Vehicle Positioning System using V2X that Combines V2V and V2I Communications

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Abstract. In this paper, we present a V2X (Vehicle to Everything) vehicle positioning system environment using V2V (Vehicle to Vehicle) and V2I (Vehicle to Infrastructure) communication server. With the growth of the 5G network technology, using V2X which exchanges information, connected car recently became an important area of research in autonomous driving. However, it takes too much risk to test autonomous driving in a real-world experiment and it also have difficulties such as road infrastructure or 5G communication system. Regarding autonomous driving research, we established V2X environment in a small RC car, similar to a vehicle environment. Our proposed Vehicle Positioning System environment uses a ceiling camera, V2V, and main server, V2I, which plays the same role as GPS and 5G in the real-world. Combining the V2I and V2V from the camera of each other car using Kalman Filter we present a vehicle positioning system.

1. Introduction

Recently, autonomous driving technology is rapidly being studied[1][2][4][6]. Its most important criteria in this technology is safety and support. Typical autonomous driving techniques such as sensor-based ADASs (Advanced Driver Assistance Systems) and connection-based V2X (Vehicle to Everything) are emerging as key technologies in autonomous driving system. The ADAS is equipped with state-of-the-art sensors such as cameras, radar, LiDAR (Light Detection and Ranging) and ultrasonic which indicates the risk of accidents during driving or parking [3][4]. However, ADAS sensors provide a short detection range and limited detection of situations behind obstacles and their constraints which can only be used within non blind spot area. This limitation can be covered with V2X system, which tells that key technology for autonomous driving, in particular, is the V2X system [5][6].

The V2X also supports autonomous driving in combination with "precision measurement technology," that measures the location of cars more precisely and informing the drivers and cars. This not only allows autonomous driving cars to reduce unexpected traffic accidents in unexpected situations that people or sensors cannot recognize, but also reduces car gas emissions by easing the traffic jam. As shown in Figure 1, V2X consists of V2V (Vehicle to Vehicle), V2I (Vehicle to Infrastructure), and V2P (Vehicle to Pedestrian) system, etc. V2X system means communication with the vehicle and all 'X' and the V2X system is a technology that can improve driving stability and
convenience using the different infrastructure [7][8]. Therefore, V2X system prevents traffic accidents by knowing vehicle and pedestrian information.

![Figure 1. Types of V2X communication](image)

V2V refers to a technology that transmits and receives information wirelessly between vehicles. Information can be exchanged between vehicles to prevent sudden accidents by exchanging location and speed information [9]. V2I refers to the technology that sends and receives information wirelessly between vehicles and road infrastructure. This refers to a technology that collects driving information from vehicles by installing base stations around roads and provides traffic information to vehicles by analysing it from a central server [10]. Through this process, traffic congestion or traffic accidents can be prevented in advance. Therefore, The V2X system, which communicates with road infrastructure and other vehicles while driving, will allow for more efficient autonomous driving.

However, autonomous driving tests using real vehicles can lead to dangerous accidents if an accident occurs due to an algorithm error or sensor error during autonomous driving. Therefore, we constructed a V2X environment using V2V and V2I system for small RC car-type experimental environment. In addition, Vehicle Positioning System was tested on the vehicle after setting up the V2X System environment using Kalman Filter. Section 2 indicates the configuration of the Vehicle Positioning System by the V2X system. Since the system was then configured, Section 3 is shown for the experiment. Section 4 consists of a conclusion.

2. Vehicle Positioning V2X System

![Figure 2. V2X System configuration](image)
This chapter explains how V2V systems and V2I systems are configured, uses the data obtained from V2V and V2I systems, and explains the Vehicle Positioning V2X System using Kalman Filter from the system model on Newton's Law. We used Kalman Filter to use vehicle information from V2X for the system model. In [11][12][13], Kalman Filter are used to predict the trajectory of objects moving in 3D, 2D coordinates. Kalman Filter requires a kinematic model that may be inaccurate due to assumptions such as constant velocity or acceleration models and does not take into account factors such as wind resistance that will affect the model. The Kalman Filter also uses a measurement model that requires measurement data for the position, speed and acceleration of the vehicle to be measured using the camera.

Figure 2 shows the overall configuration of our proposed V2X system. The V2I system locates RC cars through four cameras and the central server receives the location information of the vehicle from the V2I system. The V2V system interacts with the central server, sharing the information from the vehicle's camera. Raspberry Pi is used in RC car to communicates information with the Central server through TCP/IP communication. The vehicle's location information from the V2I system and V2V system on the central server is noisy, making it difficult to pinpoint the exact location. Therefore, Kalman Filter is used in the V2X system to measure the location of the vehicle using the information received from the two systems.

2.1. V2V System

![V2V System configuration](image)

Figure 3. V2V System configuration

\[ d = h \tan \theta \]  

(1)

In this paper, V2V system includes camera sensors which provide multiple RGB data and helps predicting distances from obstacles. Camera is placed in front of the RC car, as shown in Figure 3. The distance can be predicted as shown in equation (1) for the front vehicle recognized by the camera. In other words, the V2V system communicates information between vehicles, so location and distance information can be known. However, the V2V system should incorporate the V2I system because it can predict the distance to a single-vehicle but does not know the exact information about a number of obstacle vehicles.

2.2. V2I System

The V2I system has difficulty to experiment with real vehicles. So, we did an experiment in RC car environment. Four cameras were installed on the ceiling to create an environment where RC car location information can be received like actual GPS information. Therefore, the central server can know the location of the vehicle. In addition, the central server can check the speed and direction of the vehicle through TCP/IP communication with the RC Car. Central server can provide autonomous driving path information to other vehicles with information from integrated vehicles.
2.3. Vehicle positioning using Kalman Filter

Central server has information received from the V2V system and provides location information for other vehicles. Information on vehicles appearing suddenly or disappearing can be transmitted to vehicles via the central server. After integrating V2I system and V2V system information, vehicle positioning will be able to accurately locate using Kalman Filter using a system model based on Newton's Law. Before using Kalman Filter to track an object, it needs to model the movement of this object. Although, the movement cannot be modelled accurately, it can have an approximation model of it. Assuming that the motion on the x-axis and y-axis and angular rotation around z-axis are uncorrelated. Measuring the position of the RC car every $\Delta T$ seconds, the system equation can be expressed as below formula based on Newton’s Law. We can express the system in state equation as the follows \[14\]:

\[
\begin{align*}
X(k+1) &= FX(k) + Gu(k) + w \\
Z(k+1) &= HX(k+1) + v
\end{align*}
\]

where,
\[
X = \begin{bmatrix}
x(k) \\
y(k) \\
\theta(k) \\
V_x(k) \\
V_y(k) \\
\omega(k)
\end{bmatrix}^{T}
\]
and \[
u = \begin{bmatrix}
a_x(k) \\
a_y(k) \\
\alpha(k)
\end{bmatrix}^{T},
\]
\[
F = \begin{bmatrix}
1 & 0 & 0 & \Delta T & 0 & 0 \\
0 & 1 & 0 & 0 & \Delta T & 0 \\
0 & 0 & 1 & 0 & 0 & \Delta T \\
0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0
\end{bmatrix},
\]
\[
G = \begin{bmatrix}
\frac{\Delta T^2}{2} & 0 & 0 \\
0 & \frac{\Delta T^2}{2} & 0 \\
0 & 0 & \frac{\Delta T^2}{2} \\
\Delta T & 0 & 0 \\
0 & \Delta T & 0 \\
0 & 0 & \Delta T
\end{bmatrix},
\]
\[
H = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0
\end{bmatrix},
\]
where, \(x, y\) are position of the car, \(\theta\) represent the angle, \(V_x, V_y\) are velocity of the car, and \(\omega\) is angular velocity. \(a_x, a_y\) are acceleration, \(\alpha\) is angular acceleration, and \(w, v\) are measurement noise.

3. Experiment

As shown in Figure 4., the experimental platform for RC car 1 and 2. Experimental RC cars were built using STM32F407 board, Raspberry Pi and RGB cameras (Microsoft HD-3000). The V2V System observes RC car 2 through the camera of RC car 1 and measures the distance from RC car 2 as shown in Figure 5.
Figure 6 shows a V2I system that measures location information for RC car1 and 2. The V2V system connected four cameras to create a 640cm*480cm map and use four cameras to calibrate the camera and measure the location of RC car 1 and 2. Also, Figure 7 shows the distance over time to RC car 1 and 2. Similarly, Measurement2 shows the positioning results for the V2V. The results show that there is a lot of noise. Using the Kalman Filter based on two result values, the filtering values can be viewed as red lines and comes out more perfectly without any noise.

Figure 6. V2I Communication  
Figure 7. Vehicle Positioning results

4. Conclusions
In this paper, we proposed autonomous driving technology. Our method shows robustness in positioning. Especially, the V2X environment was constructed in RC car environment where the environment was similar to the real vehicle, and the results confirmed that the V2X environment looked for more accurate location information. There were many limitations to experiment with real vehicles in the current V2X environment such as estimating vehicle position information only by V2V system and locating vehicle by the V2I system alone. This is because autonomous driving tests using real vehicles can cause dangerous accidents if an accident occurs due to an algorithm error or sensor error during autonomous driving. So, we had difficulty experimenting with real vehicles. Since we have built the V2X environment so far, we will conduct experiments in the V2X environment in which we have built the Path Planning related research that no more can be applied to actual vehicles. So, if we continue to do research on V2X systems, we hope to have a tremendous impact on automatic driving technology in the future.

5. References
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