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Autonomous vehicle dispatch based on resource usage predictions

Abstract

Systems and techniques are provided for selecting and dispatching an autonomous vehicle (AV) in a set of AVs based on resource usage predictions. An example process includes receiving, from a user device, a ride request for a ride between a pick-up location and a drop-off location and determining, for each AV in a set of AVs, a predicted resource usage for a completion of the ride based on a distance between the pick-up location and the drop-off location, a distance between an AV location and the pick-up location, one or more environmental factors, and one or more vehicle-specific factors. The example process further includes selecting an AV in the set of AVs for the ride based on the predicted resource usage for the completion of the ride and a maintenance state of each AV.

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Background/Summary

BACKGROUND

1. Technical Field

(1) The present disclosure generally relates to an autonomous vehicle (AV) fleet management system. For example, aspects of the present disclosure relate to systems and techniques for dispatching an AV in a fleet of AVs based on resource usage predictions.

2. Introduction

(2) An autonomous vehicle is a motorized vehicle that can navigate without a human driver. An exemplary autonomous vehicle can include various sensors, such as a camera sensor, a light detection and ranging (LIDAR) sensor, and a radio detection and ranging (RADAR) sensor, amongst others. The sensors collect data and measurements that the autonomous vehicle can use for operations such as navigation. The sensors can provide the data and measurements to an internal computing system of the autonomous vehicle, which can use the data and measurements to control a mechanical system of the autonomous vehicle, such as a vehicle propulsion system, a braking system, or a steering system. Typically, the sensors are mounted at fixed locations on the autonomous vehicles.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The various advantages and features of the present technology will become apparent by reference to specific implementations illustrated in the appended drawings. A person of ordinary skill in the art will understand that these drawings only show some examples of the present technology and would not limit the scope of the present technology to these examples. Furthermore, the skilled artisan will appreciate the principles of the present technology as described and explained with additional specificity and detail through the use of the accompanying drawings in which:

(2) FIG. 1 illustrates an example system environment that can be used to facilitate autonomous vehicle (AV) dispatch and operations, according to some aspects of the disclosed technology;

(3) FIG. 2 illustrates a diagram of an example AV fleet management system, according to some examples of the present disclosure;

(4) FIG. 3 illustrates a flowchart diagram illustrating an example process for dispatching an AV in a fleet of AVs based on resource usage predictions, according to some examples of the present disclosure;

(5) FIG. 4 illustrates a diagram illustrating an example scene for dispatching an AV in a fleet of AVs based on resource usage predictions, according to some examples of the present disclosure;

(6) FIG. 5 illustrates a flow chart illustrating an example process for selecting an AV for a dispatch based on resource usage predictions, according to some examples of the present disclosure;

(7) FIG. 6 illustrates an example of a deep learning neural network that can be used to implement aspects of resource usage predictions, according to some aspects of the disclosed technology; and

(8) FIG. 7 illustrates an example processor-based system with which some aspects of the subject technology can be implemented.

DETAILED DESCRIPTION

(9) The detailed description set forth below is intended as a description of various configurations of the subject technology and is not intended to represent the only configurations in which the subject technology can be practiced. The appended drawings are incorporated herein and constitute a part of the detailed description. The detailed description includes specific details for the purpose of providing a more thorough understanding of the subject technology. However, it will be clear and apparent that the subject technology is not limited to the specific details set forth herein and may be

practiced without these details. In some instances, structures and components are shown in block diagram form to avoid obscuring the concepts of the subject technology.

(10) Some aspect of the present technology may relate to the gathering and use of data available from various sources to improve safety, quality, and experience. The present disclosure contemplates that in some instances, this gathered data may include personal information. The present disclosure contemplates that the entities involved with such personal information respect and value privacy policies and practices.

(11) Some ridesharing and/or ride-hailing services utilize autonomous vehicles (AVs) to transport passengers from one location to another. In contrast to conventional transportation services where a human driver picks up passengers and drives them to their destination, AVs can drive themselves, eliminating the need for a human driver. For example, upon receiving a ride request from a user/user device (e.g., a ride requestor), a fleet management system may match and dispatch an AV in one or more fleets of AVs to the user. In addition to matching and dispatching, the fleet management system is responsible for the operations and maintenance of the AVs in the fleet. In order to optimize the efficiency and safety of the fleet, the fleet management system needs to efficiently dispatch AVs to their respective tasks and routes, and manage timely and proper maintenance of the AV.

(12) In some cases, the fleet management system matches an AV, in response to a ride request, primarily based on the distance that is required for the AV to travel. For example, the fleet management system would select an AV that is closest to a pick-up location and has enough power to complete the ride. However, even for the same distance, the total power consumption (e.g., electric energy consumption) for the completion of the ride may vary depending on various environmental and/or vehicle-specific factors. For example, a different road condition (e.g., uphill or downhill, paved or unpaved) can result in varying power consumption of an AV. In another example, an age of an AV or a battery may affect the energy efficiency and result in a different power consumption vehicle by vehicle. Furthermore, the fleet management system needs to ensure that an AV has enough resources such as disk space (or data storage capacity) and has been kept up with maintenance so that an AV does not run out of resources or break down/fail before completing the ride request.

(13) Systems, apparatuses, processes (also referred to as methods), and computer-readable media (collectively referred to as “systems and techniques”) are described herein for selecting an AV in a fleet of AVs to dispatch based on resource usage predictions. For example, the systems and techniques can match and dispatch an AV based on a predicted resource usage that may be associated with battery usage and/or data storage usage. The predicted resource usage can be determined based on various factors such as a distance between a pick-up location and a drop-off location, one or more environmental factors (e.g., a location of the AV, a road condition, a weather condition, time of day, a traffic condition, etc.) and/or one or more vehicle-specific factors (e.g., vehicle age, battery life, tire pressure, vehicle configurations, etc.). As such, the systems and techniques can intelligently and dynamically select an AV based on resource usage predictions and optimize the resource use of AVs in a fleet.

(14) Furthermore, the systems and techniques of the present disclosure can monitor the maintenance state and/or status of AVs in a fleet so that AVs can be timely and properly maintained. For example, the systems and techniques can match and dispatch an AV in a fleet based on the maintenance state, which may be associated with data storage capacity level, remaining battery level, the remaining time until a required power cycle, the remaining time until sensor calibration, the remaining time until data offload, and so on. In some examples, the systems and techniques of the present disclosure can determine, based on the predicted resource usage for the completion of a ride request and a current maintenance state of an AV, whether an AV would need to return to a maintenance facility before and/or after the completion of the ride request. For example, the systems and techniques determine that a predicted maintenance state after the completion of the

ride request would require charging of the AV, sensor calibration of the AV, offloading data of the AV, or any other type of maintenance, a trip of the AV from a drop-off location to a maintenance facility can be scheduled. As such, the systems and techniques can enable timely and proper maintenance of an AV in a fleet without manual intervention, which can prevent the risk of running out of resources or operation failures of an AV on the road.

(15) As discussed in further detail below, various aspects of the present disclosure can be implemented (or facilitated by) a management system (e.g., fleet management system or dispatch management system) configured to make resource usage predictions based on various factors, monitor a maintenance state of each vehicle in a fleet of AVs, and dispatch an AV based on the predicted resource usage and the maintenance state to optimize the efficiency and safety of the AVs in the fleet.

(16) FIG. 1 is a diagram illustrating an example autonomous vehicle (AV) environment **100**, according to some examples of the present disclosure. One of ordinary skill in the art will understand that, for AV environment **100** and any system discussed in the present disclosure, there can be additional or fewer components in similar or alternative configurations. The illustrations and examples provided in the present disclosure are for conciseness and clarity. Other examples may include different numbers and/or types of elements, but one of ordinary skill the art will appreciate that such variations do not depart from the scope of the present disclosure.

(17) In this example, the AV environment **100** includes an AV **102**, a data center **150**, and a client computing device **170**. The AV **102**, the data center **150**, and the client computing device **170** can communicate with one another over one or more networks (not shown), such as a public network (e.g., the Internet, an Infrastructure as a Service (IaaS) network, a Platform as a Service (PaaS) network, a Software as a Service (SaaS) network, other Cloud Service Provider (CSP) network, etc.), a private network (e.g., a Local Area Network (LAN), a private cloud, a Virtual Private Network (VPN), etc.), and/or a hybrid network (e.g., a multi-cloud or hybrid cloud network, etc.).

(18) The AV **102** can navigate roadways without a human driver based on sensor signals generated by multiple sensor systems **104**, **106**, and **108**. The sensor systems **104-108** can include one or more types of sensors and can be arranged about the AV **102**. For instance, the sensor systems **104-108** can include Inertial Measurement Units (IMUs), cameras (e.g., still image cameras, video cameras, etc.), light sensors (e.g., LIDAR systems, ambient light sensors, infrared sensors, etc.), RADAR systems, GPS receivers, audio sensors (e.g., microphones, Sound Navigation and Ranging (SONAR) systems, ultrasonic sensors, etc.), engine sensors, speedometers, tachometers, odometers, altimeters, tilt sensors, impact sensors, airbag sensors, seat occupancy sensors, open/closed door sensors, tire pressure sensors, rain sensors, and so forth. For example, the sensor system **104** can be a camera system, the sensor system **106** can be a LIDAR system, and the sensor system **108** can be a RADAR system. Other examples may include any other number and type of sensors.

(19) The AV **102** can also include several mechanical systems that can be used to maneuver or operate the AV **102**. For instance, the mechanical systems can include a vehicle propulsion system **130**, a braking system **132**, a steering system **134**, a safety system **136**, and a cabin system **138**, among other systems. The vehicle propulsion system **130** can include an electric motor, an internal combustion engine, or both. The braking system **132** can include an engine brake, brake pads, actuators, and/or any other suitable componentry configured to assist in decelerating the AV **102**. The steering system **134** can include suitable componentry configured to control the direction of movement of the AV **102** during navigation. The safety system **136** can include lights and signal indicators, a parking brake, airbags, and so forth. The cabin system **138** can include cabin temperature control systems, in-cabin entertainment systems, and so forth. In some examples, the AV **102** might not include human driver actuators (e.g., steering wheel, handbrake, foot brake pedal, foot accelerator pedal, turn signal lever, window wipers, etc.) for controlling the AV **102**. Instead, the cabin system **138** can include one or more client interfaces (e.g., Graphical User Interfaces (GUIs), Voice User Interfaces (VUIs), etc.) for controlling certain aspects of the

mechanical systems **130-138**.

(20) The AV **102** can include a local computing device **110** that is in communication with the sensor systems **104-108**, the mechanical systems **130-138**, the data center **150**, and the client computing device **170**, among other systems. The local computing device **110** can include one or more processors and memory, including instructions that can be executed by the one or more processors. The instructions can make up one or more software stacks or components responsible for controlling the AV **102**; communicating with the data center **150**, the client computing device **170**, and other systems; receiving inputs from riders, passengers, and other entities within the AV's environment; logging metrics collected by the sensor systems **104-108**; and so forth. In this example, the local computing device **110** includes a perception stack **112**, a localization stack **114**, a prediction stack **116**, a planning stack **118**, a communications stack **120**, a control stack **122**, an AV operational database **124**, and an HD geospatial database **126**, among other stacks and systems.

(21) Perception stack **112** can enable the AV **102** to “see” (e.g., via cameras, LIDAR sensors, infrared sensors, etc.), “hear” (e.g., via microphones, ultrasonic sensors, RADAR, etc.), and “feel” (e.g., pressure sensors, force sensors, impact sensors, etc.) its environment using information from the sensor systems **104-108**, the localization stack **114**, the HD geospatial database **126**, other components of the AV, and other data sources (e.g., the data center **150**, the client computing device **170**, third party data sources, etc.). The perception stack **112** can detect and classify objects and determine their current locations, speeds, directions, and the like. In addition, the perception stack **112** can determine the free space around the AV **102** (e.g., to maintain a safe distance from other objects, change lanes, park the AV, etc.). The perception stack **112** can identify environmental uncertainties, such as where to look for moving objects, flag areas that may be obscured or blocked from view, and so forth. In some examples, an output of the perception stack **112** can be a bounding area around a perceived object that can be associated with a semantic label that identifies the type of object that is within the bounding area, the kinematic of the object (information about its movement), a tracked path of the object, and a description of the pose of the object (its orientation or heading, etc.).

(22) Localization stack **114** can determine the AV's position and orientation (pose) using different methods from multiple systems (e.g., GPS, IMUs, cameras, LIDAR, RADAR, ultrasonic sensors, the HD geospatial database **126**, etc.). For example, in some cases, the AV **102** can compare sensor data captured in real-time by the sensor systems **104-108** to data in the HD geospatial database **126** to determine its precise (e.g., accurate to the order of a few centimeters or less) position and orientation. The AV **102** can focus its search based on sensor data from one or more first sensor systems (e.g., GPS) by matching sensor data from one or more second sensor systems (e.g., LIDAR). If the mapping and localization information from one system is unavailable, the AV **102** can use mapping and localization information from a redundant system and/or from remote data sources.

(23) Prediction stack **116** can receive information from the localization stack **114** and objects identified by the perception stack **112** and predict a future path for the objects. In some examples, the prediction stack **116** can output several likely paths that an object is predicted to take along with a probability associated with each path. For each predicted path, the prediction stack **116** can also output a range of points along the path corresponding to a predicted location of the object along the path at future time intervals along with an expected error value for each of the points that indicates a probabilistic deviation from that point.

(24) Planning stack **118** can determine how to maneuver or operate the AV **102** safely and efficiently in its environment. For example, the planning stack **118** can receive the location, speed, and direction of the AV **102**, geospatial data, data regarding objects sharing the road with the AV **102** (e.g., pedestrians, bicycles, vehicles, ambulances, buses, cable cars, trains, traffic lights, lanes, road markings, etc.) or certain events occurring during a trip (e.g., emergency vehicle blaring a siren, intersections, occluded areas, street closures for construction or street repairs, double-parked

cars, etc.), traffic rules and other safety standards or practices for the road, user input, and other relevant data for directing the AV **102** from one point to another and outputs from the perception stack **112**, localization stack **114**, and prediction stack **116**. The planning stack **118** can determine multiple sets of one or more mechanical operations that the AV **102** can perform (e.g., go straight at a specified rate of acceleration, including maintaining the same speed or decelerating; turn on the left blinker, decelerate if the AV is above a threshold range for turning, and turn left; turn on the right blinker, accelerate if the AV is stopped or below the threshold range for turning, and turn right; decelerate until completely stopped and reverse; etc.), and select the best one to meet changing road conditions and events. If something unexpected happens, the planning stack **118** can select from multiple backup plans to carry out. For example, while preparing to change lanes to turn right at an intersection, another vehicle may aggressively cut into the destination lane, making the lane change unsafe. The planning stack **118** could have already determined an alternative plan for such an event. Upon its occurrence, it could help direct the AV **102** to go around the block instead of blocking a current lane while waiting for an opening to change lanes.

(25) Control stack **122** can manage the operation of the vehicle propulsion system **130**, the braking system **132**, the steering system **134**, the safety system **136**, and the cabin system **138**. The control stack **122** can receive sensor signals from the sensor systems **104-108** as well as communicate with other stacks or components of the local computing device **110** or a remote system (e.g., the data center **150**) to effectuate operation of the AV **102**. For example, the control stack **122** can implement the final path or actions from the multiple paths or actions provided by the planning stack **118**. This can involve turning the routes and decisions from the planning stack **118** into commands for the actuators that control the AV's steering, throttle, brake, and drive unit.

(26) Communications stack **120** can transmit and receive signals between the various stacks and other components of the AV **102** and between the AV **102**, the data center **150**, the client computing device **170**, and other remote systems. The communications stack **120** can enable the local computing device **110** to exchange information remotely over a network, such as through an antenna array or interface that can provide a metropolitan WIFI network connection, a mobile or cellular network connection (e.g., Third Generation (3G), Fourth Generation (4G), Long-Term Evolution (LTE), 5th Generation (5G), etc.), and/or other wireless network connection (e.g., License Assisted Access (LAA), Citizens Broadband Radio Service (CBRS), MULTEFIRE, etc.). Communications stack **120** can also facilitate the local exchange of information, such as through a wired connection (e.g., a user's mobile computing device docked in an in-car docking station or connected via Universal Serial Bus (USB), etc.) or a local wireless connection (e.g., Wireless Local Area Network (WLAN), Low Power Wide Area Network (LPWAN), Bluetooth®, infrared, etc.).

(27) The HD geospatial database **126** can store HD maps and related data of the streets upon which the AV **102** travels. In some examples, the HD maps and related data can comprise multiple layers, such as an areas layer, a lanes and boundaries layer, an intersections layer, a traffic controls layer, and so forth. The areas layer can include geospatial information indicating geographic areas that are drivable (e.g., roads, parking areas, shoulders, etc.) or not drivable (e.g., medians, sidewalks, buildings, etc.), drivable areas that constitute links or connections (e.g., drivable areas that form the same road) versus intersections (e.g., drivable areas where two or more roads intersect), and so on. The lanes and boundaries layer can include geospatial information of road lanes (e.g., lane centerline, lane boundaries, type of lane boundaries, etc.) and related attributes (e.g., direction of travel, speed limit, lane type, etc.). The lanes and boundaries layer can also include three-dimensional (3D) attributes related to lanes (e.g., slope, elevation, curvature, etc.). The intersections layer can include geospatial information of intersections (e.g., crosswalks, stop lines, turning lane centerlines and/or boundaries, etc.) and related attributes (e.g., permissive, protected/permissive, or protected only left turn lanes; legal or illegal u-turn lanes; permissive or protected only right turn lanes; etc.). The traffic controls lane can include geospatial information of traffic signal lights, traffic signs, and other road objects and related attributes.

(28) AV operational database **124** can store raw AV data generated by the sensor systems **104-108**, stacks **112-122**, and other components of the AV **102** and/or data received by the AV **102** from remote systems (e.g., the data center **150**, the client computing device **170**, etc.). In some examples, the raw AV data can include HD LIDAR point cloud data, image data, RADAR data, GPS data, and other sensor data that the data center **150** can use for creating or updating AV geospatial data or for creating simulations of situations encountered by AV **102** for future testing or training of various machine learning algorithms that are incorporated in the local computing device **110**.

(29) Data center **150** can include a private cloud (e.g., an enterprise network, a co-location provider network, etc.), a public cloud (e.g., an Infrastructure as a Service (IaaS) network, a Platform as a Service (PaaS) network, a Software as a Service (SaaS) network, or other Cloud Service Provider (CSP) network), a hybrid cloud, a multi-cloud, and/or any other network. The data center **150** can include one or more computing devices remote to the local computing device **110** for managing a fleet of AVs and AV-related services. For example, in addition to managing the AV **102**, the data center **150** may also support a ride-hailing service (e.g., a ridesharing service), a delivery service, a remote/roadside assistance service, street services (e.g., street mapping, street patrol, street cleaning, street metering, parking reservation, etc.), and the like.

(30) Data center **150** can send and receive various signals to and from the AV **102** and the client computing device **170**. These signals can include sensor data captured by the sensor systems **104-108**, roadside assistance requests, software updates, ride-hailing/ridesharing pick-up and drop-off instructions, and so forth. In this example, the data center **150** includes a data management platform **152**, an Artificial Intelligence/Machine Learning (AI/ML) platform **154**, a simulation platform **156**, a remote assistance platform **158**, and a ride-hailing platform **160**, and a map management platform **162**, among other systems.

(31) Data management platform **152** can be a “big data” system capable of receiving and transmitting data at high velocities (e.g., near real-time or real-time), processing a large variety of data and storing large volumes of data (e.g., terabytes, petabytes, or more of data). The varieties of data can include data having different structures (e.g., structured, semi-structured, unstructured, etc.), data of different types (e.g., sensor data, mechanical system data, ride-hailing service, map data, audio, video, etc.), data associated with different types of data stores (e.g., relational databases, key-value stores, document databases, graph databases, column-family databases, data analytic stores, search engine databases, time series databases, object stores, file systems, etc.), data originating from different sources (e.g., AVs, enterprise systems, social networks, etc.), data having different rates of change (e.g., batch, streaming, etc.), and/or data having other characteristics. The various platforms and systems of the data center **150** can access data stored by the data management platform **152** to provide their respective services.

(32) The AI/ML platform **154** can provide the infrastructure for training and evaluating machine learning algorithms for operating the AV **102**, the simulation platform **156**, the remote assistance platform **158**, the ride-hailing platform **160**, the map management platform **162**, and other platforms and systems. Using the AI/ML platform **154**, data scientists can prepare data sets from the data management platform **152**; select, design, and train machine learning models; evaluate, refine, and deploy the models; maintain, monitor, and retrain the models; and so on.

(33) Simulation platform **156** can enable testing and validation of the algorithms, machine learning models, neural networks, and other development efforts for the AV **102**, the remote assistance platform **158**, the ride-hailing platform **160**, the map management platform **162**, and other platforms and systems. Simulation platform **156** can replicate a variety of driving environments and/or reproduce real-world scenarios from data captured by the AV **102**, including rendering geospatial information and road infrastructure (e.g., streets, lanes, crosswalks, traffic lights, stop signs, etc.) obtained from a cartography platform (e.g., map management platform **162**); modeling the behavior of other vehicles, bicycles, pedestrians, and other dynamic elements; simulating inclement weather conditions, different traffic scenarios; and so on.

(34) Remote assistance platform **158** can generate and transmit instructions regarding the operation of the AV **102**. For example, in response to an output of the AI/ML platform **154** or other system of the data center **150**, the remote assistance platform **158** can prepare instructions for one or more stacks or other components of the AV **102**.

(35) Ride-hailing platform **160** can interact with a customer of a ride-hailing service via a ride-hailing application **172** executing on the client computing device **170**. The client computing device **170** can be any type of computing system such as, for example and without limitation, a server, desktop computer, laptop computer, tablet computer, smartphone, smart wearable device (e.g., smartwatch, smart eyeglasses or other Head-Mounted Display (HMD), smart ear pods, or other smart in-ear, on-ear, or over-ear device, etc.), gaming system, or any other computing device for accessing the ride-hailing application **172**. The client computing device **170** can be a customer's mobile computing device or a computing device integrated with the AV **102** (e.g., the local computing device **110**). The ride-hailing platform **160** can receive requests to pick up or drop off from the ride-hailing application **172** and dispatch the AV **102** for the trip.

(36) Map management platform **162** can provide a set of tools for the manipulation and management of geographic and spatial (geospatial) and related attribute data. The data management platform **152** can receive LIDAR point cloud data, image data (e.g., still image, video, etc.), RADAR data, GPS data, and other sensor data (e.g., raw data) from one or more AVs **102**, Unmanned Aerial Vehicles (UAVs), satellites, third-party mapping services, and other sources of geospatially referenced data. The raw data can be processed, and map management platform **162** can render base representations (e.g., tiles (2D), bounding volumes (3D), etc.) of the AV geospatial data to enable users to view, query, label, edit, and otherwise interact with the data. Map management platform **162** can manage workflows and tasks for operating on the AV geospatial data. Map management platform **162** can control access to the AV geospatial data, including granting or limiting access to the AV geospatial data based on user-based, role-based, group-based, task-based, and other attribute-based access control mechanisms. Map management platform **162** can provide version control for the AV geospatial data, such as to track specific changes that (human or machine) map editors have made to the data and to revert changes when necessary. Map management platform **162** can administer release management of the AV geospatial data, including distributing suitable iterations of the data to different users, computing devices, AVs, and other consumers of HD maps. Map management platform **162** can provide analytics regarding the AV geospatial data and related data, such as to generate insights relating to the throughput and quality of mapping tasks.

(37) In some examples, the map viewing services of map management platform **162** can be modularized and deployed as part of one or more of the platforms and systems of the data center **150**. For example, the AI/ML platform **154** may incorporate the map viewing services for visualizing the effectiveness of various object detection or object classification models, the simulation platform **156** may incorporate the map viewing services for recreating and visualizing certain driving scenarios, the remote assistance platform **158** may incorporate the map viewing services for replaying traffic incidents to facilitate and coordinate aid, the ride-hailing platform **160** may incorporate the map viewing services into the ride-hailing application **172** to enable passengers to view the AV **102** in transit en route to a pick-up or drop-off location, and so on.

(38) While the autonomous vehicle **102**, the local computing device **110**, and the autonomous vehicle environment **100** are shown to include certain systems and components, one of ordinary skill will appreciate that the autonomous vehicle **102**, the local computing device **110**, and/or the autonomous vehicle environment **100** can include more or fewer systems and/or components than those shown in FIG. 1. For example, the autonomous vehicle **102** can include other services than those shown in FIG. 1 and the local computing device **110** can also include, in some instances, one or more memory devices (e.g., RAM, ROM, cache, and/or the like), one or more network interfaces (e.g., wired and/or wireless communications interfaces and the like), and/or other hardware or

processing devices that are not shown in FIG. 1. An illustrative example of a computing device and hardware components that can be implemented with the local computing device **110** is described below with respect to FIG. 7.

(39) FIG. 2 illustrates a diagram of an example system environment **200** for an AV fleet management system. As shown, example environment **200** includes a fleet management system **210** that may be communicatively connected, over network **220**, to a user device **230** (e.g., similar to client computing device **170** as illustrated in FIG. 1) and a fleet of AVs **202** including AV **102A**, AV **102B**, . . . , AV **102N**. Although FIG. 2 illustrates a single fleet management system **210**, a single fleet **202**, a single network **220**, and a single user device **230**, the present disclosure can be implemented with any suitable number of fleet management systems, fleets, and/or user devices. For example, the system environment **200** may include one or more fleet management systems **210**, fleets **202**, networks **220**, and user devices **230**.

(40) In some examples, fleet management system **210** may send and receive various signals to and from one or more AVs **102A-102N** in fleet **202** and user device **230** over network **220**. Non-limiting examples of network **220** can include a public network (e.g., the Internet, an IaaS network, a PaaS network, a SaaS network, other CSP network etc.), a private network (e.g., a LAN, a private cloud, a VPN, etc.), a hybrid network (e.g., a multi-cloud or hybrid cloud network, etc.), or a combination of any of the above. In some cases, fleet management system **210** may be connected to one or more types of network **220**, which may be used differently when communicating with user device **230** or one or more AVs **102A-102N** in fleet **202**.

(41) In some cases, each AV **102A-102N** in fleet **202** is equipped with various sensors (e.g., sensor systems **104-108** as illustrated in FIG. 1) that may capture sensor data, which may be transmitted to fleet management system **210** in real-time over network **220**. For example, fleet management system **210** may receive sensor data from one or more AVs **102A-102N** in fleet **202** that may be collected while the AV is navigating in a real-world driving environment. In some cases, the sensor data may be descriptive of an environment around the AV that can be used to determine or verify a location, orientation, position, and/or pose of the AV, road conditions, grades of the road, traffic conditions, temperature, weather conditions, etc.

(42) In some examples, each AV **102A-102N** in fleet **202** may transmit vehicle-specific information to fleet management system **210** in real-time over network **220**. The vehicle-specific information can be associated with properties, characteristics, or attributes that may be specific to the respective AV. For example, the vehicle-specific information can include, without limitation, vehicle configurations, properties of the AV (e.g., dimensions, size, weight, shape, etc.), a vehicle age, battery data (e.g., battery age, battery capacity, battery voltage, battery charge state, battery pack size, etc.), tire pressure, energy efficiency, fuel or battery efficiency, driving range, maximum and/or minimum speed, maximal torque, vehicle history (e.g., history of accidents or safety-critical events), engine temperature, ambient temperature, and so on.

(43) In some examples, fleet management system **210** can receive various signals from any other suitable databases/data centers (e.g., data center **150** as illustrated in FIG. 1 or a third-party data store). For example, data center **150** or a third-party data system may provide the above-described data associated with AVs **102A-102N** in fleet **202** (e.g., sensor data or vehicle-specific information). Further, data center **150** or a third-party data system may provide any other available data (e.g., map data, traffic data, weather data, road condition data, etc.) to fleet management system **210** over network **220**.

(44) In some aspects, each AV **102A-102N** in fleet **202** may transmit maintenance information to fleet management system **210** in real-time over network **220**. The maintenance information may be associated with the maintenance state and/or status of the respective AV. For example, the maintenance information can include, without limitation, battery charge level, data storage capacity level, remaining time until a required power cycle, remaining time until sensor calibration, remaining time until data offload, vehicle health-check cycle, sensor fault indications, and so on.

- (45) In some examples, fleet management system **210** may monitor the maintenance state and/or status of one or more AVs **102A-102N** in fleet **202** and control any necessary and/or required maintenance of the AV(s) **102A-102N**. For example, based on the current maintenance state and/or status of an AV (e.g., AV **102-102N**), fleet management system **210** may schedule a trip to a maintenance facility for the AV and instruct the AV (or send instruction signals to the AV) to drive to the maintenance facility. In some aspects, the maintenance can include battery charging, sensor calibration, power cycling, offloading data, regular health check-ups, etc.
- (46) In some examples, fleet management system **210** may receive a ride request from user device **230** to transport one or more passengers from a pick-up location to a drop-off location (e.g., destination). In some cases, the ride request may include user's information such as a number of passengers, a preferred type of vehicle, a type of requested task (e.g., ridesharing and/or or ride-hailing services, food/grocery delivery, and/or parcel delivery services, etc.), driving preferences (e.g., comfort level, maximum speed, preferred speed, to avoid tolls, to avoid freeways/highways, etc.), accommodations, riding history, etc.
- (47) In some cases, fleet management system **210** is configured to match and dispatch an AV in response to a ride request received from user device **230**. For example, upon receipt of a ride request from user device **230**, fleet management system **210** may select an AV among one more AVs in fleet **202** based on the ride request, sensor data, vehicle-specific information, maintenance information, and/or any other available data as described above.
- (48) FIG. 3 illustrates a flowchart diagram illustrating an example process **300** for dispatching an AV in a fleet of AVs based on resource usage predictions. In some examples, process **300** may include step **302**, which includes receiving a ride request from a user device (e.g., client computing device **170** as illustrated in FIG. 1 or user device **230** as illustrated in FIG. 2). For example, a fleet management system, which is responsible for managing a fleet of AVs, can receive a ride request from a user device to transport one or more passengers from a pick-up location to a drop-off location.
- (49) In some examples, the ride request may include user's information such as a number of passengers, a preferred type of vehicle, a type of requested task (e.g., ridesharing and/or or ride-hailing services, food/grocery delivery, and/or parcel delivery services, etc.), user's preferences or driving preferences (e.g., comfort level, maximum speed, preferred speed, to avoid tolls, to avoid freeways/highways, etc.), accommodations, riding history, etc. In some aspects, the fleet management system can match an AV in a fleet of AVs and plan a route based at least in part on the user's information provided in the ride request.
- (50) In some examples, process **300** may proceed to step **304**, which includes making resource usage prediction(s) for each AV in a fleet of AVs. In some cases, upon receipt of the ride request, the fleet management system may predict a level of resource usage that may be required to fulfill the ride request. In some aspects, resource usage may be associated with battery usage, data storage usage, and/or usage of any other types of resources that may be needed to complete the ride request. In some aspects, the fleet management system may determine the predicted resource usage based on a distance between the pick-up location and the drop-off location and a distance between an AV location and the pick-up location. For example, if the distance between the pick-up location and the drop-off location and/or the distance between the AV location and the pick-up location is longer, more battery would be consumed and more data storage (or more disk space) would be needed to complete the ride request.
- (51) In some aspects, the fleet management system can determine the predicted resource usage based on one or more environmental factors such as a location, orientation, position, and/or pose of the AV, road conditions, grades of the road (e.g., road surface textures), traffic conditions, temperature, weather conditions, and so on. For example, even for the same distance, driving on an uphill grade may result in more battery or power consumption compared to driving on a downhill grade or a flat terrain since an AV would need to use more power to pull the AV up the hill and

incline. In another example, friction loss can impact power consumption. For example, more power consumption can be spent to overcome friction on the road. In another example, the grades of the road can affect the vehicle speed and vehicle control, which may also affect power consumption. In some examples, extreme weather conditions can have a significant impact on the driving range, and battery consumption. In another example, air turbulence may affect power consumption. In some examples, an AV would need to analyze more objects in urban environments (e.g., compared to a rural area that has less objects to detect in a scene). For example, an AV would need more data storage (e.g., disk space) when driving in urban environments as the AV needs to analyze more objects that are detected in a scene. In some aspects, the speed of an AV can impact the data storage use per minute. For example, an AV would need more data storage per minute when the AV is navigating at a higher speed compared to when the AV is driving at a lower speed. In some cases, an AV may use less disk usage at night as a camera of the AV would process less number of objects in a scene.

(52) In some cases, the fleet management system can determine the predicted resource usage based on one or more vehicle-specific factors such as vehicle configurations, properties of the AV (e.g., dimensions, size, weight, shape, etc.), a vehicle age, a battery age or life, a data storage age or life, battery capacity, tire pressure, energy efficiency, fuel or battery efficiency, battery pack size, driving range, maximum and/or minimum speed, maximal torque, battery voltage, a history of accidents or safety-critical events, and so on. For example, a vehicle age, a battery age or life, or a data storage age or life can have an impact on a level of degradation and resource consumption efficiency. In another example, maximum and/or minimum speed or maximal torque can affect the total travel time and the total resource usage.

(53) In some aspects, the fleet management system may comprise one or more machine learning modules or implement machine learning algorithms to generate the resource usage predictions. For example, a machine learning model can be trained to make resource usage predictions (e.g., predicted battery use or predicted data storage use). Various available data such as sensor data, vehicle-specific information, maintenance information, etc. can be fed into a machine learning model that can interpret the gathered data to predict the resource usage that may be needed to complete a ride request.

(54) In some examples, process **300** may proceed to step **306** to determine whether the AV has enough resources to complete the ride request. In some aspects, the fleet management system may receive information associated with the maintenance state and/or status of an AV in a fleet of AVs. As previously described, one or more AVs in a fleet of AVs may transmit maintenance information associated with the current maintenance state and/or status of the respective AV such as the remaining data storage level and the remaining battery level. In some cases, the fleet management system can compare the predicted resource usage and the maintenance state and/or status of the AV and determine whether the AV has enough resources (e.g., battery and data storage) to complete the ride request. If the AV does not have enough resources to fulfill the ride request, the fleet management system can exclude the AV from a candidate pool for dispatching to the pick-up location and process **300** can end.

(55) In some cases, if the AV has enough resources to complete the ride request, process **300** may proceed to step **308** to determine whether the AV would need maintenance (e.g., need to go to a maintenance facility) before, during, or after the completion of the ride request based on the predicted resource usage and the maintenance state of the AV. As previously described, the maintenance information received from the AV(s) in a fleet can include data storage capacity level (e.g., remaining data storage capacity), remaining battery level, remaining time until a required power cycle, remaining time until sensor calibration, remaining time until data offload, and so on. As such, the fleet management system can determine, based on the predicted resource usage and the maintenance information, whether the AV would need maintenance before, during, or after the completion of the ride request. If the AV does not need any maintenance services, process **300** may

proceed to step **310**.

(56) If the AV would need maintenance services, process **300** may proceed to step **310**, which includes scheduling a trip to a maintenance facility. In some cases, the fleet management system can determine, for the AV, a time to go to a maintenance facility based on the predicted resource usage for the completion of the ride request and the maintenance state and/or status of the AV. In some aspects, the fleet management system can determine that a predicted maintenance state after the completion of the ride requires a maintenance of the AV (e.g., charging of the AV, sensor calibration of the AV, power cycling of the AV, offloading data of the AV, or any other maintenance work that needs to be performed). As follows, the fleet management system can schedule a trip of the AV from the drop-off location to a maintenance facility.

(57) In some cases, the fleet management system can select, among multiple maintenance facilities, a maintenance facility based on one or more parameters (e.g., a distance between a drop-off location and a maintenance facility, availability of charging ports, availability of proper technicians, equipment, or parts that may be needed for the maintenance, etc.). For example, if the closest maintenance facility does not have the proper equipment for the maintenance that is needed for an AV, the fleet management system may route the AV to travel to the second closest maintenance facility that may have the availability.

(58) In some examples, process **300** may proceed to step **312**, which includes the dispatch of the AV to a pick-up location. For example, the fleet management system may select an AV as described above and dispatch (or send instruction signals to) the selected AV to a pick-up location to pick up one or more passengers as requested in the ride request.

(59) In some aspects, the fleet management system can, for a dispatch, prioritize an AV whose predicted resource usage for the completion of the ride request is substantially similar to the remaining resource level. For example, the fleet management system can, for a dispatch, prioritize an AV whose available resource level is greater than the predicted resource usage by the smallest value among the AVs in the fleet and schedule a trip to a maintenance facility for the AV after the completion of the ride request. Rather than dispatching an AV that has 60 kWh battery for a ride request that would only require 10 kWh battery, the fleet management system can dispatch an AV that has 20 kWh battery. The AV with a higher battery capacity can be saved for a longer-distance trip. As such, the selection of an AV, among AVs in a fleet, can utilize the resource usage predictions to optimize the resource use of the AV(s) in the fleet.

(60) FIG. 4 illustrates a diagram illustrating an example scene **400** for dispatching an AV in a fleet of AVs based on resource usage predictions. As shown, example scene **400** includes multiple AVs **102A**, **102B**, **102C**, a user **402** (or a ride requestor) who requested a ride between a pick-up location **410** and a drop-off location **420** (e.g., destination), and maintenance facilities **430A** and **430B**. As previously described, AVs **102A-102C** can be part of a fleet (e.g., fleet **202**), which may be managed and controlled by a fleet management system (e.g., fleet management system **210**).

(61) In some cases, once the fleet management system receives a ride request from a user device associated with a passenger **402** to transport the passenger from a pick-up location **410** to a drop-off location **420**, the fleet management system can determine the predicted resource usage for each AV **102A**, **102B**, **102C** to complete the ride request. For example, the fleet management can determine the total travel distance that is needed to complete the ride request, which would include a distance from a current location of an AV to pick-up location **410** and a distance from pick-up location **410** to drop-off location **420**.

(62) In some examples, the fleet management system can determine the predicted resource usage for each AV **102A**, **102B**, **102C** based on one or more environmental factors including, for example without limitation, a location, orientation, position, and/or pose of the AV, road conditions, grades of the road (e.g., road surface textures), traffic conditions, temperature, weather conditions, and so on. For example, even if the distance between a location of AV **102A** and pick-up location **410** may be shorter than the distance between a location of AV **102C** and pick-up location **420**, if the road

between the location of AV **102A** and pick-up location **410** is sloped and uphill, the predicted battery use for AV **102A** to travel between its location to pick-up location **410** might be higher/greater than the predicted battery use for AV **102C** to travel between its location to pick-up location **410**.

(63) In some aspects, the fleet management system can determine the predicted resource usage for each AV **102B**, **102B**, **102C** based on one or more vehicle-specific factors including, for example without limitation, vehicle configurations, properties of the AV (e.g., dimensions, size, weight, shape, etc.), a vehicle age, a battery age or life, battery capacity, tire pressure, energy efficiency, fuel or battery efficiency, battery pack size, driving range, maximum and/or minimum speed, maximal torque, battery voltage, a history of accidents or safety-critical events, and so on.

(64) In some cases, the fleet management system can determine which AV to dispatch to pick-up location **410** based on the predicted resource usage and a maintenance state and/or status of each AV. As previously described, the maintenance state and/or status can be associated with remaining battery level, data storage capacity level, remaining time until a required power cycle, remaining time until sensor calibration, remaining time until data offload, vehicle health-check cycle. For example, the fleet management system can select an AV that has enough battery and data storage as well as enough time until a required power cycle, sensor calibration, data offload, or health-check cycle so that an AV does not run out of resources or fail operations while completing the ride request.

(65) In some examples, if the selected AV needs a maintenance after the completion of the ride request, the fleet management system may schedule a trip to maintenance facility **430A** or **430B**. In some cases, the fleet management system can select a maintenance facility based on one or more parameters such as a distance between drop-off location **420** and maintenance facility **430A** or **430B**, availability of charging ports, availability of proper technicians, equipment, or parts that may be needed for the maintenance, etc. For example, if AV **102A** needs to offload data after completing the ride request and the closest maintenance facility **430** from drop-off location **420** does not have availability for offloading data, the fleet management system may instruct or schedule for AV **102A** to travel to maintenance facility **430A** that has availability for offloading data.

(66) FIG. 5 is a flowchart illustrating an example process **500** for selecting an AV for a dispatch based on resource usage predictions. Although the example process **500** depicts a particular sequence of operations, the sequence may be altered without departing from the scope of the present disclosure. For example, some of the operations depicted may be performed in parallel or in a different sequence that does not materially affect the function of process **500**. In other examples, different components of an example device or system that implements process **500** may perform functions at substantially the same time or in a specific sequence.

(67) At block **510**, process **500** includes receiving, from a user device, a ride request for a ride between a pick-up location and a drop-off location. For example, fleet management system **210** can receive a ride request from user device **230** (e.g., a user device associated with user **402**) for a ride between pick-up location **410** and drop-off location **420** over network **220**.

(68) At block **520**, process **500** includes determining, for each AV in a set of AVs, a predicted resource usage for a completion of the ride based on a distance between the pick-up location and the drop-off location, a distance between an AV location and the pick-up location, one or more environmental factors, and one or more vehicle-specific factors. For example, fleet management system **210** can determine, for each AV in fleet **202**, a predicted resource usage for a completion of the ride between pick-up location **410** and drop-off location **420**. In some aspects, the predicted resource usage can be associated with battery usage, data storage usage, and/or any other types of resources that may be needed to control/operate an AV.

(69) In some examples, the predicted resource usage can be determined based on various factors including a distance between pick-up location **410** and drop-off location **420** and a distance between a location of AV (e.g., AV **102A-102N**) and pick-up location **410**. For example, the longer

distance that the AV needs to travel to complete the ride request may require more resource consumption (e.g., more battery use, more disk space required, etc.). In another example, the shorter distance that the AV needs to travel to fulfill the ride request may result in less resource consumption (e.g., less battery use, less disk space required, etc.).

(70) In some examples, the predicted resource usage can be determined based on one or more environmental factors (e.g., predicted usage of data storage, a road condition, a travel time, a weather condition, time of day, a traffic condition, etc.) and/or vehicle-specific factors (e.g., vehicle age, battery life, tire pressure, vehicle configurations, etc.).

(71) At block **530**, process **500** includes selecting an AV in the set of AVs for the ride based on the predicted resource usage for the completion of the ride and a maintenance state of each AV. For example, fleet management system **210** can select an AV (AV **102A-102N**) in fleet **202** for the ride based on the predicted resource usage for the completion of the ride and a maintenance state of each AV (e.g., AV **102A-102N**) in fleet **202**.

(72) In some aspects, the maintenance state of each AV each AV (e.g., AV **102A-102N**) in fleet **202** can be associated with data storage capacity level, remaining battery level, remaining time until a required power cycle, remaining time until sensor calibration, remaining time until data offload, and so on.

(73) In some examples, process **500** can include dispatching the AV in the set of AVs to the pick-up location. For example, the fleet management system **210** can dispatch the AV (e.g., AV **102A-102N**) in fleet **202**, which has been selected based on the predicted resource usage and the maintenance state, to pick-up location **410**.

(74) In FIG. **6**, the disclosure now turns to a further discussion of models that can be used through the environments and techniques described herein. FIG. **6** is an example of a deep learning neural network **600** that can be used to implement all or a portion of the systems and techniques described herein as discussed above (e.g., neural network **600** can be used to implement aspects of resource usage predictions). An input layer **620** can be configured to receive sensor data and/or data relating to an environment surrounding an AV. Neural network **600** includes multiple hidden layers **622a**, **622b**, through **622n**. The hidden layers **622a**, **622b**, through **622n** include “n” number of hidden layers, where “n” is an integer greater than or equal to one. The number of hidden layers can be made to include as many layers as needed for the given application. Neural network **600** further includes an output layer **621** that provides an output resulting from the processing performed by the hidden layers **622a**, **622b**, through **622n**.

(75) Neural network **600** is a multi-layer neural network of interconnected nodes. Each node can represent a piece of information. Information associated with the nodes is shared among the different layers and each layer retains information as information is processed. In some cases, the neural network **600** can include a feed-forward network, in which case there are no feedback connections where outputs of the network are fed back into itself. In some cases, the neural network **600** can include a recurrent neural network, which can have loops that allow information to be carried across nodes while reading in input.

(76) Information can be exchanged between nodes through node-to-node interconnections between the various layers. Nodes of the input layer **620** can activate a set of nodes in the first hidden layer **622a**. For example, as shown, each of the input nodes of the input layer **620** is connected to each of the nodes of the first hidden layer **622a**. The nodes of the first hidden layer **622a** can transform the information of each input node by applying activation functions to the input node information. The information derived from the transformation can then be passed to and can activate the nodes of the next hidden layer **622b**, which can perform their own designated functions. Example functions include convolutional, up-sampling, data transformation, and/or any other suitable functions. The output of the hidden layer **622b** can then activate nodes of the next hidden layer, and so on. The output of the last hidden layer **622n** can activate one or more nodes of the output layer **621**, at which an output is provided. In some cases, while nodes in the neural network **600** are shown as

having multiple output lines, a node can have a single output and all lines shown as being output from a node represent the same output value.

(77) In some cases, each node or interconnection between nodes can have a weight that is a set of parameters derived from the training of the neural network **600**. Once the neural network **600** is trained, it can be referred to as a trained neural network, which can be used to classify one or more activities. For example, an interconnection between nodes can represent a piece of information learned about the interconnected nodes. The interconnection can have a tunable numeric weight that can be tuned (e.g., based on a training dataset), allowing the neural network **600** to be adaptive to inputs and able to learn as more and more data is processed.

(78) The neural network **600** is pre-trained to process the features from the data in the input layer **620** using the different hidden layers **622a**, **622b**, through **622n** in order to provide the output through the output layer **621**.

(79) In some cases, the neural network **600** can adjust the weights of the nodes using a training process called backpropagation. A backpropagation process can include a forward pass, a loss function, a backward pass, and a weight update. The forward pass, loss function, backward pass, and parameter/weight update is performed for one training iteration. The process can be repeated for a certain number of iterations for each set of training data until the neural network **600** is trained well enough so that the weights of the layers are accurately tuned.

(80) To perform training, a loss function can be used to analyze error in the output. Any suitable loss function definition can be used, such as a Cross-Entropy loss. Another example of a loss function includes the mean squared error (MSE), defined as $E_{\text{total}} = \sum (\frac{1}{2} (\text{target} - \text{output})^2)$. The loss can be set to be equal to the value of E_{total} .

(81) The loss (or error) will be high for the initial training data since the actual values will be much different than the predicted output. The goal of training is to minimize the amount of loss so that the predicted output is the same as the training output. The neural network **600** can perform a backward pass by determining which inputs (weights) most contributed to the loss of the network, and can adjust the weights so that the loss decreases and is eventually minimized.

(82) The neural network **600** can include any suitable deep network. One example includes a Convolutional Neural Network (CNN), which includes an input layer and an output layer, with multiple hidden layers between the input and out layers. The hidden layers of a CNN include a series of convolutional, nonlinear, pooling (for downsampling), and fully connected layers. The neural network **600** can include any other deep network other than a CNN, such as an autoencoder, Deep Belief Nets (DBNs), Recurrent Neural Networks (RNNs), among others.

(83) As understood by those of skill in the art, machine-learning based classification techniques can vary depending on the desired implementation. For example, machine-learning classification schemes can utilize one or more of the following, alone or in combination: hidden Markov models; RNNs; CNNs; deep learning; Bayesian symbolic methods; Generative Adversarial Networks (GANs); support vector machines; image registration methods; and applicable rule-based systems. Where regression algorithms are used, they may include but are not limited to: a Stochastic Gradient Descent Regressor, a Passive Aggressive Regressor, etc.

(84) Machine learning classification models can also be based on clustering algorithms (e.g., a Mini-batch K-means clustering algorithm), a recommendation algorithm (e.g., a Minwise Hashing algorithm, or Euclidean Locality-Sensitive Hashing (LSH) algorithm), and/or an anomaly detection algorithm, such as a local outlier factor. Additionally, machine-learning models can employ a dimensionality reduction approach, such as, one or more of: a Mini-batch Dictionary Learning algorithm, an incremental Principal Component Analysis (PCA) algorithm, a Latent Dirichlet Allocation algorithm, and/or a Mini-batch K-means algorithm, etc.

(85) FIG. 7 illustrates an example processor-based system with which some aspects of the subject technology can be implemented. For example, processor-based system **700** can be any computing device making up, or any component thereof in which the components of the system are in

communication with each other using connection **705**. Connection **705** can be a physical connection via a bus, or a direct connection into processor **710**, such as in a chipset architecture. Connection **705** can also be a virtual connection, networked connection, or logical connection.

(86) In some examples, computing system **700** is a distributed system in which the functions described in this disclosure can be distributed within a datacenter, multiple data centers, a peer network, etc. In some examples, one or more of the described system components represents many such components each performing some or all of the function for which the component is described. In some examples, the components can be physical or virtual devices.

(87) Example system **700** includes at least one processing unit (Central Processing Unit (CPU) or processor) **710** and connection **705** that couples various system components including system memory **715**, such as Read-Only Memory (ROM) **720** and Random-Access Memory (RAM) **725** to processor **710**. Computing system **700** can include a cache of high-speed memory **712** connected directly with, in close proximity to, or integrated as part of processor **710**.

(88) Processor **710** can include any general-purpose processor and a hardware service or software service, such as services **732**, **734**, and **736** stored in storage device **730**, configured to control processor **710** as well as a special-purpose processor where software instructions are incorporated into the actual processor design. Processor **710** may essentially be a completely self-contained computing system, containing multiple cores or processors, a bus, memory controller, cache, etc. A multi-core processor may be symmetric or asymmetric.

(89) To enable user interaction, computing system **700** includes an input device **745**, which can represent any number of input mechanisms, such as a microphone for speech, a touch-sensitive screen for gesture or graphical input, keyboard, mouse, motion input, speech, etc. Computing system **700** can also include output device **735**, which can be one or more of a number of output mechanisms known to those of skill in the art. In some instances, multimodal systems can enable a user to provide multiple types of input/output to communicate with computing system **700**.

Computing system **700** can include communication interface **740**, which can generally govern and manage the user input and system output. The communication interface may perform or facilitate receipt and/or transmission wired or wireless communications via wired and/or wireless transceivers, including those making use of an audio jack/plug, a microphone jack/plug, a Universal Serial Bus (USB) port/plug, an Apple® Lightning® port/plug, an Ethernet port/plug, a fiber optic port/plug, a proprietary wired port/plug, a BLUETOOTH® wireless signal transfer, a BLUETOOTH® low energy (BLE) wireless signal transfer, an IBEACON® wireless signal transfer, a Radio-Frequency Identification (RFID) wireless signal transfer, Near-Field Communications (NFC) wireless signal transfer, Dedicated Short Range Communication (DSRC) wireless signal transfer, 802.11 Wi-Fi® wireless signal transfer, Wireless Local Area Network (WLAN) signal transfer, Visible Light Communication (VLC) signal transfer, Worldwide Interoperability for Microwave Access (WiMAX), Infrared (IR) communication wireless signal transfer, Public Switched Telephone Network (PSTN) signal transfer, Integrated Services Digital Network (ISDN) signal transfer, 3G/4G/5G/LTE cellular data network wireless signal transfer, ad-hoc network signal transfer, radio wave signal transfer, microwave signal transfer, infrared signal transfer, visible light signal transfer signal transfer, ultraviolet light signal transfer, wireless signal transfer along the electromagnetic spectrum, or some combination thereof.

(90) Communication interface **740** may also include one or more Global Navigation Satellite System (GNSS) receivers or transceivers that are used to determine a location of the computing system **700** based on receipt of one or more signals from one or more satellites associated with one or more GNSS systems. GNSS systems include, but are not limited to, the US-based Global Positioning System (GPS), the Russia-based Global Navigation Satellite System (GLONASS), the China-based BeiDou Navigation Satellite System (BDS), and the Europe-based Galileo GNSS. There is no restriction on operating on any particular hardware arrangement, and therefore the basic features here may easily be substituted for improved hardware or firmware arrangements as they

are developed.

(91) Storage device **730** can be a non-volatile and/or non-transitory and/or computer-readable memory device and can be a hard disk or other types of computer readable media which can store data that are accessible by a computer, such as magnetic cassettes, flash memory cards, solid state memory devices, digital versatile disks, cartridges, a floppy disk, a flexible disk, a hard disk, magnetic tape, a magnetic strip/stripe, any other magnetic storage medium, flash memory, memristor memory, any other solid-state memory, a Compact Disc (CD) Read Only Memory (CD-ROM) optical disc, a rewritable CD optical disc, a Digital Video Disk (DVD) optical disc, a Blu-ray Disc (BD) optical disc, a holographic optical disc, another optical medium, a Secure Digital (SD) card, a micro SD (microSD) card, a Memory Stick® card, a smartcard chip, a EMV chip, a Subscriber Identity Module (SIM) card, a mini/micro/nano/pico SIM card, another Integrated Circuit (IC) chip/card, Random-Access Memory (RAM), Atatic RAM (SRAM), Dynamic RAM (DRAM), Read-Only Memory (ROM), Programmable ROM (PROM), Erasable PROM (EPROM), Electrically Erasable PROM (EEPROM), flash EPROM (FLASHEPROM), cache memory (L1/L2/L3/L4/L5/L #), Resistive RAM (RRAM/ReRAM), Phase Change Memory (PCM), Spin Transfer Torque RAM (STT-RAM), another memory chip or cartridge, and/or a combination thereof.

(92) Storage device **730** can include software services, servers, services, etc., that when the code that defines such software is executed by the processor **710**, it causes the system **700** to perform a function. In some examples, a hardware service that performs a particular function can include the software component stored in a computer-readable medium in connection with the necessary hardware components, such as processor **710**, connection **705**, output device **735**, etc., to carry out the function.

(93) Examples within the scope of the present disclosure may also include tangible and/or non-transitory computer-readable storage media or devices for carrying or having computer-executable instructions or data structures stored thereon. Such tangible computer-readable storage devices can be any available device that can be accessed by a general purpose or special purpose computer, including the functional design of any special purpose processor as described above. By way of example, and not limitation, such tangible computer-readable devices can include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other device which can be used to carry or store desired program code in the form of computer-executable instructions, data structures, or processor chip design. When information or instructions are provided via a network or another communications connection (either hardwired, wireless, or combination thereof) to a computer, the computer properly views the connection as a computer-readable medium. Thus, any such connection is properly termed a computer-readable medium. Combinations of the above should also be included within the scope of the computer-readable storage devices.

(94) Computer-executable instructions include, for example, instructions and data which cause a general-purpose computer, special purpose computer, or special purpose processing device to perform a certain function or group of functions. Computer-executable instructions also include program modules that are executed by computers in stand-alone or network environments. Generally, program modules include routines, programs, components, data structures, objects, and the functions inherent in the design of special-purpose processors, etc. that perform tasks or implement abstract data types. Computer-executable instructions, associated data structures, and program modules represent examples of the program code means for executing steps of the methods disclosed herein. The particular sequence of such executable instructions or associated data structures represents examples of corresponding acts for implementing the functions described in such steps.

(95) Other examples of the disclosure may be practiced in network computing environments with many types of computer system configurations, including personal computers, hand-held devices,

multi-processor systems, microprocessor-based or programmable consumer electronics, network Personal Computers (PCs), minicomputers, mainframe computers, and the like. Examples may also be practiced in distributed computing environments where tasks are performed by local and remote processing devices that are linked (either by hardwired links, wireless links, or by a combination thereof) through a communications network. In a distributed computing environment, program modules may be located in both local and remote memory storage devices.

(96) The various examples described above are provided by way of illustration only and should not be construed to limit the scope of the disclosure. For example, the principles herein apply equally to optimization as well as general improvements. Various modifications and changes may be made to the principles described herein without following the examples and applications illustrated and described herein, and without departing from the spirit and scope of the disclosure.

(97) Claim language or other language in the disclosure reciting “at least one of” a set and/or “one or more” of a set indicates that one member of the set or multiple members of the set (in any combination) satisfy the claim. For example, claim language reciting “at least one of A and B” or “at least one of A or B” means A, B, or A and B. In another example, claim language reciting “at least one of A, B, and C” or “at least one of A, B, or C” means A, B, C, or A and B, or A and C, or B and C, or A and B and C. The language “at least one of” a set and/or “one or more” of a set does not limit the set to the items listed in the set. For example, claim language reciting “at least one of A and B” or “at least one of A or B” can mean A, B, or A and B, and can additionally include items not listed in the set of A and B.

(98) Illustrative examples of the disclosure include:

(99) Aspect 1. A fleet management system comprising: a memory; and one or more processors coupled to the memory, the one or more processors being configured to: receive, from a user device, a ride request for a ride between a pick-up location and a drop-off location; determine, for each autonomous vehicle (AV) in a set of AVs, a predicted resource usage for a completion of the ride based on a distance between the pick-up location and the drop-off location, a distance between an AV location and the pick-up location, one or more environmental factors, and one or more vehicle-specific factors; and select an AV in the set of AVs for the ride based on the predicted resource usage for the completion of the ride and a maintenance state of each AV.

(100) Aspect 2. The fleet management system of Aspect 1, wherein the one or more processors are configured to: dispatch the AV in the set of AVs to the pick-up location.

(101) Aspect 3. The fleet management system of Aspects 1 or 2, wherein the predicted resource usage is associated with battery usage and data storage usage.

(102) Aspect 4. The fleet management system of any of Aspects 1 to 3, wherein the one or more environmental factors comprise at least one of a location of the AV, a road condition, a weather condition, time of day, and a traffic condition.

(103) Aspect 5. The fleet management system of any of Aspects 1 to 4, wherein the one or more vehicle-specific factors comprise at least one of a vehicle age, battery life, tire pressure, and vehicle configurations.

(104) Aspect 6. The fleet management system of any of Aspects 1 to 5, wherein the maintenance state of each AV is associated with at least one of data storage capacity level, remaining battery level, remaining time until a required power cycle, remaining time until sensor calibration, and remaining time until data offload.

(105) Aspect 7. The fleet management system of any of Aspects 1 to 6, wherein the one or more processors are configured to: determine a time to go to a maintenance facility, for each AV in the set of AVs, based on the predicted resource usage for the completion of the ride and the maintenance state of each AV.

(106) Aspect 8. The fleet management system of any of Aspects 1 to 7, wherein the one or more processors are configured to: determine that a predicted maintenance state after the completion of the ride requires a maintenance of the AV, wherein the maintenance includes at least one of

charging of the AV, sensor calibration of the AV, power cycling of the AV, and offloading data of the AV; and schedule a trip of the AV from the drop-off location to a maintenance facility.

(107) Aspect 9. The fleet management system of any of Aspects 1 to 8, wherein selecting the AV in the set of AVs for the ride based on the predicted resource usage for the completion of the ride and the maintenance state of each AV comprises: determining the predicted resource usage for the completion of the ride based on a level of battery charge and data storage space needed to complete the ride; determining an available resource level of the AV based on a remaining battery level and a data storage capacity level of the AV; and selecting the AV, among AVs in the set, based on the predicted resource usage and the available resource level of the AV, wherein the available resource level of the AV is greater than the predicted resource usage by a smallest value among the AVs in the set.

(108) Aspect 10. A method comprising: receiving, from a user device, a ride request for a ride between a pick-up location and a drop-off location; determining, for each autonomous vehicle (AV) in a set of AVs, a predicted resource usage for a completion of the ride based on a distance between the pick-up location and the drop-off location, a distance between an AV location and the pick-up location, one or more environmental factors, and one or more vehicle-specific factors; and selecting an AV in the set of AVs for the ride based on the predicted resource usage for the completion of the ride and a maintenance state of each AV.

(109) Aspect 11. The method of Aspect 10, further comprising: dispatching the AV in the set of AVs to the pick-up location.

(110) Aspect 12. The method of Aspects 10 or 11, wherein the predicted resource usage is associated with battery usage and data storage usage.

(111) Aspect 13. The method of any of Aspects 10 to 12, wherein the one or more environmental factors comprise at least one of a location of the AV, a road condition, a weather condition, time of day, and a traffic condition.

(112) Aspect 14. The method of any of Aspects 10 to 13, wherein the one or more vehicle-specific factors comprise at least one of a vehicle age, battery life, tire pressure, and vehicle configurations.

(113) Aspect 15. The method of any of Aspects 10 to 14, wherein the maintenance state of each AV is associated with at least one of data storage capacity level, remaining battery level, remaining time until a required power cycle, remaining time until sensor calibration, and remaining time until data offload.

(114) Aspect 16. The method of any of Aspects 10 to 15, further comprising: determining a time to go to a maintenance facility, for each AV in the set of AVs, based on the predicted resource usage for the completion of the ride and the maintenance state of each AV.

(115) Aspect 17. The method of any of Aspects 10 to 16, further comprising: determining that a predicted maintenance state after the completion of the ride requires a maintenance of the AV, wherein the maintenance includes at least one of charging of the AV, sensor calibration of the AV, power cycling of the AV, and offloading data of the AV; and scheduling a trip of the AV from the drop-off location to a maintenance facility.

(116) Aspect 18. The method of any of Aspects 10 to 17, further comprising: predicting a user demand for one or more ride requests associated with the set of AVs based on historical data; and scheduling a trip of the AV from the drop-off location to a maintenance facility based on the user demand.

(117) Aspect 19. A non-transitory computer-readable storage medium comprising at least one instruction for causing a computer or processor to perform method according to any of Aspects 10 to 18.

(118) Aspect 20. A computer-program product comprising instructions which, when executed by one or more processors, cause the one or more processors to perform a method according to any of Aspects 10 to 18.

Claims

1. A fleet management system comprising: a memory; and one or more processors coupled to the memory, the one or more processors being configured to: receive in real time sensor data from sensor systems of autonomous vehicles (AVs) navigating through a dynamic environment without a human driver; wherein the sensor data is received at a sufficient volume and in sufficient variety to determine AV resource usage and a maintenance state of each of the AVs; use the sensor data to determine the maintenance state of each of the AVs; receive, from a user device, a ride request for a ride between a pick-up location of the ride and a drop-off location of the ride; use the sensor data to determine, for each of the AVs, a predicted AV resource usage for a completion of the ride based on a distance between the pick-up location of the ride, the drop-off location of the ride, a distance between an AV location and the pick-up location of the ride, one or more environmental factors associated with the ride, and one or more vehicle-specific factors associated with the ride; and select a selected AV from among the AVs for the ride based on the predicted AV resource usage for the completion of the ride and the maintenance state of each of the AVs.
2. The fleet management system of claim 1, wherein the one or more processors are configured to: dispatch the selected AV to the pick-up location of the ride.
3. The fleet management system of claim 1, wherein the predicted AV resource usage is associated with battery usage and data storage usage.
4. The fleet management system of claim 1, wherein the one or more environmental factors comprise at least one of the AV location, a road condition, a weather condition, time of day, and a traffic condition.
5. The fleet management system of claim 1, wherein the one or more vehicle-specific factors comprise at least one of a vehicle age, battery life, tire pressure, and vehicle configurations.
6. The fleet management system of claim 1, wherein the maintenance state of each of the AVs is associated with at least one of data storage capacity level, remaining battery level, remaining time until a required power cycle, remaining time until sensor calibration, and remaining time until data offload.
7. The fleet management system of claim 1, wherein the one or more processors are configured to: determine a time to go to a maintenance facility, for each of the AVs, based on the predicted AV resource usage for the completion of the ride and the maintenance state of each of the AVs.
8. The fleet management system of claim 1, wherein the one or more processors are configured to: determine that a predicted maintenance state after the completion of the ride requires a maintenance of the selected AV, wherein the maintenance includes at least one of charging of the selected AV, sensor calibration of the selected AV, power cycling of the selected AV, and offloading data of the of the selected AV; and schedule a trip of the selected AV from the drop-off location to a maintenance facility.
9. The fleet management system of claim 1, wherein selecting the selected AV from among the AVs for the ride based on the predicted AV resource usage for the completion of the ride and the maintenance state of each of the AVs comprises: determining the predicted AV resource usage for the completion of the ride based on a level of battery charge and data storage space needed to complete the ride; determining an available resource level of the AVs based on a remaining battery level and a data storage capacity level of each of the AVs; and selecting the selected AV from among the AVs based on the predicted AV resource usage and the available resource level of the selected AV, wherein the available resource level of the selected AV is greater than the predicted AV resource usage by a smallest value among the AVs.
10. A computer-implemented method comprising: using a processor system to receive in real time sensor data from sensor systems of autonomous vehicles (AVs) navigating through a dynamic environment without a human driver; wherein the sensor data is received at a sufficient volume and

in sufficient variety to determine AV resource usage and a maintenance state of each of the AVs; wherein the processor system uses the sensor data to determine the maintenance state of each of the AVs; using the processor to receive, from a user device, a ride request for a ride between a pick-up location of the ride and a drop-off location of the ride; using the processor system to determine, for each of the AVs, a predicted AV resource usage for a completion of the ride based on a distance between the pick-up location of the ride, the drop-off location of the ride, a distance between an AV location and the pick-up location of the ride, one or more environmental factors associated with the ride, and one or more vehicle-specific factors associated with the; and using the processor system to select a selected AV from among the AVs for the ride based on the predicted AV resource usage for the completion of the ride and the maintenance state of each AV.

11. The computer-implemented method of claim 10, further comprising: using the processor system to dispatch the selected AV the pick-up location of the ride.

12. The computer-implemented method of claim 10, wherein the predicted AV resource usage is associated with battery usage and data storage usage.

13. The computer-implemented method of claim 10, wherein the one or more environmental factors comprise at least one of the AV location, a road condition, a weather condition, time of day, and a traffic condition.

14. The computer-implemented method of claim 10, wherein the one or more vehicle-specific factors comprise at least one of a vehicle age, battery life, tire pressure, and vehicle configurations.

15. The computer-implemented method of claim 10, wherein the maintenance state of each of the AVs is associated with at least one of data storage capacity level, remaining battery level, remaining time until a required power cycle, remaining time until sensor calibration, and remaining time until data offload.

16. The computer-implemented method of claim 10, further comprising: using the processor system to determine a time to go to a maintenance facility, for of the AVs, based on the predicted AV resource usage for the completion of the ride and the maintenance state of each of the AVs.

17. The computer-implemented method of claim 10, further comprising: using the processor system to determine that a predicted maintenance state after the completion of the ride requires a maintenance of the predicted AV, wherein the maintenance includes at least one of charging of the AV, sensor calibration of the AV, power cycling of the AV, and offloading data of the AV; and scheduling a trip of the AV from the drop-off location to a maintenance facility.

18. The computer-implemented method of claim 10, further comprising: using the processor system to predict a user demand for one or more ride requests associated with the set of AVs based on historical data; and using the processor system to schedule a trip of the selected AV from the drop-off location of the ride to a maintenance facility based on the user demand.

19. A non-transitory computer-readable storage medium comprising at least one instruction for causing a computer or processor to: receive in real time sensor data from sensor systems of autonomous vehicles (AVs) navigating through a dynamic environment without a human driver; wherein the sensor data is received at a sufficient volume and in sufficient variety to determine AV resource usage and a maintenance state of each of the AVs; use the sensor data to determine the maintenance state of each of the AVs; receive, from a user device, a ride request for a ride between a pick-up location of the ride and a drop-off location of the ride; using the sensor data to determine, for each of the AVs, a predicted AV resource usage for a completion of the ride based on a distance between the pick-up location of the ride, and the drop-off location of the ride, a distance between an AV location and the pick-up location of the ride, one or more environmental factors associated with the ride, and one or more vehicle-specific factors associated with the ride; and select a selected AV from among the AVs for the ride based on the predicted AV resource usage for the completion of the ride and the maintenance state of each of the AVs.

20. The non-transitory computer-readable storage medium of claim 19, wherein the at least one

instruction causes the computer of processor to: dispatch the selected AV to the pick-up location of the ride.
