Context-Aware Navigator for Road Safety in Vehicular Cyber-Physical Systems

Bien Aime Mugabarigira*, Yiwen (Chris) Shen*, Daegeun Choe*, Jaehoon (Paul) Jeong†
*Department of Electrical and Computer Engineering, Sungkyunkwan University, Suwon, Republic of Korea
†Department of Interaction Science, Sunkyunkwan University, Suwon, Republic of Korea
E-mail: {bienaime, chrisshen, cdg1994, pauljeong} @skku.edu

Abstract

The advance of Vehicular Cyber-Physical Systems (VCPS) has been revolutionizing not only the realm of transportation systems but also the safety in the roads. This paper proposes a context-aware navigator for road safety in VCPS that will significantly enhance the safety of vehicular transportation. Our proposed model exploits both vehicular kinematics, such as speed, position, direction, steering angle, and vehicular networks to strengthen a safe driving. This model suggests a cooperative driving that relies on each vehicle's minimal contour tracking area to make a safe vehicular motion planning in hazardous situations.

Keywords: vehicular cyber-physical systems, context-aware navigator, road safety, minimal contour.

1. Introduction

Despite a significant reduction of the number injuries, casualties from driving accidents within years due to traditional safety technologies, such as seat belts, airbags, active brake assist and so on, road injuries are still classified among the top ten causes of death globally by World Health Organization (WHO) [1]. More than 1.2 million people are killed and up to 50 million are injured every year. Most of accidents are due to a driver's inattention while lane changing, over-speeding or brutality at pedestrian crossing area as Fig. 1 states. A non-assured road safety cost is too high, which takes lives of people, makes others disabled, and destroys both infrastructures and environments. The advances recently made in the area of sensing and networking can strongly improve road safety.

The fact that vehicles in the future will be equipped with various advanced sensors and the Dedicated Short Range Communication (DSRC) devices, which enable them to sense and communicate with its surrounding environment. Those kinds of vehicles systems are known as Vehicular Cyber-Physical Systems (VCPS) [2] [3]. VCPSs exploit the sensing, computing, communications and networking technologies to improve the transportation systems [4] [5]. Those technologies enable vehicles to understand and cooperate with the environments, making vehicles to be continuously aware of the driving contexts, such as speed and position of neighboring vehicles, walking direction of pedestrians, traffic light information and so on.

The effective context-aware navigation requires an accurate vehicle positioning. Different researches were carried out for vehicle positioning [6] [7] [8]. The cooperative vehicle positioning is proved to be a better alternative to improve the accuracy of GPS position that is characterized by uncertainty. In this work, we cooperatively use both the Local Sensing Estimate (LSE) and Remote Sensing Estimate (RSE) to estimate the vehicle position [9] [10]. For context-awareness, a vehicle can sense the surroundings, perceive the sensed data, and the vehicle will correctly respond to different situations it senses.

The Cooperative Context Awareness model we propose can ensure road safety for VCPS nodes by cooperatively tracking the locations of vehicles. Each vehicle will track the surrounding vehicles according to remote sensed information such as kinematic data of neighbor vehicles. Each vehicle keeps tracks of its minimal contour by a vehicle kinematic model in the Minimal Contour Tracking Algorithm (MCTA) [11] to react to context kinematics of VCPS nodes such as speed, position, steering angle and acceleration to assess circumstances under which misbehaviors arise. When there are vehicles in its contour, using risks assessing algorithm in our model, it assesses hazardous conditions, followed of progressive path maneuver, like change steering angle, and speeding up or down.

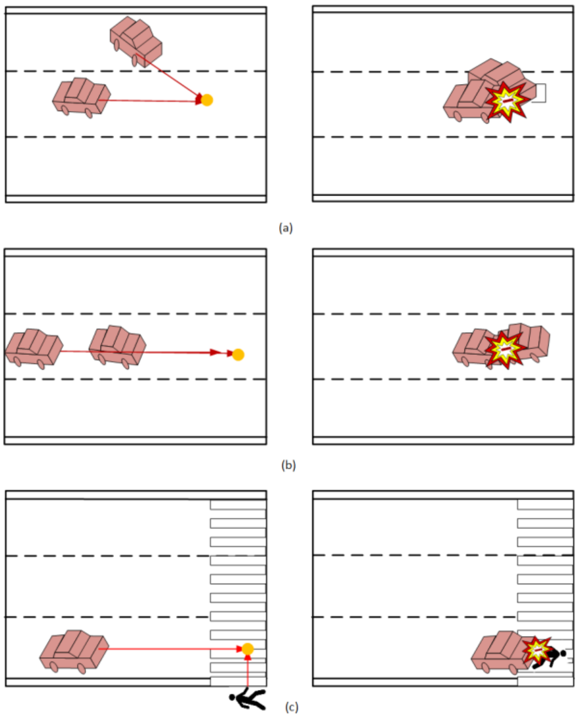

Fig. 1. VCPS Nodes Collision Scenarios: (a) inter-lanes crossing accident, (b) Over speeding accident and (c) Pedestrian crossing area accident.

The remaining part of our paper is organized as follows: Section II describes the related works. Section III discussed our cooperative context-aware navigation, and lastly in Section IV we conclude this paper along with future work.

2. Related Work

Some Context-Aware schemes in VCPSs have been proposed in the recent researches. To note some, in this section we describe proposed models.

One of the proposed models, is a multi-layered context-aware architecture proposed in [2]. They propose the exchange of location information between the Road Side Equipment (RSE) and the Onboard Equipment (OBE) at the location computation layer, the application and service exchanges, and the corporation with traffic authorities in the cloud computational layer. In addition, they also suggest the implementation of security and privacy issues in Context-aware vehicular security mechanisms (CVSMs) framework. Despite a great importance attached to security and privacy issues in this model, the hazard prediction framework does not treat the road safety of vehicular network nodes considering proactive measures.

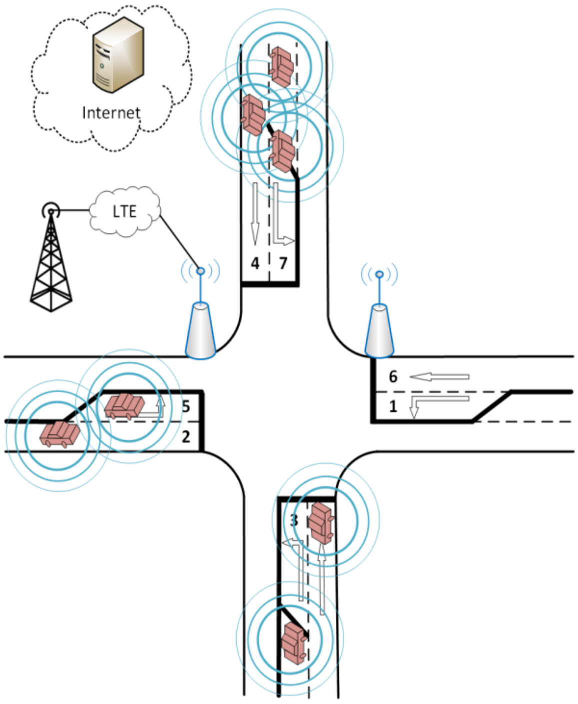

Fig. 2. VCPS Model

Another model proposed is the service provisioning in ad hoc networks based on the concept of context-aware migratory services that migrates to different nodes in the network to accomplish its task [12]. Due to the fact that context-awareness in this work relies on location information provided from resources available on car and that it contains high rate of uncertainties, and that the on demand code distribution relies on unrealistic distribution, this model cannot be practical in hazardous systems such as safety in roads.

Lastly, Context Awa-Aware Rate Selection for vehicle networks [13] developed a framework for developing migratory services that is triggered by the change of operation context. Not only the above mentioned models are proposed, but also they are more others, just we mentioned few.

3. Cooperative Context-Aware Navigation

The model we describe consists of minimizing the vehicle-to-vehicle (V2V) and vehicle-to-pedestrian (V2P) collision probability by keeping tracking vehicles following the Minimal Contour Tracking Algorithm (MCTA) [11]. To avoid V2V collision, each vehicle keeps track of the context in its minimal contour area. The minimal contour is significantly smaller than the vehicle Basic Safety Messages (BSM) that we name Cooperative Context-Aware messages (CCAM) system coverage area. Our model exploits infrastructures such as Road Side Unity, LTE networks together with small Ad Hoc networks as Fig. 2 states. This allows us to qualify

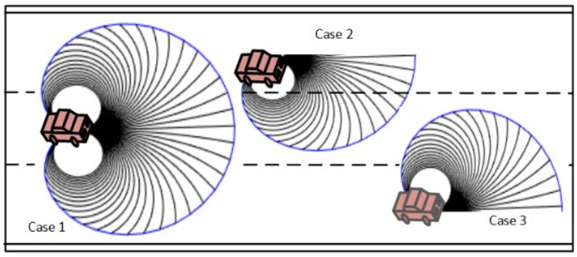

Fig. 3. Lane Based Minimal Tracking Area

a vehicle v2 tracked in a vehicle v1 Minimal Contour area of a vehicle in a hazardous area. For this vehicle, our model accords special attention from vehicle v1 depending on both vehicles' kinematics. Let notate v1's speed V_{v1} position (X_{v1}, Y_{v1}), acceleration A_{v1}, orientation Φ_{v1} together its steering angle $\Theta_{v,}$ and v2's speed V_{v2}, position (X_{v2}, Y_{v2}), acceleration A_{v2}, orientation Φ_{v2} together its steering angle Θ_{v2}. We model vehicle kinematics as linear vector in R^6.

In fact, a vehicle moving though a three or more lane road can have 3 possibilities of main focuses to track its surrounding vehicles depending on what lane it is moving as Fig. 3 shows. For a vehicle moving in middle lane, it has possibility to turn either left or right, while the one in the left lane can turn right toward the middle lane and the other in right lane can turn left toward the middle lane.

A vehicle at pedestrian zebra crossing area gets attention messages via Cooperative Context-Aware messages from the pedestrian smart-phone or road side unit. In a similar war, a pedestrian also will be alerted of the road dangers and traffic in real time as long as he is closer to the road crossing area.

3.1. Cooperative Minimal Contour Tracking Scheme

A. Cooperative Risk Assessment

Algorithm 1 Risk Assessment Algorithm

$(tl, pl, vl, \theta l) \leftarrow$ *Decapsulate LN data*
$(tr, pr, vr, \theta r) \leftarrow$ *Decapsulate RN data*
$flag1 \leftarrow$ *remote node in my MCA*
if $flag1 = true$ **then**
    Context_Response_Activation()
    Send_Context_Aware_Message()
end if
$flag2 \leftarrow$ *RN slower than me*
if $flag2 = true$ **then**
    Send_Context_Aware_Message()
end if
Update RN time Stamp Kinematics Information.

Whenever the VCPS node senses either remote data (from cooperative awareness message exchange) or local data from its onboard sensors, it will analyze how risk those data are according to algorithm 1. The

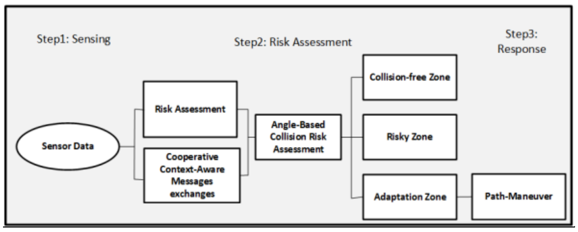

Fig. 4. Context-Aware Navigation Model

level of risks from neighbor VCPS nodes can vary in three categories: riskless, low level risk and high level risk. Riskless sending node which is in a safe area present no danger to the receiver. Low level risk VCPS node, is a node which cannot directly affect the receiving node even though it present a probability to affect it. The high level node is node that is sensed to be present in the minimal contour area of the receiving vehicle.

B. Responses Scenario in the Contour Area

Two consecutive task will be taken in the case of a vehicle in the contour.
Case Low risk: for a vehicle in the contour but whose speed, direction and steering angle assessed to not be dangerous, it will send cooperative awareness Messages to it alerting its presence in the risk zone
Case high risk: for a vehicle in the contour but whose speed, direction and steering angle assessed to be dangerous, hazardous proactive and reactive mechanisms will be taken by the vehicle.

Algorithm 2 Risk response algorithm

procedure RISK HADLING PROCEDURE
    $(tl, pl, vl, \theta l, tr, pr, vr, \theta r) \leftarrow$ *Perceive sensed data*
    if $vr < vl$ **then**
        $flag1 \leftarrow$ *RN in my direction*
        if $flag1 = true$ **then**
            High_Risk_Collision_Avoidance()
        end if
        Send_Maneuver_Aware_Message()
    end if
    $flag2 \leftarrow$ *RN not in direction*
    if $flag2 = true$ **then**
        Adaptation_an_Interaction_Scheme()
        Send_Context_Aware_Message()
    end if
    $flag3 \leftarrow$ *multiple VCPS nodes in My MCA*
    if $flag3 = true$ **then**
        Motion_Planner()
    end if
end procedure

i. Proactive Responses

Following the kinematics of the neighboring hazardous vehicle, a combination of path manoeuver and sending cooperative awareness Messages alerting its presence in high risk zone will be taken. Path maneuver consists of speeding up or down, turning right or left and changing lanes. The imprudent path maneuver can lead to disastrous accident. Fig. 4 Shows the techniques and algorithm our model follow to counter measure in risk area. This model will collaboratively though VANET facilities both senses local kinematics and remote VCPS kinematics to assess the applicability of the measures it is going to take.

In fact, whatever measures the VCPS node will take in this condition follows the response mechanisms as described in algorithm 2. The VCPS node will firstly analyze the source of anomaly whether the neighbor node violated driving rules, an abnormal event occurring, everything to be calm or a combination of any of. The next decision will follow well context-aware response algorithm.

ii. Reactive Responses

When a neighboring CPS node reacts to the situation, the node that triggered the hazardous driving mechanisms also will respond. Collaboratively, they keep exchanging sensed data to calm the situation by avoiding the accident.

4. Conclusion

In this paper, we describe a scheme that exploit the VCPS nodes context-awareness to improve road safety. The scheme we designed consist of tracking VCPS nodes by using minimal contour algorithm and following the vehicle kinematics, vehicle cooperatively will avoid collisions. When a vehicle is in hazardous situations, a model for road safe driving is also designed. In the future, we will improve our model to also include the avoidance of colliding with obstacles, and increase the adaptability of our mechanism by allow it to learn the road context.

5. Acknowledgement

This research was supported by Next-Generation Information Computing Development Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT (2017M3C4A7065980).

References

[1] W. H. organization (WHO et al., “Global health risks-mortality and burden of disease attributable to selected major risks,” *Cancer*, 2017.

[2] J. Wan, D. Zhang, S. Zhao, L. Yang, and J. Lloret, “Context-aware vehicular cyber-physical systems with cloud support: architecture, challenges, and solutions,” *IEEE Communications Magazine*, vol. 52, no. 8,pp. 106–113, 2014.

[3] S. Wang, T. Lei, L. Zhang, C.-H. Hsu, and F. Yang, “Offloading mobile data traffic for qos-aware service provision in vehicular cyber-physical systems, ”*Future Generation Computer Systems*, vol. 61, pp. 118–127, 2016.

[4] X. Li, C. Qiao, X. Yu, A. Wagh, R. Sudhaakar, and S. Addepalli, “Toward effective service scheduling for human drivers in vehicular cyber-physical systems, ”*IEEE Transactions on Parallel and Distributed Systems*, vol. 23, no. 9, pp. 1775–1789, 2012.

[5] J. Wan, D. Zhang, Y. Sun, K. Lin, C. Zou, and H. Cai, “Vcmia: a novel architecture for integrating vehicular cyber-physical systems and mobile cloud computing,” *Mobile Networks and Applications*, vol. 19, no. 2, pp. 153–160, 2014.

[6] M. Rohani, D. Gingras, V. Vigneron, and D. Gruyer, “A new decentralized bayesian approach for cooperative vehicle localization based on fusion of gps and vanet based inter-vehicle distance measurement,”*IEEE Intelligent Transportation Systems Magazine*, vol. 7, no. 2, pp. 85–95, 2015

[7] A. H. Sakr and G. Bansal, “Cooperative localization via dsrc and multi-sensor multi-target track association,” in Intelligent Transportation Systems (ITSC), *2016 IEEE 19th International Conference on. IEEE*, 2016, pp. 66–71.

[8] A. Fascista, G. Ciccarese, A. Coluccia, and G. Ricci, “Angle of arrival-based cooperative positioning for smart vehicles,”*IEEE Transactions on Intelligent Transportation Systems*, 2017.

[9] A. Bhawiyuga, H.-H. Nguyen, and H.-Y. Jeong, “An accurate vehicle positioning algorithm based on vehicle-to-vehicle (v2v) communications,” in Vehicular Electronics and Safety (ICVES), *2012 IEEE International Conference on. IEEE*, 2012, pp. 273–278.

[10] A. Bhawiyuga, H.-H. Nguyen, J. Kwon, and H.-Y. Jeong, “A greedy data matching for vehicular localization with temporal-spatial weighting factor,” in Communications (APCC), *2013 19th Asia-Pacific Conference on. IEEE*, 2013, pp. 415–420.

[11] J. Jeong, T. Hwang, T. He, and D. Du, “Mcta: Target tracking algorithm based on minimal contour in wireless sensor networks,” in INFOCOM 2007. *26th IEEE International Conference on Computer Communications. IEEE.* IEEE, 2007, pp. 2371–2375.

[12] O. Riva, T. Nadeem, C. Borcea, and L. Iftode, “Context-aware migratory services in ad hoc networks,” *IEEE Transactions on Mobile Computing*, vol. 6, no. 12, 2007.

[13] O. Riva, T. Nadeem, C. Borcea, and L. Iftode, “Context-aware migratory services in ad hoc networks,” *IEEE Transactions on Mobile Computing*, vol. 6, no. 12, 2007.[12] O. Riva, T. Nadeem, C. Borcea, and L. Iftode, “Context-aware migratory services in ad hoc networks,” *IEEE Transactions on Mobile Computing*, vol. 6, no. 12, 2007.