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A probabilistic approach for collision avoidance of uncertain moving objects within black zones

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ABSTRACT

This work addresses the problem of collision avoidance for vehicles in black zones where the risk of accidents increases. Vehicles have an inherent uncertainty of location because the exact position of a moving object is known, with certainty, only at the time of an update on position information. This paper proposes a collision prediction model and a monitoring algorithm for collision avoidance within black zones by considering the location uncertainty of moving vehicles. It formalizes the impact of trajectories of moving vehicles on probabilistic collision prediction. The proposed approach provides approximate answers to the user at the user's required level of accuracy while achieving near-optimal communication and computational costs. Finally, extensive experiments were conducted to show the efficiency and efficacy of the proposed approach.

1. Introduction

Collision avoidance is one of the most critical concerns in traffic safety, and it is becoming increasingly important as traffic volume increases. Recently, with changes in social needs and automotive technology, autonomous driving has become an important concern. Collision avoidance has been becoming a significant component in the current autonomous driving research to ensure driving safety. According to traffic accident statistics from the Korean Road Traffic Authority, approximately 75% of fatal traffic accidents in Korea between 2000 and 2013 resulted from collisions among vehicles [33–38]. In particular, depending on the country and region, 30%–60% of all crashes causing injuries or fatalities worldwide occur in black zones [5,11], which refer to places in which the risk of accidents is elevated. Intersections and curves are typical examples of black zones. Therefore, a number of solutions have been proposed to mitigate or avoid collisions [39–42].

Collision avoidance systems provide a service based on the locations of moving objects; therefore, the accuracy of the location information has a direct influence on the service quality of the system. The key factor of system quality is to know the exact present position of a vehicle, and to predict its future position accurately by monitoring the movement of a vehicle for collision avoidance.

Positioning systems utilizing technology such as a GPS device in a vehicle and roadside sensors can provide location samples only at discrete time instants. Thus, the location of a moving object is never definite between two consecutive samples. Because a vehicle moves continuously, the moving information such as position, velocity, and direction of a vehicle changes constantly. Typically, the exact location of a moving object is known only at the time of the position information update. The location uncertainty increases with longer update intervals. The degree of location uncertainty depends on sampling rates and measurement errors such as device failure or the inaccuracy of devices [19,23,32]. The assumption on which many proposed methods for collision avoidance are based is that the position data of moving objects are precise points. A few methods have considered the inaccuracy in the position data of moving objects [1,22,28]. However, little attention has been given to handling uncertain moving objects for collision avoidance.

Assume that a moving vehicle travelling at a speed of 72 km/h updates its location information once per 0.1 s. Then, the next update point is approximately 2 m away from the object location at its current time. The location between the two sampled positions is the line segment between them, which is referred to as an interpolation. However, an interpolation cannot reflect the exact movement pattern of an object. It is not easy to identify the exact

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position of a moving vehicle at a time instant because the travelling speed is usually not constant [34].

A solution to the problem highlighted above is that the report dissemination scheme enables a server and other objects within their vicinity to track the movement of objects. If a moving object disseminates a report at every timestamp, its movement can be monitored continuously. However, this simple method is unacceptable because wireless bandwidth availability is typically limited in a mobile environment [15]. In particular, in the case of a high-density intersection with traffic congestion, resource consumption such as computational cost or network bandwidth, which enables communication between a server and vehicles in the black zone at the same time, must be minimized.

Therefore, this paper introduces to vehicular ad hoc networks a novel type of query called a Fixed Range Collision Candidates (FRCC) query over moving objects such as vehicles and devices of pedestrians. The FRCC query provides a vehicle with the locations of vehicles as collision candidates within a certain range such as the black zone. In terms of FRCC queries in distributed server-centric environments, this paper introduces a collision prediction model considering the location uncertainty of vehicles in a black zone to increase the accuracy of collision risk detection. The collision prediction model within a black zone utilizes the graphs of the minimum vector difference between a query issuer (as a target vehicle) and other vehicles and provides a probability density function (pdf) for collision between moving vehicles at a given time instant. It is very important for transportation safety that true warnings are not missed, because collisions are life-threatening events. Conversely, it is necessary to minimize false warnings to maintain the reliability of collision prediction systems [2]. Therefore, the server first asks a query issuer to offer a desired accuracy level for approximate answers. This work, through simulations, attempts to determine the approximate answer at the optimal accuracy level to minimize false warnings. Therefore, the paper proposes a probabilistic algorithm, namely, MOCA, MOnitoring algorithm for Collisions Avoidance, between moving vehicles within a black zone, which reduces the computational cost of a server and the communication cost between a server and vehicles and uses the limited network bandwidth effectively.

The primary contributions of this paper are summarized as follows:

- This paper introduces the novel type of query, called FRCC queries.
- This paper proposes a probabilistic algorithm, called MOCA, for processing FRCC queries to predict collision considering location uncertainty of moving objects in black zones.
- This paper presents the graphs of the minimum vector difference between moving vehicles and a probability density function for collision between moving vehicles.
- A series of simulations are conducted to demonstrate that MOCA markedly outperforms a conventional solution in terms of network bandwidth and computational consumption.

The remainder of this paper is organized as follows: Section 2 discusses related work, Section 3 presents background information relevant to this study, Section 4 details the proposed approach for collision avoidance, Section 5 presents simulation results obtained under various conditions, and Section 6 concludes this paper.

2. Related work

2.1. Collision avoidance system

In recent years, significant research and development activities have been performed to avoid collisions [10,12,16,17,40,42]. There are two primary system architectures for collision avoidance in mobile environments: a centralized approach based on vehicle-to-infrastructure (V2I) communication and a decentralized approach based on vehicle-to-vehicle (V2V) communication. Compared to a decentralized approach in which each vehicle mainly handles local information, a centralized approach requires one server that fulfills the task for the whole group.

V2V and V2I communications are the basis for sharing information about the environment and improving overall situational awareness by having moving objects such as vehicles cooperate with each other and with the nearby infrastructure [12]. Connected Vehicles, USA project for providing connectivity between and among vehicles, infrastructure, and wireless devices, [39] reports V2I communications have the potential to resolve an additional 12 percent of crash types not addressed under V2V communications. SAFESPOT [42], the European research project, identified two classes of implementation steps depending on the level of intelligence required on the vehicle. The first is based on V2I communication with applications mainly running on the infrastructure side. These applications may represent a first step of the future exploitation and aim to cover static and dynamic black zones in which a RSU (Road-Side Unit) is located. It is very important to predict and avoid collisions in black zones to improve the overall safety of road networks. The second involves V2V based applications, which aim to cover dynamic areas potentially occurring in any location and require a higher level of intelligence on the vehicle.

When a vehicle predicts collisions within a black zone, it has one to many relationships with other vehicles. By evaluating information independently, the objects also assess the situation independently and make separate decisions on whether the situation is critical or not [4], and different judgments cause traffic congestion and conflicts. To resolve these problems, a supervisory role that manages the overall situation of a black zone is necessary. Therefore, this study uses a centralized approach to solve priority and information conflicts for improving safety.

The Intelligent Cooperative Intersection Safety system (IRIS) [27,42], a part of the European research project SAFESPOT, is a roadside application that aims to minimize the number of accidents at intersections. IRIS uses vehicle-to-infrastructure communication to track and analyze the movements of all individual vehicles. Many proposed collision-predicting methods assume that position data of moving vehicles are precise, and the future positions of vehicles are predicted based on periodically updated information such as position and velocity at every time instant (e.g., 0.1 s). However, these approaches can cause undesirable consequences such as missing a true warning and poor response times [31]. In addition, in real traffic scenarios, thousands of vehicles operate in the same district at the same time. It is unlikely for a server to fulfill the task of cooperative localization owing to limited computational resources as well as limited network bandwidth. This study addresses this issue by proposing a method that achieves minimal use of wireless network bandwidth and optimal computational cost while not missing true warnings.

2.2. Location-based query processing

The method of modeling the future locations of a moving object is introduced through the concept of dynamic attributes [22]. The database location of the moving object is modeled with the start time, start location, and velocity of the object. In this paper, the dynamic attributes are chosen to predict the future locations of a vehicle.

Uncertain data management of moving vehicles has been extensively researched in the context of moving object databases (MOD)

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