved

by the SAC **302**B from a remote server **1510**.
(315) In one embodiment, one or more onboard image sensor reports **374**, received by the SAC **302**B, are processed in feature extraction **530**, and one of the unique fiducials is recognized by one or more of the pattern recognition processes previously disclosed (FIG. **19**). The SAC **302**B sensor fusion **500** associates the fiducial identified by feature extraction **530** as a specific location on an onboard map maintained (in memory **120**). This association of the fiducial and the location serves to increase the accuracy and/or confidence of the situational awareness map maintained by the tactical manager **527**. Based on this location, the SAC **302**B may run one or more drive assist functions **4010** such as approach or adjust to automatically drive the S-MMS along a pre-defined path along the map between the sensed fiducial (e.g., 1) and another fiducial location (e.g., 2). The user may select a target location using an onboard or linked HMI and/or via a voice command. In some embodiments, fiducials may incorporate, be replaced by, or be assisted by ultrawide-band transceivers, RFID chips, Bluetooth beacons, or other computer RF transceivers, such that they may be recognized by, and transmit their coordinates to, the S-MMS controller **1108** wirelessly as previously disclosed for general, precision indoor navigation.
(316) In an exemplary embodiment, the tactical manager **527** of the SAC **302**B utilizes inputs from one or more of stability manager **525**, collision manager **526**, navigation **363**, drive path manager **529**, sensor track fusion **500**, and the threat assessor **528** to maintain a master 360-degree map of known objects and conditions around the S-MMS. This may be accomplished with simultaneous localization and mapping (SLAM). In this example, the tactical manager **527** of the SAC uses one or more fiducial at known locations (as shown in FIG. **51**) recognized by feature extraction **530** to correct for long-term drift in its map as well as the ability to quickly adjust the map to changing environments such as the rearranging of furniture. Using identifier fiducials, the tactical manager **527** gains additional accuracy and resilience to change. One or more of the methods listed below may be used by the tactical manager of the SAC:
(317) Method One: A single fiducial can provide centimeter level accuracy pose measurements and therefore makes a great secondary source of location confirmation. A fiducial, recognized by feature extraction based on parameters stored in memory **120**, at a known location (i.e., a location in memory with the fiducial's location referenced to a global coordinate frame) can be used to calculate a global transform to the map of the tactical manager and update the S-MMS known position. Implementing fiducials throughout the environment allows the S-MMS to continuously update its own position, nearly eliminating long-term positional drift.
(318) Fiducials may be especially helpful when used by S-MMS that have reduced navigation/pose accuracy when operating autonomously. This could be due to missing encoders (drive side error) or sparse depth frames (sensor or map error). If this is the case, then the traversal of more narrow pathways could be tricky or lead to failure. Examples include but are not limited to doorways, hallways, and kitchen areas. In these situations, a fiducial can be placed that allows the S-MMS to use its increased tactical manager map accuracy to easily traverse the environment. See fiducial 1 placed on a door frame to allow easy navigation through a frame.
(319) Method Two: Using one or more fiducials to automatically register and/or remember map waypoints with the tactical manager. Currently if a user would like to allow SLAM to autonomously navigate to a waypoint this information needs to be set ahead of time usually using config files (e.g., in build-time memory on the S-MMS). However, if utilizing fiducials, the system could be set to identify fiducials not seen before where either the user or the fiducial provides a name (e.g., “toilet”, “bedroom”, etc.) and have the exact location of the fiducial saved for future use in memory. Using preset fiducials, the S-MMS can encode this information automatically into the memory for enhanced knowledge and tracking of existing objects. This allows for the removal of more manually assigned waypoints and allows the user to establish key map locations dynamically. a. Fiducials to enhance navigation/localization capabilities as described previously can be used indoors, outdoors, in moving or stationary settings. For example, while vans always

move the relationship between entry and parking location can be standardized across multiple types. Infrastructure examples in a city such as curb cuts, accessible parking spots, and others could be marked with fiducials to assist precision automated navigation, cause automated actions, notifications, or other behaviors for S-MMS. The automated mapping and navigation capabilities described for an S-MMS have many uses in hospitals, large facilities like airports and other public places.
(320) To facilitate the understanding of the embodiments described herein, a number of terms are defined below. The terms defined herein have meanings as commonly understood by a person of ordinary skill in the relevant art. Terms such as “a,” “an,” and “the” are not intended to refer to only a singular entity, but rather include the general class of which a specific example may be used for illustration. The terminology herein is used to describe specific embodiments, but their usage does not delimit the disclosure, except as set forth in the claims.
(321) The term “circuit” means at least either a single component or a multiplicity of components, either active and/or passive, that are coupled together to provide a desired function. Terms such as “wire,” “wiring,” “line,” “signal,” “conductor,” and “bus” may be used to refer to any known structure, construction, arrangement, technique, method, and/or process for physically transferring a signal from one point in a circuit to another. Also, unless indicated otherwise from the context of its use herein, the terms “known,” “fixed,” “given,” “certain”, and “predetermined” generally refer to a value, quantity, parameter, constraint, condition, state, process, procedure, method, practice, or combination thereof that is, in theory, variable, but is typically set in advance and not varied thereafter when in use.
(322) Conditional language used herein, such as, among others, “can,” “might,” “may,” “e.g.,” and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements, and/or states. Thus, such conditional language is not generally intended to imply that features, elements, and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment.
(323) Communication between various systems and devices is disclosed herein. Communication may occur using wired and/or wireless communication methods and protocols including, but not limited to, cellular, 802.11, Wi-Fi, 802.15, Bluetooth, 802.20, and WiMAX.
(324) Non-Transitory Computer Readable Medium
(325) The various operations of methods described above may be performed by any suitable means capable of performing the operations, such as various hardware and/or software component(s), circuits, and/or module(s).
(326) The various illustrative logical blocks, modules, and circuits described in connection with the present disclosure may be implemented or performed with a hardware processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array signal (FPGA) or other programmable logic device (PLD), discrete gate or transistor logic, discrete hardware components, or combinations thereof designed to perform the functions described herein. A hardware processor may be a microprocessor, commercially available processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of two computing components, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.
(327) In one or more aspects, the functions described may be implemented in software, firmware, or any combination thereof executing on a hardware processor. If implemented in software, the functions may be stored as one or more executable instructions or code on a non-transitory computer-readable storage medium. A computer-readable storage media may be any available

media that can be accessed by a processor. By way of example, and not limitation, such computer-readable storage media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to store executable instructions or other program code or data structures and that can be accessed by a processor. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.
(328) The methods disclosed herein comprise one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is specified, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims. Processes or steps described in one implementation can be suitably combined with steps of other described implementations.
(329) Certain aspects of the present disclosure may comprise a computer program product for performing the operations presented herein. For example, such a computer program product may comprise a computer readable storage medium having instructions stored (and/or encoded) thereon, the instructions being executable by one or more processors to perform the operations described herein.
(330) Software or instructions may be transmitted over a transmission medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of transmission medium.
(331) Further, it should be appreciated that modules and/or other appropriate means for performing the methods and techniques described herein can be downloaded and/or otherwise obtained by a user terminal and/or base station as applicable. For example, such a device can be coupled to a server to facilitate the transfer of means for performing the methods described herein. Alternatively, various methods described herein can be provided via storage means (e.g., RAM, ROM, a physical storage medium such as a compact disc (CD) or floppy disk, etc.), such that a terminal and/or base station can obtain the various methods upon coupling or providing the storage means to the device.
(332) For the sake of convenience, the operations are described as various interconnected functional blocks or distinct software modules. This is not necessary, however, and there may be cases where these functional blocks or modules are equivalently aggregated into a single logic device, program, or operation with unclear boundaries. In any event, the functional blocks and software modules or described features can be implemented by themselves or in combination with other operations in either hardware or software.
(333) Having described and illustrated the principles of the systems, methods, processes, and/or apparatuses disclosed herein in a preferred embodiment thereof, it should be apparent that the systems, methods, processes, and/or apparatuses may be modified in arrangement and detail without departing from such principles. Claim is made to all modifications and variation coming within the spirit and scope of the following claims.

Claims

1. A motorized mobile system comprising: an optical sensor capturing an image of a fiducial located proximate to the motorized mobile system, the fiducial located within a field of view of the optical sensor; a tangible storage medium storing instructions and one or more identifiers associated with one or more fiducials; and a processor executing the instructions to: generate, based

on the captured image of the fiducial, a data report; verify the fiducial with the stored one or more identifiers associated with one or more fiducials to indicate a ramp structure associated with the fiducial; determine a relative location of an edge of the ramp structure from the data report; and alter one or more operating modes of the motorized mobile system in response to the determined location of the edge of the ramp structure.
2. The motorized mobile system of claim 1, the processor further to: extract one or more features from the generated data report of the captured image of the fiducial.
3. The motorized mobile system of claim 2, wherein the extraction of the one or more features from the generated data report of the captured image of the fiducial comprises at least one of a convolution image processing technique, a Fourier transform image processing technique, or a wavelet image processing technique.
4. The motorized mobile system of claim 2, wherein the extraction of the one or more features from the generated data report of the captured image of the fiducial comprises detecting at least one corner of the fiducial in the image of the fiducial.
5. The motorized mobile system of claim 1, the processor further to: determine a pose of the fiducial from the data report, wherein altering the one or more operating modes of the motorized mobile system is further in response to the pose of the fiducial.
6. The motorized mobile system of claim 1, the processor further to: generate a second data report of an image of a second fiducial located proximate to the motorized mobile system.
7. The motorized mobile system of claim 6, the processor further to: verify the second fiducial with a second stored identifier associated with a top edge of the ramp structure.
8. The motorized mobile system of claim 1, wherein altering the one or more operating modes of the motorized mobile system in response to verifying the fiducial with the one or more identifiers comprises activating a portion of a human interface.
9. The motorized mobile system of claim 1, wherein altering the one or more operating modes of the motorized mobile system in response to verifying the fiducial with the one or more identifiers comprises an auto-driving operation the motorized mobile system based at least on a location of the fiducial.
10. The motorized mobile system of claim 9, wherein the auto-driving operation comprises an approach operation to operate the motorized mobile system to a setpoint.
11. The motorized mobile system of claim 10, the processor further to: determine a distance to the setpoint; determine a vector to the setpoint; and operate the motorized mobile system to the setpoint based on the determined distance and vector.
12. The motorized mobile system of claim 10, wherein the setpoint approximately coincides with a centerline along the ramp structure.
13. The motorized mobile system of claim 12, the processor further to: orient the motorized mobile system towards the ramp structure after arriving at the setpoint.
14. The motorized mobile system of claim 9, wherein the auto-driving operation comprises an adjust operation to operate the motorized mobile system onto the ramp structure.
15. The motorized mobile system of claim 14, the processor further to: determine an offset of the motorized mobile system from an ideal drive path; and operate the motorized mobile system based on the determined offset.
16. The motorized mobile system of claim 15, wherein the adjust operation is further based on a determined speed of the motorized mobile system.
17. The motorized mobile system of claim 1, wherein the fiducial comprises a plurality of ArUco markers.
18. A method for controlling a motorized mobile system comprising: generating, by a processor of the motorized mobile system and based on an image of a fiducial located proximate to the motorized mobile system captured by an optical sensor, a data report, the fiducial located within a field of view of the optical sensor; comparing a portion of the image of the fiducial to one or more

identifiers associated with one or more fiducials; verifying the fiducial corresponds to an identifier of the one or more identifiers to indicate a ramp structure associated with the fiducial; determining a relative location of an edge of the ramp structure from the data report; and altering one or more operating modes of the motorized mobile system in response to the determined location of the edge of the ramp structure.

19. The method of claim 18 further comprising: extracting one or more features from the data report of the image of the fiducial.

20. The method of claim 19, wherein extracting the one or more features from the data report of the image of the fiducial comprises at least one of a convolution image processing technique, a Fourier transform image processing technique, or a wavelet image processing technique.

21. The method of claim 19, wherein extracting the one or more features from the data report of the image of the fiducial comprises detecting at least one corner of the fiducial in the image of the fiducial.

22. The method of claim 18 further comprising: determining a pose of the fiducial from the data report, wherein altering the one or more operating modes of the motorized mobile system is further in response to the pose of the fiducial.

23. The method of claim 18, wherein the optical sensor is operably configured to generate a second data report of an image of a second fiducial located proximate to the motorized mobile system.

24. The method of claim 23 further comprising: verifying the second fiducial with a second stored identifier associated with a top edge of the ramp structure.

25. The method of claim 18, wherein altering the one or more operating modes of the motorized mobile system in response to verifying the fiducial with the one or more identifiers comprises an auto-driving operation the motorized mobile system based at least on a location of the fiducial.

26. The method of claim 25, wherein the auto-driving operation comprises an approach operation to operate the motorized mobile system to a setpoint.

27. The method of claim 26 further comprising: determining a distance to the setpoint; determining a vector to the setpoint; and operating the motorized mobile system to the setpoint based on the determined distance and vector.

28. The method of claim 26, wherein the setpoint approximately coincides with a centerline along the ramp structure.

29. The method of claim 28 further comprising: rotating the motorized mobile system towards the ramp structure after arriving at the setpoint.

30. The method of claim 25, wherein the auto-driving operation comprises an adjust operation to operate the motorized mobile system onto the ramp structure.

31. The method of claim 30 further comprising: determining an offset of the motorized mobile system from an ideal drive path; and operating the motorized mobile system based on the determined offset.

32. The method of claim 31, wherein the adjust operation is further based on a determined speed of the motorized mobile system.