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Lane change decision aid and warning system using LoRa-based vehicle-to-vehicle communication technology

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ABSTRACT

Among the most severe crash scenarios are those caused by driver's decisions to manoeuvre the vehicle to the adjacent lanes. In most scenarios, drivers' intentionally change lanes to take over another slower vehicle and preserving the current vehicle speed especially on highway road. The decision may be fatal for drivers of incoming or approaching vehicles which are not aware of the intention and fail to reduce their vehicle speed to avoid lane change collision. Hence, this study proposes a lane change decision aid and warning system which aims to support the driver's decision prior to performing the lane change on highway road where vehicles are travelling in a single direction. The system implements vehicle-to-vehicle communication (V2V) via long-range (LoRa) communication technology to alert the host vehicle of approaching vehicles and warns the approaching vehicle when a host vehicle intends to change lane. Visual and audible warning will be triggered as precaution mechanism for both host and approaching vehicle drivers. Experiments shows that V2V using LoRa can provide contextual information which are useful to assist drivers in deciding whether to change lane or not on highway use case settings.

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1. INTRODUCTION

The transportation sector is undergoing rapid changes in terms of adopting cutting-edge construction technology, adjusting to industry evaluation, and using intelligent transportation systems (ITS) in line with industry 4.0. Numerous ITS technologies have been created to improve vehicle safety, avoid collisions, lessen trauma during or after a crash, and be utilized to lessen traffic congestion [1]. Nevertheless, compared to other risky driving behavior such as speeding, alcohol consumption, and distracted driving, not much attention has been given to traffic crashes due to unsafe lane changing by drivers [2]. In Malaysia, most vehicle collisions happened when both vehicles were travelling in the same direction and one of the vehicles was performing a turning maneuver [3]. Moreover, the driver who intends to maneuver the vehicle to an adjacent lane fails to recognize the danger of changing lane, unaware of approaching vehicle, and an apparent inability to take precautionary actions in avoiding the collision. The collision may be avoided if the driver pays attention to the surroundings and use the mirrors before lane-change intention [2].

Therefore, advanced driver assistance systems like lane departure warning system (LDWS) and lane change assistance system (LCAS) are proposed to minimize lane change collisions due to unexpected lane change by drivers. For instance, LDWS is proposed to warn drivers of accidental lane departure related to actual or impending lane departure. The warning performed by LDWS can assist in preventing lateral collisions and lane departure incidents [4]. Moreover, lane departure warning (LDW) testing have been a part of the European new vehicle assessment programme (EuroNCAP) since year 2015 [5], [6].

Assuming all vehicles on the road are equipped with LDWS, researchers have predicted LDWS provides safety benefits in preventing lane change collisions. Most of the LDWS in the market requires the use of camera to detect the lane marking and make use of the image processing technique like hough transform through. These systems are known as visual-based LDWS. The systems are frequently used on straight highways and curves with a radius of 230 meters or more [7]. Depending on the technology, different warning thresholds apply and depend on the visibility of the lane markings. Furthermore, the minimum speed at which the LDWS activates is set differently by different automobile manufacturers. For example, general motors defined minimum speed is 57 km/h, Honda minimum speed is 72 km/h and for Toyota, the minimum speed is 51 km/h [8].

Moreover, the international standards organization (ISO) 17387:2008 standard defines LDWS or LCSA as devices that alert the driver to potential collisions that might result from lane change maneuvers [7]. Drivers will remain in control of the vehicle. According to the standard, LDWS or LCSA known also as lane change decision aid systems (LCDAS) operates in accordance with a state diagram as shown in Figure 1.

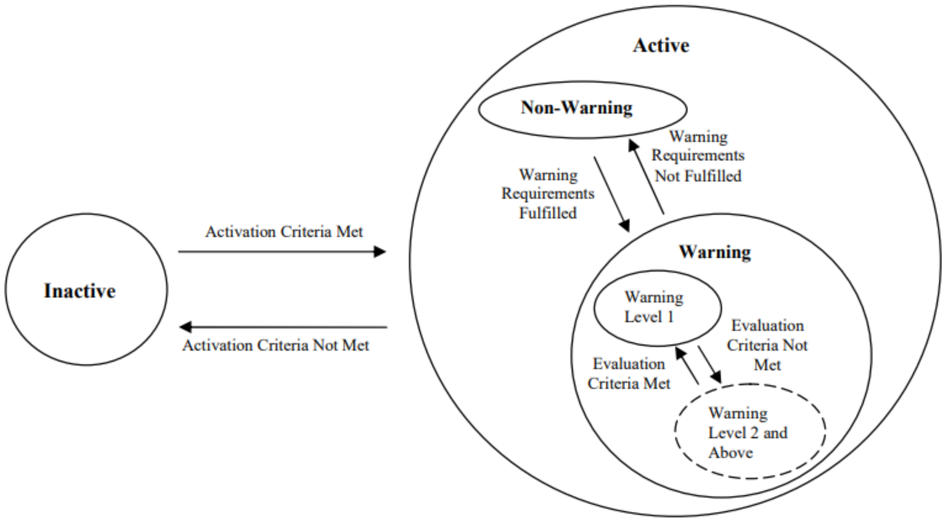


Figure 1. ISO 17387:2008 state diagram for LCDAS

- Vehicle-to-vehicle communication

The vehicle-to-vehicle communication (V2V) communication aims there are many different research themes within V2V including V2V protocol design, V2V security, V2V performance evaluation, V2Vimplementation and V2V integration [9]. All share the same idea and viewpoint to reduce travel time, prevent crashes, reduce traffic congestion, avoid emergency braking, and enable autonomous driving [10] by enabling the exchange of necessary data among vehicles [11]. Implementations of V2V have been used to alert drivers of nearby moving vehicles within potentially harmful proximity [12]. The periodic safety broadcasts employ cooperative awareness messages (CAM) with a maximum delay of 100 milliseconds. When an emergency occurs, the high priority decentralized environmental notification message (DENM) with a strict latency requirement of 50 milliseconds is sent [13]. A V2V protocol sample [9] is shown in Figure 2.

For V2V communications, medium and long-range (LoRa) low-power wireless technologies, such as Wi-Fi, Zigbee, BLE, and LoRa communication have been proposed. In addition, researchers have also utilized wireless technologies including Wi-Max, IEEE 802.11p, IEEE 802.16e, LTE, and 5G new radio (NR) from the third-generation partnership project (3GPP). However, using these technologies comes with a variety of difficulties. When selecting any of those technologies for V2V, it’s necessary to consider factors like communication latency, transmission range, transmission throughput, and power consumption. Table 1 summarizes wireless technology characteristics which support mobility.

Previous work has investigated the application V2V communication for drivers’ safety including lane change. For instance, Wang *et al.* [14] presented two V2V-based lane-changing strategies for connected vehicles. The suggested approach employs basic ACK to guarantee the validity of the messages sent during lane switching. The lane changing message (LCM) is added to the basic safety messages. Additionally, a customized VANET simulator designed in the MATLAB discrete-event system environment evaluates the suggested approach.

In addition, V2V communication based on the novel optimal velocity function (OVF) was merged with prior car-following models to enhance cars' mobility, safety, fuel consumption, and emissions in various traffic scenarios. The simulation study found that V2V communication for the car-following theory increased traffic flow performance by taking drivers' characteristics into consideration [15]. Moreover, Lyu *et al.* [16] performed detail data analytics on V2V performance based on communication traces, described the V2V channel, and suggested context aware reliable beconing scheme (CoBeto) to improve the broadcast reliability by dealing with difficult non-line-of-sight (NLoS) circumstances. A two-state Markov chain model has been developed for performance analysis, and extensive trace-driven simulations have been carried out to assess its performance. Results revealed the CoBe improves V2V broadcast reliability in NLoS situations.

Sachez-Mateo *et al.* [17] describes a merging aid system based on vehicle communication that enables sharing of internal variables like position and speed. The algorithm that manages the data from V2Vcommunications and from a digital map has been installed in a smartphone that acts as the driver interface. The system algorithm determines where and when the car may begin the merging move in a safe situation and gives the driver the necessary information. However, the type of communication technology utilized was not mentioned.

On the other hand, Han *et al.* [18] proposed a distributed and lightweight physical layer key generation system for secure V2V/vehicle-to-infrastructure (V2I) communication. Authors used LoRa communication, which enables the signal sequence to be measured beforehand for channel probing. Lourenco *et al.* [19] proposed an integration between V2V and V2I for traffic management. Dedicated roadside unit (RSU) is responsible to store information about traffic conditions under its coverage. Moreover, Leilabadi and Schmidt [20] investigates the potential V2V communication topologies between on-road vehicles in an uncertain mixed environment and in the presence of intelligent and conventional vehicles during on-ramp highway merge.

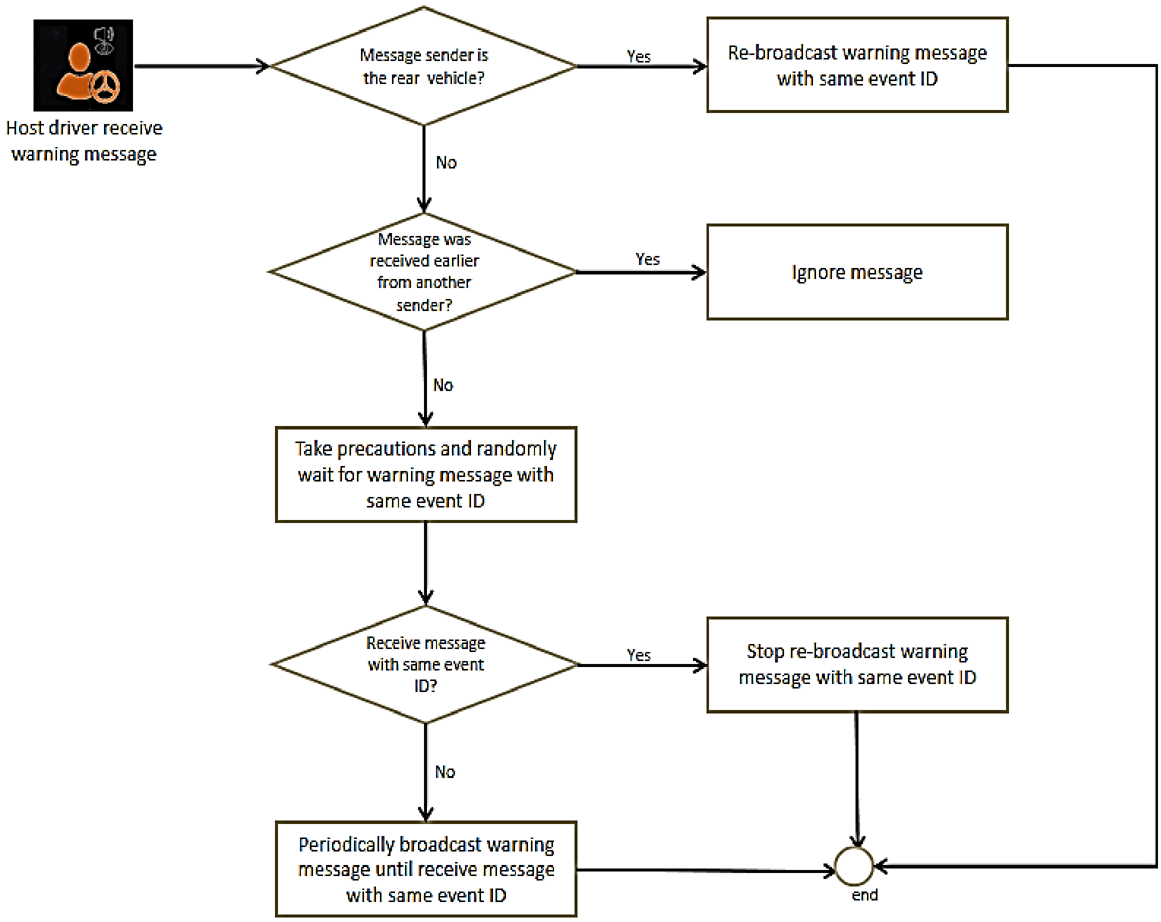


Figure 2. V2V protocol

Table 1. Wireless technology with mobility support

Wireless technology	Network type	Spectrum	Transmission range	Transmission throughput
LoRa	WAN	433, 868 and 915 MHz	2-5 km (Urban) 15 km (suburban)	27 kbps
Zigbee	PAN	433, 868 and 915 MHz	10-100 m	250 kbps for 2.4 Ghz; 40 kbps for 915 MHz; 20 kbps for 868 MHz
DSRC	Wireless ad-hoc	5.8-5.9 GHz	1,000 m	2.5 Mbps
WiMAX	Wireless broadband	5.8 GHz	100 m	1,400 Kbps (BLE5)
C-V2X	Cellular wireless broadband	5.9 GHz	~250 m using direct communication via using cellular network infrastructure	~600 Mbps and above for downlink rates; ~200 Mbps and above for uplink rates

- Long-range communication

The low power wide area network (LPWAN) paradigm guarantees long-distance connectivity with low energy usage but at the cost of providing constrained transmission rate. Examples of LPWAN technologies include: i) narrowband internet of things (NB-IoT), which is a cellular ecosystem-integrated solution; ii) long-range wide area network (LoRaWAN), which enables manageable private large-scale deployments; and iii) Sigfox, a proprietary technology with a set-up infrastructure in North America and Europe [12]. LoRa is adaptable and has minimal power requirements for extended communication in any area [11]. This makes it an excellent IoT alternative in many situations including in the context of smart vehicles, smart cities, smart grids, smart farms, health, location, industry, and military [21].

The WAN, which operate with minimal power and low transmission speeds, are the foundation of LoRa. The LoRa Alliance oversees maintaining LoRaWAN, which uses the sub-gigahertz industrial, scientific, and medical (ISM) bands of 433 MHz, 915 MHz (for Australia and America), and 868 MHz (Europe). With a maximum raw data rate of 27 kbps, LoRaWAN offers ubiquitous connection for both indoor and outdoor applications. In urban regions, the transmission range is 2–5 km, while in a suburban area with direct line of sight, the range is increased to 15 km. Class A, class B, and class C are three different categories of devices, and each has a unique set of characteristics. It is frequently used for LoRa applications such monitoring of agriculture and the environment, monitoring of healthcare, monitoring of traffic, localization, and numerous smart city applications. Communications using LoRa benefits from higher transmission range, adaptability, and low energy usage. Additionally, it has difficulties such as slower transmission speed and constrained bandwidth, which make handling multiple duplex transmission difficult [18].

Moreover, LoRa expands wireless connection for vehicles with high number of nodes and low energy use, which appeals to automakers leveraging long-distance data transfer. LoRa uses a licensed channel spectrum, and its range may vary depending on the area. The LoRa technology offers strong signal propagation and obstacle penetration at frequencies below 1 GHz. It offers a big range, open-source, basic, reliable, and affordable hardware, a wide range of configuration options, and applications ranging from agriculture to medical that don’t utilize licensed bands [22].

LoRa struck a balance between data transfer rate and transmission range among other communication technologies for V2V. It is based on IEEE 802.15.4, a low power communication standard with a data transmission rate of 300 bps-37.5 kbps. Additionally, LoRa enables WAN through a LoRaWAN server, which is required for certain ITS applications. These characteristics of LoRa make it appropriate for a more straightforward yet effective V2V connection that can dependably carry data with little delay and little battery usage. However, one drawback is that it has a relatively low throughput, which could indicate restrictions on the volume of data that can be transferred [23].

Even though LoRa has a low transmission capacity for applications like streaming video, it is sufficient for the data transmission required for applications like congestion prediction, autonomous traffic signalling, and accident avoidance [24]. Due to its modularity, LoRa-based vehicular communication infrastructure and applications can offer an ideal solution for all the legacy vehicles that to be V2V enabled. Sanchez-Iborra *et al.* [25] proposed an architecture to integrate LoRa in-vehicle communication utilising IPv6 and assessing its performance in a campus setting. The V2V coverage allows traffic occurrences in the campus to be broadcasted to the whole campus. The architecture design enables dependability and a high communication range with actual moving cars. In a recent work, Santa *et al.* [26] created a UNIX-based network interface for LPWAN communications in a real-time remote vehicle tracking scenario. The platform improves vehicle monitoring by offering a range of services including mechanical failure prediction and detection, fleet management, and traffic monitoring.

Chaffo *et al.* [27] proposed a device to enable the sensing of vehicle proximity on two-way straight roadways using LoRa Ra-02 module, a bidirectional transceiver, and a Raspberry Pi 3B to address risky overtaking situations. A few steps are required to install the device in a vehicle. Based on 55 proximity tests which have been conducted throughout the validation procedure, a success percentage in the identification of vehicles of up to 92.7% was recorded.

Gehlot *et al.* [28] proposed a local city node framework which integrates mobile nodes using LoRa communication module and GPS module to track location of vehicles involved in accidents. A microcontroller unit is used to acquire data from the accelerometer, vibration sensor and piezo electric sensor to determine that an accident has occurred. Communication between the local city node and distant city node is established using the LoRa module. The city node alerts the authority of the mishap and transmits data to a cloud storage.

The signal intensity, reception ratio, and signal-to-noise ratio between V2I, V2V, and stationary vehicles utilizing LoRa technology were assessed in field experiments. Various scattering factors (SF) built into LoRa (SF7 and SF12) were employed and the Doppler impact on communication was evaluated. Even in a crowded metropolitan area, the tests demonstrated good reach. Hence, LoRa can emerge as a viable option for applications which require brief message transmissions and do not necessitate the continuous transmission of information packages [22]. In addition, the bit error rate (BER) performance of LoRa schemes were assessed for vehicle-to-everything (V2X) communications including both V2I and V2V channels. Because of quick fading, simulation findings revealed that LoRa systems with longer symbol times display lower BER performance and even error or under most conditions. Therefore, it is advised to choose parameter configurations with greater BW and lower SF values to withstand the quick fading brought on by the Doppler effect when LoRa was utilized for V2X communications [29].

Chou *et al.* [30] proposed a LoRa-based LPWAN vehicle diagnostic tool for improving driving security known as i-car system. A cloud platform, a LoRa gateway, and a remote diagnostic system make up the planned i-car system. Abnormal events are promptly transmitted to the LoRa gateway through the Arduino and LoRa module when aberrant vehicle information is discovered. Additionally, a LoRa gateway sends data about anomalous vehicle behavior to a cloud platform through Ethernet so that the odd occurrences may be recorded. Additionally, the recording of unusual events might be provided to a car maintenance facility which can actively provide the help needed for vehicles to attain driving safety.

This study proposes a lane change decision aid and warning system where the system uses the V2V communication via LoRa based on the ISO17387:2008 state diagram. The system will capture contextual information including the distance and speed data from the approaching vehicle using ultrasonic distance sensors then transmits to the application by using Bluetooth connection. The host driver can view the transmitted data using his Android mobile phone. In addition, the system provides communication between vehicles to share contextual information before a lane change is performed thru LoRa-based V2V implementation to overcome the issue of non-visible lane markings for lane detection faced by camera-based LDWS. Therefore, when the host driver intends to change lane, an alert message will be transmitted to the approaching vehicle's application. Visual and audio-type warning will also be triggered to remind driver of approaching vehicle to pay attention to lane-changing action taken by the host vehicle. This paper is organised as follows; in section 2, the proposed work is presented. The experimental work and outcome are shown in section 3. In section 4, the conclusion and future work is highlighted.

2. METHOD

The lane change decision aid and warning system was designed and developed based on the conceptual framework shown in Figure 3. Equipped vehicles will be able to perform spatial awareness or vehicle sensing by utilizing sensors placed on the vehicle. Connected vehicles will transmit contextual information required for the V2V safety application i.e., lane change decision aid and warning. The proposed system creates awareness of approaching vehicles to the host vehicle driver and provides information including the approaching vehicle's speed and distance from the host vehicle. The host driver can use the contextual information to decide whether safe lane change can be performed or not (aid). If the host driver decides to maneuver the vehicle to the adjacent lane, the approaching vehicle driver will be notified to take precautionary actions such as reducing the vehicle speed (warn).

In this study, we applied embedded system method, and the system architecture of the lane change decision aid and warning system is shown in Figure 4. Sensors were connected to the Arduino Uno and LoRa module on the approaching vehicle side. A total of four ultrasonic distance sensors were placed at different sides of the front and rear of the approaching vehicle, so as to capture the distance data of the host vehicle. Once the distance data is acquired, the data will be transmitted to the host vehicle together with the speed data captured from the app. The two-way communication between the host and approaching vehicle utilized LoRa communication technology.

Two mobile applications are developed using the Massachusetts Institute of Technology (MIT) app inventor for the host and approaching vehicle drivers, namely the LDWS host and LDWS approach. The host vehicle would be able to visualise data by using the LDWS host application via Bluetooth communication. Besides, a warning message would be shown to the approaching vehicle using LDWS approach to alert the driver of potential lane change by the host vehicle (1st level warning). If the host vehicle manoeveur's the vehicle to the adjacent lane, audible warning will be trigger as 2nd level warning as outlined in the ISO17387:2008 standard state diagram. Integrated components of the host and approaching vehicles were placed in two different transparent boxes as prototypes of the vehicles, shown in Figures 5(a) and (b). Four ultrasonic sensors were placed at four different corners of the prototypes and two mobile power banks were used to provide the power source for the prototypes.

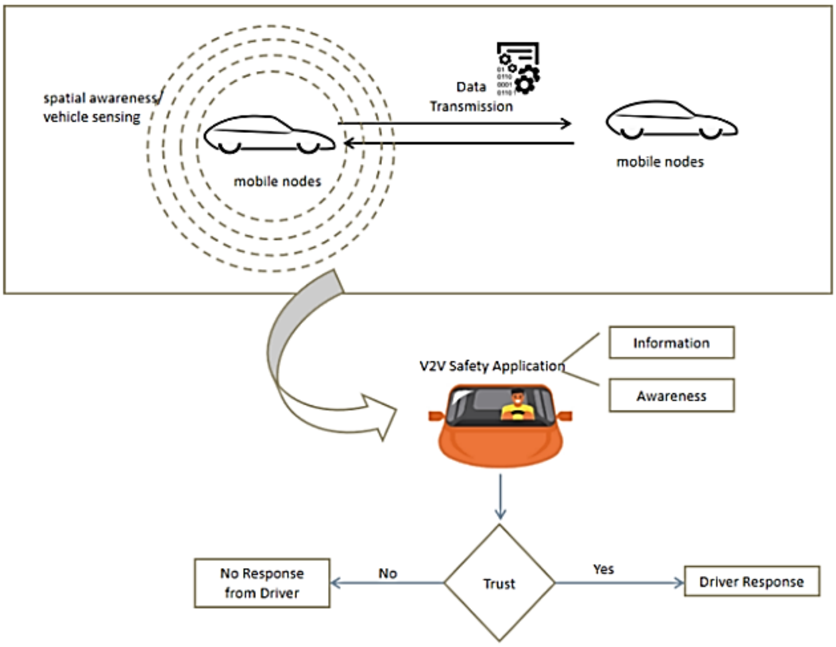


Figure 3. Conceptual framework

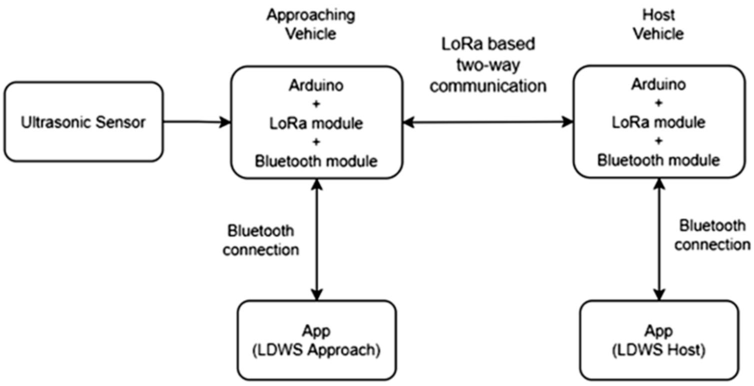


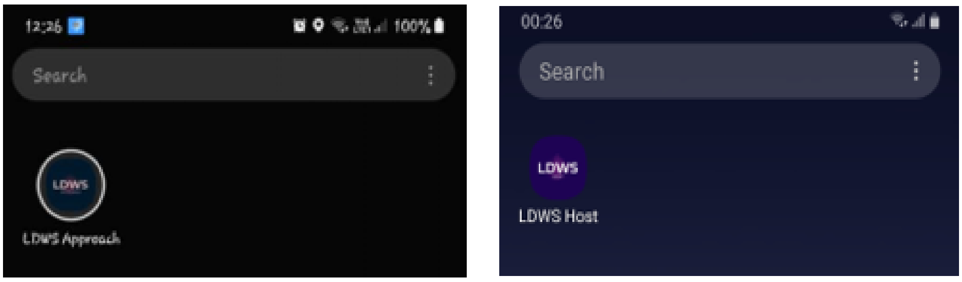
Figure 4. System architecture

(a) (b)

Figure 5. Prototype (a) approaching vehicle and (b) host vehicle

3. RESULTS AND DISCUSSION

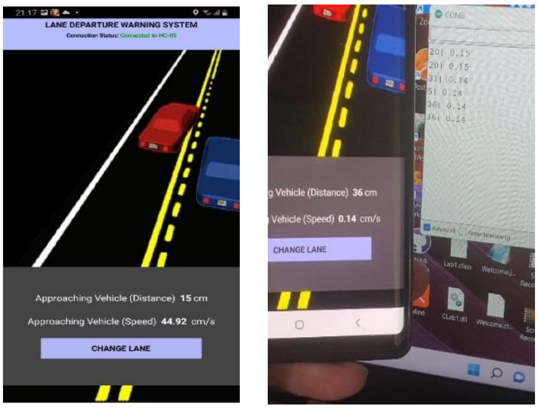
In this study, a lane change decision aid and warning system using LoRa-based V2V communication technology is designed and developed. Two mobile applications are linked to the protypes to display the contextual information, known as LDWS approach (Figure 6(a)) and LDWS host (Figure 6(b)). The prototypes were manually moved to simulate the driving scenario in an experimental setting.



(a) (b)

Figure 6. Mobile applications (a) LDWS approach and (b) LDWS host

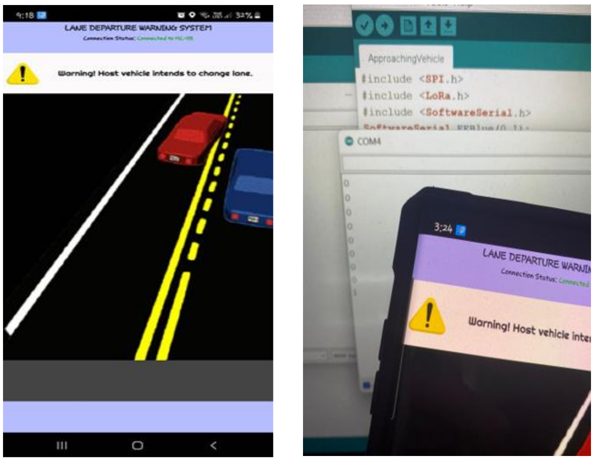
The ultrasonic sensors attached to the approaching vehicle prototype detect the distance data from the host vehicle prototype. Moreover, by using the LDWS approach application, speed data would be captured if it detects the shaking of the mobile device. The shaking action mimicked the movement of the approaching vehicle. Based on Figure 7(a), once the LoRa communication is established and ready, both distance and speed data are transmitted from the approaching vehicle to the host vehicle. Arduino IDE serial monitor was used to prove that the LoRa module were successfully powered up (Figure 7(b)). The connection status of the Bluetooth HC-05 from application, status displayed in green text means Bluetooth module was successfully connected with the smartphone. The data were successfully delivered from LoRa module 1 (approaching vehicle site) to the LoRa module 2 (host vehicle site) using LoRa based two-way communication. Then, data successfully displayed on host vehicle's application (LDWS host) by using Bluetooth.



(a) (b)

Figure 7. Distance and speed data received from approaching vehicle (decision aid) (a) application and (b) terminal

When the host vehicle driver has intention to change lane, he should click the "change lane" button from the LDWS host application. This will trigger an alert message to be sent to the LDWS approach application. The host vehicle successfully sent the alert message via Bluetooth and LoRa connection. Approaching vehicle successfully received the notification alert from the application when the host vehicle intends to change lane (Figure 8(a)). Arduino IDE serial monitor was used to prove the result. In serial monitor, printed 0 means do not display the alert message while printed 1 means display the alert message (Figure 8(b)). At the approaching vehicle's side, the buzzer also would be triggered to provide audible alert to inform the driver of the approaching vehicle that the host vehicle is changing lane and precautionary measures should be taken.



(a) (b)

Figure 8. Alert message received from host vehicle (warning) (a) application and (b) terminal

4. CONCLUSION AND FUTURE WORK

In this study, a lane change decision aid and warning system is proposed to increase road safety. The system implements LoRa-based V2V communication technology to assist drivers in intentional lane change decisions and alert drivers when another vehicle is attempting to change lane. Two hardware prototypes and mobile application known as LDWS host and LDWS approach were designed and developed to demonstrate the proof-of-concept. Communication between the host and approaching vehicles in a lane change scenario is established using LoRa communication whereas Bluetooth communication was utilized to feed information to the applications. Although it is against the law to use a smartphone while driving in many countries, it should be highlighted that the mobile application serves as the human-machine interface and cannot be used while driving. Drivers will be required to clip a car phone holder to the dashboard to place the mobile phone when they are driving on the road. Further improvement can be made by integrating the system with the in-vehicle entertainment and navigation system. Besides, we plan to explore PubNub in-app communication platform since it can support mobile device forecasted for the IoT. The platform is able to receive real-time data from sensors and transmit data on what is happening in real time for prototype communication. Despite having manual way of calculating speed, speedometer sensors can be implemented to improve the speed detecting process. Additionally, an image processing approach can be included to provide better distance measurement between vehicles. When the computed distance between the vehicle and the camera is sufficiently precise, this approach achieves very high accuracy. In conclusion, this study demonstrates the opportunity of providing contextual information to support safe lane change by drivers who intends to perform discretionary lane change (aid) and provide warning to drivers who are approaching from behind, enabling them to avoid potential lane change collision. LoRa-based V2V communication can be implemented to extend current sensor-based lane departure warning systems.

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