Vehicle-to-Vehicle Message Sender Identification for Co-operative Driver Assistance Systems

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***Abstract*—A growing number of vehicles are equipped with Vehicle-to-vehicle (V2V) communication modules (*e.g.,* Dedicated Short Range Communications) that allow them to exchange messages over the network. The V2V communication is expected to improve the road safety by overcoming limitation of conventional Advanced Driver Assistance Systems (ADASs). For a safe feature using V2V communication-based applications, it is essential to identify sender vehicles since V2V communication is typically implemented using a broadcast mechanism. Especially here, our focus is to correctly determine whether the preceding vehicle is the sender of the received message or not in order to realize cooperative driving such as platooning. Vehicle location information obtained by an onboard GPS module is typically used for the identification. However, the GPS module often provides wrong location information due to the limited accuracy in a certain environment such as an urban road surrounded by tall buildings. To prevent this GPS error from causing misidentifications, we propose a novel method which additionally uses shared ranging sensor data and behavioral control of the ego vehicle. Simulation result shows that our proposed method successfully reduces the number of misidentifications by 64 % compared with a method which fully depends on GPS information.**

***Index Terms*—V2V Communication, ADAS, Autonomous Driving, Sender Identification, GPS, Sensor Fusion, Simulation**

I. Introduction

A growing number of vehicles are equipped with Vehicle-to-vehicle (V2V) communication modules (*e.g.,* Dedicated Short Range Communications) [1] that allow them to exchange messages over the network. Such V2V communication is expected to improve the road safety by overcoming limitation of conventional Advanced Driver Assistance Systems (ADASs). Traditional ADASs fully rely on onboard ranging sensor data. By using radars, cameras, lidars or combinations of those sensors, systems observe other vehicles' behaviors (*e.g.,* acceleration, deceleration, turning, *etc.*). Then, systems predict intentions of those behaviors and respond to them. The accuracy of the prediction is important for their performance, but it is sometime very difficult to improve it due to limited information. In contrast, if systems can access internal status data of other vehicles via V2V communications, such as the target speed of the cruise control system, activation of the automatic emergency braking system and the steering angle, those concrete information can be of great help for the accurate prediction. Moreover, if systems can share onboard sensor data, vehicles are able to know what is happening on the outside of detection ranges of onboard sensors [2]. Platooning [3] or sensor network are advanced examples. Those are expected to significantly improve the traffic safety and to realize the highest level of automated driving.

On the other hand, for the safe operation of such V2V communication-based applications, it is essential to correctly map the received message to the right sender, to be specific, to a right object detected by onboard ranging sensors. Typically, V2V communication is implemented using a broadcast mechanism since it is practically difficult to establish a connection-oriented communication (*e.g.,* TCP/IP connection) among vehicles due to their fast mobility. Therefore, vehicles normally don't know where the message comes from at the moment they receive it. Without correct mapping, receivers have difficulty to understand the importance of the information in the message. This is named the sender identification problem.

Especially here, our focus is to correctly determine whether or not the preceding vehicle is the sender of the received message. This is particularly important for follow-up type safety systems. For example, when vehicles try to make a platoon with exchanging messages, all the participants must understand which message comes from the vehicle right in front and make sure that everyone is following the correct vehicle. High reliability is required for this use-case because misidentification may cause a danger. Suppose a situation where platooning vehicles are entering a curve. Some platooning systems may utilize the preceding vehicle's steering angle included in V2V messages as a part of the control gain. If the message is sent by a different vehicle but the ego vehicle wrongly recognizes it is from the preceding vehicle, the stability could be affected, or in the worst case, it might cause a departure from the lane.

One way to identify the sender is to include the GPS information in the message, but the GPS measurement is not accurate enough under some circumstances. For example, Modsching *et al.* [4] reported that the mean error of the GPS location became 15.43 meters on a street surrounding by 3-4 stories buildings. This large error may cause misidentification. To tackle this problem, several works have been made. Yuan *et al.* [5] proposed a track-to-track association method to identify the sender by matching the track obtained from GPS information of the message sender to a set of tracks obtained from receiver's onboard ranging sensors. They also applied Kalman filters to reduce the effect of GPS errors. Sakr *et al.* [6] also proposed a similar track association approach to map received

GPS information to objects detected by ranging sensors. These approaches have difficulty when vehicles driving stably, *e.g.,* just following the same road stably. In those cases, tracks sometimes become too similar to be distinguished. Also, filters may be affected by offset errors. Under some situations such as in urban roads surrounded by tall buildings, multipath GPS signals cause large offset errors. Advanced GPS calibration solutions using base stations also suffer from the same problem in addition to their high cost. For example, DGPS cannot alleviate the effect of the multipath error.

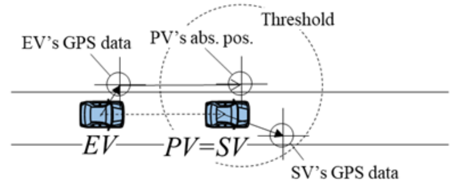
Some other approaches are trying not to use GPS data. Fujii *et al.* [7] proposed a method based on topological comparison of shared ranging sensor data. Vehicles having V2V communication capability share their own onboard ranging sensor data with others and then they cooperatively try to find out which observation is most likely taken from which vehicle. This approach also have difficulty under specific traffic conditions. For example, if a vehicle accidentally forms a similar positional pattern with surrounding vehicles to others, misidentification may be caused. Chen *et al.* [8] proposed an approach to recognize a license plate using the image processing algorithm, and match the license plate of the preceding vehicle (extracted from the image processing) to the license information delivered in V2V messages. However, the main drawback of this approach is to require vehicles to equip with high performance cameras to produce sufficient quality of image of license plate. Khattab *et al.* [9] proposed another method which does not rely on GPS data. However, this approach requires an assistant road side unit.

Our goal is to construct a reliable identification method which 1) properly works under any type of large GPS errors and 2) doesn't require additional expensive sensors nor road side units. In this paper, we propose a novel sender identification method. Our method primely uses GPS location. However, instead of applying filters to eliminate its errors, we applied an additional conditional judgement based on ranging sensor data and a behavioral control of the ego vehicle (receiver) to prevent GPS errors from affecting the identification accuracy. Our method does not assume any specific statistical characteristics of GPS errors.

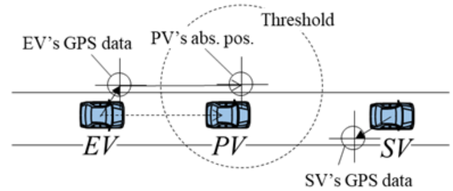
The rest of the paper is organized as follows. In Section II, we describe our proposed sender identification method. Then, we evaluate the performance of the proposed method in Section III and conclude the paper in Section IV.

II. Proposed Sender Identification Method

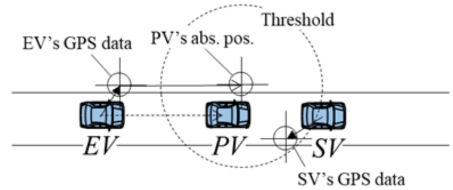
Our specific focus is to find a reliable way to correctly determine whether the preceding vehicle, which is the vehicle driving right in front of the ego vehicle, is the sender of the broadcast V2V message when the ego vehicle receives it. Suppose a situation where the preceding vehicle is actually not the sender, but the true sender is driving just in front of the preceding vehicle very closely. It is quite difficult to distinguish those two vehicles only with GPS data due to its large error as mentioned. However, this difficulty doesn't appear if it can be always ensured that there is a certain distance between those two vehicles. Our basic idea is to add another condition for the determination which cannot be satisfied when the preceding vehicle is not the sender and those two vehicles are driving closely.



(a) When PV is SV and the condition is satisfied



(b) When PV is not SV and the condition is not satisfied



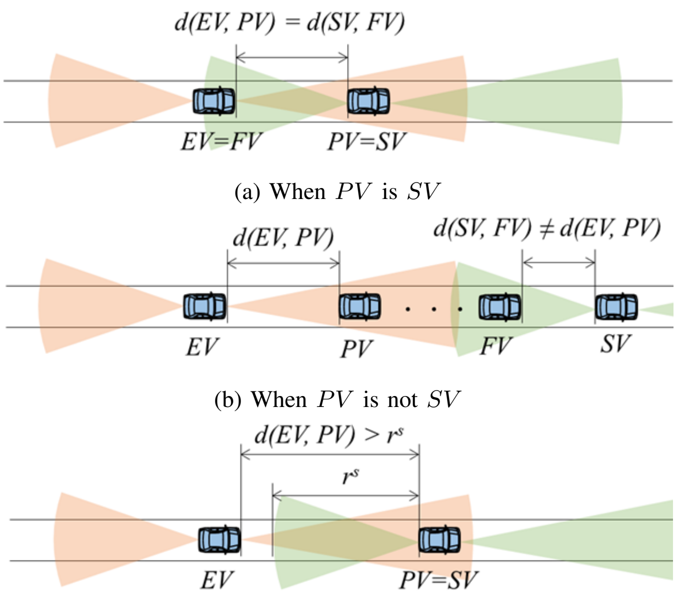
(c) When PV is not SV but the condition is satisfied

Fig. 1: Condition 1: based on shared GPS data

Our proposed method consists of three parts; a conditional determination based on shared GPS data, a conditional determination based on shared ranging sensor data, and behavioral control of the ego vehicle. Our method basically works only in single lane roads, but it can be extended to multiple lane roads by adding lane information in V2V messages as mentioned in the later part of this section. Note that the following description of our method focuses on a single lane road. Also, our method is compatible with the situation where multiple senders exist in a scene although only one sender is assumed in the following description. If the ego vehicle receives messages from multiple senders at the same time, the same sender identification process will be applied to each message.

A. Condition 1: Based on Shared GPS Data

This is a traditional conditional determination based on a comparison of the absolute position of the preceding vehicle and that of the sender as shown in Fig. 1. Note that EV, PV, SV and FV in this paper mean the ego vehicle, the preceding vehicle of the ego vehicle, the sender and the following vehicle of the sender, respectively. Although the absolute position of the preceding vehicle cannot be obtained directly, it can be calculated from the GPS data of the ego vehicle and the relative position of the preceding vehicle measured by the ego vehicle's front ranging sensor. The absolute position of the



(a) When PV is SV

(b) When PV is not SV

(c) When EV is outside of the sensor range of SV (r^s)

Fig. 2: Condition 2: based on shared ranging sensor data

sender is directly measured by the sender's GPS module and shared with the ego vehicle through their V2V communication capability. If the distance between those two absolute positions is shorter than a given threshold, this condition is satisfied. The distance is ideally zero when the preceding vehicle is the sender; however, the distance is affected by GPS error as depicted in Fig. 1(c).

B. Condition 2: Based on Shared Ranging Sensor Data

This is an additional condition based on the comparison of the distance between the ego vehicle and its preceding vehicle and the distance between the sender and its following vehicle. See Fig. 2(a)(b). Note that $d(X, Y)$ means a distance between vehicle X and vehicle Y. While the distance between the ego vehicle and the preceding vehicle is simply measured by the ego vehicle's front ranging sensor, the distance between the sender and its following vehicle is measured by the sender's rear ranging sensor and shared with the ego vehicle through the V2V communication capability. The difference of those two distances is compared with the given threshold. Considering the relatively high accuracy of ranging sensors, the difference should be very close to zero when the preceding vehicle is the sender. However, it can happen that the sender which is not the preceding vehicle and its following vehicle accidentally make the same positional relation as the ego vehicle and its preceding vehicle.

In addition, if the sender does not detect any vehicle behind, the distance between the ego vehicle and its preceding vehicle is compared with the detection range of the sender's rear ranging sensor. If the distance is longer than the detection range as depicted in Fig. 2(c), this condition comes to be satisfied. This case happens due to the difference of the detection range of the front ranging sensor and the rear ranging sensor. Most front ranging sensors have a longer detection range than rear ranging sensors nowadays. The sensor range information is also assumed to be shared with the receiver through V2V communication capability.

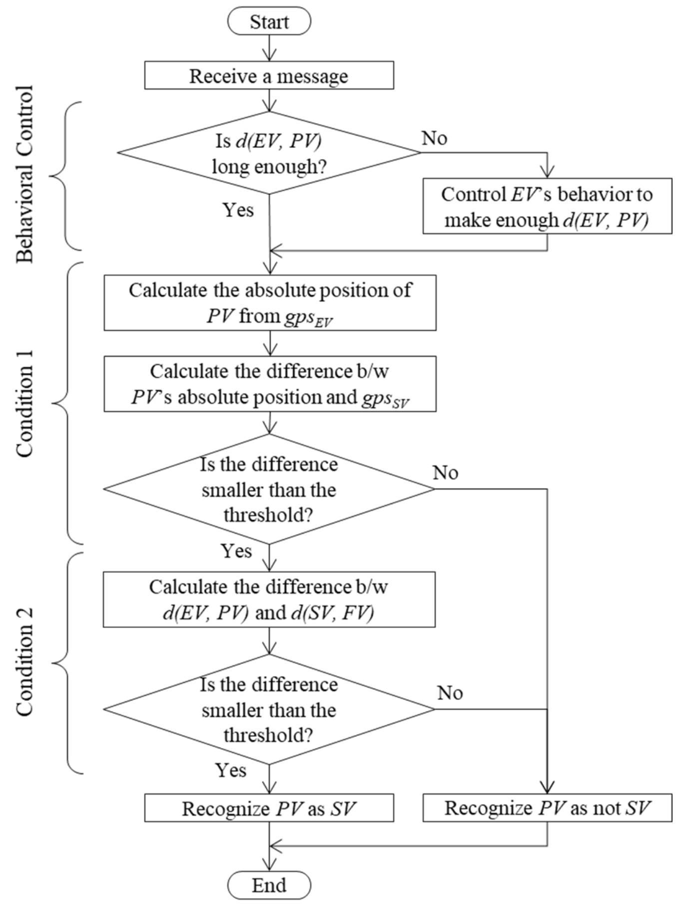


Fig. 3: Flow chart of our sender identification process

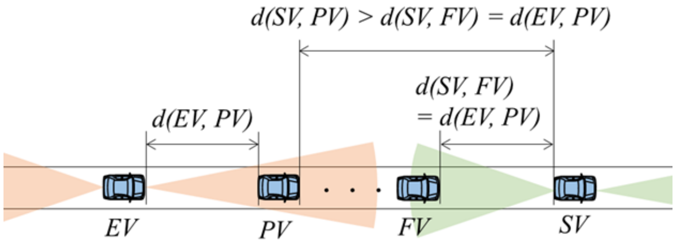
C. Behavioral Control

The last part of our proposed method is a behavioral control of the ego vehicle. When its system tries to identify the sender and the distance toward the preceding vehicle is shorter than the given minimum length, the system enlarges the distance, for example, by deceleration. The minimum length depends on the size of the GPS error. Details are mentioned in the following section.

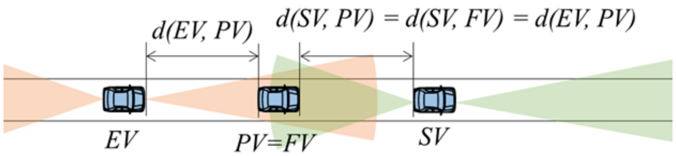
Fig. 3 describes the whole structure of our method. Note that gps_X means the GPS information of vehicle X.

D. Complementary Relationship

We here describe how those three parts in our proposed method work in a complementary way. Suppose the situation in which Condition 2 is satisfied and the sender detects a vehicle behind. If the preceding vehicle is the sender, the distance between the preceding vehicle and the sender is obviously zero because those two vehicles are actually the same one. On the other hand, if the preceding vehicle is not the sender, the distance must be longer than the distance between



(a) General positional relation



(b) When SV is right in front of PV

Fig. 4: Distance between SV and PV

the ego vehicle and the preceding vehicle as shown in Fig. 4. This is because Condition 2 ensures that there is the same distance between the sender and its following vehicle. The distance becomes the shortest when the sender is right in front of the preceding vehicle. Therefore, if the ego vehicle keeps an enough distance toward the preceding vehicle, Condition 1 can avoid being affected by the GPS error.

Suppose e_{gps} represents the upper limit of the GPS error, $d(X, Y)$ represents the ground truth distance between vehicle X and vehicle Y and the ranging sensor error is enough small to be ignored, the distance between the sender and the preceding vehicle calculated from the GPS data and the ranging sensor data, $d'(SV, PV)$, satisfies following conditions.

When the preceding vehicle is the sender,

$$0 \leq d'(SV, PV) \leq 2e_{gps} \tag{1}$$

When the preceding vehicle is not the sender,

$$d(SV, PV) - 2e_{gps} \leq d'(SV, PV) \leq d(SV, PV) + 2e_{gps} \tag{2}$$

This means that if the ego vehicle keeps the distance toward the preceding vehicle longer than $4e_{gps}$, the sender can be always correctly identified. The threshold of Condition 1 should be selected from $2e_{gps}$ to $d(EV, PV) - 2e_{gps}$.

The same thing can be said when the sender doesn't detect any vehicle behind. In this case, our proposed method can guarantee that the distance between the sender and the preceding vehicle is longer than the detection range of the sender's rear ranging sensor.

E. Application to Multi-lane roads

Our discussion above focused on the scenario in which vehicles driving in a single lane road. However, our method can be extended to deal with general multiple lane situations by adding another information which indicates in which lane the vehicle is driving into V2V messages. In multiple lane situations, senders driving in different lanes are simply ignored based on this lane information. We suppose that this information will be able to be obtained by advanced vision sensor systems in near future.

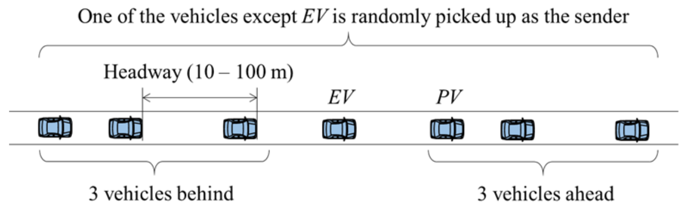


Fig. 5: Traffic setup in the evaluation

III. Performance Evaluation

For the evaluation, the performance of our method is compared to two other methods which fully rely on GPS. One is a method which only uses Condition 1 of our proposed method with raw GPS data. The other one is also a method which only uses Condition 1, but Kalman filter is applied to the GPS data. A simulator is constructed with MATLAB for this evaluation. The employed traffic situation is illustrated in Fig. 5. Here, seven vehicles are running in a straight single lane road at the same constant speed with keeping different headways. The middle (4th) vehicle is the ego vehicle and judges whether the preceding (3rd) vehicle is the sender or not when it receives a message. Detailed simulation settings and assumptions are listed below:

- The vehicle speed is 60 km/h.
- Headways are randomly chosen from 10 meters to 100 meters and given to each vehicle at the beginning of each simulation.
- Also at the beginning of each simulation, one of the vehicles except the ego vehicle randomly picked up as to be the sender.
- Vehicles have a front and a rear ranging sensor which can see up to 120 meters ahead and up to 60 meters behind.
- The sender broadcasts a message which includes its 2-D GPS position and ranging sensor data every 100 milliseconds.
- The GPS positioning error follows the standard distribution whose standard deviation is 10 meters.
- The ranging sensor error also follows the standard distribution whose standard deviation is 0.2 meters.
- Each simulation time is 100 second.

For each sender identification method, 10,000 times of the simulation, which resulting in 10,000,000 judgements, are conducted. Then, precision, recall and F-score are calculated for anaysis. Precision is defined as $\frac{TP}{TP+FP}$, and recall is defined as $\frac{TP}{TP+FN}$. In which, *TP* is the number of correct judgements when the preceding vehicle is the sender. *FP* and *FN* are the numbers of incorrect judgements respectively when the preceding vehicle is the sender and when the preceding vehicle is not the sender. F-score is a harmonic average average of precision and recall defined as $\frac{2*Precision*Recall}{Precision+Recall}$.

TABLE I: Simulation result

Th: Threshold Hw: Headway		Fully GPS-based								Proposed Method				Proposed Method w/ KF
		w/o filters				w/ Kalman filter								
	Parameter	Expt. 1	Expt. 2	Expt. 3	Expt. 4	Expt. 5	Expt. 6	Expt. 7	Expt. 8	Expt. 9	Expt. 10	Expt. 11	Expt. 12	Expt. 13
Condition 1	Th: 10.0 m	✓				✓				✓				
	Th: 20.0 m		✓				✓				✓			
	Th: 30.0 m			✓				✓				✓		✓
	Th: 40.0 m				✓				✓				✓	
	Kalman Filter					✓	✓	✓	✓					✓
Condition 2	Th: 1.0 m									✓	✓	✓	✓	✓
Behavioral Control	Hw: 20.0 m									✓				
	Hw: 40.0 m										✓			
	Hw: 60.0 m											✓		✓
	Hw: 80.0 m												✓	
	Precision	92.75%	89.53%	83.58%	75.55%	99.37%	94.57%	84.87%	75.30%	99.81%	99.97%	99.99%	99.94%	100.00%
	Recall	20.94%	61.12%	88.03%	97.72%	68.54%	99.22%	99.98%	100.00%	20.92%	61.11%	87.95%	97.72%	99.83%
	F-score	34.17%	72.65%	85.75%	85.22%	81.13%	96.84%	91.81%	85.91%	34.59%	75.85%	93.58%	98.82%	99.92%

Results are shown in Table 1. The first eight columns show results of the two fully GPS-based methods. In each experiment, a different threshold shown in the ”Parameter” column is applied. Results show a trade-off relationship between precision and recall. When the threshold becomes tighter, the precision is improved; however, more *FN* appears and the recall becomes worse. A certain number of incorrect judgements must remain due to large GPS errors. The highest F-scores are marked when the threshold is 30 meters, which is 85.75 % without filters and 96.84 % with Kalman filter.

Following four columns show results of our proposed method. As well as the first eight experiments, several combinations of the threshold of Condition 1 and the minimum headway for the behavioral control are tried. Note that, as a simplified implementation of the behavioral control, the randomly chosen headway of the ego vehicle is forcibly replaced with the minimum headway at the beginning of the simulation if it was shorter than the given minimum headway. As shown in the results, the trade-off relationship regarding the threshold for GPS locations is resolved. The precision is improved and even can become better when a loose threshold is applied to improve the recall. The highest F-score is 98.82 %, which means that the number of incorrect judgements is reduced by 64 % compared with the best result of the fully GPS-based methods.

In addition, Kalman filter can be also applied to our proposed method. The last column shows an example result of this combination. By virtue of the GPS error alleviation, the overall performance is improved. The F-score is 99.92 %.

IV. Conclusion

In this paper, we proposed a novel sender identification method which can correctly determine whether the preceding vehicle is the sender of broadcast V2V messages or not. Our method primely uses GPS data which may include a large error; however, an additional conditional judgement based on ranging sensor data and a behavioral control of the ego vehicle (receiver) to prevent the GPS error from affecting the identification accuracy. Our method does not assume any specific statistical characteristics of GPS errors and works without additional high-cost sensors. As shown in simulation results, our proposed method successfully reduced the number of misidentifications. Although our method is easily extendable for multiple lane scenarios if the lane information is available, we are also planning to explore another way which doesn’t rely on the lane information. We expect that the combination of the behavioral control and historical ranging sensor data can be useful to improve the accuracy of the sender identification in multiple lane scenarios.

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