Early Warning and Collision Avoidance

This application is entitled to the benefit of the filing dates of United States application nos. 15/994,568, filed on May 31, 2018, 15/994,826, filed on May 31, 2018, 15/994,702, filed on May 31, 2018, 15/994,915, filed on May 31, 2018, 16/222,536 filed on December 17, 2018, 15/994,850 filed May 31, 2018 which all claim priority to and the benefit of United States provisional patent application 62/644,725, filed March 19, 2018, the entire contents of which are incorporated here by reference.

Background

This description relates to early warning and collision avoidance.

Collision avoidance systems have become abundant. King et al. (US patent publication 2007/0276600 A1, 2007), for example, described placing sensors ahead of an intersection and applying a physics-based decision rule to predict if two vehicles are about to crash at the intersection based on heading and speed.

In Aoude et al. (USA patent 9,129,519 B2, 2015, the entire contents of which are incorporated here by reference) the behavior of drivers is monitored and modeled to allow for the prediction and prevention of a violation in traffic situations at intersections.

Collision avoidance is the main defense against injury and loss of life and property in ground transportation. Providing early warning of dangerous situations aids collision avoidance.

Summary

In general, in an example, equipment is located at an intersection of a transportation network. The equipment includes an input to receive data from a sensor oriented to monitor ground transportation entities at or near the intersection. A wireless communication device sends to a device of one of the ground transportation entities, a warning about a dangerous situation at or near the intersection, there is a processor and a storage for instructions executable by the processor to perform actions including the following. A machine learning model is stored that can predict behavior of ground transportation entities at or near the intersection at a current time. The machine learning model is based on training data about previous motion and related behavior of ground transportation entities at or near the intersection. Current motion data

received from the sensor about ground transportation entities at or near the intersection is applied to the machine learning model to predict imminent behaviors of the ground transportation entities. An imminent dangerous situation for one or more of the ground transportation entities at or near the intersection is inferred from the predicted imminent behaviors. The wireless communication device sends the warning about the dangerous situation to the device of one of the ground transportation entities.

Implementations may include one or a combination of two or more of the following features. The wireless communication device sends the warning about the dangerous situation to a sign or other infrastructure presentation device. The warning includes an instruction or command capable of controlling a specific ground transportation entity. The equipment includes a roadside equipment. There is a housing for the equipment and the sensor is attached to the housing. The warning is sent by broadcasting the warning for receipt by any of the ground transportation entities at or near the intersection. The machine learning model includes an artificial intelligence model. The training data and the motion data include at least one of speed, location, or heading. The training data and motion data may also include intent, posture, direction of look, or interaction with other vulnerable road users, such as in a group. The processor is configured to be capable of generating the machine learning model at the equipment. The training data is stored at the equipment. The intersection includes a non-signalized intersection. The intersection includes a signalized intersection. The transportation network includes a road network. The ground transportation entities include vulnerable road users. The ground transportation entities include vehicles. The imminent dangerous situation includes a collision or a near miss. The ground transportation entities include pedestrians crossing a road at a crosswalk. There is another communication device to communicate with a central server. The device of one of the ground transportation entity includes a mobile communication device.

In general, in an example, equipment is located at an intersection of the transportation network. The equipment includes an input to receive data from a sensor oriented to monitor ground transportation entities at or near the intersection. A wireless communication device sends to a device of one of the ground transportation entities, a warning about a dangerous situation at or near the intersection. There is a processor and a storage for instructions executable by the processor to store a machine learning model that can predict behavior of ground transportation

entities at or near the intersection at a current time. The machine learning model is based on training data about previous motion and related behavior of ground transportation entities at or near the intersection. Current motion data received from the sensor about ground transportation entities at or near the intersection is applied to the machine learning model to predict imminent behaviors of the ground transportation entities, including a ground transportation entity the device of which cannot receive a warning from the wireless communication device. An imminent dangerous situation for a ground transportation entity the device of which can receive a warning from the wireless communication device is inferred. The imminent dangerous situation is the result of predicted imminent behavior of the ground transportation entity that cannot receive the warning. The warning about the dangerous situation is sent to the device of the ground transportation entity that can receive the warning from the wireless communication device.

Implementations may include one or a combination of two or more of the following features. The equipment includes a roadside equipment. There is a housing for the equipment and the sensor is attached to the housing. The warning is sent by broadcasting the warning for receipt by any of the ground transportation entities at or near the intersection that can receive the warning. The machine learning model includes an artificial intelligence model. The intersection includes a non-signalized intersection. The intersection includes a signalized intersection. The transportation network includes a road network. The ground transportation entities include vulnerable road users. The ground transportation entities include vehicles. The imminent dangerous situation includes a collision. The ground transportation entity the device of which cannot receive the warning from the wireless communication device includes a vehicle. The ground transportation entity the device of which can receive the warning from the wireless communication device includes a pedestrian crossing a road at a crosswalk. There is another communication device to communicate with a central server. The device of one of the ground transportation entity includes a mobile communication device.

In general, in an example, on board a road vehicle traveling in a ground transportation network messages and data are received including messages from external sources about location, motion, and state of other ground transportation entities, data from on board sensors about road and driving conditions and about the locations of static objects and moving ground transportation entities in the vehicle surroundings, data about quality of driving by a driver of the road vehicle,

and basic safety messages from other ground transportation entities and personal safety messages from vulnerable road users. The received data and messages are fused and applied to an artificial intelligence model to predict an action of a driver of the road vehicle or of a vulnerable road user or a collision risk for the road vehicle or both.

Implementations may include one or a combination of two or more of the following features. The road vehicle creates a map of the static objects and moving ground transportation entities in the vicinity of the road vehicle. The driver of the road vehicle is alerted to a collision risk. The collision risk is determined based on probabilities of predicted trajectories of nearby other moving ground transportation entities. Basic safety messages and personal safety messages are filtered to reduce the number of alerts provided to the driver of the road vehicle.

In general, in a first aspect, the present disclosure provides a method comprising using electronic sensors located in a vicinity of a crosswalk that crosses a road to monitor an area in and nearby the crosswalk, the electronic sensors generating motion data about vulnerable roadway users who are in or nearby the crosswalk, the motion data including location and direction of the vulnerable roadway users, applying the generated motion data to a machine learning model running in equipment located in the vicinity of the crosswalk to make a prediction that one of the vulnerable roadway users is about to enter the road in or nearby the crosswalk, the prediction being made prior to the vulnerable roadway user entering the road in or nearby the crosswalk, the machine learning model having been trained using motion data generated in the vicinity of the crosswalk and indicative of intent or behavior of vulnerable roadway users who previously had been in or nearby the crosswalk, the motion data comprising location, speed, acceleration, and orientation, and before the vulnerable roadway users has entered the road in or nearby the crosswalk, transmitting a warning to at least one of: a device associated with the vulnerable roadway user, a device associated with another ground transportation entity that is approaching the crosswalk on the road, or a road sign configured to alert the vulnerable roadway user or a driver.

Implementations may include one or a combination of two or more of the following features. The equipment includes a roadside equipment. The vulnerable roadway user includes a pedestrian, animal, or cyclist. The device associated with the vulnerable roadway user includes a smart watch or other wearable, a smart phone, or another mobile device. The other ground transportation entity includes a motorized vehicle. The device associated with the other ground

transportation entity includes a smart phone or another mobile device. The machine learning model is provided to the equipment located in the vicinity of the crosswalk by a remote server through the Internet. The machine learning model is generated at the equipment located in the vicinity of the crosswalk. The machine learning model is trained using motion data generated by the sensors located in the vicinity of the crosswalk. Motion data generated by the sensors located in the vicinity of the crosswalk is sent to a server for use in training the machine learning model.

The motion data generated by the sensors located in the vicinity of the crosswalk is segmented based on corresponding zones in the vicinity of the crosswalk. The electronic sensors are used to generate motion related data representing physical properties of the vulnerable road user. Trajectory information about the vulnerable road user is derived from motion data generated by the sensor.

In general, in an example, electronic sensors located in a vicinity of an intersection of a ground transportation network are used to monitor the intersection and approaches to the intersection. The electronic sensors generate motion data about ground transportation entities moving on the approaches or in the intersections. One or more of the ground transportation entities are not capable of sending basic safety messages to other ground transportation entities in the vicinity of the intersection. Based on the motion data generated by the electronic sensors, virtual basic safety messages are sent to one of more of the ground transportation entities that are capable of receiving the messages. The virtual basic safety messages incorporate information about one or more of the ground transportation entities that are not capable of sending basic safety messages. The incorporated information in each of the virtual basic safety messages includes at least one of the location, heading, speed, and predicted future trajectory of one of the ground transportation entities that are not capable of sending basic safety messages.

Implementations may include one or a combination of two or more of the following features. The equipment includes a roadside equipment. The incorporated information includes a subset of information that would be incorporated in a basic safety message generated by the ground transportation entity if it were capable of sending basic safety messages. The generated motion data is applied to a machine learning model running in equipment located in the vicinity of the intersection to predict a trajectory of the ground transportation entity that is not capable of sending basic safety messages. One of the ground transportation entities includes a motorized vehicle. The machine learning model is provided to the equipment located in the vicinity of the intersection by a remote server through the Internet. The machine learning model is generated at the equipment located in the vicinity of the intersection. The machine learning model is trained using motion data generated by the sensors located in the vicinity of the intersection. Motion data generated by the sensors located in the vicinity of the intersection is sent to a server for use in training the machine learning model.

In general, in an example, electronic sensors located in a vicinity of an intersection of a ground transportation network are used to monitor the intersection and approaches to the intersection. The electronic sensors generate motion data about ground transportation entities moving on the approaches or in the intersections. Distinct virtual zones are defined in the intersection and the approaches to the intersection. The motion data is segmented according to corresponding virtual zones to which the generated motion data relates. The generated motion data is applied for each of the respective segments to a machine learning model running in equipment located in the vicinity of the intersection to predict an imminent dangerous situation in the intersection or one of the approaches involving one or more of the ground transportation entities. Before the imminent dangerous situation becomes an actual dangerous situation, a warning is wirelessly transmitted to a device associated with at least one of the involved ground transportation entities.

Implementations may include one or a combination of two or more of the following features. The equipment includes a roadside equipment. The device associated with each of the ground transportation entities includes a wearable, a smart phone, or another mobile device. One of the ground transportation entities includes a motorized vehicle. The machine learning model is provided to the equipment located in the vicinity of the intersection by a remote server through the Internet. The machine learning model is generated at the equipment located in the vicinity of the intersection. The machine learning model is trained using motion data generated by the sensors located in the vicinity of the intersection. The motion data generated by the sensors located in the vicinity of the intersection is sent to a server for use in training the machine learning model. The electronic sensors are used to monitor an area in or nearby a crosswalk that crosses one of the approaches to the intersection. The electronic sensors are used to generate motion related data representing physical properties of a vulnerable road user in the vicinity of the crosswalk. Trajectory information about the vulnerable road user is derived from motion data generated by the sensor. There is a machine learning model for each of the approaches to the intersection. A determination is made whether to transmit the warning based also on motion data generated by sensors with respect to another nearby intersection. A determination is made whether to transmit the warning based also on information received from ground transportation entities moving on the approaches or in the intersection. The intersection is signalized and information about the state of the signals is received. The intersection is not signalized and is

controlled by one or more signs. The defined virtual zones include one or more approaches controlled by the signs. The signs include a stop sign or a yield sign. One of the ground transportation entities includes a rail vehicle.

In general, in an example, equipment is located in or on a ground transportation entity. The equipment includes an input to receive data from sensors in or on the ground transportation entity and oriented to monitor nearby features of a ground transportation network and other information about a context in which the ground transportation entity is traversing the ground transportation network. A wireless communication device receives information about the context. A signal processor applies signal processing to data from the sensor and other information about the context. There is a processor and a storage for instructions executable by the processor to perform actions that include the following: store a machine learning model that can predict behavior of an operator of the ground transportation entity and intent and movement of other ground transportation entities in the vicinity, and apply the current received data from the sensors and other information about the context to predict behavior of the operator and the intent and movement of other ground transportation entities in the vicinity.

Implementations may include one or a combination of two or more of the following features. The equipment includes a roadside equipment. The instructions are executable by the processor to monitor users or occupants of the ground transportation entity. The other information about the context includes emergency broadcasts, traffic and safety messages road side equipment, and messages about safety, locations, and other motion information from other ground transportation entities. The sensors include cameras, range sensors, vibration sensors, microphones, seating sensors, hydrocarbon sensors, sensors of volatile organic compounds and other toxic materials, and kinematic sensors or combinations of them. The instructions are executable by the processor to filter received alerts that the vehicle receives by applying the alerts to a machine learning model to predict which alerts are important in the current location, environmental conditions, driver behavior, vehicle health and status, and kinematics.

In general, in an example, motion data are acquired for unconnected ground transportation entities moving in a transportation network. Virtual safety messages incorporating information about the motion data for the unconnected ground transportation entities at sent to connected ground transportation entities in the vicinity of the unconnected ground transportation entities.

Implementations may include one or a combination of two or more of the following features. the virtual safety messages are substitutes for safety messages that would be sent by the unconnected ground transportation entities if they were connected. The unconnected ground transportation entities include vehicles and the virtual safety messages are substitutes for basic safety messages. The unconnected ground transportation entities include vulnerable road users and the virtual safety messages are substitutes for personal safety messages. The motion data are detected by infrastructure sensors.

In general, in an example, equipment located at an intersection of a transportation network includes inputs to receive data from sensors oriented to monitor ground transportation entities at or near the intersection. The data from each of the sensors represents at least one location or motion parameter of at least one of the ground transportation entities. The data from each of the sensors is expressed in a native format. The data received from at least two of the sensors is inconsistent with respect to the location or motion parameters or the native formats or both. There is a storage for instructions executable by a processor to convert the data from each of the sensors into data having a common format independent of the native formats of the data of the sensors. The data having the common format is incorporated into a global unified representation of the ground transportation entities being monitored at or near the intersection. The global unified representation includes the location, speed, and heading of each of the ground transportation entities. Relationships of locations and motions of two of the ground transportation entities are determined using the global unified representation. A dangerous situation is predicted involving the two ground transportation entities, and a message is sent to at least one of the two ground transportation entities alerting it to the dangerous situation.

Implementations may include one or a combination of two or more of the following features. The sensors include at least two of: radar, lidar, and a camera. The data received from one of the sensors includes image data of a field of view at successive moments. The data received from one of the sensors includes points of reflection in 3D space. The data received from one of the sensors includes distance from the sensor and speed. The global unified representation represents locations of the ground transportation entities in a common reference frame. Two sensors from which the data is received are mounted in fixed positions at or near the intersection and have at least partially non-overlapping fields of view. One of the sensors includes radar and the

converting of the data includes determining locations of ground transportation entities from a known location of the radar and distances from the radar to the ground transportation entities. One of the sensors includes a camera and the converting of the data includes determining locations of ground transportation entities from a known location, direction of view, and tilt of the camera and the locations of the ground transportation entities within an image frame of the camera.

In general, in a second aspect, the present disclosure provides an apparatus comprising equipment located at a level crossing of a transportation network, the level crossing comprising an intersection of a road, a pedestrian crossing, and a rail line, the equipment comprising inputs to receive data from sensors oriented to monitor road vehicles and pedestrians at and near the level crossing and to receive phase and timing data for signals on the road and on the rail line, a wireless communication device to send to a device of one of the ground transportation entities, pedestrians, or rail vehicles on the rail line, a warning about a dangerous situation at or near the level crossing, a processor, and a storage for instructions executable by the processor to store a machine learning model that can predict behavior of ground transportation entities at or near the level crossing at a current time, the machine learning model being based on training data about previous motion and related behavior of road vehicles and pedestrians at or near the intersection, and previous phase and timing data for signals on the road and on the rail line, apply current motion data received from the sensors about road vehicles and pedestrians at or near the level crossing and current phase and timing data for signals on the road and on the rail line to the machine learning model to predict imminent behaviors of the road vehicles and pedestrians, infer an imminent dangerous situation for a rail vehicle on the rail line at or near the intersection from the predicted imminent behaviors, cause the wireless communication device to send the warning about the dangerous situation to a device of at least one of the road vehicles, pedestrians, and rail vehicle.

Implementations may include one or a combination of two or more of the following features. The warning is sent to an on-board equipment of the rail vehicle. The rail line is on a segregated right of way. The rail line is not on a segregated right of way. The equipment includes a roadside equipment. The warning is sent by broadcasting the warning for receipt by any of the ground

transportation entities, pedestrians, or rail vehicles at or near the level crossing. The imminent dangerous situation includes a collision or a near miss.

In general, in a third aspect, the present disclosure provides a method comprising receiving data from infrastructure sensors representing positions and motions of road vehicles being driven or pedestrians walking in a ground transportation network,

receiving data in basic safety messages or virtual basic safety messages and personal safety message and virtual personal safety messages about states of the road vehicles and pedestrians, the basic safety messages, virtual basic safety messages, personal safety messages, and virtual personal safety messages comprising location, heading, and speed information about the road vehicles or pedestrians, the basic safety messages and the personal safety messages being received from the road vehicles or pedestrians, the virtual basic safety messages and the virtual personal safety messages comprising location, heading, and speed information about the road vehicles and the pedestrians reconstructed from the data received from the infrastructure sensors, applying the received data from the infrastructure sensors and the data from the basic safety messages, the virtual basic safety messages, the personal safety messages, and the virtual personal safety messages to a machine learning model trained to identify dangerous driving or walking behavior of one of the road vehicles or pedestrians, and automatically reporting the dangerous driving or walking behavior to authorities.

Implementations may include one or a combination of two or more of the following features. The road vehicles are identified based on plate number recognition. The pedestrians are identified based on biometric recognition. The road vehicles or pedestrians are identified based on social networking.

These and other aspects, features, and implementations can be expressed as methods, apparatus, systems, components, program products, methods of doing business, means or steps for performing a function, and in other ways.

These and other aspects, features, and implementations will become apparent from the following descriptions, including the claims.

Description

Figures 1, 2, 3, and 15 are block diagrams.

Figures 4, 5, 8 through 11, 13, 14, 17, and 18 are schematic views of road networks from above.

Figures 6 and 7 are annotated perspective views of intersections.

Figures 12 and 16 are schematic side and perspective views of road networks.

With advancements in sensor technologies and computers, it has become feasible to predict (and to provide early warning of) dangerous situations and in that way to prevent collisions and near misses of ground transportation entities (that is, to enable collision avoidance) in the conduct of ground transportation.

5 We use the term "ground transportation" broadly to include, for example, any mode or medium of moving from place to place that entails contact with the land or water on the surface of the earth, such as walking or running (or engaging in other pedestrian activities), non-motorized vehicles, motorized vehicles (autonomous, semi-autonomous, and non-autonomous), and rail vehicles.

Claims

1. A method comprising

using electronic sensors located in a vicinity of a crosswalk that crosses a road to monitor an area in or nearby the crosswalk, the electronic sensors generating motion data about vulnerable roadway users who are in and nearby the crosswalk, the motion data including location and direction of the vulnerable roadway users,

applying the generated motion data to a machine learning model running in equipment located in the vicinity of the crosswalk to make a prediction that one of the vulnerable roadway users is about to enter the road in or nearby the crosswalk, the prediction being made prior to the vulnerable roadway user entering the road in or nearby the crosswalk, the machine learning model having been trained using motion data generated in the vicinity of the crosswalk and indicative of intent or behavior of vulnerable roadway users who previously had been in or nearby the crosswalk, the motion data comprising location, speed, acceleration, and orientation, and

before the vulnerable roadway user has entered the road in or nearby the crosswalk, transmitting a warning to at least one of: a device associated with the vulnerable roadway user, a device associated with another ground transportation entity approaching the crosswalk on the road, or a road sign configured to alert the vulnerable roadway user or a driver.

2. The method of claim 1 in which the vulnerable roadway user comprises a pedestrian, animal, or cyclist.

3. The method of claim 1 in which the device associated with the vulnerable roadway user comprises a smart watch or other wearable, a smart phone, or another mobile device.

4. The method of claim 1 in which the other ground transportation entity comprises a motorized vehicle.

5. The method of claim 1 in which the device associated with the other ground transportation entity comprises a smart phone or another mobile device.

6. The method of claim 1 in which the machine learning model is provided to the equipment located in the vicinity of the crosswalk by a remote server through the Internet.

7. The method of claim 1 in which the machine learning model is generated at the equipment located in the vicinity of the crosswalk.

8. The method of claim 1 comprising training the machine learning model using motion data generated by the sensors located in the vicinity of the crosswalk.

9. The method of claim 1 comprising sending motion data generated by the sensors located in the vicinity of the crosswalk to a server for use in training the machine learning model.

10. The method of claim 1 comprising segmenting the motion data generated by the sensors located in the vicinity of the crosswalk based on corresponding zones in the vicinity of the crosswalk.

11. The method of claim 1 comprising using the electronic sensors to generate motion related data representing physical properties of the vulnerable road user.

12. The method of claim 1 comprising deriving trajectory information about the vulnerable road user from motion data generated by the sensor.

13. An apparatus comprising

equipment located at a level crossing of a transportation network, the level crossing comprising an intersection of a road, a pedestrian crossing, and a rail line, the equipment comprising

inputs to receive data from sensors oriented to monitor road vehicles and pedestrians at and near the level crossing and to receive phase and timing data for signals on the road and on the rail line,

a wireless communication device to send to a device of one of the ground transportation entities, pedestrians, or rail vehicles on the rail line, a warning about a dangerous situation at or near the level crossing,

a processor, and

a storage for instructions executable by the processor to

store a machine learning model that can predict behavior of ground transportation entities at or near the level crossing at a current time, the machine learning model

being based on training data about previous motion and related behavior of road vehicles and pedestrians at or near the intersection and previous phase and timing data for signals on the road and on the rail line,

apply current motion data received from the sensors about road vehicles and pedestrians at or near the level crossing and current phase and timing data for signals on the road and on the rail line to the machine learning model to predict imminent behaviors of the road vehicles and pedestrians,

infer an imminent dangerous situation for a rail vehicle on the rail line at or near the intersection from the predicted imminent behaviors, and

cause the wireless communication device to send the warning about the dangerous situation to a device of at least one of the road vehicles, pedestrians, and rail vehicle.

14. The apparatus of claim 13 in which the warning is sent to an on-board equipment of the rail vehicle.

15. The apparatus of claim 13 in which the rail line is on a segregated right of way.

16. The apparatus of claim 13 in which the rail line is not on a segregated right of way.

17. The apparatus of claim 13 in which the equipment comprises a roadside equipment.

18. The apparatus of claim 13 in which the warning is sent by broadcasting the warning for receipt by any of the ground transportation entities, pedestrians, or rail vehicles at or near the level crossing.

19. The apparatus of claim 13 in which the imminent dangerous situation comprises a collision or a near miss.

20. A method comprising

receiving data from infrastructure sensors representing positions and motions of road vehicles being driven or pedestrians walking in a ground transportation network,

receiving data in basic safety messages or virtual basic safety messages and personal safety message and virtual personal safety messages about states of the road vehicles and pedestrians,

the basic safety messages, virtual basic safety messages, personal safety messages, and virtual personal safety messages comprising location, heading, and speed information about the road vehicles or pedestrians,

the basic safety message and the personal safety message being received from the road vehicles or pedestrians,

the virtual basic safety messages and the virtual personal safety messages comprising location, heading, and speed information about the road vehicles and the pedestrians reconstructed from the data received from the infrastructure sensors,

applying the received data from the infrastructure sensors and the data from the basic safety messages, the virtual basic safety messages, the personal safety messages, and the virtual personal safety messages to a machine learning model trained to identify dangerous driving or walking behavior of one of the road vehicles or pedestrians, and

automatically reporting the dangerous driving or walking behavior to authorities.

21. The method of claim 20 comprising

identifying the road vehicles based on plate number recognition.

22. The method of claim 20 comprising

identifying the pedestrians based on biometric recognition.

23. The method of claim 20 comprising

identifying the road vehicles or pedestrians based on social networking.