UNIVERSITY OF ILLINOIS
URBANA-CHAMPAIGN

ECE445

SENIOR LABORATORY DESIGN

V2V Based Network Cooperative Control System

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Contents

1 Introduction

1.1 Problem: Safety and Efficiency at Urban Intersections

Intersections pose a significant risk to transportation safety, as they account for a vast majority of severe urban traffic accidents. For example, about 43all crashes in the United States occur at or near an intersection [1], about 40% of all casualty crashes in Norway occur at junctions, about 33% of crashes in Singapore. Moreover, these numbers kept increasing over the years[3].

A few major factors influencing accidents at intersections have been unearthed, such as intersection approach conditions, signal timing , curvature etc. In our project, we mainly focus on the intersection approach conditions. Vehicles passing intersection often do not have perception to the traffic condition on other lanes due to lack of attention and visual blocks such as buildings, bridge piles, passing-by vehicles and even pillar blind spots. It would be very helpful if a vehicle can get a holistic view of the intersection conditions for crash avoidance.

Additionally, today, most of the urban intersections are under passive control mechanisms such stop signs, yield signs and traffic lights. For example, even with light or no traffic, stop signs require vehicle to fully decelerate and accelerate and passive traffic lights leads to meaningless idle running engines. According to a very conservative calculation performed by Victor Miller at Stanford University[2], unnecessary traffic stops in the United States can account for 1.2 billion gallon consumption per year, which can satisfy an average American to fill up a 15 gallon tank every other week. Such passive intersection control mechanisms have lead to significant amount of energy waste and call for adaptive control mechanisms.

1.2 Solution

To address the safety and efficiency issues at urban intersections, we propose to use V2V communication technology. V2V communication can help enlarge the perception field of one single vehicle, allowing it to intelligently understand the intersection's traffic condition and make decisions accordingly.

Our proposed system consists of several subsystems:

1. All vehicles equipped with V2V communication technology will be able to share their current state, including location, velocity, acceleration, and heading, with each other in real-time. This will enable each vehicle to have a holistic view of the intersection's traffic condition and make informed decisions to avoid potential accidents.

2. Computer vision and radar technology will be used to recognize and track approaching vehicles and other road users (pedestrians, motorcyclists, etc.) at the intersection. This subsystem will detect the presence and direction of the vehicles and send this information to the V2V communication subsystem. Besides, this subsystem also use the data from the V2V communication and intersection approach recognition subsystems to control the flow of vehicles through the intersection.

3. The avoidance algorithm running on the server will analyze the data received from the V2V communication and intersection approach recognition subsystems and make decisions on the best course of action to avoid potential collisions. The server will take into account factors such as vehicle velocity, distance, and direction of travel to ensure safe and efficient vehicle movements at the intersection.

We plan to implement the proposed system in two phases. In phase one, we will focus on the collision avoidance algorithm and the V2V communication subsystem. We will use simulation software to test and optimize the algorithms' performance. In phase two, we will integrate the intersection approach recognition and adaptive intersection control mechanism subsystems into the system and perform real-world testing.

1.3 Visual Aid

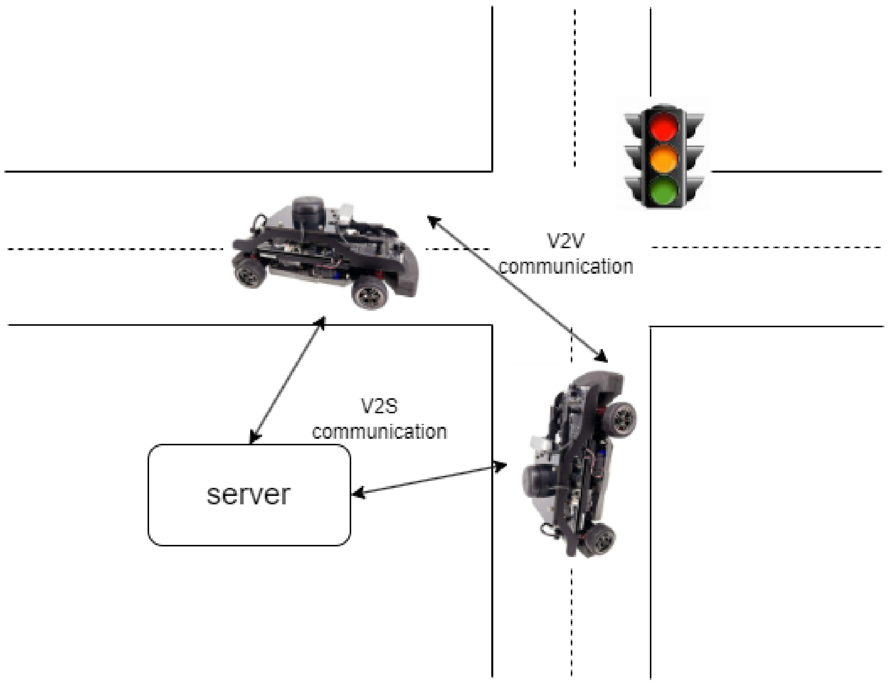

Figure 1: Visual Aid

1.4 High-level requirements

To ensure that our proposed solution is effective and efficient, we have established the following high-level requirements:

1. **Collision avoidance algorithm**: The system must achieve a minimum of 95% success rate in simulating collision avoidance at intersections.

2. **Object detection algorithm**: The vision-based object detection system must achieve a minimum of 90vehicles and pedestrians at intersections.

3. **Energy efficiency**: The overall energy consumption of the system must be lower than the energy consumption required by traditional traffic control mechanisms, such as traffic lights and stop signs.

By meeting these high-level requirements, we can ensure that our proposed solution addresses the safety and efficiency challenges at urban intersections effectively and sustainably.

2 Design

2.1 Block Diagram

The Block Diagram of our design is shown in Figure 2

2.2 Subsystem overview

V2V/V2S Communication. We select the Qcar as our experiment vehicle, which adopts the ROS2 as the communication protocol. The Robot Operating System (ROS) is a distributed communication mechanism built on TCP/UDP, and it process communication at the granularity of process. In the ROS communication framework, every process is regarded as a *node*, and messages are passed via logic channels called *topic*s. When a node release a topic, all other nodes subscribe to him will receive that topic. Besides, the protocol of ROS also has its own data format that can characterise the status of the vehicle, including speed, poses, trajectory, and the point cloud module. Therefore, ROS satisfies our requirement for both vehicle-vehicle and vehicle-server communication.

Sensing and Control of the Vehicle. Quanser vehicle contains a 360 camera and an on-vehicle GPU. We can run multiple objects tracking (MOT) algorithm on the vehicle to detect other vehicles. Also, the radar on the vehicle will help generate a point cloud model and position vehicles in the intersection more precisely. After detecting vehicles, our vehicle will control its motor and steering wheel to avoid collision and send the result of recognition algorithm to other connected vehicles (or server).

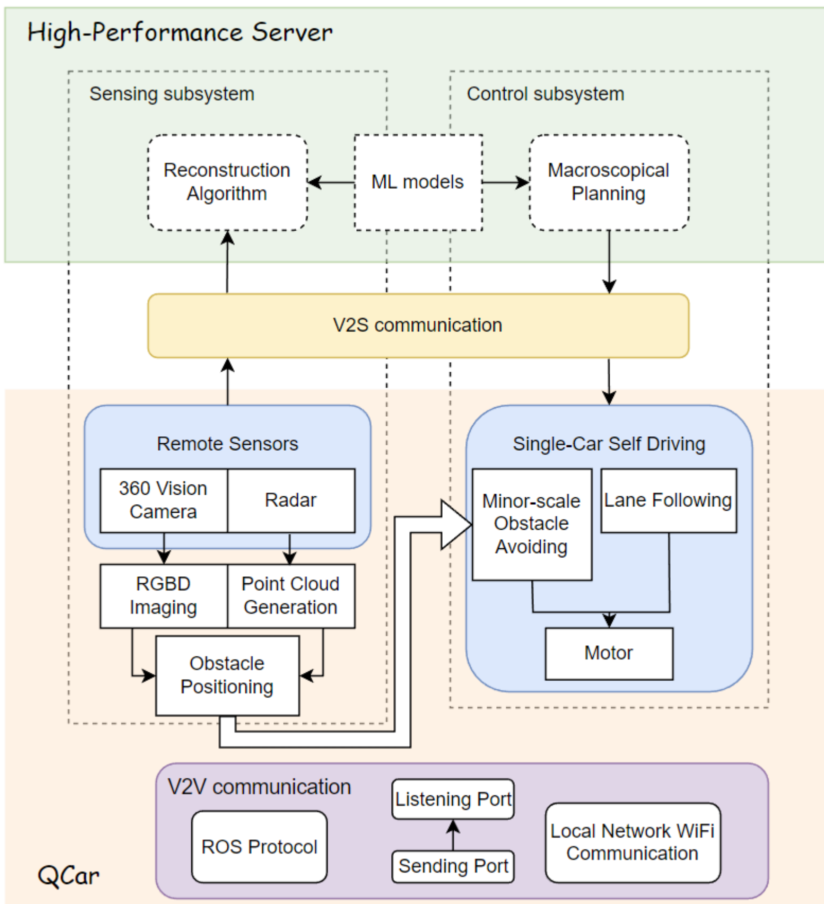

Figure 2: Block Diagram

High-Performance Server. In our autonomous driving system, a server is responsible for managing and processing large amounts of data that are generated by the various sensors and components of the system. The server receives and processes data from various sources, including GPS, LiDAR, radar, cameras, and other sensors that are used to gather information about the vehicle's surroundings. This data is used to build a 3D map of the environment and to identify objects such as other vehicles, pedestrians, and obstacles. The server also uses machine learning algorithms and artificial intelligence to analyze and interpret the data and to make decisions about how the vehicle should respond. For example, the server might determine that the vehicle needs to slow down or change lanes to avoid a potential collision. Overall, the server plays a critical role in the operation of an autonomous driving system by managing and processing the vast amounts of data that are required for safe and efficient operation.

2.3 Subsystem requirement

2.3.1 V2V/V2S Communication

Firstly, a robust ROS communication system is supposed to be built. With vast libraries built on ROS1, we need to support the communication of mixed ROS1 and ROS2 nodes to support full functionality of the ROS protocol. Specifically, we should build a ROS1-bridge inside each vehicle and server to put the data from ROS1 to ROS2 packages. In addition, The ROS protocol requires that all nodes, i.e. vehicles and servers, stay in the same wifi network, so we must configure them in a local area network as well.

Secondly, the ROS protocol itself makes no assumption about the latency, but high latency may cause fatal problem since messages passing through affects the decision and control of the vehicles. Therefore, we need to set an upper bound of the latency to guarantee the security. We will discard packets whose arrival time exceeds the bound, and set a policy to ensure most of packets to arrive on time by setting priorities.

2.3.2 Sensing and Control of the Vehicle

The sensing system should be able to precisely detect the position, velocity and acceleration of other vehicles. By analyzing the image stream and radar signal, we can know the relative position of the obstacles around. Then the information of other vehicles can be inferred by the data collected from the sensors. The information of position, velocity, acceleration should be accurate enough to avoid possible collision.

The information of vehicles will be sent to server and the server will help deciding which vehicle to move on and which one to stop. Also, the control system of Quanser vehicle should be able to predict the track of other vehicles in the intersection. Then it controls the velocity to avoid driving into the range of collision.

2.3.3 High-Performance Server

We divide our server to several critical parts. First, the image module processes the camera data from vehicles and performs image reconstruction in 3D space or point cloud space. Second, the trajectory planning module processes the obstacle data and performs microscopical trajectory planning (in comparison of micro trajectory planning by a vehicle itself).

When the server is in use, the data transmission and server reliability should be stable. The algorithms running on the server should be efficient. The reconstructed image should be clear enough and is eligible for further processing. The server should be able to be manually switched to down mode to test other parts, such as individual driving and V2V communication. Lastly, if any visualization is achieved in the server, it should be comfort to view for the best human-computer interaction.

2.4 Tolerance Analysis

When the server is down, individual vehicles should have some basic abilities to ensure safe operation until the server is restored. Here are some of the key abilities that individual vehicles should have:

1. **Basic navigation and control**: The accuracy of GPS position, velocity and acceleration will affect the decision made by control system on Quanser vehicle. The decision should be more conservative if accuracy is low. Individual vehicles should be able to navigate using pre-existing maps and GPS data, and maintain control over their velocity, direction, and braking.

2. **Object detection**: If the MOT algorithm is not accurate enough, we will mostly rely on the radar. Then we need to design an efficient algorithm to separate each vehicle clearly on the point cloud model.

3. **Collision avoidance**: Vehicles should be able to use their sensors and machine learning algorithms to avoid collisions with other vehicles or obstacles. When vehicle is disconnected from all the other vehicles and server, it should drive conservatively and break when it detect possible collision by itself at least.

4. **Emergency response**: Vehicles should be able to detect when an emergency situation has occurred, such as a sudden obstacle in the road, and respond appropriately, such as by stopping the vehicle or swerving to avoid the obstacle.

5. **Communication**: When the server is down, individual vehicles should have the ability to communicate with each other, so that they can coordinate their movements and avoid collisions. As to the communication latency mentioned in 2.3.1, we set the latency upper bound as 20ms for collision avoidance related packets, and 100ms for other V2V/V2S communications.

Fortunately, the Qcar itself is powerful and can handle most of the issues above. Our V2V communication protocol and mechanism will enable more effectiveness of self-driving.

3 Ethics and Safety

Ethics and safety are crucial aspects of any new technology, especially those involving autonomous or semi-autonomous systems. Below are some key points to consider:

- **Privacy**: The use of V2V technology raises concerns about privacy, as it involves the exchange of sensitive information between vehicles. It is important to ensure that personal information is properly protected and that the data is only used for the intended purpose.

- **Bias and discrimination**: As with any technology, there is a risk of bias and discrimination in the development and deployment of V2V systems. It is important to ensure that the algorithms and systems are designed to be fair and equitable, and that they do not perpetuate or exacerbate existing inequalities.

- **Accountability and liability**: With the introduction of V2V technology, there may be questions about who is responsible in the event of an accident or malfunction. It is important to establish clear lines of accountability and liability, and to ensure that there are mechanisms in place for addressing any issues that may arise.

- **User trust and acceptance**: For V2V technology to be successful, it is important that users trust and accept the system. This requires clear communication about how the technology works, what data is being collected and how it is being used, and what the benefits and risks are. It is also important to involve users in the design and testing of the system to ensure that their needs and concerns are taken into account.

- **Regulatory compliance**: V2V technology will be subject to various regulations and standards, both at the national and international level. It is important to ensure that the technology is developed and deployed in compliance with these regulations, and that there is ongoing monitoring and evaluation to ensure that the system continues to meet these standards.

References

[1] Dominique Lord, Ida van Schalkwyk, Susan Chrysler, and Loren Staplin. A strategy to reduce older driver injuries at intersections using more accommodating roundabout design practices. *Accident Analysis Prevention*, 39(3):427–432, 2007.

[2] Victor Miller. The impact of stopping on fuel consumption. `http://large.stanford.edu/courses/2011/ph240/miller1/`, 2011.

[3] Richard Tay and Shakil Rifaat. Factors contributing to the severity of intersection crashes. *Journal of Advanced Transportation*, 41:245 – 265, 06 2007.