A Generic and Real – Time Collision Warning and Avoidance Framework in a Ubiquitous Intersection Environment

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Abstract

The number of intersection accidents around the world has reached a plateau and has not decreased in spite of the innovation and improvement in road and vehicle safety technologies. Therefore, intersection collision warning and avoidance systems that are able to warn potential drivers of an impending collision are required. The existing systems have not utilized recent innovations in vehicular communication and sensor technology. Moreover, those systems are mainly configured only for certain intersection types. There is a need for an intersection collision warning and avoidance system that is able to predict and warn about collisions in real-time and adapt to different types of intersections. By utilizing the ubiquity of sensors and computing devices in road infrastructures and vehicles, learning from sensory data can be done and results of such learning can increase the awareness of road users of possible threats at the intersection. Therefore, the primary aim of this research is to propose a generic and real-time framework for collision warning and avoidance in intersections.

1. Background

The rate of fatalities of road intersection collisions has not significantly changed in more than two decades, regardless of improved intersection design, innovation of vehicles, and more sophisticated ITS technology [1]. Intersections are among the most hazardous sites on U.S. roads [2]. The statistic of crashes in the year 2002 in the USA reported that 50 percents of all reported crashes, approximately 3.2 million crashes, were intersection-related [1].

In order to enhance safety, road safety stakeholders around the world are joining forces to implement state-of-the-art technologies on the road and in vehicles. One of the rapidly developing technologies used in transportation systems is sensor technology. Sensors are designed and created to monitor the conditions of the vehicles, the road, and the environment in specific vicinities, such as weather information and traffic conditions. In all the currently released vehicles, there are more than one hundred sensors on board each car [3]. Table 1 lists the various sensors of each sensor type that are currently available.

Table 1. Available sensors on vehicles

Sensor Types	Sensors
Imaging sensors	camera modules, 3D range cameras, driver face and gaze trackers, road surface condition sensors
Range sensors	Infrared sensors, radar, forward collision sensor, rear collision sensor, side collision sensor
Digital maps	Global Positioning System (GPS), Geographic Information System (GIS)
Communication devices	Wireless communication, local weather broadcast
Tachometers	Speedometers, thermometers, clocks, wheel speed.
Mechanical sensors	Engine condition sensors, tire pressure sensors

There is a need for sensory data to be learnt so that useful information can be extracted and communicated to other possible affected vehicles. Therefore, we need to leverage sensory information for more intelligent decision making in ITS. We view that the ubiquity of sensors and computing devices on the road and in vehicles opens a vast opportunity for sensory data to be exploited and learnt for the purpose of enhancing intersection safety. This paper presents our novel approach to intersection safety. This paper focuses its discussion on the proposed generic and real-time intersection safety framework that is able to learn collision patterns, predict impending collisions and warn drivers of relevant vehicles. Parts of our research have been previously published in [4], [5], [6], [7]. The paper is organized as follows: Section 2 discusses our underlying motivations and objectives, Section 3 presents the proposed framework, Section 4 discusses the development of the simulation bed and the evaluation of the framework, and Section 5 concludes the paper.

2. Motivations and Objectives

Intersection collisions are multifaceted problems. The high crash rate in intersections is chiefly determined by the complexity at each intersection. Therefore, the complex nature of intersection collisions requires systems that warn drivers about possible collisions. In addition, given the uniqueness of each intersection, rather than manually fine-tuning a system for each intersection, an intelligent system for intersection safety should be able to adapt to different types of intersections automatically [4]. The complexity of intersection safety issues is mainly caused by the variety of intersection characteristics, such as intersection legs, traffic controls, permissible maneuvers and turns, can cause a different set of collision patterns. Hence, it is necessary to identify these collision patterns in each intersection so that generic warning, avoidance, and mitigation strategies can be deployed for variety of intersections. Multi-disciplinary approaches should be taken into account to develop a generic and adaptive intersection system that increases awareness of the road users.

Existing intersection collision warning and avoidance systems [8], [9], [10], [11], [12], [13], [14] mainly consist of two components: detection and warning. None of these systems have considered the enormous value of learning sensory data. The advances in computational data analysis techniques lead to the potential of extracting the vast amount of sensory data available in vehicles and on the road. The information and knowledge learnt from those sensory data are useful for both the adaptability of the system for various intersections and also the efficiency and effectiveness of the system to detect, issue warning, and avoid future collisions in real time.

Hence, there is a necessity to find the remedy of the following questions:

- How to develop an intersection safety system that can adapt to all kinds of intersection?
- How to predict collisions at road intersection in real time?
- How to warn drivers of potential collisions or hazards in real time?

Therefore, this research seeks to develop a framework that is capable of real-time collision warning and avoidance to avoid impending threats. Furthermore, it must be adaptive to different intersection types through the knowledge acquisition of intersection accidents. In brief, the main objective of this thesis is to *propose a real-time and generic context-aware framework for collision detection and warning in road intersections*.

The next section presents our proposed framework for intersection awareness and safety.

3. The U & I Aware Framework

We need to design a framework that takes into account all possible data sources in order to comprehend the situations in an intersection so that the framework can assist the road users to be aware of the threats in the intersection surroundings. This can be facilitated by having a framework that is able to learn characteristics of collisions, predict future collisions, and warn accordingly. Thus, the framework must possess collision *learning*, *detection*, and *warning* components. To facilitate this, we investigate an integration of knowledge based systems, data mining, and kinematics.

Learning of collision patterns is performed using data mining techniques. As these patterns are extracted from historical collision and near-collision events in an intersection, the collision patterns are comprehensive up to the time of learning. Hence, this approach helps to deal with the possibility of incompleteness of collision patterns and human error in manual field observation. The set of collision patterns that are localised to each intersection can be stored in the knowledge base of the intersection safety system for the basis of threat detection. A dynamic knowledge base technique for robotic collision avoidance [15] can be adapted to road collision avoidance, instead of a static knowledge base. A dynamic knowledge base involves learning to accumulate and refine rules to adapt to situational changes. Conversely, no new rules are added to a static knowledge base. Since an intersection safety system should also have the ability to adjust and adapt to any intersection vicinity, a dynamic knowledge base that keeps all the collision patterns that are only relevant to a particular intersection is needed. The dynamic knowledge base can be used as a basis for collision detection.

As the detection of imminent collisions must take place in real time, the methodology for collision detection should be simple and optimized. However, a simple collision detection algorithm involves kinematics equations to calculate point of collision and time to collision between two vehicles [14]. Therefore, in order to optimize collision detection, the number of vehicle pairs to be calculated in real time needs to be minimised to reduce the computational time. This is because calculating each possible pair of vehicles located at an intersection for a potential collision is not prudent due to time constraints. The number of possible pairs of vehicles that need to be calculated for potential collisions should be reduced. A means of filtering the vehicle pairs that have the potential of colliding with each other through the patterns in the knowledge base needs to be proposed and developed in order to reduce the number of collision detection computations. We propose that patterns can be used as preselection criteria for finding and matching a pair of vehicles. In our framework, only vehicle pairs that match particular collision patterns will be calculated for collision detection [5].

In order to avoid an imminent collision, the message structure and protocol, and avoidance mechanisms should be effective and efficient. The time available before a future collision occurs must be known and compared against the time available for avoiding the collision. The time to warn drivers of an impending collision must be lesser than the time to collision in order to avoid a collision. If there is not enough time to warn the driver, the warning message should not be sent to the driver, instead, a direct command message needs to be sent to the vehicle system. Therefore, we need to have different schemes of warning messages in order to deal with different situations [7].

Therefore, we propose the Ubiquitous Intersection Awareness (U&I Aware) Framework to achieve holistic situation recognition and real-time collision detection and warning at road intersections. Figure 1 illustrates the framework's process of learning, detection, and warning of collisions at an intersection. The U&I Aware Framework is proposed to learn from collision and near collision events using the historical collision data and also online real-time sensory data from the intersection vicinity. The results of learning that are relevant only for that particular intersection are integrated into the knowledge base of the framework; hence the knowledge base is specific to an intersection and context-aware of the situations in the intersection. The knowledge base is used as the basis for preselection, which is an algorithm to match the vehicles that pass through the intersection with the collision patterns in the knowledge base. Based on the status data of a vehicle, the preselection algorithm selects the vehicle pair combinations that have possibilities to collide and then pass the data of those vehicles to the collision detection algorithm. Each vehicle pair selected by preselection is assessed if a future collision point exists. When a point of collision is detected, then time to collision of each vehicle in the pair to the future collision point is calculated and compared. When the times to collision of both cars are almost equivalent, then a future collision is imminent. Depends on the time available to avoid collision, either warning messages are issued to drivers of the relevant vehicles or command messages are generated and sent directly to the vehicle systems. The following section presents the evaluation of the framework that is performed on a simulation bed.

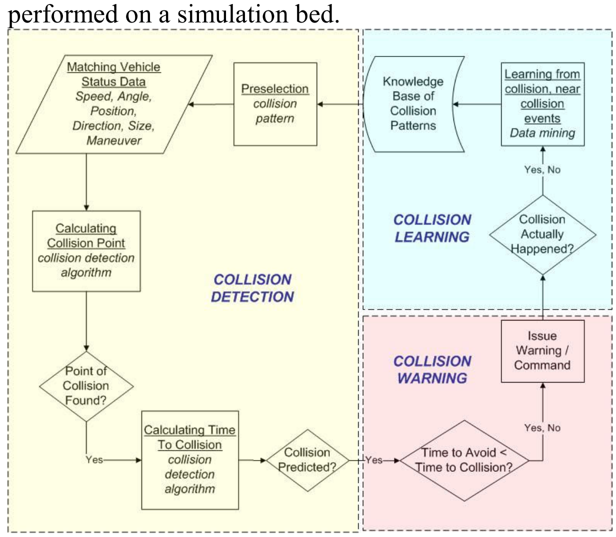

Figure 1. The U&I Aware Framework

4. Evaluation

This research is implemented and evaluated on a computer based simulation where the road and vehicle sensors used in the implementation are simulated (Figure 2), because the resources and license to do such extensive experimentation in the real world is not feasible within the scope of the project.

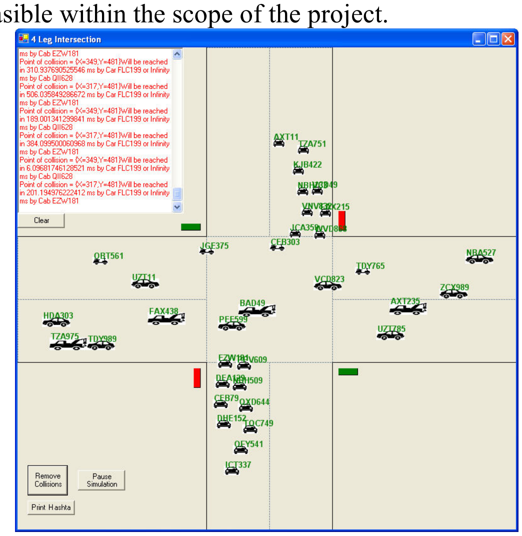

Figure 2. Intersection Simulation

In order to simulate the collision and traffic data, we use the simulation to generate vehicles and traffic movements that eventually lead to collisions. The collision and traffic data are learnt by applying classification and clustering mining techniques [4]. The collision patterns, the results of the data mining, are stored in the system's knowledge base. This knowledge base contains patterns that are specific to the intersection, where learning is performed. The knowledge base is used as the basis of our pattern matching method, namely *preselection* algorithm [5], so that collision detection is only performed on pairs of cars that have the possibility of collisions based on the known intersection collision patterns. Preselection is implemented by choosing only the vehicles that exhibits behaviours, location, and driving manoeuvres that match the collision patterns in the knowledge base. Therefore, performance is improved by not needing to check every pair of cars at the intersection for possible collision [5]. We evaluate our approach using the following methods [6]:

1) Speed of detection,

2) Performance/accuracy: precision and coverage.

The speed of the detection is evaluated by calculating the average of time to collision in the first prediction of a future collision event. Preselection improves the speed of collision detection, as shown in Figure 3. As the number of vehicles in the vicinity increases, preselection is found to be more efficient. The accuracy of collision detection is evaluated using precision and coverage measurements. Real-time side collision detection can be achieved with 100% precision and 100% coverage. When such system is adapted to different intersection types, the same approach can be deployed; however, there can be different collision detection algorithm that must be applied for other types of collisions that are not covered in this paper. The message protocol and warning model of the U&I Aware Framework are presented in [7].

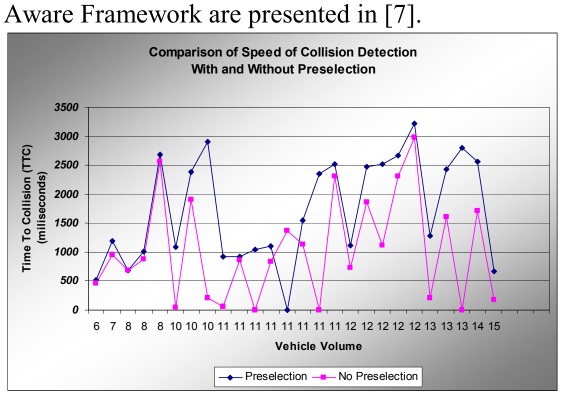

Figure 3. Evaluation of Preselection Algorithm

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