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A Real-time Vehicle Tracking and Security Monitoring System for Logistics Companies

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Abstract: This study presents a real-time system for monitoring the security of commercial vehicles. Embedded in the security monitoring system is a commercial vehicle tracking and incident detection algorithm which relies on a combination of vehicle telemetry data obtained from Global Positioning Systems and on-board sensors to continuously monitor the route choice and overall security condition of the concerned vehicle. The performance of this algorithm has been tested in a microscopic simulation model, on a set of hypothetical scenarios which included deviations from the approved routes, forced to travel at unreasonably low speeds, or even stopped at unexpected places in the network. The initial results indicate that the proposed system has good potential in detecting abnormal driving behaviors with a high detection rate and quick mean detection time.

Key words: Transportation security, commercial vehicle operations, vehicle tracking

INTRODUCTION

The security of transportation systems, especially those involving vehicles that may be subjected to abuse by terrorists, has been a great concern following the tragic events that occurred on September 11, 2001. Intelligent Transportation Systems (ITS) can play an active role in enhancing the security of the transportation systems (ITS America, 2002; Yang and Yan, 2010; Dan and Claudel, 2013).

Hazardous materials, such as radioactive substances, explosive chemicals and bioactive agents, may be possessed by terrorists while being transported by commercial vehicles and used as weapons of mass destruction. This would lead to severe social and economic consequences if occurred in an urban area. Commercial vehicles carrying sensitive and valuable goods should also be tracked continuously on the road network against potential criminal acts.

One way of improving the security of commercial vehicle operations is to monitor their movements in real-time. With many operators having large vehicle fleet it becomes impractical for a company's traffic manager to manually check the movements of many vehicles on a map display. The automated tracking and checking of a vehicle's route adherence (along the predetermined and approved routes) and expected speed or travel time is helpful in identifying and locating any incident that may have occurred to the commercial vehicle during its trip.

The objective of this study is to introduce an en-route security monitoring system for commercial vehicles carrying hazardous, dangerous, sensitive or valuable goods. The heart of the security monitoring system is a Vehicle INCident and EN-route Tracking algorithm, or VINCENT in short. It makes use of a commercial vehicle's telemetry data, in the form of longitudinal and latitudinal positioning coordinates and instantaneous speed obtained from a Global Positioning System (GPS) receiver, as the primary input. In addition, relative speed and car-following gaps (space headways) with the vehicle ahead of it are measured by an on-board sensor and input into the algorithm. Such sensor is available in several high-end passenger car models in the commercial market, as part of the advanced collision warning system. It can be fitted to a commercial vehicle and synchronized with the GPS receiver for real-time data collection. The data processing part of the algorithm may take place on board the vehicle or in the computer server at a security monitoring center, depending on the wireless communication requirement.

VINCENT has been tested under several sets of hypothetical incident scenarios in a microscopic traffic simulation model. After this introduction, a description of the security monitoring system and VINCENT algorithm is presented. Next, the performance measures and the simulated road network are provided. This is followed by sections that illustrate the experimental scenarios and selections of algorithm parameters. The results of our simulation experiments are next presented and the performance of VINCENT is discussed. Finally, the needs and directions for future research are highlighted.

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PROPOSED SECURITY MONITORING SYSTEM

Real-time vehicle positioning systems using GPS receivers have been widely available in the market. An automatic vehicle location system, when combined with a two-way wireless communication system, enables a fleet manager to identify the current locations of the company's vehicles and to communicate with the drivers in real-time. For example, in Singapore, large-scale GPS-based automated taxi dispatching systems are currently employed by the taxi companies to handle taxi bookings. Each of these systems has a fleet size of at least four thousand taxis, all equipped with GPS receivers.

It is assumed that, for a concerned commercial vehicle being tracked by our proposed security monitoring system its GPS receiver continuously output the vehicle's x-y coordinates and instantaneous speed at every time interval of Δ t. At the same time, an in-vehicle device such as a laser gun installed at the front end of the vehicle also continuously measures the relative speed and gap between the vehicle itself and the vehicle ahead of it, also at regular intervals of Δ t. Therefore, the commercial vehicle installed with such devices continuously reports the real-time positioning and car-following data. These data are fed into VINCENT to detect any possible security breach. The execution of VINCENT may take place inside the vehicle (on a microprocessor board complete with map matching function), or in the server at a security monitoring center. If VINCENT is residing in the commercial vehicle, only suspected incident alarms or security warnings are reported to the monitoring center. If VINCENT is residing in the monitoring server, all the vehicle telemetry data and car-following have to be transmitted continuously from the vehicle to the server. It should be emphasize that our complete security monitoring system consists of several hardware and software components: The central computer server, the wireless communication system, in-vehicle devices and the detection and tracking algorithm VINCENT.

Based on the aforementioned vehicle telemetry and car-following data gathered, VINCENT has been designed to operate at every Δ t interval to detect the following abnormal behaviors of a vehicle: (1) The vehicle is deviating from the original planned or approved route; (2) The current vehicle speed is lower than a user defined speed threshold (denoted by VTH1) and is not caused by the slow moving vehicle ahead of it; and (3) The vehicle is forced to stop or stopping (with a speed below a user defined threshold, VTH2) at an unexpected location.

The detection logic of VINCENT is illustrated in Fig. 1. When the GPS coordinates indicate that the commercial vehicle is deviating from the original route, a route deviation alarm will be reported immediately. When the instantaneous speed of the vehicle (VC) is lower than the speed threshold defined for normal traffic operations (VTH1), a further check is made on the relative speed and gap with the vehicle ahead. No car-following action is deemed to be taking place if the subject vehicle is traveling at a speed lower than 80% of its lead vehicle's speed or the gap is larger than 60 m and the slow speed of the commercial vehicle may be caused by its own problem. For a regular driver who is always assigned to the same vehicle its car-following patterns could be recorded for this test. When there is a car-following interaction, another speed threshold (VTH2) is used to check whether the subject vehicle is forced to stop by the lead vehicle. For this purpose VTH2 may be set to be the normal walking speed. When a commercial vehicle has effectively come to a stop, i.e., VC<VTH2, a further check was made on the vehicle position to ensure that it is not near an intersection, where it could be stopping for the red signal phase. If the vehicle's instantaneous speed is lower than VTH2 and is not within 30 m upsteam of an intersection's stop line, the vehicle could be deliberately forced to stop and an alarm should be issued by VINCENT to the security manager.

It has been mentioned that VINCENT continuously receives data and output a decision (incident or no-incident) at every Δt interval. To filter out false alarms caused by random fluctuations in traffic flow and driving behavior, a Persistence Test (PT) is used to filter VINCENT's output. To declare an incident alarm and alert the security manager, the monitoring system will wait until (1) It has received PT+1 alarms reported by VINCENT on the same commercial vehicle and (2) The time difference between the first and (PT+1)th reports is shorter than time period T_{max}.

PERFORMANCE MEASURES

To quantify the effectiveness and efficiency of the VINCENT algorithm, conventional performance measures of AID algorithms have been adopted. These are:

- **Detection rate (DR):** Defined as the ratio of the number of incident cases correctly detected by the algorithm to the total number of cases
- **False alarm rate (FAR):** Defined as the ratio of the number of false alarm cases to the total number of applications or decisions of the algorithm
- Mean time to detection (MTTD): Defined as the average time it takes to detect an incident from the time it first occurred, computed from all correctly detected cases

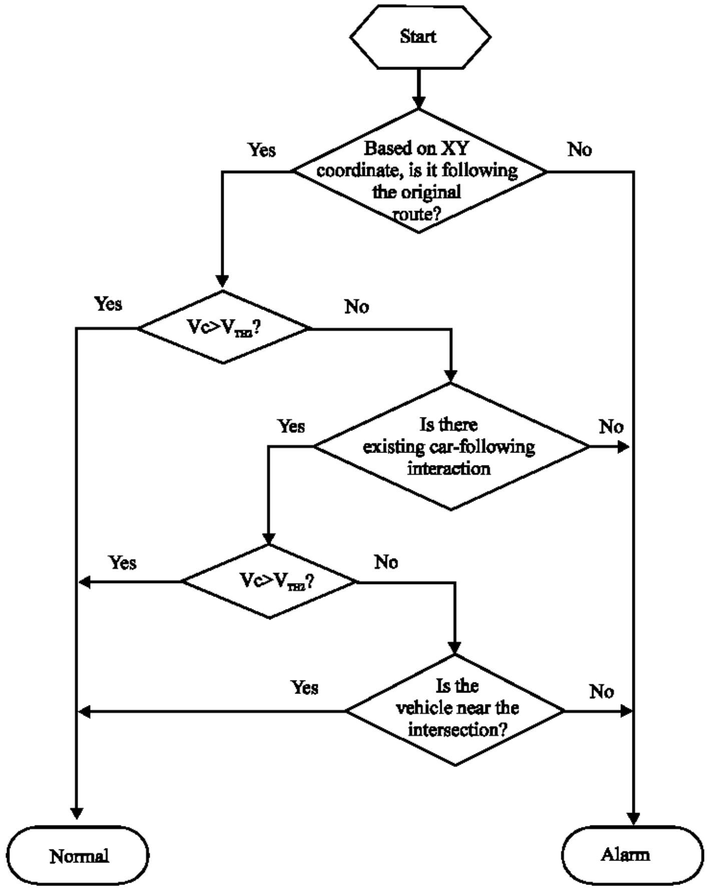

Fig. 1: VINCENT algorithm

- **Misclassification rate (MCR):** Defined as the ratio of the number of misclassified data patterns or wrong algorithm output to the total number of data patterns presented to the algorithm

A good detecting algorithm should have high DR, low FAR, low MTTD and low MCR.

SIMULATION SOFTWARE

Although not impossible it is relatively costly, time-consuming and laborious to collect an extensive set of GPS coordinates, instantaneous speed and gap simultaneously on a test vehicle, for a set of simulated route diversions and/or driving behaviors resulting from different terrorist or criminal activities. An established microscopic traffic simulation tool named PARAMICS (Quadstone, 2009) capable of modeling route diversions, speed reductions and forced stoppages of selected vehicles and output data similar to GPS receivers and car-following sensors was used to test and evaluate the VINCENT algorithm, prior to conducting field tests.

PARAMICS is a suite of customized microscopic simulation software used to model the movement and behavior of vehicles in urban and highway road networks. Its Application Programming Interface (API) allows advanced users to customize many features of the underlying model. In this research, the authors have developed an API plug-in that controls the route choice and speed of a commercial vehicle along its trip and simultaneously records its position, speed and distance from its lead vehicle at every Δt interval. The API plug-in also executes VINCENT's logic, the filtering of output by PT.

STUDY NETWORK

A portion of the Central Business District (CBD) network in Singapore which is bounded by Electronic Road Pricing gantries, covering an area of approximately 3.0 by 2.5 km has been used for the simulations.

For the network coding, the details of the geometry and physical layout of the roads were collected via field surveys. The coded details include the number of lanes,

Fig. 2: Coded CBD network of Singapore in PARAMICS

turning restrictions, speed limit and etc. The data of signal timing and phasing and Origin-Destination (OD) statistics were collected from the local transportation authority. As shown in Fig. 2, the coded network consists of 894 nodes (inclusive of 113 signalized intersections), 2,558 directional links and 100 traffic zones. The CBD network was chosen because it has the highest concentration of offices and commercial activities, making it a densely populated area during the office hours. The commercial buildings also serve as the generators for commercial vehicles which is otherwise relatively uncommon in residential areas.

EXPERIMENT SCENARIOS AND SIMULATION RESULTS

Simulation experiments were conducted for background traffic conditions with and without arterial traffic congestion. In each simulation run, a commercial vehicle was released into the network after 10 min of simulation warm-up time and tracked as it traveled across the CBD. In some of the simulation runs, the tracked vehicle was programmed to divert from its original assigned route at specified intersections in the network and/or slow down to specified speeds at certain links.

The performance of VINCENT in detecting abnormal behaviors of the tracked vehicle maneuvering through normal background traffic was first analyzed. Subsequently, performance analysis was repeated with congestion in the background traffic. Traffic congestion was artificially generated, by closing one lane in a randomly selected link between I and O, to add noise into the network so as to test the robustness of VINCENT in coping with such situation.

Table 1: Detail of the simulation runs

Incident scenarios	No. of incident locations	No. of vehicle released times	No. of runs
1	5	5	25
2	5	5	25
3	5	5	25
1 and 2	5	5	25
1 and 3	5	5	25
1 with congestion	5	5	25
2 with congestion	5	5	25
3 with congestion	5	5	25
Total			200

Table 2: Performance of VINCENT algorithm

	DR (%)	FAR (%)	MTTD (sec)	MCR (%)
Without congestion	100	0.11	6	0.95
With congestion	100	0.57	6	34.04
Total	100	0.28	6	13.36

The following commercial vehicle incident scenarios were simulated:

- The commercial vehicle was diverted from its original route against the instruction given to the driver. In the worst scenario, a rogue driver may divert his vehicle towards a sensitive target which is not along the approved route
- The commercial vehicle slowed down or stopped in the middle of its trip. In this case, there may be a mechanical problem with the vehicle, or the driver may be facing difficulty in controlling the vehicle
- The commercial vehicle, in the middle of its trip, was forced by to slow down or stop by an intercepting vehicle ahead of it. Hijacking and robbery are hence suspected

A PARAMICS API plug-in was developed to simulate the above scenarios. The logic of VERSED system was embedded into the API program.

The performance of VINCENT is evaluated with the combinations of incident and congestion scenarios listed in Table 1. For each scenario, five incident locations (diversion points, or links where the vehicle start to slow down) were randomly assigned along the trip. Furthermore, the tracked vehicle was released at five different clock times during the simulations. Hence, a total of 200 simulation runs were conducted (Table 1).

The simulation results illustrated in Table 2 show that under normal traffic conditions, the performance of VINCENT is excellent in terms of the balance in high DR, low MTTD and low MCR. VINCENT detected all the simulated incidents while keeping the FAR at 0.11% when the network has no traffic congestion. It detected the incidents with a MTTD of 6.0 sec. The MTTD is controlled by the PT, currently set to 5. The FAR and MCR increased considerably when traffic congestion existed in the network. Based on the detailed analysis of the simulation and VINCENT's output, the false alarms were induced by (1) the traffic congestion caused by the lane closures; (2) the queues near intersections and (3) other en-route traffic speed fluctuations.

SUMMARY

This study has presented a security monitoring system for commercial vehicles based on telemetry and car-following data. Based on these data acquired, an algorithm called VINCENT has been proposed to detect any route departure and unusual driving behavior. The algorithm has been tested in a set of simulated scenarios, using a microscopic traffic simulation model based on the Singapore CBD network. The results have shown that the proposed system has good potential in detecting abnormal driving behaviors.

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