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Development of LiDAR-based Motorcycle Collision Alert System (MCAS) for Small-displacement Motorcycles

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ABSTRACT – *In Malaysia, motorcycle fatalities are alarmingly high, and crashes involving motorcycles striking a stationary or slow-moving vehicle on highways are not uncommon. This paper describes the invention of a collision alert system for motorcycles (MCAS) as one of the potential solutions for this type of crash. MCAS is a LiDAR-based collision alert system comprised of visual alerts, auditory alerts, and an automated phone call, activated at specified distances from the hazards. The visual and auditory alerts include light-emitting devices and the sound of the motorcycle's horn. Four units of MCAS prototype were successfully developed and installed on four different motorcycle models (100cc – 150cc). The functionality of MCAS was evaluated at the GPS-measured riding speeds of 20 km/h, 30 km/h, 40 km/h, 50 km/h, 60 km/h, 70 km/h and 80 km/h. Overall, a 100% operational ability was recorded for LiDAR, GPS, visual alert, and auditory alert at different riding speeds. For the automated phone call alert, the operational ability was 88.9% for riding speeds of 40 km/h or slower but it was found to be less than 20% at higher speeds. In summary, this retrofittable collision warning system was found to demonstrate strong safety benefits and a promising level of operational capacity as a potential active safety technology for small-displacement motorcycles.*

KEYWORDS: LiDAR, collision alert system, active safety technology, small-displacement motorcycle

1. INTRODUCTION

Motorcyclists are considered "Vulnerable Road Users" and due to the lack of physical protection, are at a high risk of fatality when involved in a crash. Fatalities involving motorcyclists in Malaysia are three times higher compared to passenger car fatalities, six times higher than pedestrian fatalities, and nearly 50 times higher than bus passenger fatalities (Abdul Manan & Várhelyi, 2012). Ibrahim et al. (in press) presented an analysis of five years of crash data (2013 to 2017) in Malaysia and reported that motorcycle-truck rear-end crashes were the most prominent of all the rear-end crashes involving heavy trucks, resulting in 588 motorcycle fatalities. The study also reported a substantial increase in the number of fatal rear-end truck-struck crashes with motorcyclists contributing to more than a third of the yearly fatalities. The risk of a collision involving motorcyclists and other vehicles in Malaysia was also reported extensively in previous studies (Hamidun et al., 2019; Ibrahim et al., 2017, 2019).

Motorcycle is a widely used mode of transport in Malaysia and Southeast Asia, either for leisure or work purposes. From another point of view, domestic parcels and other deliveries in Malaysia are highly reliant on the use of land transport, of which 46.6% of the total volume was delivered using motorcycles (MCMC, 2021). A similar MCMC report recorded the delivery of more than 188 million documents, packages, and other domestic deliveries throughout the country in the fourth quarter of 2021, or 2.1 million deliveries per day on average. This represents a three-fold increase in the average number of parcels per capita, compared to 2018. From a road safety perspective, this trend means higher total vehicle travel distances and increased exposure to the risk of road crashes, particularly for courier workers who use motorcycles for delivery.

In terms of motorcycle crash risk on highways, Abdul Manan and Várhelyi (2012) reported a staggering 7.4 motorcycle fatalities for each 100 km traveled on Malaysian highways. Emergency lanes and work zones are the hot spots for crashes involving a stationary or slow-moving vehicle and a motorcycle. In the case of work zones on high-speed roads and highways, the risk of road crashes and other safety issues is well documented (Che Ahmad et al., 2016; Gannapathy et al., 2008; Harb et al., 2008). From a rider's perspective, work zones on high-speed roads can create a hazard, resulting from a divergence from normal operations, that increases the load on cognitive resources related to vehicle control and lane-keeping. Evidently, crashes involving motorcycles striking a stationary or slow-moving vehicle on highways are not uncommon in Malaysia (Bunyan, 2018; Hilmy, 2022).

1.1 Hazard Alerting for Motorcycles

Based on the research and crash data, it is clear there is an opportunity to address motorcycle crashes; particularly those that occur in high-speed roads, emergency lanes, and work zones that involve unexpected, and unanticipated hazards. It is evident that there is almost zero margin for error for a motorcyclist in terms of hazard detection and emergency evasive maneuvering. A failure to detect and respond sufficiently to an obstacle along the riding path can be fatal to a motorcyclist, particularly when it results in a high-speed collision. Motorcyclists would thus greatly benefit from timely notifications of hazards in their forward travel path such that they could better anticipate hazards and adjust their travel path accordingly. Thus, enhancing rider awareness and prompting timely responses to potentially hazardous situations are the main purposes of the invention discussed in the present paper.

1.2 Project for Research on Powered Two-Wheeler Crash Evasion Technology (PROSPECT)

In 2020, the Malaysian Institute of Road Safety Research (MIROS) started a research project called the Project for Research on Powered Two-Wheeler Crash Evasion Technology (PROSPECT). The main objective of the project was to conduct full-scale research and develop crash evasion technologies for small-displacement motorcycles that conform to the standards for motorcycle component type approval. In February 2021, MIROS successfully developed a prototype for a system that can detect an object (e.g., hazards such as a slow-moving or stationary vehicle) along the riding path of a motorcycle and warn the rider, with sufficient time, to perform a safe crash avoidance maneuver (BERNAMA, 2021). The system is called the MIROS Motorcycle Collision Alert System (MCAS). Figure 1 summarizes the planned milestones and expected progress of the project.

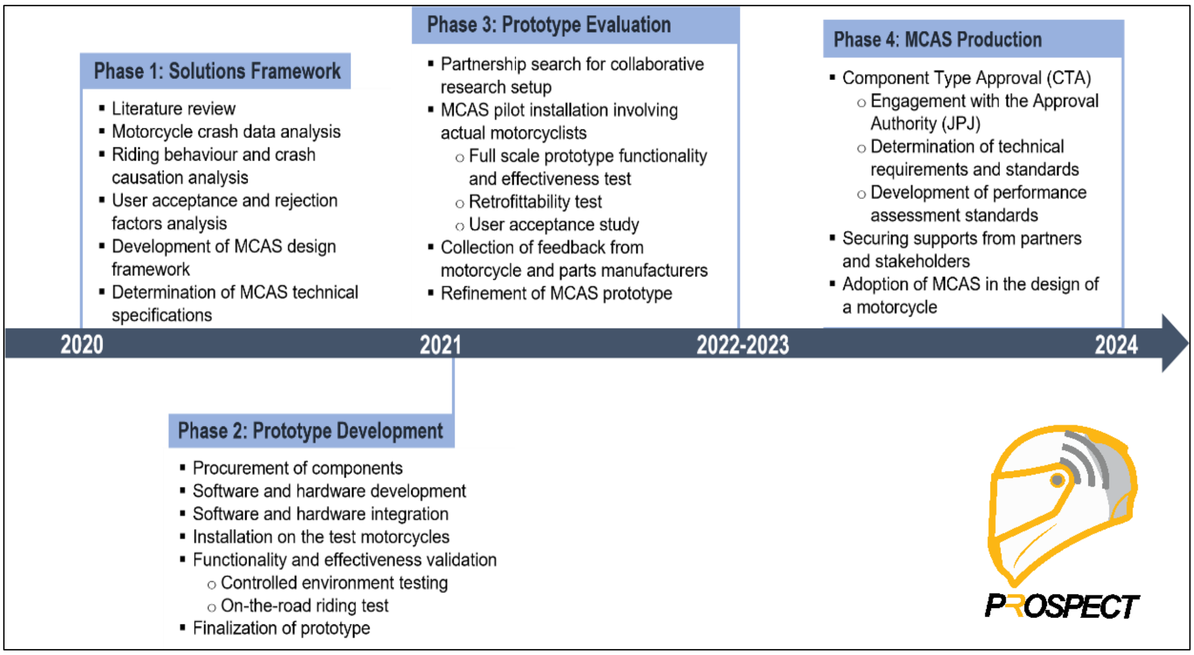


FIGURE 1: Key milestones and expected progress of PROSPECT

During the early stage of the PROSPECT project, an online survey was conducted among the motorcyclists who traveled frequently on highways to determine their lane positioning on highways. The respondents were 747 experienced motorcyclists (mean riding experience of 19.3 years) with 75.1% of them reported riding a motorcycle at least a couple of days a week. On average, the total motorcycle riding hours per day was 2.8 hours with 61.5% reported riding for 1-2 hours daily. The respondents rode on the highways for an average distance of 70.1 km per day with 44.6% of them being daily commuters on highways for the past year. They were asked to name their most frequent lane positioning on highways. The two most common lane positioning reported by the respondents were riding in emergency lanes 80-90% of the time (except during overtaking) and riding in the emergency lanes 50% of the time and another 50% in either the slowest lane or other lanes. A small group of the respondents (7.4%) reported using the emergency lanes during their whole trip on highways and only 1.0% reported using the exclusive motorcycle lanes for the whole trip. In total, the use of emergency lanes was reported in 82% of the total responses suggesting the frequent use of emergency lanes on highways among motorcyclists. In terms of crash experience on emergency lanes or during lane closure on highways, 79 respondents (11.5%) reported having been involved in at least one crash. The results of the survey highlighted the risk of a crash with stationary vehicles or other hazards on emergency lanes or during lane closures and the need for effective pre-collision warning technology for motorcyclists.

2. METHODS

2.1 Design of the MCAS Prototype

The main function of MCAS is to provide a forward collision warning system for motorcycles that alerts the motorcycle operator of an impending hazard or collision risk with other vehicles or obstacles within the forward path of the motorcycle's riding direction. Providing a timely alert allows the motorcycle operator to adjust the bike's trajectory and perform safe collision avoidance actions. The MCAS prototype was designed, constructed, and programmed using the Arduino microcontroller platform (Badamasi, 2014).

A LiDAR-based distance sensor coupled with a GPS module is used to detect vehicles or obstacles within the forward travel path of the motorcycle and activates an automated alert in the form of visual, audio, and cellular input to the motorcycle operator. The alert will increase its intensity as the motorcycle gets closer to the hazard. A key purpose of the GPS module is to monitor the speed of the motorcycle and send the signal to the alarm control unit, thereby delaying the activation of all alerts to allow predetermination of a minimum operating speed of 30 km/h. The main reason the alerts are suppressed at lower speeds is to prevent overwhelming the operator with false alarms, especially during traffic congestion.

A Global System for Mobile Communication (GSM) module (SIM900A) is used to activate an automated phone-calling mechanism for cellular input. The visual and auditory alerts include light-emitting devices and the sound of the motorcycle's horn. We hypothesize that an alert system that changes in form and increases in intensity as the hazard becomes more imminent would increase the effectiveness of the system. The MCAS is connected to and powered by an independent and rechargeable battery (output voltage = 6V). An adjustable step-down voltage regulator (LM2596) was used to produce a variable voltage sourcing for the MCAS electronic circuit. Using an independent battery minimizes the need to modify the original setting of the motorcycle thereby increasing the retrofittability of the system. Figure 2 illustrates the overall system architecture of the MCAS system.

2.2 Installation of MCAS on a Motorcycle

MCAS was designed to be easily retrofitted to increase the acceptance and usage of the system among motorcyclists. Based on the 2019 data, the cumulative number of registered motorcycles in Malaysia was more than 14 million (Road Transport Department-Road Safety Division, 2020). Thus, it is important to ensure the retrofittability of the device. Figure 3 displays an option for MCAS installation on one of the test motorcycles retrieved from its patent application submission to the Intellectual Property Corporation of Malaysia (MyIPO, 2021), which indicates its retrofittability.

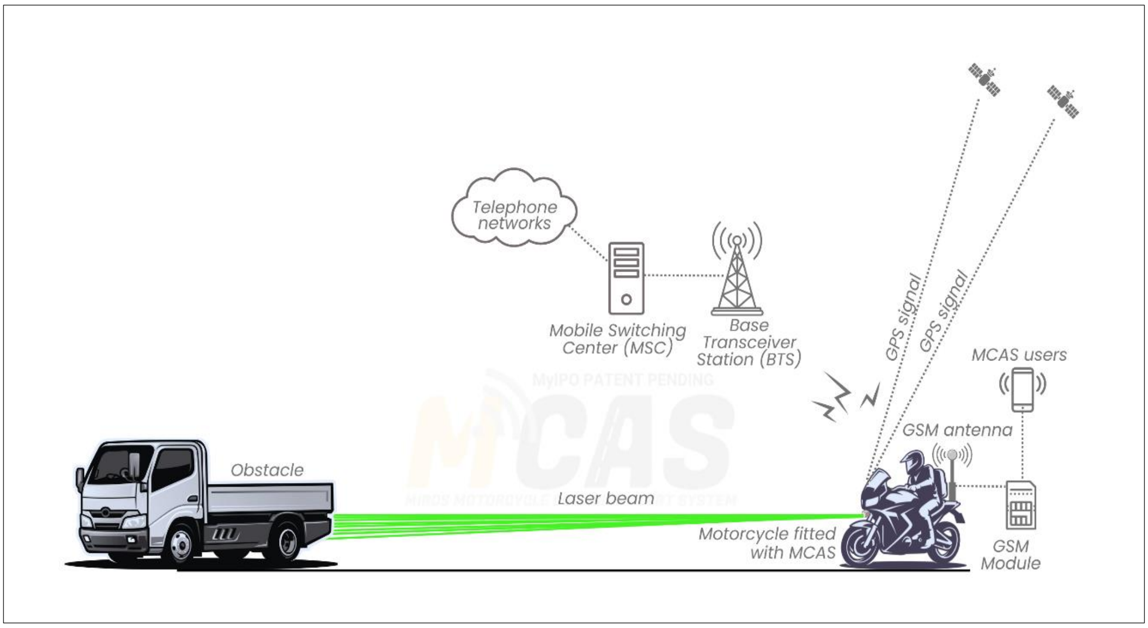


FIGURE 2: MCAS system architecture for hazard detection and alert activation

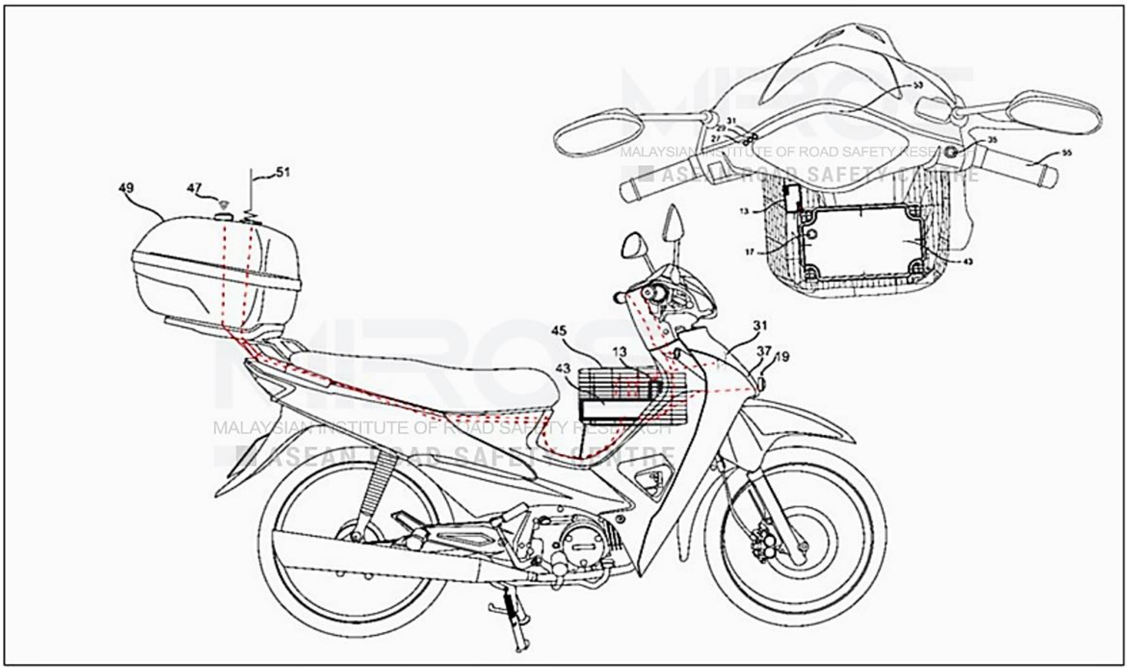


FIGURE 3: An option for MCAS installation on a 2007 motorcycle model (100cc)

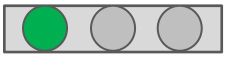
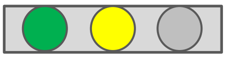
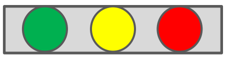
The distance sensor (maximum detection range = 180 m, accuracy = ± 15 cm) was rigidly attached to the motorcycle's front panel (see Figure 4). The MCAS alarm control unit and battery were fitted either inside a cargo basket or a helmet box. The light-emitting devices (visual alert) were fitted onto the instrument panel. A modification was made to connect the MCAS alarm control unit to the horn device to enable the auditory alert.

FIGURE 4: Installation of the LiDAR-based distance sensor on a 2006 motorcycle model (115cc)

2.3 MCAS Alerts Activation Method

The GPS module was used to set a minimum riding speed of 30 km/h before any MCAS alarm was activated. Alert activation and intensity were controlled based on the distance to the detected hazard. The initial, and lowest alert is a benign visual alert (green color LED) activated within 170 - 180 m from the hazard. At that distance and within the same circumstance, a call alert will also be activated. Assuming a trajectory change to a clear path is not initiated when the distance to the hazard is within 150 – 169 m, the visual alert turns from just green to both green and amber. In addition, a more intense auditory alert (motorcycle horn) will be activated. At a distance of 100 m or less from the hazard, the visual alert will become more intense with an additional red color LED activated, along with audio and call alert. Table 1 summarizes the configuration of MCAS alert activation.

TABLE 1: Configuration of MCAS alert activation based on the distance to a detected hazard

Distance to Hazard	Visual Alert	Audio Alert	Call Alert
170 – 180 m		Off	On
150 – 169 m		On	On
≤ 100 m		On	On

2.4 MCAS Prototype Functionality and Effectiveness Test

For testing purposes, the MCAS prototype was equipped with a data acquisition system that was capable of recording the distance from the motorcycle to the objects detected by the distance sensor and the riding speeds detected by the GPS module. Four units of MCAS prototype were developed for this study. The units were installed on four different motorcycle models manufactured in 2006 (115cc), 2007 (100cc), 2018 (150cc) and 2019 (150cc) respectively. The validity tests were conducted in a controlled environment and through on-the-road riding sessions.

In a controlled environment, a test rider rode a motorcycle installed with MCAS from a stopping position (0 km/h) towards a fixed target placed at a distance that varies from 150 - 200 m from the starting point. Figure 5 shows one of the setups for the validity test in a controlled environment. A small-scale naturalistic data collection was also conducted to test the MCAS prototype which involved a test rider riding the test motorcycles on actual roads. The test rider was fitted with a forward-facing action camera with speed measurement capability to record the video images and speed data for proof of MCAS activation and rider behavior analysis.

FIGURE 5: A setup for MCAS validity test in a controlled environment

3. RESULTS

3.1 Detection of Objects

The recorded data from the MCAS data acquisition system throughout the test sessions were analyzed to validate the detection of objects by the LiDAR-based distance sensor. The 164,286 data points recorded during the test were examined and plotted using a hexagonal bin plot to visualize the recorded distance from the detected objects and the respective riding speeds. The plots shown in Figure 6 validated the detection of objects by the distance sensor during the test sessions with a maximum detection range of 180 m. The maximum riding speed measured by the GPS module during the test sessions was around 100 km/h.

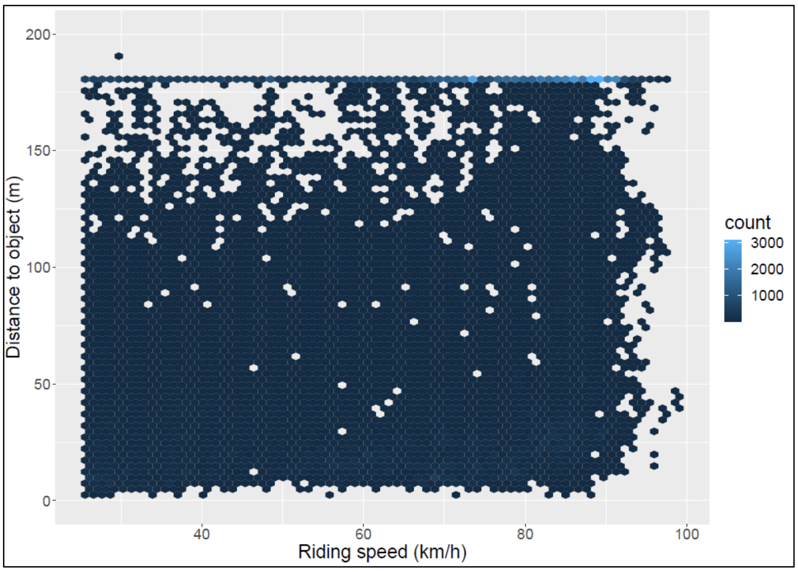


FIGURE 6: Hexagonal bin plot of the recorded data points

3.2 Activation of Alerts

Out of the 164,286 recorded data points, 555 data points were collected when objects/hazards were present within the forward path of the motorcycle's riding direction and the MCAS alert system was activated during the controlled environment tests and through on-the-road riding trips. These data points were analyzed to determine the rate of success for hazard detection and activation of alerts across different riding speeds. Table 1 lists all the output from the analysis.

TABLE 1: The success rate of MCAS alerts and component activation

Speed (km/h)	Success Rate (%)					
	LiDAR (*N*=105)	**GPS (*N*=105)**	**LED (*N*=105)**	**Horn (*N*=105)**	**GSM 2.5 dBi (*N*=102)**	**GSM 15.0 dBi (*N*=33)**
20	89.66	89.66	72.41	82.76	17.39	100.00
30	67.86	67.86	60.71	57.14	7.14	83.33
40	81.82	81.82	77.27	77.27	27.27	83.33
50	100.00	100.00	100.00	100.00	27.27	-
60	100.00	100.00	85.71	100.00	33.33	14.29
70	85.71	85.71	85.71	85.71	0.00	0.00
80	100.00	100.00	100.00	100.00	0.00	0.00
Avg. (%)	89.29	89.29	83.12	86.13	16.06	46.83
SD (%)	12.06	12.06	14.34	15.85	13.83	46.77

Overall, a 100% operational ability was achieved for LiDAR, GPS, visual alert, and auditory alert at different riding speeds. The average success rates (i.e., activation rates) were 89.3%, 89.3%, 83.1%, and 86.1% respectively. For the automated phone call alert, the average operational ability was only 16.1% when a 2.5 dBi GSM antenna was used. A marked improvement was observed when the antenna was replaced with a 15.0 dBi antenna (46.8% average activation rate). It was observed that the operational ability of MCAS's automated phone call alert was affected significantly as the riding speed increased. Figure 7 shows the plot of the success rate (in percentage) for each alert and the main MCAS components. There was no event with the presence of objects/hazards recorded during the test at 50 km/h riding speed with a 15.0 dBi antenna.

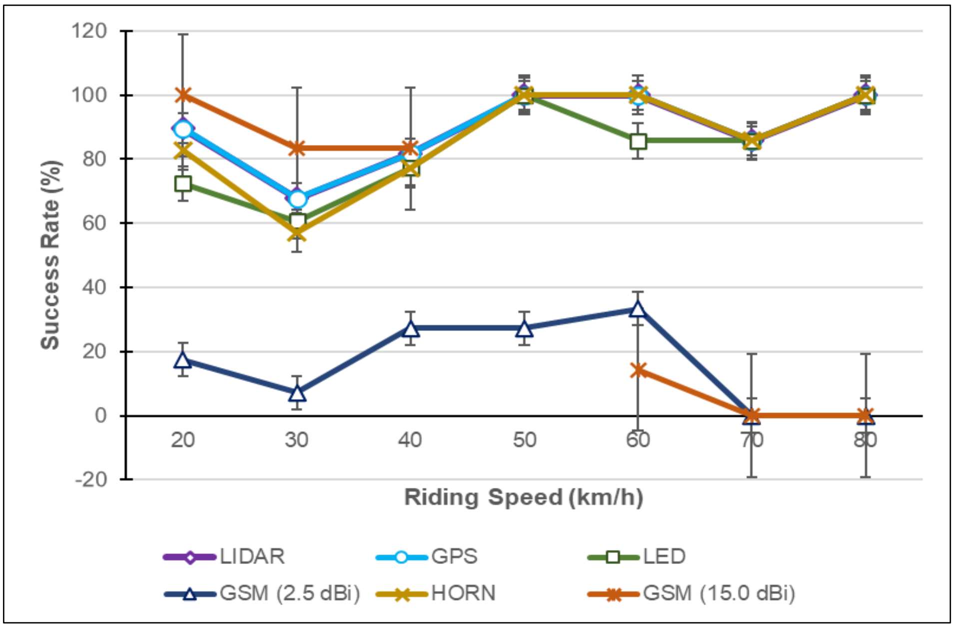
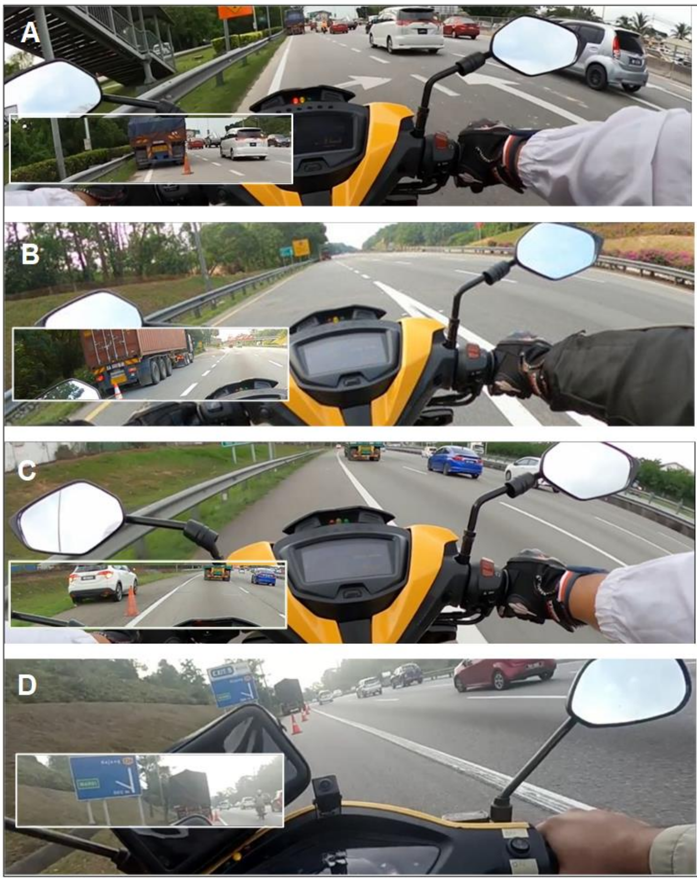


FIGURE 7: Success rate for each alert and the main MCAS components

3.3 Effectiveness of MCAS

Video data recorded using the action camera fitted on the test rider during the on-the-road riding trips were analyzed to estimate the impact of MCAS on the rider's riding behaviors and collision avoidance capacity. Four Safety Critical Events (SCEs) involving the presence of stationary vehicles within the forward travel path of the test rider were analyzed specifically for this analysis. The distance to the hazards, when the first alert of MCAS was activated, ranged from a minimum of 60 m to a maximum of 158 m. The riding speeds when the test rider was first alerted by MCAS ranged from 36 km/h to 86 km/h. Based on the safe rider responses and collision avoidance actions, it was concluded that the MCAS was effective in detecting the hazards and providing a timely alert for the rider to adjust the bike's trajectory safely. Figure 8 displays the footage of each event.



Event	Distance to hazards[a]	Riding speed[b]	Collision avoidance[c]
A	60 m	36 km/h	12 m
B	70 m	86 km/h	35 m
C	123 m	85 km/h	37 m
D	158 m	77 km/h	80 m

[a] *Distance to hazards when the first alert of MCAS was activated.*
[b] *Riding speed when the first alert of MCAS was activated.*
[c] *Distance to hazards when the collision avoidance maneuver was first initiated.*

FIGURE 8: MCAS alerts activation and collision avoidance actions

One specific SCEs recorded during the study were also analyzed to highlight the feedback from the users on the effectiveness of MCAS in collision warning and prompting safe evasive actions. Figure 9 displays a chain of events recorded during an SCE that was related to fatigue, microsleep, and sudden encroaching of the traveling path by another vehicle. MCAS was effective in alerting the rider to the impending collision. Adjustments of riding speeds for safe collision avoidance actions were observed.

The following feedback was recorded from the test rider:

"I was riding along the emergency lane of a multi-lane highway on a long trip. The sun was very intense, and I was starting to feel drowsy. Suddenly, I was startled by the sound of the MCAS audio alert. I realized that I had drifted off and was about to fall asleep. There was a pickup truck veering onto my path. I slammed on my brakes to avoid a collision. I was shaken by the experience, but grateful that I had been able to avoid a collision."

-Test rider A

FIGURE 9: A near-crash event experienced by test rider A

5. DISCUSSION AND CONCLUSION

The main aim of this paper is to document our work in developing the prototype of MCAS, validating its functionality, and estimating its effectiveness. The analysis of validity focuses on the device's accuracy level in detecting objects and activating the alarms. In addition, the retrofittability and transferability of the system were examined. Overall, the prototype of MCAS was found to achieve a promising level of operational capacity and effectiveness. The prototypes developed in this study were successfully retrofitted onto different models of a small-displacement motorcycle with a 13-year gap in their manufacturing dates. In addition, the test methods were found to be effective and replicable to achieve the objective of the study.

Specific issues related to the design of the prototype, installation methods, and environmental factors were also discovered. The automated phone call alert was found to be the least stable in the current prototype's design framework, especially at higher speeds (more than 50 km/h). The main suspected reasons were related to Arduino program execution time and GSM antenna performance issues. There is a possibility that the Arduino program execution time (from the presentation of the first input to termination at the delivery of the last outputs) was affected by riding speeds and the rapid change in the rate of proximity to the detected object. The GSM antenna issue was solved by using an antenna with higher gain values, but the Arduino program execution time issue was found to be more dominant, as evidenced by the poor performances at higher speeds.

We also found that the LiDAR-based distance sensor needs to be installed at an angle of 90 degrees to the front panel of a motorcycle. This perpendicularity is a must for MCAS to operate. In addition, installing the GSM antenna within a closed box was found to reduce its performance. The capacity of the battery and power disruption were also found to be an issue for long-distance trips. In addition, the intensity of sunlight and the resulting glare were found to affect the distance sensor. We found that the sensor was not functioning during several test sessions when the sunlight was very bright. It is possible that this issue was related to the ambient light resistance capacity of the sensor. This issue has been discussed previously by Sun et al. (2016).

In conclusion, the study has demonstrated the strong safety benefits of MCAS as a solution for traffic conflicts involving motorcycles, especially for the small-displacement motorcycle models. This retrofittable collision warning system has also shown a promising level of operational capacity as a potential option for an active safety feature for motorcycles. A natural progression of this work is to develop more units of MCAS prototype and to conduct a full-scale field test involving actual motorcyclists to measure its feasibility, effectiveness, and acceptance among motorcyclists and other road users.

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