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Responses to vulnerable road user's adversarial behavior

Abstract

A system for responding to adversarial behavior within an autonomous vehicle includes a pedestrian detection system in communication with a vehicle controller and an adversarial intent algorithm adapted to determine a risk level of adversarial behavior from at least one pedestrian within proximity of the autonomous vehicle, the vehicle controller adapted to provide proactive and reactive actions to be performed by the autonomous vehicle in response to the adversarial behavior based on the risk level of the adversarial behavior.

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Background/Summary

INTRODUCTION

(1) The present disclosure relates to recognizing adversarial behavior on the part of vulnerable road users in proximity to an automated driving vehicle. With the introduction of automated driving vehicles, adversarial behaviors by pedestrians and other vulnerable road users toward autonomous vehicles is becoming an issue, particularly in urban environments. Adversarial behaviors, often in the form of bullying, come from both pedestrians and other road users. Adversarial behavior can take the form of rude gestures and utterances, challenging the autonomous vehicle to brake, driving up close behind an autonomous vehicle, and tending not to give an autonomous vehicle the right of way at intersections and crossings.

(2) Thus, while current systems and methods achieve their intended purpose, there is a need for an improved system and method for automatically detecting adversarial behavior directed toward an autonomous vehicle, and providing response actions for the autonomous vehicle to take in response to such adversarial behavior.

SUMMARY

(3) According to several aspects of the present disclosure, a method of responding to adversarial behavior directed toward an autonomous vehicle includes determining, with a pedestrian detection system, a vehicle controller and an adversarial intent algorithm, a risk level of adversarial behavior

from at least one pedestrian within proximity of the autonomous vehicle, and providing, with the vehicle controller, actions to be performed by the autonomous vehicle in response to the adversarial behavior based on the risk level of the adversarial behavior.

(4) According to another aspect, the method further includes determining, with the pedestrian detection system and the vehicle controller, if the adversarial behavior is persistent, and providing, with the vehicle controller, actions to be performed by the autonomous vehicle further in response to if the adversarial behavior is persistent.

(5) According to another aspect, when the adversarial intent algorithm determines that there is no risk of adversarial behavior, the method includes providing no action responsive to adversarial behavior to be performed by the autonomous vehicle.

(6) According to another aspect, when the adversarial intent algorithm determines that there is low risk of adversarial behavior, the method includes, initiating, with the vehicle controller, at least one of visual and auditory warnings to the pedestrian.

(7) According to another aspect, when the adversarial behavior continues for less than a third pre-determined time window, the method includes stopping the at least one of visual and auditory warnings, and resetting the classification, by the adversarial intent algorithm, of the adversarial behavior risk level.

(8) According to another aspect, when the adversarial behavior continues for more than the third pre-determined time window, the method includes causing, with the vehicle controller, the autonomous vehicle to at least one of back away from the adversarial behavior and re-route to avoid the adversarial behavior.

(9) According to another aspect, when the adversarial intent algorithm determines that there is high risk of adversarial behavior, the method includes, reporting, with the vehicle controller, the high risk of adversarial behavior to at least one of vehicle assistance service providers, authorities, infrastructure services providers and crowd-sensing services.

(10) According to another aspect, when the adversarial behavior continues for less than a third pre-determined time window, the method includes stopping the reporting, with the vehicle controller, the high risk of adversarial behavior to at least one of vehicle assistance service providers, authorities, infrastructure services providers and crowd-sensing services.

(11) According to another aspect, when the adversarial behavior continues for more than a third pre-determined time window, the method includes at least one of causing, with the vehicle controller, the autonomous vehicle to at least one of: back away from the adversarial behavior, and, re-route to avoid the adversarial behavior, causing, with the vehicle controller, control of the autonomous vehicle to be transferred from the vehicle controller to an eligible occupant within the autonomous vehicle, and, causing, with the vehicle controller, control of the autonomous vehicle to be transferred from the vehicle controller to a remotely located tele-driving entity.

(12) According to another aspect, the method further includes verifying that there is an eligible occupant within the autonomous vehicle prior to the causing, with the vehicle controller, control of the autonomous vehicle to be transferred from the vehicle controller to an eligible occupant within the autonomous vehicle.

(13) According to several aspects of the present disclosure, a system for responding to adversarial behavior within an autonomous vehicle, includes a pedestrian detection system in communication with a vehicle controller and an adversarial intent algorithm adapted to determine a risk level of adversarial behavior from at least one pedestrian within proximity of the autonomous vehicle, the vehicle controller adapted to provide actions to be performed by the autonomous vehicle in response to the adversarial behavior based on the risk level of the adversarial behavior.

(14) According to another aspect, the pedestrian detection system and the vehicle controller are further adapted to determine if the adversarial behavior is persistent, and to provide, actions to be performed by the autonomous vehicle in response to if the adversarial behavior is persistent.

(15) According to another aspect, when the adversarial intent algorithm determines that there is no

risk of adversarial behavior, the vehicle controller is adapted to provide no action responsive to adversarial behavior to be performed by the autonomous vehicle.

(16) According to another aspect, when the adversarial intent algorithm determines that there is low risk of adversarial behavior, the vehicle controller is adapted to initiate at least one of visual and auditory warnings to the pedestrian.

(17) According to another aspect, when the adversarial behavior continues for less than a third pre-determined time window, the vehicle controller is adapted to stop the at least one of visual and auditory warnings, and reset the classification, by the adversarial intent algorithm, of the adversarial behavior risk level.

(18) According to another aspect, when the adversarial behavior continues for more than the third pre-determined time window, the vehicle controller is adapted to cause the autonomous vehicle to at least one of back away from the adversarial behavior and re-route to avoid the adversarial behavior.

(19) According to another aspect, when the adversarial intent algorithm determines that there is high risk of adversarial behavior, the vehicle controller is adapted to report the high risk of adversarial behavior to at least one of vehicle assistance service providers, authorities, infrastructure services providers and crowd-sensing services.

(20) According to another aspect, when the adversarial behavior continues for less than a third pre-determined time window, the vehicle controller is adapted to stop the reporting to at least one of vehicle assistance service providers, authorities, infrastructure services providers and crowd-sensing services, and, when the adversarial behavior continues for more than a third pre-determined time window, the vehicle controller is adapted to at least one of: cause the autonomous vehicle to at least one of: back away from the adversarial behavior, and, re-route to avoid the adversarial behavior, cause control of the autonomous vehicle to be transferred from the vehicle controller to an eligible occupant within the autonomous vehicle, and, cause control of the autonomous vehicle to be transferred from the vehicle controller to a remotely located tele-driving entity.

(21) According to another aspect, the vehicle controller is adapted to verify that there is an eligible occupant within the autonomous vehicle prior to the causing, with the vehicle controller, control of the autonomous vehicle to be transferred from the vehicle controller to an eligible occupant within the autonomous vehicle.

(22) Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

(2) FIG. **1** is a schematic diagram of an autonomous vehicle including a system according to an exemplary embodiment of the present disclosure;

(3) FIG. **2** is a perspective view of an autonomous vehicle approaching a cross-walk where a pedestrian is preparing to cross;

(4) FIG. **3** is a schematic view of an adversarial intent algorithm according to an exemplary embodiment;

(5) FIG. **4** is a perspective view of a cross walk, wherein a pedestrian is crossing in front of an autonomous vehicle;

(6) FIG. **5** is schematic view of a non-verbal cue algorithm according to an exemplary embodiment;

(7) FIG. **6** is a schematic view wherein the non-verbal cue algorithm has identified key points of a

hand of a pedestrian;
(8) FIG. **7** is a schematic view of an audible cue algorithm according to an exemplary embodiment;
(9) FIG. **8** is a schematic view illustrating how a remote database creates an optimized model of threatening acoustic signals;
(10) FIG. **9** is a flow chart illustrating a method according to an exemplary embodiment;
(11) FIG. **10** is a flow chart illustrating a method of determining if the autonomous vehicle has the right of way at a cross walk;
(12) FIG. **11** is a flow chart illustrating an alternate embodiment of the method shown in FIG. **9**; and
(13) FIG. **12** is a flow chart illustrating an alternate embodiment of the method shown in FIG. **11**, including responses to be made by the autonomous vehicle in response to adversarial behavior.
(14) The figures are not necessarily to scale and some features may be exaggerated or minimized, such as to show details of particular components. In some instances, well-known components, systems, materials or methods have not been described in detail in order to avoid obscuring the present disclosure. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present disclosure.

DETAILED DESCRIPTION

(15) The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features. As used herein, the term module refers to any hardware, software, firmware, electronic control component, processing logic, and/or processor device, individually or in any combination, including without limitation: application specific integrated circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that executes one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality. Although the figures shown herein depict an example with certain arrangements of elements, additional intervening elements, devices, features, or components may be present in actual embodiments. It should also be understood that the figures are merely illustrative and may not be drawn to scale.
(16) As used herein, the term “vehicle” is not limited to automobiles. While the present technology is described primarily herein in connection with automobiles, the technology is not limited to automobiles. The concepts can be used in a wide variety of applications, such as in connection with aircraft, marine craft, other vehicles, and consumer electronic components.
(17) In accordance with an exemplary embodiment, FIG. **1** shows a vehicle **10** with an associated system **11** for automatically detecting adversarial behavior directed toward an automated driving vehicle. The vehicle **10** generally includes a chassis **12**, a body **14**, front wheels **16**, and rear wheels **18**. The body **14** is arranged on the chassis **12** and substantially encloses components of the vehicle **10**. The body **14** and the chassis **12** may jointly form a frame. The front wheels **16** and rear wheels **18** are each rotationally coupled to the chassis **12** near a respective corner of the body **14**.
(18) In various embodiments, the vehicle **10** is an automated driving vehicle and the system **11** is incorporated into the automated driving vehicle **10** (hereinafter referred to as the autonomous vehicle **10**). The autonomous vehicle **10** is, for example, a vehicle that is automatically controlled to carry passengers from one location to another, or to perform tasks with no passengers present. The autonomous vehicle **10** is depicted in the illustrated embodiment as a passenger car, but it should be appreciated that any other vehicle including motorcycles, trucks, sport utility vehicles (SUVs), recreational vehicles (RVs), self-driving shuttles (SDSs), etc., can also be used. In an exemplary embodiment, the autonomous vehicle **10** is a so-called Level Four or Level Five

automation system. A Level Four system indicates "high automation", referring to the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene. A Level Five system indicates "full automation", referring to the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.

(19) As shown, the autonomous vehicle **10** generally includes a propulsion system **20**, a transmission system **22**, a steering system **24**, a brake system **26**, a sensor system **28**, an actuator system **30**, at least one data storage device **32**, a vehicle controller **34**, and a communication system **36**. In an embodiment in which the autonomous vehicle **10** is an electric vehicle, there may be no transmission system **22**. The propulsion system **20** may, in various embodiments, include an internal combustion engine, an electric machine such as a traction motor, and/or a fuel cell propulsion system. The transmission system **22** is configured to transmit power from the propulsion system **20** to the vehicle's front wheels **16** and rear wheels **18** according to selectable speed ratios. According to various embodiments, the transmission system **22** may include a step-ratio automatic transmission, a continuously-variable transmission, or other appropriate transmission. The brake system **26** is configured to provide braking torque to the vehicle's front wheels **16** and rear wheels **18**. The brake system **26** may, in various embodiments, include friction brakes, brake by wire, a regenerative braking system such as an electric machine, and/or other appropriate braking systems. The steering system **24** influences a position of the front wheels **16** and rear wheels **18**. While depicted as including a steering wheel for illustrative purposes, in some embodiments contemplated within the scope of the present disclosure, the steering system **24** may not include a steering wheel.

(20) The sensor system **28** includes one or more external sensors **40***a*-**40***n* that sense observable conditions of the exterior environment and/or the interior environment of the autonomous vehicle **10**. The external sensors **40***a*-**40***n* can include, but are not limited to, radars, lidars, global positioning systems, optical cameras, thermal cameras, ultrasonic sensors, and/or other sensors. The external sensors **40***a*-**40***n* are adapted to collect data relative to an environment surrounding the autonomous vehicle **10** as well as pedestrians and objects within proximity of the autonomous vehicle **10**. The cameras can include two or more digital cameras spaced at a selected distance from each other, in which the two or more digital cameras are used to obtain stereoscopic images of the surrounding environment in order to obtain a three-dimensional image. The sensing devices **40***a*-**40***n* can include sensors that monitor dynamic variables of the vehicle **10**, such as its velocity, its acceleration, a number of times that the brake is applied, etc. The actuator system **30** includes one or more actuator devices **42***a*-**42***n* that control one or more vehicle features such as, but not limited to, the propulsion system **20**, the transmission system **22**, the steering system **24**, and the brake system **26**.

(21) The vehicle controller **34** includes at least one processor **44** and a computer readable storage device or media **46**. The at least one processor **44** can be any custom made or commercially available processor, a central processing unit (CPU), a graphics processing unit (GPU), an auxiliary processor among several processors associated with the controller **34**, a semiconductor based microprocessor (in the form of a microchip or chip set), a macro-processor, any combination thereof, or generally any device for executing instructions. The computer readable storage device or media **46** may include volatile and nonvolatile storage in read-only memory (ROM), random-access memory (RAM), and keep-alive memory (KAM), for example. KAM is a persistent or non-volatile memory that may be used to store various operating variables while the at least one processor **44** is powered down. The computer-readable storage device or media **46** may be implemented using any of a number of known memory devices such as PROMs (programmable read-only memory), EPROMs (electrically PROM), EEPROMs (electrically erasable PROM), flash memory, or any other electric, magnetic, optical, or combination memory devices capable of storing data, some of which represent executable instructions, used by the controller **34** in

controlling the autonomous vehicle **10**.

(22) The instructions may include one or more separate programs, each of which includes an ordered listing of executable instructions for implementing logical functions. The instructions, when executed by the at least one processor **44**, receive and process signals from the sensor system **28**, perform logic, calculations, methods and/or algorithms for automatically controlling the components of the autonomous vehicle **10**, and generate control signals to the actuator system **30** to automatically control the components of the autonomous vehicle **10** based on the logic, calculations, methods, and/or algorithms. Although only one controller is shown in FIG. **1**, embodiments of the autonomous vehicle **10** can include any number of controllers that communicate over any suitable communication medium or a combination of communication mediums and that cooperate to process the sensor signals, perform logic, calculations, methods, and/or algorithms, and generate control signals to automatically control features of the autonomous vehicle **10**.

(23) The communication system **36** includes a wireless communication module **38** that is configured to wirelessly communicate information and data to and from other remote entities **48**, such as but not limited to, other vehicles ("V2V" communication,) infrastructure ("V2I" communication), remote systems, remote servers, cloud computers, and/or personal devices. In an exemplary embodiment, the communication system **36** is a wireless communication system configured to communicate via a wireless local area network (WLAN) using IEEE 802.11 standards or by using cellular data communication such as Cellular Vehicle to Anything (C-V2X) communication. However, additional or alternate communication methods, such as a dedicated short-range communications (DSRC) channel, are also considered within the scope of the present disclosure. DSRC channels refer to one-way or two-way short-range to medium-range wireless communication channels specifically designed for automotive use and a corresponding set of protocols and standards.

(24) A pedestrian detection system **50** is in communication with the vehicle controller **34**. The pedestrian detection system **50** is adapted to identify a pedestrian **52** within proximity of the autonomous vehicle **10**. It should be understood that the pedestrian detection system **50** is adapted to detect any objects within proximity to the autonomous vehicle **10**. The term "pedestrian", as used herein, includes walking pedestrians, cyclists, or other vulnerable road users. Referring to FIG. **2**, the pedestrian detection system **50** uses information collected by at least one of the external sensors **40***a*-**40***n* and/or other vehicles' perception system and/or sensors available as part of intelligent infrastructure such as smart intersections to identify the pedestrian **52** that is standing along side the roadway at a cross-walk **54** in front of the autonomous vehicle **10**. It should be understood, that the system **11** will detect the presence of a pedestrian at a designated or marked cross-walk **54**, as well as detect the presence of a pedestrian that is approaching or about to cross the roadway in front of the autonomous vehicle **10** at a non-designated or un-marked location.

(25) The pedestrian detection system **50**, using data that is continuously collected by the external sensors **40***a*-**40***n*, is adapted to track the pedestrian **52** and to determine if the pedestrian **52** is intending to cross in front of the autonomous vehicle **10**. The pedestrian detection system **50** makes this determination based on the location and movement of the pedestrian **52**. Various methods to identify, track and determine the pedestrian's **52** intention to cross in front of the autonomous vehicle **10** are known. It should be understood that the pedestrian detection system **50** of the present disclosure may utilize any suitable method or algorithm for identification, tracking and determination of a pedestrian's **52** intention to cross in front of the autonomous vehicle **10**.

(26) If the pedestrian tracking system **50** determines that the pedestrian **52** is not intending to cross in front of the autonomous vehicle **10**, the pedestrian tracking system **50** is further adapted to continue tracking the pedestrian **52**. If the pedestrian tracking system **50** determines that the pedestrian **52** is intending to cross in front of the autonomous vehicle **10**, the pedestrian tracking system **50** is further adapted to determine, with an adversarial intent algorithm **56**, if the pedestrian

52 is exhibiting any adversarial behavior.

(27) In an exemplary embodiment, when the pedestrian tracking system **50** determines that the pedestrian **52** is intending to cross in front of the autonomous vehicle **10**, the pedestrian tracking system **50** is further adapted to determine, with the vehicle controller **34**, if the autonomous vehicle **10** has right of way. The autonomous vehicle **10** has the right of way when, based on the type of crossing **54** and any signs, lights or other signals **58** present, the autonomous vehicle **10** is allowed to proceed and pedestrians **52** should wait to cross. When determining if the autonomous vehicle **10** has a right of way, the vehicle controller **34** is further adapted to determine what type of crossing **54** is present in front of the autonomous vehicle **10**, to be used by the pedestrian **52**, to identify crossing signals **58** for the identified crossing type, and to determine if the autonomous vehicle **10** has the right of way based on the identified crossing signals **58**. If the autonomous vehicle **10** does not have the right of way, the pedestrian tracking system **50** is further adapted to continue tracking the pedestrian **52**. If the autonomous vehicle **10** does have the right of way, the pedestrian tracking system **50** is further adapted to determine, with the adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior.

(28) Referring to FIG. **3**, in an exemplary embodiment, the adversarial intent algorithm **56** is adapted to determine if the pedestrian **52** is exhibiting any adversarial behavior based on at least one of crossing behavior of the pedestrian **52**, non-verbal cues from the pedestrian **52** and audible cues. The adversarial intent algorithm **56** includes a crossing behavior algorithm **60**, a non-verbal cue algorithm **62**, and an audible cue algorithm **64**. The crossing behavior algorithm **60** determines if the pedestrian **52** is exhibiting adversarial behavior based on the crossing behavior of the pedestrian **52**. The non-verbal cue algorithm **62** determines if the pedestrian **52** is exhibiting adversarial behavior based on non-verbal cues of the pedestrian **52**. The audible cue algorithm **64** determines if the pedestrian **52** is exhibiting adversarial behavior based on audible cues detected by a microphone included among the external sensors **40***a*-**40***n* of the autonomous vehicle **10**.

(29) The adversarial intent algorithm **56** receives input from the pedestrian detection system **50**, as indicated by arrow **66**, and input from the external sensors **40***a*-**40***n* via the vehicle controller **34**, as indicated by arrow **68**. An information fusion algorithm **70** is adapted to combine information related to the crossing behavior of the pedestrian **52**, received from the crossing behavior algorithm **60**, information related to non-verbal cues from the pedestrian **52**, received from the non-verbal cue algorithm **62**, and information related to audible cues, received from the audible cues algorithm **64** to identify adversarial behavior.

(30) In an exemplary embodiment, when determining, with the adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior based on the crossing behavior of the pedestrian **52**, the vehicle controller **34**, using the crossing behavior algorithm **60**, is further adapted to calculate an estimated crossing time for the pedestrian **52** to cross in front of the autonomous vehicle **10**. The adversarial intent algorithm **56** is further adapted to determine that the pedestrian **52** is not exhibiting any adversarial behavior when the pedestrian **52** finishes crossing in front of the autonomous vehicle **10** within a predetermined time window, and to determine that the pedestrian **52** is exhibiting adversarial behavior when the pedestrian **52** does not finish crossing in front of the autonomous vehicle **10** within the predetermined time window.

(31) In an exemplary embodiment, the crossing behavior algorithm uses a Simple Online and Realtime Tracking (SORT) tracking algorithm to estimate a motion model for the pedestrian **52** using an intersection-over-union distance. An expected crossing time is calculated using information such as the location of the autonomous vehicle and features of the cross-walk **54**. The pre-determined time window is calculated based on an estimated crossing time, the formula for which may be tuned, wherein a shorter pre-determined time window is more sensitive and will provide an indication of adversarial behavior more often than a less-sensitive, longer pre-determined time window.

(32) In an exemplary embodiment, when determining, with the non-verbal cue algorithm **62** of the

adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior based on non-verbal cues from the pedestrian **52**, the pedestrian tracking system **50** is adapted to identify physical properties of the pedestrian **52**. Referring to FIG. **4**, the pedestrian detection system **50** is adapted to identify all pedestrians **52** within proximity to the autonomous vehicle **10**. As shown, the pedestrian detection system **50** has identified one pedestrian **52** walking through the cross-walk **54** in front of the autonomous vehicle **10**. At least one of the external sensors **40***a*-**40***n* of the autonomous vehicle **10** is a camera **72** adapted to capture images of the pedestrian **52** in front of the autonomous vehicle **10**.

(33) The pedestrian detection system **50**, using the non-verbal cue algorithm **62**, is adapted to identify, at **76**, for each pedestrian **52**, physical properties and generate a profile for each pedestrian **52**. Physical properties include the location of the pedestrian **52**, body actions, such as is the pedestrian **52** walking, running, crawling, lying down, laughing, crying, reading, pushing, pulling, etc. The pedestrian detection system **50** further identifies physical properties such as the location and dynamics of the legs, arms and head of the pedestrian **52**. Referring to FIG. **4**, two-dimensional and three-dimensional skeletal location and dynamics of the pedestrian **52** are located and tracked as indicated by vector representations **74** of various skeletal features of the pedestrian **52**. The pedestrian detection system **50** further tracks movement dynamics of the pedestrian **52**, such as direction, speed and acceleration, as well as duration of any actions (how long has the pedestrian **52** been doing that?).

(34) The vehicle controller **34**, at **78**, is adapted to analyze spatiotemporal characteristics of the physical properties of the pedestrian **52**. For each of the pedestrians **52**, in different zones, the system **11** estimates the following: number of pedestrians **52**, distribution of actions, dynamics and durations, maximum and minimum values of dynamics and durations, and mean and standard deviation of dynamics and durations. A critical zone is defined as the overlapping area between a field of view of the camera **72** and a predicted path of the pedestrian **52**. For each pedestrian within the critical zone, at **80**, the system **11** is adapted to check if the profile generated for the pedestrian **52** should be categorized as “suspicious”, indicating adversarial behavior.

(35) The non-verbal cue algorithm **62** and the vehicle controller **34** are adapted to determine if any physical properties of the pedestrian **52** indicate adversarial behavior by the pedestrian **52**. The system **11** is adapted to compare the physical properties of the pedestrian **52** to “normal” patterns which are obtained from a remote database **82** of known patterns which indicate adversarial behavior, or from a neural network stored within the system **11** that uses machine learning to compile a set of know patterns that indicate adversarial behavior. In addition to comparing current patterns to known patterns, other characteristics are used to determine if the movements and actions of a pedestrian **52** should be interpreted as adversarial behavior. For instance, in a crowd of people, if an individual pedestrian **52** exhibits a gesture or action, it may be interpreted by the system **11** as adversarial behavior. However, if multiple pedestrians **52** within a group are exhibiting the same gesture or action there is a higher likelihood of adversarial behavior. Time is always a significant factor. The longer an action or activity persists, the higher a likelihood that such action or activity constitutes adversarial behavior. Similarly, distance from the autonomous vehicle **10** is a significant consideration. The farther away from the autonomous vehicle **10** a pedestrian **52** is, the less likely it is that any behavior on the part of the pedestrian **52** is adversarial. If the vehicle controller **34** determines that the physical properties of the pedestrian **52** do not indicated adversarial behavior on the part of the pedestrian **52**, then, as indicated by line **81**, the vehicle controller **34**, at **78**, is adapted to continue to analyze spatiotemporal characteristics of the physical properties of the pedestrian **52** that are continuously collected.

(36) If the vehicle controller **34**, at **80**, determines that the physical properties of the pedestrian **52** do not indicate adversarial behavior on the part of the pedestrian **52**, then, as indicated by line **81**, the vehicle controller **34**, at **78**, is adapted to continue to analyze spatiotemporal characteristics of the physical properties of the pedestrian **52** that are continuously collected. If the vehicle controller

34, at **80**, determines that the physical properties of the pedestrian **52** do indicate adversarial behavior on the part of the pedestrian **52**, then, as indicated by line **83**, the non-verbal cue algorithm **62** is adapted to indicate that there is adversarial behavior to the adversarial intent algorithm **56**.

(37) Referring to FIG. **6** and FIG. **7**, in another exemplary embodiment of the present disclosure, when analyzing, with the vehicle controller **34**, spatiotemporal characteristics of the physical properties of the pedestrian **52**, at **78**, the pedestrian tracking system **50** is further adapted, at **88**, to identify key points **84** of a hand **86** of the pedestrian **52**. Referring to FIG. **6**, in an enlarged view of the hand **86** of the pedestrian **52** from FIG. **4**, key points **84** (as shown, joint locations within the hand and fingers) of the hand **86** of the pedestrian **52** are highlighted and linked, to allow the vehicle controller **34** to determine a shape or gesture that the hand **86** is displaying. The system **11** may use, by way on non-limiting examples, mesh model matching, depth-based methods, deep learning-based post estimation methods, such as Open Pose or Deep Pose, or multi-view bootstrapping when creating a key-point model of the hand **86**.

(38) The vehicle controller **34**, at **90**, is further adapted to compare identified key points **84** of the hand **86** of the pedestrian **52** to a remote database **92** of known threatening gestures. Alternatively, the vehicle controller **34** may compare the identified key points **84** of the hand **86** of the pedestrian **52** to known threatening gestures stored within a neural network stored within the system **11** that uses machine learning to compile a set of know threatening gestures. At **94**, if the non-verbal cue algorithm **62** determines that the identified key points **84** of the hand **86** of the pedestrian match at least one of the known threatening gestures stored within the database **92**, then the non-verbal cue algorithm **62** is adapted to indicate to the adversarial intent algorithm **56** that the pedestrian **52** is exhibiting adversarial behavior, as indicated by line **96**. The adversarial intent algorithm **56** is adapted to determine that the pedestrian **52** is exhibiting adversarial behavior when the identified key points **84** of the hand **86** of the pedestrian **52** match at least one of the known threatening gestures within the remote database **92**. If the non-verbal cue algorithm **62** determines that the identified key points **84** of the hand **86** of the pedestrian do not match at least one of the known threatening gestures stored within the database **92**, then the non-verbal cue algorithm **62** is adapted to, at **90**, continue to compare identified key points **84** of the hand **86** of the pedestrian **52** to a remote database **92** of known threatening gestures, as indicated by line **98**.

(39) In another exemplary embodiment, when determining, with the adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior based on audible cues, the vehicle controller **34** is further adapted to extract features of acoustic signals captured with one of the external sensors **40*a*-40*n*** which is an external microphone **100**, and compare features of the acoustic signals to a remote database **102** which includes an optimized model **104** of known sounds that indicate adversarial behavior. The adversarial intent algorithm **56** is further adapted to determine that the pedestrian **52** is exhibiting adversarial behavior when the captured acoustic signals match known sounds from the optimized model **104** of the acoustic cue algorithm that indicate adversarial behavior. Speech and non-speech sounds that are indicative of adversarial behavior includes, but are not limited to, shouting, hit/hitting with a stick sound, impact or crash sounds, cursing, insulting words, threatening words, and bullying and sarcastic sounds such as laugh/derisive deep male voice.

(40) Referring to FIG. **8**, the optimized model **104** is created and updated within the remote database **102**. Beginning with a non-speech audio event dataset **105** including data collected, augmented and grouped considering different noise factors such as season, weather conditions, locations, background noise and reverberations, vehicle speed, etc. The data of the non-speech audio event dataset **105** is processed, at **106**, to create a pre-processed non-speech audio event dataset **108**. At **110**, discriminative features of the pre-processed non-speech audio event dataset **108** are identified and fed to a training and testing dataset **112** wherein model training/testing takes place at **114**, using machine learning algorithms **116** to optimize a candidate model **118**, creating

the optimized model **104** of recognized threatening audible cues.

(41) In an exemplary embodiment, acoustic signals are captured by the microphone **100**, and then, at **120**, the audible cue algorithm **64** extracts features of the acoustic signals, such as, but not limited to, Mel-frequency cepstral coefficients (MFCC), Filterbank Energies, Log Filterbank Energies and Spectral Sub-band Centroids. When such features match features within the optimized model of known threatening sounds, the audible cue algorithm **64**, as indicated by line **122**, communicates this information to the adversarial intent algorithm **56**, which is further adapted to determine that the pedestrian **52** is exhibiting adversarial behavior when the captured acoustic signals match known sounds from the optimized model **104** of the acoustic cue algorithm **64** that indicate adversarial behavior.

(42) As previously mentioned, the information fusion algorithm **70** is adapted to combine information related to the crossing behavior of the pedestrian **52**, received from the crossing behavior algorithm **60**, information related to non-verbal cues from the pedestrian **52**, received from the non-verbal cue algorithm **62**, and information related to audible cues, received from the audible cues algorithm **64** to identify adversarial behavior.

(43) In an exemplary embodiment, the information fusion algorithm **70** is adapted to provide a two-level indication of adversarial behavior, wherein, based on the output from the crossing behavior algorithm **60**, the non-verbal cue algorithm **62**, and the audible cues algorithm **64**, the information fusion algorithm provides a binary answer, in that, there either is adversarial behavior on the part of the pedestrian **52**, or there is not adversarial behavior on the part of the pedestrian **52**.

(44) TABLE A below includes a summary of the possible outcomes from the information fusion algorithm **70**. The first column represents the crossing behavior algorithm **60**, wherein “no” indicates that the crossing behavior algorithm **60** did not determine that the crossing behavior of the pedestrian indicates adversarial behavior on the part of the pedestrian **52**, and “yes” indicates that the crossing behavior algorithm **60** did determine that the crossing behavior of the pedestrian **52** indicates adversarial behavior on the part of the pedestrian **52**. The second column represents the non-verbal cue algorithm **62**, wherein “no” indicates that the non-verbal cue algorithm **62** did not determine that the non-verbal cues by the pedestrian **52** indicate adversarial behavior on the part of the pedestrian **52**, and “yes” indicates that the non-verbal cue algorithm **62** did determine that the non-verbal cues by the pedestrian **52** indicate adversarial behavior on the part of the pedestrian **52**. The third column represents the audible cue algorithm **64**, wherein “no” indicates that the audible cue algorithm **64** did not detect acoustic signals that indicate adversarial behavior, and “yes” indicates that the audible cue algorithm **64** did detect acoustic signals that indicate adversarial behavior. The fourth column is the result provided by the adversarial intent algorithm **56**.

(45) TABLE-US-00001 TABLE A Crossing Non-Verbal Adversarial Behavior Cue Audible Cue Behavior? No No No No No No Yes Yes No Yes No Yes No Yes Yes Yes Yes No No Yes Yes No Yes Yes Yes Yes No Yes Yes Yes Yes Yes

(46) As, shown, for the two-level indication of adversarial behavior, the adversarial intent algorithm **56** will indicate that there is adversarial behavior whenever any one or more of the crossing behavior algorithm **60**, the non-verbal cue algorithm **62**, and the audible cues algorithm **64** indicate that there is adversarial behavior.

(47) In another exemplary embodiment, the information fusion algorithm **70** is adapted to provide a three-level indication of adversarial behavior, wherein, based on the output from the crossing behavior algorithm **60**, the non-verbal cue algorithm **62**, and the audible cues algorithm **64**, the information fusion algorithm provides either no risk of adversarial behavior, a low risk of adversarial behavior, or a high risk of adversarial behavior.

(48) TABLE B below includes a summary of the possible outcomes from the information fusion algorithm **70**. The first, second and third columns of TABLE B are the same as the first, second and third columns from TABLE A. The fourth column is the result provided by the adversarial intent algorithm **56**.

(49) TABLE-US-00002 TABLE B Crossing Non-Verbal Adversarial Behavior Cue Audible Cue Behavior? No No No No No No Yes Low No Yes No Low No Yes Yes Low Yes No No Low Yes No Yes Low Yes Yes No Low Yes Yes Yes High

(50) As shown, for the three-level indication of adversarial behavior, the adversarial intent algorithm **56** will indicate that there is no risk of adversarial behavior when none of the crossing behavior algorithm **60**, the non-verbal cue algorithm **62**, and the audible cues algorithm **64** indicate that there is adversarial behavior. The adversarial intent algorithm **56** will indicate that there is a low risk of adversarial behavior when any one or two of the crossing behavior algorithm **60**, the non-verbal cue algorithm **62**, and the audible cues algorithm **64** indicate that there is adversarial behavior. The adversarial intent algorithm **56** will indicate that there is a high risk of adversarial behavior when all three of the crossing behavior algorithm **60**, the non-verbal cue algorithm **62**, and the audible cues algorithm **64** indicate that there is adversarial behavior.

(51) In another exemplary embodiment, when the pedestrian **52** is exhibiting adversarial behavior, a persistence algorithm **124** is adapted to classify the adversarial behavior as “no risk” when a duration of such adversarial behavior is less than a first pre-determined length of time, classify the adversarial behavior as “low risk” when the duration of such adversarial behavior is greater than the first pre-determined length of time and less than a second pre-determined length of time, and classify the adversarial behavior as “high risk” when the duration of such adversarial behavior is greater than the second pre-determined length of time.

(52) Other approaches can be used to fuse the crossing behavior pattern, non-verbal cues and verbal cues such as using a weight scheme that combines the three indicators using weights that inversely proportional with the uncertainty of each indicator quantified by its variance or using Dempster's rule of combination that takes into consideration the degree of belief of each indicator.

(53) In an exemplary embodiment the system **11** is adapted to respond to adversarial behavior within the autonomous vehicle **10**. The pedestrian detection system **50** in communication with the vehicle controller **34** and the adversarial intent algorithm **56** are adapted to determine a three-level risk level of adversarial behavior from at least one pedestrian **52** within proximity of the autonomous vehicle **10**, and if the adversarial behavior is persistent. The adversarial behavior will be considered persistent if the adversarial behavior continues for an amount of time that exceeds a third pre-determined time window.

(54) The vehicle controller **34** is adapted to provide actions to be performed by the autonomous vehicle **10** in response to the adversarial behavior based on the risk level of the adversarial behavior, and if the adversarial behavior is persistent.

(55) When the adversarial intent algorithm **56** determines that there is no risk of adversarial behavior, the vehicle controller **34** is adapted to provide no actions to be performed by the autonomous vehicle **10**.

(56) When the adversarial intent algorithm **56** determines that there is low risk of adversarial behavior, the vehicle controller **34** is adapted to initiate at least one of visual and auditory warnings to the pedestrian **52**. When the adversarial behavior continues for less than a third pre-determined time window, the vehicle controller **34** is adapted to stop the at least one of visual and auditory warnings, and reset the classification, by the adversarial intent algorithm **56**, of the adversarial behavior risk level. When the adversarial behavior continues for more than the third pre-determined time window, the vehicle controller **34** is adapted to cause the autonomous vehicle **10** to at least one of back away from the adversarial behavior and re-route to avoid the adversarial behavior.

(57) When the adversarial intent algorithm **56** determines that there is high risk of adversarial behavior, the vehicle controller **34** is adapted to report the high level adversarial behavior to at least one of vehicle assistance service providers, authorities, infrastructure services providers and crowd-sensing services. When the adversarial behavior continues for less than a third pre-determined time window, the vehicle controller **34** is adapted to stop the reporting to at least one of vehicle assistance service providers, authorities, infrastructure services providers and crowd-sensing

services. When the adversarial behavior does not exceed the third pre-determined time window, the adversarial behavior becomes less relevant, and less likely to be a risk.

(58) When the adversarial behavior continues for more than a third pre-determined time window, the adversarial behavior becomes more relevant and much more likely to be a risk. In this circumstance, the vehicle controller **34** is adapted to cause the autonomous vehicle **10** to at least one of: back away from the adversarial behavior, and, re-route to avoid the adversarial behavior, cause control of the autonomous vehicle **10** to be transferred from the vehicle controller **34** to an eligible occupant within the autonomous vehicle **10**, and, cause control of the autonomous vehicle **10** to be transferred from the vehicle controller **34** to a remotely located tele-driving entity.

(59) When high level adversarial behavior continues longer than the third pre-determined time window, the system **10** prompts the autonomous vehicle **10** to take more significant action to pro-actively and reactively respond to the adversarial behavior. For example, the vehicle controller can prompt the autonomous vehicle to back away from the adversarial behavior, putting distance between the autonomous vehicle **10** and the pedestrian **52** or pedestrians **52** that are instigating the adversarial behavior. Further, due to the continuing nature of the adversarial behavior, the vehicle controller **34** may cause the autonomous vehicle to calculate a new route to a destination to avoid the location altogether, specifically in the case of a zero-occupant vehicle (ZOV).

(60) Further still, the vehicle controller **34** may cause control of the autonomous vehicle **10** to be transferred from the vehicle controller **34** to an eligible occupant within the autonomous vehicle **10**. If high level adversarial behavior continued beyond the third pre-determined time window, it is possible that the adversarial behavior can escalate. Chaotic activity in proximity to the autonomous vehicle **10** may make autonomous control of the autonomous vehicle **10** difficult and/or dangerous, thus, the vehicle controller **34** may cause control of the autonomous vehicle **10** to be transferred from the vehicle controller **34** to an eligible occupant within the autonomous vehicle **10**. An eligible occupant is a passenger within the autonomous vehicle **10** that is determined, by the vehicle controller **34**, using onboard sensors and occupant monitoring systems, as eligible to take over control of the autonomous vehicle **10**. In an exemplary embodiment, the vehicle controller **34** is adapted to verify that there is an eligible occupant within the autonomous vehicle **10** prior to the causing, with the vehicle controller **34**, control of the autonomous vehicle **10** to be transferred from the vehicle controller **34** to an eligible occupant within the autonomous vehicle **10**.

(61) For all the reasons mentioned above, if the system **11** determines that control of the autonomous vehicle **10** should be transferred, but there is no eligible occupant within the autonomous vehicle **10** to transfer control too, the vehicle controller **34** may transfer control of the autonomous vehicle **10** to a remotely located tele-driving entity. The remotely located tele-driving entity may be provided by a vehicle support service provider, such as OnStar, or may be the owner of the autonomous vehicle **10** that is contacted by the autonomous vehicle **10** via an application on a personal device, such as a tablet or cell phone.

(62) Referring to FIG. **9**, a method **200** of identifying adversarial behavior directed to an autonomous vehicle **10** includes, starting at block **202**, identifying, with a pedestrian detection system **50** in communication with a vehicle controller **34**, a pedestrian **52** within proximity of the autonomous vehicle **10**, moving to block **204**, tracking the pedestrian **52** with the pedestrian tracking system **50**, and moving to block **206**, determining, with the pedestrian tracking system **50**, if the pedestrian **52** is intending to cross in front of the autonomous vehicle **10**.

(63) Moving to block **208**, if the pedestrian tracking system **50** determines that the pedestrian **52** is not intending to cross in front of the autonomous vehicle **10**, then, moving back to block **204**, as indicated by line **210**, the method **200** includes continuing tracking of the pedestrian **52** with the pedestrian tracking system **50**. If, at block **208**, the pedestrian tracking system **50** determines that the pedestrian **52** is intending to cross in front of the autonomous vehicle **10**, moving to block **212**, the method **200** includes determining, with an adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior.

(64) In an exemplary embodiment, if the pedestrian tracking system **50** determines that the pedestrian **52** is intending to cross in front of the autonomous vehicle **10**, moving to block **214**, the method **200** further includes determining, with the vehicle controller **34**, if the autonomous vehicle **10** has right of way. If the autonomous vehicle **10** does not have the right of way, the method **200** further includes, moving back to block **204**, as indicated by line **216**, continuing tracking of the pedestrian **52** with the pedestrian tracking system **50**. If, at block **214**, the autonomous vehicle **10** does have the right of way, the method **200** further includes, moving to block **212**, determining, with the adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior.
(65) Referring to FIG. **10**, the determining, with the vehicle controller **34**, if the autonomous vehicle **10** has a right of way at block **214** of FIG. **9**, further includes, moving to block **218**, determining, with the vehicle controller **34**, what type of crossing is present in front of the autonomous vehicle **10**, to be used by the pedestrian **52**, moving to block **220**, identifying, with the vehicle controller **34**, crossing signals **58** for the identified crossing type, and, moving to block **222**, determining, with the vehicle controller **34**, if the autonomous vehicle **10** has the right of way based on the identified crossing signals **58**.
(66) Moving to block **224**, if the vehicle controller **34** determines that the crossing signals **58** for the identified crossing type are signalized, then, moving to block **226**, if the crossing signal **58** is flashing green, then, moving to block **228**, the system **11** will determine that the autonomous vehicle **10** has the right of way. If, at block **226**, if the vehicle controller **34** determines that the crossing signals **58** for the identified crossing type are not flashing green, then, moving to block **230**, the system **11** will determine that the autonomous vehicle **10** does not have the right of way.
(67) Moving to block **232**, if the vehicle controller **34** determines that the crossing signals **58** for the identified crossing type are marked with red flashing beacons, then, moving to block **234** if the crossing signal **58** is flashing red beacons, then, moving to block **228**, the system **11** will determine that the autonomous vehicle **10** has the right of way. If, at block **234**, the vehicle controller **34** determines that the crossing signals **58** for the identified crossing type are not flashing red beacons, then, moving to block **236**, the system **11** will determine that the autonomous vehicle **10** does not have the right of way. Moving again to block **232**, if the vehicle controller **34** determines that the crossing signals **58** for the identified crossing type are marked with a yield sign, then, moving to block **238** if the pedestrian **52** must yield, then, moving to block **228**, the system **11** will determine that the autonomous vehicle **10** has the right of way. If, at block **238**, the pedestrian **52** does not yield, then, moving to block **240**, if the pedestrian crosses within a predetermined window of time, then, moving to block **228**, the system **11** will determine that the autonomous vehicle **10** has the right of way. If, at block **240**, the pedestrian does not cross within the predetermined window of time, then, moving to block **242**, the system **11** will determine that the autonomous vehicle **10** does not have the right of way.
(68) Moving to block **244**, if the vehicle controller **34** determines that the crossing type is un-marked, then, moving to block **240**, if the pedestrian crosses within a predetermined window of time, then, moving to block **228**, the system **11** will determine that the autonomous vehicle **10** has the right of way. If, at block **240**, the pedestrian does not cross within the predetermined window of time, then, moving to block **242**, the system **11** will determine that the autonomous vehicle **10** does not have the right of way.
(69) Moving to block **246**, in situations where the cross-walk **54** is a school crossing, or a crossing that is controlled by an authorized patrolman, policeman, construction worker or traffic warden, then, moving to block **242**, the system **11** will determine that the autonomous vehicle **10** does not have the right of way, and further that there is no adversarial behavior.
(70) Referring again to FIG. **9**, the determining, with the adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior at block **212** further includes determining, with the adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior based on at least one of crossing behavior of the pedestrian, non-verbal cues from the pedestrian and

audible cues.

(71) In an exemplary embodiment, the determining, with the adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior based on the crossing behavior of the pedestrian **52**, using a crossing behavior algorithm, further includes calculating, with the vehicle controller **34**, an estimated crossing time for the pedestrian **52** to cross in front of the autonomous vehicle **10**, determining, with the adversarial intent algorithm **56**, that the pedestrian **52** is not exhibiting any adversarial behavior when the pedestrian **52** finishes crossing in front of the autonomous vehicle **10** within a predetermined time window, and determining, with the adversarial intent algorithm **56**, that the pedestrian is exhibiting adversarial behavior when the pedestrian **52** does not finish crossing in front of the autonomous vehicle **10** within the predetermined time window.

(72) In another exemplary embodiment, the determining, with the adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior based on non-verbal cues from the pedestrian **52**, using a non-verbal cue algorithm at block **212**, further includes, as shown in FIG. **5**, at block **76**, identifying, with the pedestrian tracking system **50**, physical properties of the pedestrian **52**, and, moving to block **78**, analyzing, with the vehicle controller **34**, spatiotemporal characteristics of the physical properties of the pedestrian **52**, and determining, with the vehicle controller **34**, if any physical properties of the pedestrian **52** indicate adversarial behavior by the pedestrian **52**.

(73) In another exemplary embodiment, the analyzing, with the vehicle controller **34**, spatiotemporal characteristics of the physical properties of the pedestrian **52**, at block **78** of FIG. **5**, further includes, referring to FIG. **7** and moving to block **88**, identifying, with the pedestrian tracking system **50**, key points of a hand **86** of the pedestrian **52**, moving to block **90**, comparing, with the vehicle controller **34**, identified key points **84** of the hand **86** of the pedestrian **52** to a remote database **92** of known threatening gestures, and, moving to block **94**, determining, with the adversarial intent algorithm **56**, that the pedestrian **52** is exhibiting adversarial behavior when the identified key points **84** of the hand **86** of the pedestrian **52** match at least one of the known threatening gestures within the remote database **92**.

(74) In another exemplary embodiment, the determining, with the adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior based on audible cues, using an audible cue algorithm **64**, further includes, referring to FIG. **8**, capturing, with an external microphone **100**, acoustic signals, moving to block **120**, extracting, with the vehicle controller **34**, features of the acoustic signals, and, moving to block **104**, comparing, with the vehicle controller **34**, features of the acoustic signals to a remote database **102** which includes an optimized model of known sounds that indicate adversarial behavior, and, moving to block **212** in FIG. **9**, determining, with the adversarial intent algorithm **56**, that the pedestrian **52** is exhibiting adversarial behavior when the captured acoustic signals match known sounds that indicate adversarial behavior.

(75) In yet another exemplary embodiment, the determining, with the adversarial intent algorithm **56**, if the pedestrian **52** is exhibiting any adversarial behavior based on at least one of crossing behavior of the pedestrian, non-verbal cues from the pedestrian and audible cues, at block **212**, further includes using an information fusion algorithm **70** within the adversarial intent algorithm **56** and the vehicle controller **34** to combine information related to the crossing behavior of the pedestrian **52**, information related to non-verbal cues from the pedestrian **52** and audible cues to identify adversarial behavior.

(76) Referring again to FIG. **9**, in an exemplary embodiment the information fusion algorithm **70** is adapted to provide a two-level indication of adversarial behavior, wherein, based on the output from the crossing behavior algorithm **60**, the non-verbal cue algorithm **62**, and the audible cues algorithm **64**, the information fusion algorithm provides a binary answer, in that, there either is adversarial behavior on the part of the pedestrian **52**, or there is not adversarial behavior on the part of the pedestrian **52**.

(77) Moving to block **248**, if the adversarial intent algorithm **56**, at block **212**, determines that there is no adversarial behavior, then, moving back to block **212**, as indicated by line **250**, the adversarial intent algorithm continues to look for adversarial behavior. If the adversarial intent algorithm **56** determines that the pedestrian **52** is exhibiting adversarial behavior, the system **11** initiates a persistence algorithm **124**. Moving to block **252**, when a duration of such adversarial behavior is less than a first pre-determined length of time, moving to block **254**, the system **11** is adapted to classify the adversarial behavior as "no risk". Moving back to block **252**, when a duration of such adversarial behavior is more than the first pre-determined length of time, and, moving to block **256**, less than a second predetermined length of time, moving to block **258**, the system **11** is adapted to classify the adversarial behavior as "low risk". Moving back to block **256**, when a duration of such adversarial behavior is more than the second pre-determined length of time, moving to block **260**, the system **11** is adapted to classify the adversarial behavior as "high risk".
(78) Referring to FIG. **11**, in another exemplary embodiment, the information fusion algorithm **70** is adapted to provide, at block **262**, a three-level indication of adversarial behavior, wherein, based on the output from the crossing behavior algorithm **60**, the non-verbal cue algorithm **62**, and the audible cues algorithm **64**, the information fusion algorithm **70** provides either no risk of adversarial behavior, a low risk of adversarial behavior, or a high risk of adversarial behavior. Moving to block **262**, if the adversarial intent algorithm **56**, at block **212**, determines that there is no adversarial behavior, then, moving back to block **212**, as indicated by line **264**, the adversarial intent algorithm continues to look for adversarial behavior. If the adversarial intent algorithm **56**, at block **262**, determines that there is a high risk of adversarial behavior, moving to block **266**, the system **11** determines that there is a high risk of adversarial behavior at block **260**. If the adversarial intent algorithm **56**, at block **262**, determines, moving to block **268**, that there is a low risk of adversarial behavior, then the system **11** initiates the persistence algorithm **124**.
(79) Moving to block **252**, when a duration of such adversarial behavior is less than a first pre-determined length of time, moving to block **254**, the system **11** is adapted to classify the adversarial behavior as "no risk". Moving back to block **252**, when a duration of such adversarial behavior is more than the first pre-determined length of time, and, moving to block **256**, less than a second predetermined length of time, moving to block **258**, the system **11** is adapted to classify the adversarial behavior as "low risk". Moving back to block **256**, when a duration of such adversarial behavior is more than the second pre-determined length of time, moving to block **260**, the system **11** is adapted to classify the adversarial behavior as "high risk".
(80) Referring to FIG. **12**, in another exemplary embodiment of the method **200**, the information fusion algorithm **70** of the adversarial intent algorithm **56** is adapted to provide, at block **262**, a three-level indication of adversarial behavior, wherein, based on the output from the crossing behavior algorithm **60**, the non-verbal cue algorithm **62**, and the audible cues algorithm **64**, the information fusion algorithm **70** provides either no risk of adversarial behavior, a low risk of adversarial behavior, or a high risk of adversarial behavior.
(81) Moving from **262** to block **270**, the method includes providing, with the vehicle controller **34**, actions to be performed by the autonomous vehicle **10** in response to the adversarial behavior based on the risk level of the adversarial behavior and if the adversarial behavior is persistent.
(82) In an exemplary embodiment, when the adversarial intent algorithm **56** determines, at block **262**, that there is no risk of adversarial behavior, the method **200** includes, moving to block **274**, providing no actions to be performed by the autonomous vehicle **10**.
(83) In another exemplary embodiment, when the adversarial intent algorithm **56** determines, at block **262**, that there is low risk of adversarial behavior, the method **200** includes, moving to block **276**, initiating, with the vehicle controller **34**, at least one of visual and auditory warnings to the pedestrian **52**. Moving to block **278**, when the adversarial behavior continues for less than a third pre-determined time window, the method **200** includes, moving to block **280**, stopping the at least one of visual and auditory warnings, and resetting the classification, by the adversarial intent

algorithm **56**, of the adversarial behavior risk level. When the adversarial behavior continues for more than the third pre-determined time window, at block **278**, the method **200** includes, moving to block **282**, causing, with the vehicle controller **34**, the autonomous vehicle **10** to at least one of: back away from the adversarial behavior, and, re-route to avoid the adversarial behavior.
(84) In another exemplary embodiment, when the adversarial intent algorithm **56**, at block **262**, determines that there is high risk of adversarial behavior, the method **200** includes, moving to block **284**, reporting, with the vehicle controller **34**, the high risk adversarial behavior to at least one of vehicle assistance service providers, authorities, infrastructure services providers and crowd-sensing services. Moving to block **286**, when the adversarial behavior continues for less than a third pre-determined time window, the method **200** includes, moving to block **288**, stopping the reporting, with the vehicle controller **34**, to at least one of vehicle assistance service providers, authorities, infrastructure services providers and crowd-sensing services.
(85) When the adversarial behavior continues, at block **286**, for more than the third pre-determined time window, moving to block **290**, the method **200** includes at least one of: causing, with the vehicle controller **34**, the autonomous vehicle **10** to at least one of: back away from the adversarial behavior, and, re-route to avoid the adversarial behavior, causing, with the vehicle controller **34**, control of the autonomous vehicle **10** to be transferred from the vehicle controller **34** to an eligible occupant within the autonomous vehicle **10**, and, causing, with the vehicle controller **34**, control of the autonomous vehicle **10** to be transferred from the vehicle controller **34** to a remotely located tele-driving entity.
(86) In an exemplary embodiment, moving to block **292**, the method **200** further includes verifying that there is an eligible occupant within the autonomous vehicle **10** prior to the causing, with the vehicle controller **34**, at block **290**, control of the autonomous vehicle **10** to be transferred from the vehicle controller **34** to an eligible occupant within the autonomous vehicle **10**.
(87) A system and method of the present disclosure offers the advantage of automatically detecting adversarial behavior directed toward an autonomous vehicle and providing proactive and reactive responses for the autonomous vehicle to perform in response to adversarial behavior.
(88) The description of the present disclosure is merely exemplary in nature and variations that do not depart from the gist of the present disclosure are intended to be within the scope of the present disclosure. Such variations are not to be regarded as a departure from the spirit and scope of the present disclosure.

Claims

1. A method of responding to adversarial behavior directed toward an autonomous vehicle, comprising: determining, with a pedestrian detection system, a vehicle controller and an adversarial intent algorithm, that a risk level of adversarial behavior from at least one pedestrian within proximity of the autonomous vehicle is one of no risk of adversarial behavior, low risk of adversarial behavior or high risk of adversarial behavior by: analyzing, with a crossing behavior algorithm, crossing behaviors of the at least one pedestrian and determining if crossing behaviors of the at least one pedestrian are adversarial based on whether the autonomous vehicle has the right of way, the type of crossing including any signs, lights or signals present, and how long the at least one pedestrian takes to complete the crossing; analyzing, with a non-verbal cue algorithm, non-verbal cues displayed by the at least one pedestrian and determining if non-verbal cues displayed by the at least one pedestrian are adversarial based on comparing captured images and body gestures and actions of the at least one pedestrian to known patterns of adversarial behavior; analyzing, with an audible cues algorithm, audible cues displayed by the at least one pedestrian and determining if audible cues displayed by the at least one pedestrian are adversarial based on comparing captured acoustic signals from the at least one pedestrian to known sounds that indicate adversarial behavior; and combining, with an information fusion algorithm, information from the

crossing behavior algorithm, the non-verbal cue algorithm and the audible cues algorithm; and providing, with the vehicle controller, actions to be performed by the autonomous vehicle in response to the adversarial behavior based on the risk level of the adversarial behavior.

2. The method of claim 1, further including: determining, with the pedestrian detection system and the vehicle controller, if the adversarial behavior continues for an amount of time that exceeds a pre-determined threshold, and if the adversarial behavior continues longer than the pre-determined threshold, determining that the adversarial behavior is persistent; and providing, with the vehicle controller, actions to be performed by the autonomous vehicle in response to the persistent adversarial behavior.

3. The method of claim 2, wherein, when the adversarial intent algorithm determines that there is no risk of adversarial behavior, the method includes providing no action responsive to adversarial behavior to be performed by the autonomous vehicle.

4. The method of claim 2, wherein, when the adversarial intent algorithm determines that there is low risk of adversarial behavior, the method includes, initiating, with the vehicle controller, at least one of visual or auditory warnings to the pedestrian.

5. The method of claim 4, wherein, when the adversarial behavior continues for less than a pre-determined time window, the method includes stopping the at least one of visual and auditory warnings, or resetting the classification, by the adversarial intent algorithm, of the adversarial behavior risk level.

6. The method of claim 5, wherein, when the adversarial behavior continues for more than the pre-determined time window, the method includes causing, with the vehicle controller, the autonomous vehicle to at least one of back away from the adversarial behavior or re-route to avoid the adversarial behavior.

7. The method of claim 1, wherein, when the adversarial intent algorithm determines that there is high risk of adversarial behavior, the method includes, reporting, with the vehicle controller, the high risk of adversarial behavior to at least one of vehicle assistance service providers, authorities, infrastructure services providers or crowd-sensing services.

8. The method of claim 7, wherein, when the adversarial behavior continues for less than a third pre-determined time window, the method includes stopping the reporting, with the vehicle controller, the high risk of adversarial behavior to at least one of vehicle assistance service providers, authorities, infrastructure services providers or crowd-sensing services.

9. The method of claim 7, wherein, when the adversarial behavior continues for more than a pre-determined time window, the method includes at least one of: causing, with the vehicle controller, the autonomous vehicle to at least one of: back away from the adversarial behavior, or, re-route to avoid the adversarial behavior; causing, with the vehicle controller, control of the autonomous vehicle to be transferred from the vehicle controller to an eligible occupant within the autonomous vehicle; or causing, with the vehicle controller, control of the autonomous vehicle to be transferred from the vehicle controller to a remotely located tele-driving entity.

10. The method of claim 9, further including verifying that there is an eligible occupant within the autonomous vehicle prior to the causing, with the vehicle controller, control of the autonomous vehicle to be transferred from the vehicle controller to an eligible occupant within the autonomous vehicle.

11. A system for responding to adversarial behavior within an autonomous vehicle, comprising a pedestrian detection system in communication with a vehicle controller and an adversarial intent algorithm adapted to: determine that a risk level of adversarial behavior from at least one pedestrian within proximity of the autonomous vehicle is one of no risk of adversarial behavior, low risk of adversarial behavior or high risk of adversarial behavior by: analyzing, with a crossing behavior algorithm, crossing behaviors of the at least one pedestrian and determining if crossing behaviors of the at least one pedestrian are adversarial based on whether the autonomous vehicle has the right of way, the type of crossing including any signs, lights or signals present, and how

long the at least one pedestrian takes to complete the crossing; analyzing, with a non-verbal cue algorithm, non-verbal cues displayed by the at least one pedestrian and determining if non-verbal cues displayed by the at least one pedestrian are adversarial based on comparing captured images and body gestures and actions of the at least one pedestrian to known patterns of adversarial behavior; analyzing, with an audible cues algorithm, audible cues displayed by the at least one pedestrian and determining if audible cues displayed by the at least one pedestrian are adversarial based on comparing captured acoustic signals from the at least one pedestrian to known sounds that indicate adversarial behavior; and combining, with an information fusion algorithm, information from the crossing behavior algorithm, the non-verbal cue algorithm and the audible cues algorithm; and provide actions to be performed by the autonomous vehicle in response to the adversarial behavior based on the risk level of the adversarial behavior.
12. The system of claim 11, wherein the pedestrian detection system and the vehicle controller are further adapted to determine that the adversarial behavior is persistent if the adversarial behavior continues for an amount of time that exceeds a pre-determined threshold, and to provide, actions to be performed by the autonomous vehicle in response to the persistent adversarial behavior.
13. The system of claim 12, wherein, when the adversarial intent algorithm determines that there is no risk of adversarial behavior, the vehicle controller is adapted to provide no action responsive to adversarial behavior to be performed by the autonomous vehicle.
14. The system of claim 12, wherein, when the adversarial intent algorithm determines that there is low risk of adversarial behavior, the vehicle controller is adapted to initiate at least one of visual or auditory warnings to the pedestrian.
15. The system of claim 14, wherein, when the adversarial behavior continues for less than a pre-determined time window, the vehicle controller is adapted to stop the at least one of visual or auditory warnings, and reset the classification, by the adversarial intent algorithm, of the adversarial behavior risk level.
16. The system of claim 14, wherein, when the adversarial behavior continues for more than the pre-determined time window, the vehicle controller is adapted to cause the autonomous vehicle to at least one of back away from the adversarial behavior or re-route to avoid the adversarial behavior.
17. The system of claim 12, wherein, when the adversarial intent algorithm determines that there is high risk of adversarial behavior, the vehicle controller is adapted to report the high risk of adversarial behavior to at least one of vehicle assistance service providers, authorities, infrastructure services providers or crowd-sensing services.
18. The system of claim 17, wherein, when the adversarial behavior continues for less than a pre-determined time window, the vehicle controller is adapted to stop the reporting to at least one of vehicle assistance service providers, authorities, infrastructure services providers or crowd-sensing services, and, when the adversarial behavior continues for more than a pre-determined time window, the vehicle controller is adapted to at least one of: cause the autonomous vehicle to at least one of: back away from the adversarial behavior, or, re-route to avoid the adversarial behavior; cause control of the autonomous vehicle to be transferred from the vehicle controller to an eligible occupant within the autonomous vehicle; or cause control of the autonomous vehicle to be transferred from the vehicle controller to a remotely located tele-driving entity.
19. The system of claim 18, wherein, the vehicle controller is adapted to verify that there is an eligible occupant within the autonomous vehicle prior to the causing, with the vehicle controller, control of the autonomous vehicle to be transferred from the vehicle controller to an eligible occupant within the autonomous vehicle.
20. A system for responding to adversarial behavior directed toward an autonomous vehicle, comprising a pedestrian detection system in communication with a vehicle controller and an adversarial intent algorithm adapted to: determine that a risk level of adversarial behavior from at least one pedestrian within proximity of the autonomous vehicle is one of no risk of adversarial

behavior, low risk of adversarial behavior or high risk of adversarial behavior by: analyzing, with a crossing behavior algorithm, crossing behaviors of the at least one pedestrian and determining if crossing behaviors of the at least one pedestrian are adversarial based on whether the autonomous vehicle has the right of way, the type of crossing including any signs, lights or signals present, and how long the at least one pedestrian takes to complete the crossing: analyzing, with a non-verbal cue algorithm, non-verbal cues displayed by the at least one pedestrian and determining if non-verbal cues displayed by the at least one pedestrian are adversarial based on comparing captured images and body gestures and actions of the at least one pedestrian to known patterns of adversarial behavior; analyzing, with an audible cues algorithm, audible cues displayed by the at least one pedestrian and determining if audible cues displayed by the at least one pedestrian are adversarial based on comparing captured acoustic signals from the at least one pedestrian to known sounds that indicate adversarial behavior; and combining, with an information fusion algorithm, information from the crossing behavior algorithm, the non-verbal cue algorithm and the audible cues algorithm; determine if the adversarial behavior is persistent; and provide actions to be performed by the autonomous vehicle in response to the adversarial behavior based on the risk level of the adversarial behavior; wherein: when the adversarial intent algorithm determines that there is no risk of adversarial behavior, the vehicle controller is adapted to provide no actions to be performed responsive to adversarial behavior by the autonomous vehicle; when the adversarial intent algorithm determines that there is low risk of adversarial behavior, the vehicle controller is adapted to initiate at least one of visual and auditory warnings to the pedestrian; when the adversarial behavior continues for less than a pre-determined time window, the vehicle controller is adapted to stop the at least one of visual and auditory warnings, and reset the classification, by the adversarial intent algorithm, of the adversarial behavior risk level; when the adversarial behavior continues for more than the pre-determined time window, the vehicle controller is adapted to cause the autonomous vehicle to at least one of back away from the adversarial behavior or re-route to avoid the adversarial behavior; when the adversarial intent algorithm determines that there is high risk of adversarial behavior, the vehicle controller is adapted to report the high risk of adversarial behavior to at least one of vehicle assistance service providers, authorities, infrastructure services providers or crowd-sensing services; when the adversarial behavior continues for less than a third pre-determined time window, the vehicle controller is adapted to stop the reporting to at least one of vehicle assistance service providers, authorities, infrastructure services providers or crowd-sensing services, and, when the adversarial behavior continues for more than a pre-determined time window, the vehicle controller is adapted to at least one of: cause the autonomous vehicle to at least one of: back away from the adversarial behavior, or, re-route to avoid the adversarial behavior; cause control of the autonomous vehicle to be transferred from the vehicle controller to an eligible occupant within the autonomous vehicle; or cause control of the autonomous vehicle to be transferred from the vehicle controller to a remotely located tele-driving entity.