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Intelligent Transportation Systems with Wireless Sensor Support for Law Enforcement Use

Introduction

In a conventional Intelligent Transportation System (ITS), services are designed to improve transportation and traffic management. The first type of ITS which is funded by government entities use ultrasonic sensors, video recognition systems, and inductive loops to monitor traffic. The data that is extrapolated with this system is used to track the direction and speed of vehicles travelling on a road. The second type of ITS which is funded by private enterprises like Google uses GPS to track the direction, speed, and location of vehicles travelling on a road. The data from both of these systems are collected anonymously, so there is no identifiable information that can be extrapolated from individual vehicles. The purpose is to monitor traffic patterns and identify congested locations. These conventional systems deeply underutilize the potential of Intelligent Transportation Systems.

If a wireless sensor network (WSN) was used to implement a vehicle ad-hoc network (VANET) in an ITS, the new data collected from this system can be used to improve public safety and offer a wide range of valuable services that stretches beyond transportation and traffic management. Using VANET, vehicles can communicate with each other directly via its sensors, and a collision warning system can be utilized to prevent traffic accidents. By connecting the vehicle sensors with sensors on the road, an individual vehicle monitoring systems can be setup to track criminal suspects remotely by law enforcement agencies. This will have the potential to eliminate dangerous high speed chases. This new type of ITS can be used by law enforcement to increase public safety and automate parking and traffic enforcement tasks as well. Other potential benefits include reduced cost to traffic violation enforcement for police departments and reallocation of valuable police resources back to preventing and investigating more serious crimes.

This project is relevant to this course because an Intelligent Transportation System which is designed to support public safety and law enforcement requires an eclectic mix of networking technologies for it to succeed. The technology used in our project includes elements from every layer of a conventional networking model. This project will not succeed without a well devised network framework.

Our scope of investigation will focus on a four-way intersection to simulate how and what type of data is collected in an ITS with WSN support which will benefit public safety services used by law enforcement agencies. The simulation will contain a multi-lane road to emulate realistic traffic scenarios. Car to car communication, car to road communication, and road to base station communication will be implemented to simulate the data that will be generated and transferred from this type of ITS.

Current ITS deployed in the US are used solely to monitor traffic patterns and identify congestion locations. There is a lack of interest from the government to implement a centralized system. Because the conventional systems offer benefits limited to traffic monitoring, the push to upgrade is ignored. If we implemented a WSN to support ITS, new services can be created which will significantly benefit many areas in public safety and generate powerful results that can display the potential of an advanced ITS. Furthermore, the reduced costs to police departments and increase in public safety can spur additional development and advancements to ITS in the US.

Theoretical Bases and Literature Review

What is an ITS? It is advanced applications that can provide different types of services which are geared towards improving transport and traffic management.

What are wireless sensor networks? Wireless Sensor Network is a specialized wireless network with multiple numbers of nodes used for communication. Each node is equipped with embedded processors, sensors and radios. All the nodes in a network collaborate to accomplish a common task such as collecting information in a target area. Since every node has its own processing capability. It is beneficial to ITS because it can process and analyze data before it transmits.

The system which we will model our ITS with WSN support after is the Wireless Intelligent Transportation System (WITS). This system consists of four major subsystems which include the surveillance subsystem, strategy subsystem, execution subsystem, and communication subsystem. The surveillance subsystem collects the vehicle and road information. The strategy subsystem processes and calculates the data that was collected such as maximum throughout, minimum wait time, etc. The execution subsystem outputs a signal which can control or guide traffic. The communication subsystem transfer data between two separate subsystems. There are three types of nodes that WITS uses. These include the vehicle, roadside, and intersection units. The vehicle unit measures parameters such as speed and direction and transfer it to the roadside units. The roadside units gather data from vehicles nearby and transfer it to the intersection unit. Each roadside unit will aggregate the data it collects before it is transmitted. The intersection unit receives and analyzes the information from the roadside unit and passes it on to the strategy subsystem. The strategy subsystem analyzes and calculates the data and then passes it onto the execution system which can direct or guide traffic based on this information.

The network architecture of this system is very simple. For each sensor, a unique ID number is used as its address. Only broadcast messages and the message whose destination address matches will be received and processed by a node. Every roadside unit only needs to know the address of its next or previous node. The messages sent by the vehicle unit will be detected by the roadside unit closes to it, and only roadside unit on the same side of the road is in charge of processing them.

Vehicle units provide dynamic data like location, lane, and distance to the intersection. The roadside units will query the vehicle unit based on the request of the execution sub-system. If an intersection unit wants to know how many vehicles in every lane will reach the intersection before the signal phase ends, it will send out a request message to the vehicle unit. The roadside unit will then be responsible for collecting the vehicle message and transforming the data back to the execution sub-system.

The node architecture is composed of two aspects. Vertically, it contains the hardware layer, OS (operating system) layer, communication protocol layer, and the application layer. Horizontally, there are several management planes, which cross through every layer. These are the power management plane, clock synchronization management plane, and other management plane which contain security and location functions. Similar to common communication protocols, the communication stack of the node is divided into 3 layers which contain the physical layer, MAC (Media Access Control) layer and network layer. The physical layer and MAC layer will cover a range of about 100m to 200m. It will also be implemented under the condition that consumes low power and that the power is adjustable. WITS node uses solar cell as power supply. Power requirement is looser here than general WSN applications since each individual node only communicates with its upstream or downstream node. The node module itself comprises of 3 main components which are the RF (Radio Frequency), MCU (Micro Control Unit) and Power Supply. The RF encodes, modulates and sends the signal. The MCU integrates processor and memories. It is where the programs resides and executes. The power supply provides the power to the entire module.

The infrastructure that defines vehicle to vehicle communication in our system will also model a VANET framework. VANET is a sub-application of Mobile Ad-hoc Network (MANET) which is a self configuring network of mobile devices connected wirelessly. The general principle is that sensors will be installed in every car. This will allow vehicles to broadcast emergency messages such as an early collision warning. VANET is deployed in our system with the purpose of reducing traffic accidents by increasing reaction time for drivers. It can also be used to warn drivers about dangerous situations which include adverse environmental conditions or the presence of pedestrians. Traffic law enforcement applications can also be developed for this framework. Benefits of a VANET developed with WSN include automated enforcement for violations such as speeding, illegal parking, red light, and unauthorized use of bus and carpool lanes. In addition, travel history can be stored in a central system where post-accident investigation can be accomplished by analyzing the data that has been captured. Smart parking applications will be able to take advantage of the monitoring capabilities of WSN to monitor parking activity. Parking citations can be automated and law enforcement agencies can be notified directly if a parking offender’s vehicle needs to be towed or booted.

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The main objective of our ITS is to collect useful vehicle and road data that can be used by law enforcement agencies to improve public safety. ITS currently in use does not provide real time data. It is also unable to monitor traffic activity along the full length of the road. These conventional ITS are primarily used to monitor traffic patterns and congestion locations, because the data it collects is limited to speed and direction. Furthermore, information is transferred by cables which elevate the cost of construction and maintenance of this type of system. WSN has no cables, consumes low energy and is smaller in size. It will be easier to deploy and distribute than conventional ITS. WSN nodes deployed in vehicles can form a VANET which will measure and transmit dynamic vehicle information along the entire road. By implementing an ITS with WSN support, real time data such as driving history and individual vehicle identification information can be logged and processed by law enforcement agencies. Real time support can be used to monitor vehicles for parking or moving violations. It can issue citations directly to the owner of the vehicle without support from a parking attendant or police officer. Suspect vehicles can be tracked or disabled remotely. Vehicle to vehicle communication will provide valuable information that can be used in a warning system to aid drivers in avoiding collisions.

Hypothesis

Due to its limited data collection techniques, conventional Intelligent Transportation Systems has zero support for law enforcement use. If an advanced ITS with Wireless Sensor Network support was implemented, real time vehicle and individual identification data can be collected and used by law enforcement agencies to automate parking and traffic enforcement. Benefits include vehicle monitoring which can automate both long and short term surveillance of vehicles. This has the potential to eliminate dangerous high speed chases. Parking monitoring and citations will be fully automated which can reduce cost to the parking divisions. Traffic enforcement can also be automated which will allow police departments to redirect officers who are assigned to the traffic department back to other more serious crime prevention or investigative roles. The data collected from an ITS with WSN designed for law enforcement use will reduce cost for police agencies and increase public safety.

Methodology

Java programming language will be used to build the four way intersection traffic simulator. This is a GUI traffic simulator which will feature a two lane road with one lane assigned to each direction. Traffic flow will be randomly generated and vehicles will be displayed on screen travelling along the road and through the intersection. The simulator will emulate three types of ITS: the conventional method using radar, the conventional method using GPS, and our new method using WSN.

The radar method will feature vehicles travelling on the road through the intersection. Radar units will be placed on opposite sides of the intersection to collect speed and location data of vehicles passing through. A server function will emulate a central processing server which will use the data to calculate congestion levels. An accident event can be called to illustrate the reaction time that a driver gets to initiate and complete braking without any warning systems.

The GPS method will also feature vehicles travelling on the road. Each vehicle will generate dynamic data such as direction, speed, and location. A server function emulating a central processing server will aggregate the data and display information showing congestion levels on the road. An accident event can also be called to illustrate the reaction time that a driver gets to initiate and complete braking without any warning systems.

The ITS with WSN support method will feature vehicles travelling on the road as well. Each individual vehicle will generate dynamic data such as speed, direction, location, travel history, and number of passengers as well as identification information such as car make and type, license plate, and violation history. It will also have artificial intelligence, so it can respond to events such as an emergency stop on the road. Vehicles can be tracked by the central system so that its travelling history and current location can be monitored and logged. Road units will monitor vehicles and transmit data to the base stations at each intersection. Road units will only read data from the closest vehicles, and it will only transmit data to the upstream node. The intersection unit will process data from roadside units and display aggregated information to the screen. In addition to tracking location, it can track and issue citations to vehicles that have violated traffic regulations such as speeding or red light. Parking violations will also be monitored and citations will also be automated. An accident event can be called to illustrate the reaction time that a driver gets to initiate and complete braking with an early warning system. Other events which demonstrate the benefits of an ITS with WSN support will also be implemented. These include red light and speeding violations, parking violations, live vehicle surveillance, vehicle identification and travel history, etc.

The data aggregated and displayed in our GUI application will simulate the information that an ITS with WSN support can collect for law enforcement use. This will provide support to our claim that ITS with WSN can offer valuable data which can be used by police agencies to increase public safety and reduce costs by automating their services.

Implementation

We implemented this project using the Java AWT library to render our GUI ITSDemo application. The ITSDemo consists of four scenarios which demonstrate the different types of vehicular information that can be collected and modified in an ITS and used by law enforcement. Each scenario can be accessed via a tab in the ITSDemo. There are four main classes in our application. Detailed descriptions of each class are provided below.

ITSDemo.java

ITSDemo is the main GUI application. It creates a tabbed pane which is used to demo our ITS functionalities. A border layout is used to arrange the main demo frame and the log window.

- ITSDemo(): Creates scenario objects. Adds scenarios to the tabbed pane.
- Main(): Creates the frame of the application.

Scenario.java

Scenario.java controls the main logic of the ITSDemo application. It draws vehicles to the screen and handles actions that are triggered during the demo.

- Scenario(): Creates a scenario with a name, canvas, timer, autos, and timer.
- getName: Gets name of the current scenario.
- setName(): Sets name of the current scenario.
- getAutos(): Gets array list of autos in this scenario.
- setAutos(): Sets array list with autos in this scenario.
- shouldDrawCrashing(): Returns value that determine if crash should be drawn.
- start(): Starts scenario by adding vehicles. Start the timer and set crashing value.
- restart(): Resets scenario properties by restarting the timer and redrawing vehicles.
- stop(): Stops the timer.
- log(): Writes demo status messages to the log window
- clearLog(): Clears the log window
- actionPerformed(): Handles actions that are triggered such as updating the timer and repainting the canvas.
    - Crashing: After crash event is triggered, apply braking for vehicle for the crashing scenario
    - Red Light: Apply braking for vehicle A to stop at the red light. Increment violation count for vehicle B after it runs the red light.
    - Parking: Increment violation count for vehicle when the meter expires.

Auto.java

Auto.java represents vehicles in the ITSDemo application. It contains static information such as vehicle id, make, model, license, speed, acceleration, direction, number of passengers, parking violations, moving violations, etc. Each auto object represents a vehicle that is travelling on the road.

- Auto(): Create an auto object with id, make, license, width, length, running, speed, direction, acceleration, location, number of passengers.
- Draw(): Draws auto as an object that represents a vehicle in the demo. Draw vehicle specific data to the bottom of the application screen.

- Brake(): Sets acceleration of vehicles.
- setMovingViol(): Sets moving violation count of current vehicle.
- getMovingViol(): Gets moving violation count of current vehicle.
- setParkingViol(): Sets parking violation count of current vehicle.
- getParkingViol(): Gets parking violation count of current vehicle.
- updateState(): Updates the state of current vehicle with its changes in speed and acceleration given its direction of travel and time elapsed.
- onEvent(): has not been fully implemented yet.

Canvas.java

Canvas.java draws the background of the ITSDemo application by using the given scenario as its parameter. It is used to model the road in which our vehicles are traveling on.

- Canvas(): Create a canvas object using a given scenario object as its parameter.
- getSenario(): Retrieve the current scenario for this canvas.
- paintComponent(): Paints the background for this current scenario and draw all vehicles.
  - Crashing: Paints a 2 way road.
  - Red Light: Paints a 2 way road with an intersection and a red traffic light.
  - Parking: Paints a 1 way road with 3 parking spaces.
- setTimer(): Sets the timer for this canvas.

LogWindow.java

LogWindow.java writes status messages for the application to a scrollable text area.

- getInstance(): Returns an instance of this log window
- LogWindow(): Creates a default log window with a text area inside a scroll pane.
- getComponent(): Returns the scroll pane for this log window object.
- append(): Appends text to the log window.
- clear(): Clears text in the log window.

Data Analysis and Discussion

In the four scenarios of the ITSDemo, the application demonstrates the efficiency at which traffic and parking regulations can be enforced using ITS. Furthermore, it displays the plethora of useful vehicle identification and real time information which can be collected and analyzed by law enforcement.

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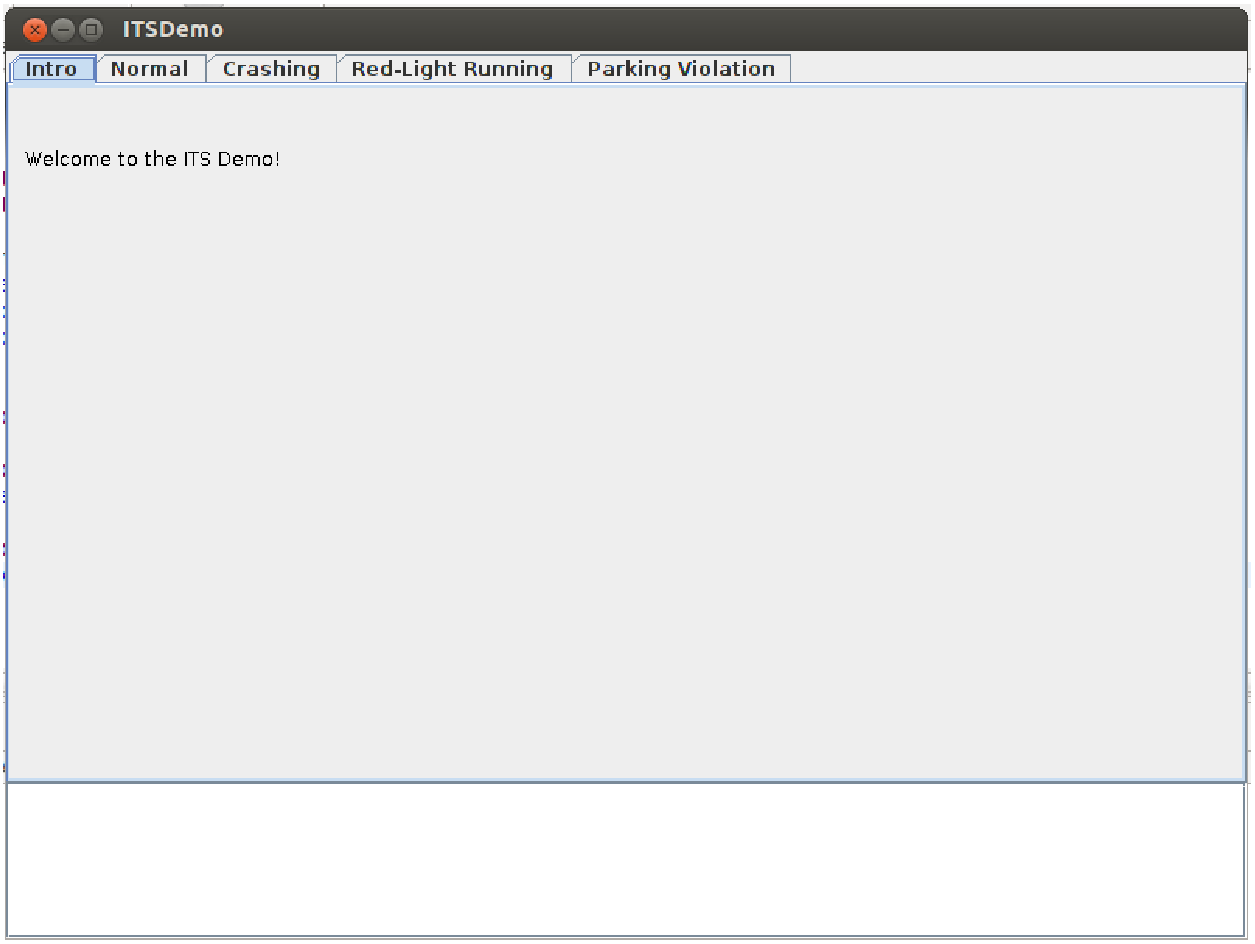
Team 4



In the Normal scenario, two vehicles are generated on screen to illustrate the power of ITS to collect identification and real time information from vehicles travelling on the road. Law enforcement officials can identify make, license, parking and moving violations without a vehicle stop or even line of sight. Real time information such as speed, direction, location, and number of passengers can also be gathered for surveillance use. Via a logging system, vehicle location and travel history can also be tracked. This scenario illustrates how vehicles can be centrally monitored and it can be done without the physical presence of a police officer. This has the potential to reduce costs and increase efficiency for law enforcement agencies.

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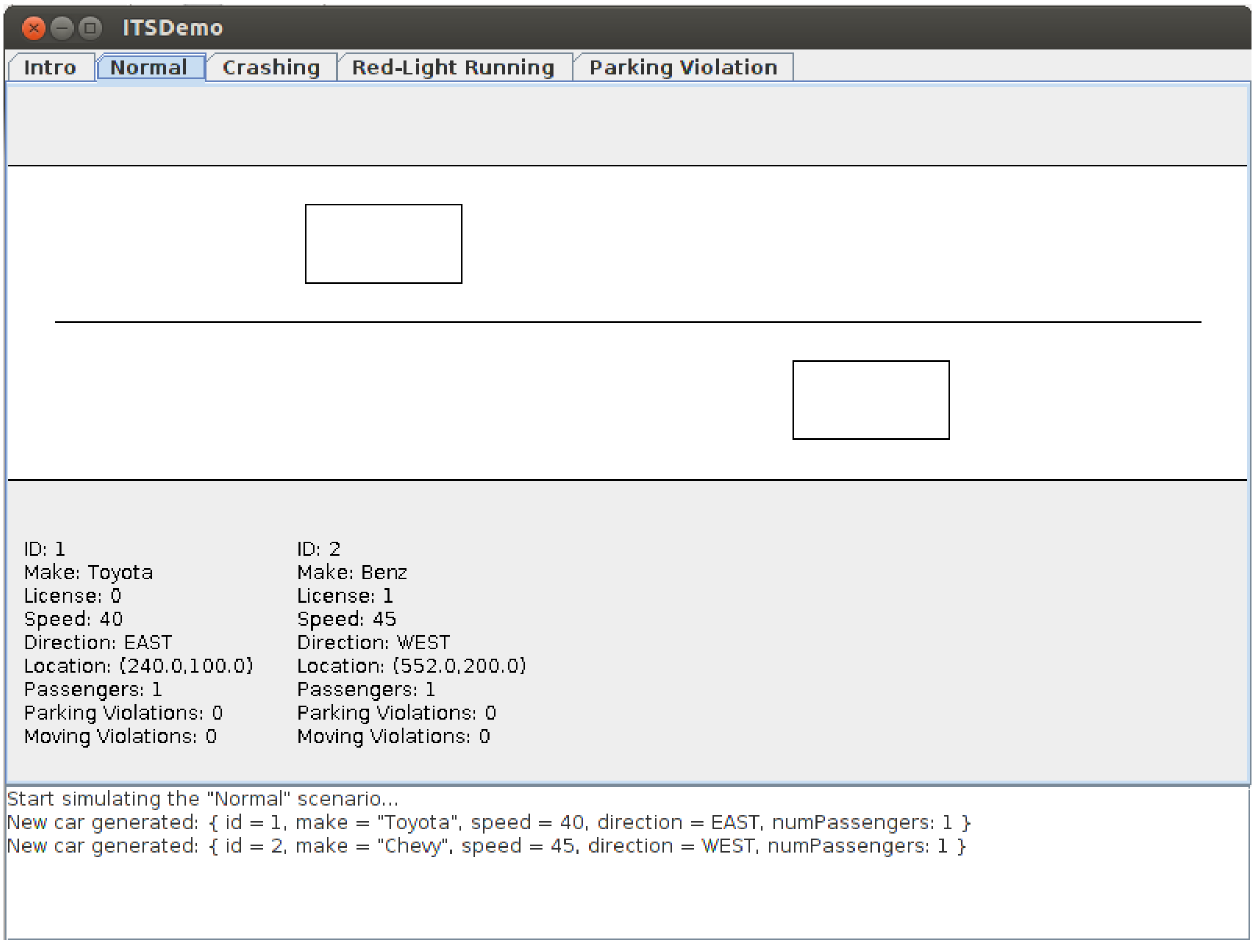
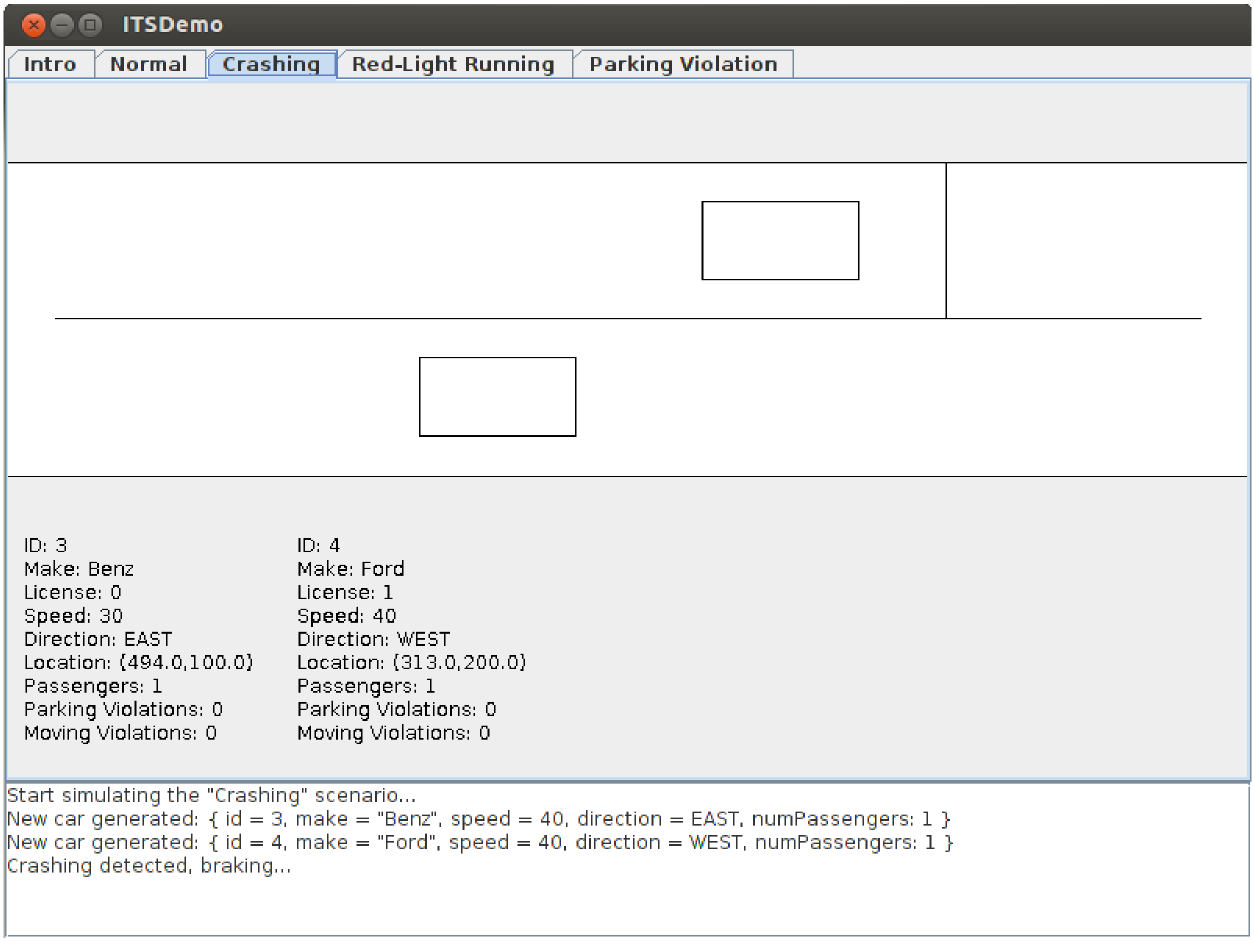
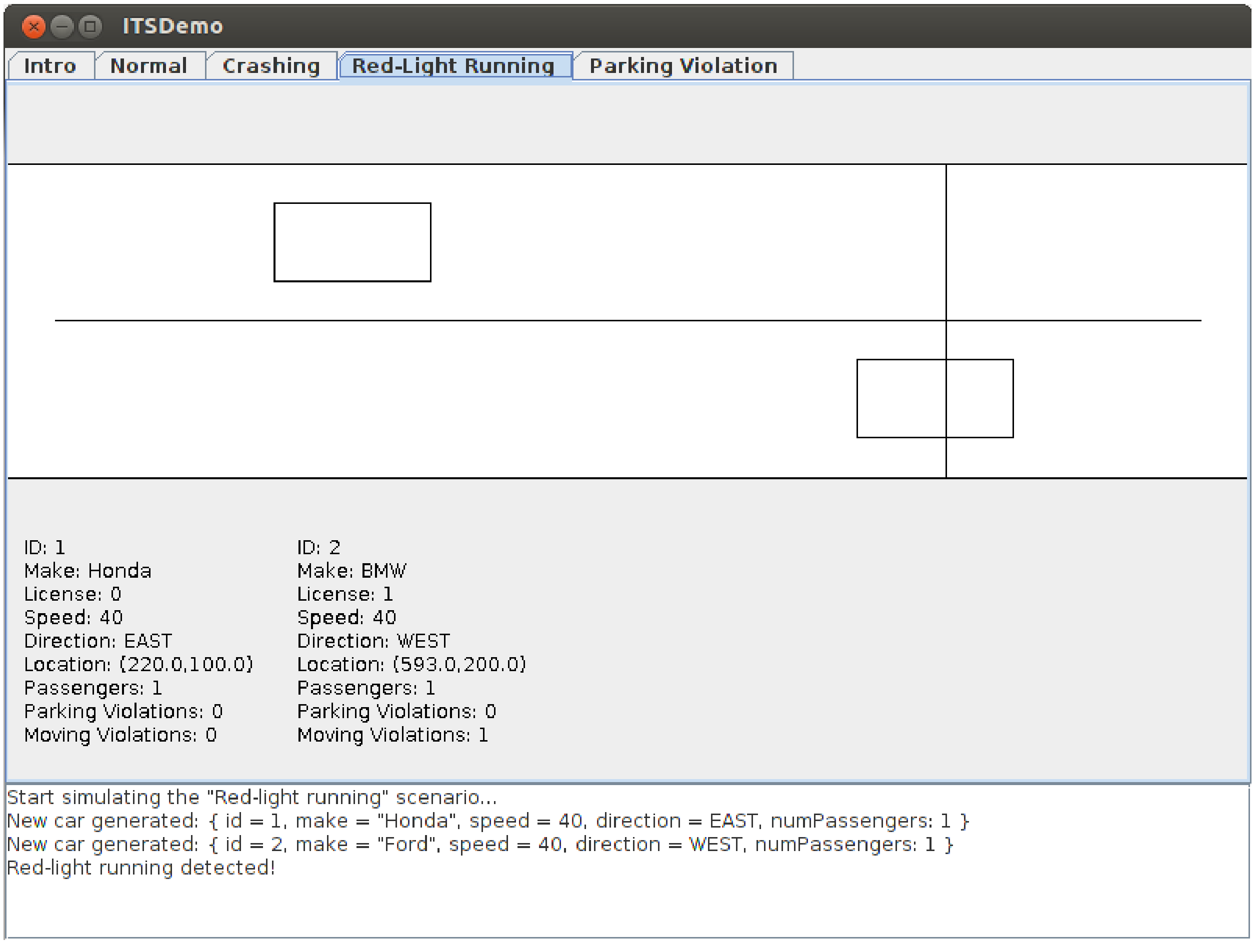


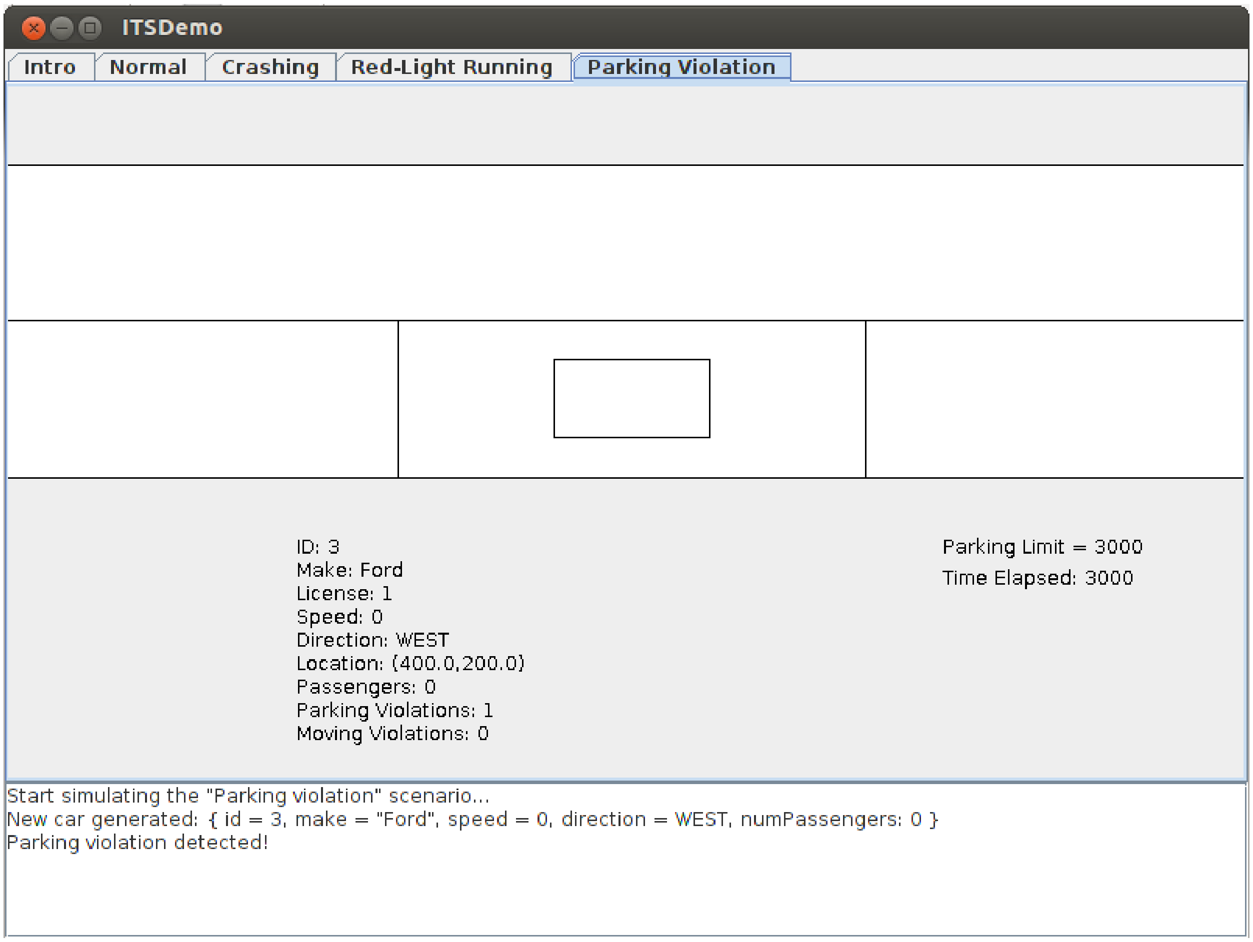
In the Crash scenario, the application shows the increased response time a vehicle will get for braking with ITS. Without the system, vehicles have to rely on line of sight to respond to emergency stops. By implementing an intelligent network where vehicles can communicate with each other, line of sight is not required for a vehicle to respond to an emergency event. The vehicle stops gracefully after receiving an emergency event trigger and maintains a safe distance from the accident detected ahead.



In the Red Light scenario, the ITSDemo shows the efficiency that ITS can achieve to regulate moving violations. Without sensors in place, a red light violation will normally require a traffic stop initiated by a police officer. This takes more time and money to execute. Also, there are not enough police officers to cover all of the intersections on the road in a city. This type of coverage is hard to achieve even with red light cameras. With ITS, the location tracker on each vehicle node works with the intersection node to fire the moving violation event. As soon as the violation occurs, the vehicle is immediately notified of its violation and an update is triggered via the network.



In the Parking scenario, the application demonstrates the effectiveness of ITS to regulate parking violations. Without sensors in place, parking violations require a parking enforcement officer to physically issue violations. It would be impossible to hire enough parking officers to cover the entire city. Also, parking officers cannot evenly distribute citations to every location. With ITS, parking regulation is automated. As soon as a violation occurs, the vehicle is notified and an update is triggered via the network.



Conclusion

The ITSDemo application gives a brief overview of the valuable identification and real time information that can be collected from an Intelligent Transportation System. It demonstrates the efficiency that moving and parking regulation automation can bring to law enforcement agencies. We created four scenarios: Normal, Crash, Red Light, and Parking to illustrate how an ITS can easily collect and analyze traffic data on the road. The Normal scenario showed the type of vehicle information that an ITS may collect. The Crash scenario demonstrated its ability to increase safety on the road. The Moving and Parking scenarios displayed the efficiency with which ITS can be used to regulate traffic and parking violations. The scope of our demo did not cover in-depth of how an ITS system can be implemented and executed due to the time restraints of the course. For future studies or projects, it would be very interesting to see how a fully implemented program will function and to compare metrics collected from it against the traditional traffic systems without ITS.

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