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THREAT ASSESSMENT ALGORITHM FOR ACTIVE BLIND SPOT ASSIST SYSTEM USING SHORT RANGE RADAR SENSOR

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ABSTRACT
Road safety has become more concern due to the number of accidents that keeps increasing every year. The safety systems include from simple installation such as seat belt, airbag, and rear camera to more complicated and intelligent systems such as braking assist, lane change assist, steering control and blind spot monitoring. This paper proposes another intelligent safety system to be implemented in passenger vehicle by monitoring the blind-spot region by using automotive short range radar as sensor to assess its surrounding. This system is called Active Blind-Spot Assist (ABSA) system and this system will collaborate with a Steering Intervention system for autonomous steering maneuvers. The objective of ABSA system is to deploy safety interventions by giving warning to the driver whenever other vehicle is detected within the blind-spot region. Furthermore, this active system also triggers autonomous steering control when the potential of collision with the detected vehicle increases greatly. Consequently, a threat assessment algorithm is developed to evaluate the right moment to give safety interventions to the driver and the conditions for autonomous steering maneuvers. The process of developing the threat assessment algorithm explained in this paper.

Keywords: autonomous vehicle, blind spot assist, threat assessment, radar.

INTRODUCTION
Recently, road safety has become more concern as the number of accidents occur is growing. In 2014, a total of 476,196 road accidents has occurred in Malaysia alone with 6, 674 deaths [1]. Therefore, vehicle technologies are rapidly advancing worldwide specifically on safety securities [2, 3] including a passive blind-spot assist. The differences between the passive blind-spot assist system and Active Blind-Spot Assist (ABSA) system is that ABSA system is an upgraded version from the passive system. The passive blind-spot assist system is only focusing on giving warning signals to the driver. On the other hand, ABSA system is not only giving warning signals, ABSA system has authorization on maneuvering the direction of the vehicle itself. In other words, the word 'active' in ABSA system means that this system is capable of controlling the steering autonomously. Therefore, a threat assessment algorithm is developed for autonomous assistance to act accordingly at the right moment and situations when the system to autonomously take over control of the vehicle. The threat assessment algorithm of active blind-spot assist system or ABSA system consists of two major algorithms. The first algorithm is called collision warning algorithm, this algorithm is to warn the driver of potential collision in terms of visual and audio signals when vehicle is detected in blind-spot region. Audible and/or visible can increase the driver's attention in such way that the driver can avoid or mitigate the collision [6]. The second algorithm is called collision avoidance algorithm for active autonomous steering controls, triggered when all the warning indicators ignored by the driver and the distance between the two vehicles get too close. A challenging aspect of the threat assessment is that it has great potential of conflicting with its main purposes. Warnings and interventions that driver consider unnecessary contribute negatively to their confidence in the ABSA system. For example, if the ABSA system gives warning signals too frequently, it will create annoyance to the driver and the driver's trust to such system will decline greatly, and it gets worst if the steering control unexpectedly activated. Therefore, the threat assessment algorithm must be developed so that the system is able to assist the driver to ensure the vehicle safety thus increasing the system's reliability. This system will collaborate with other autonomous systems such as lane change assist, lane keeping assist, braking assist, obstacle avoidance where ultimately will be combined to create a complete autonomous vehicle that can drive itself. Therefore, it is necessary for ABSA system to be able to provide more information as much as it can such as the target vehicle's velocity. This paper shows the process of how the threat assessment algorithm is developed.

SYSTEM HARDWARE AND DETECTION REGION
ABSA system uses a couple of short range radar as sensor to monitor the blind-spot region and these radars are designed for automotive applications. They are mounted at the back corner of multi-purpose vehicle (MPV) as shown in Figure-1.

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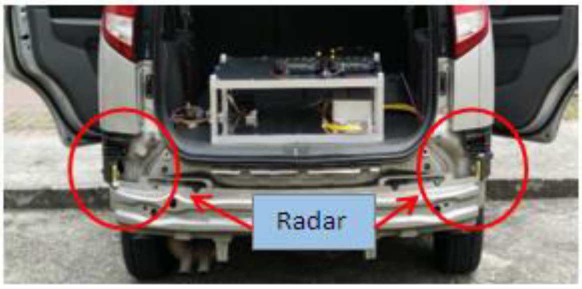

Figure-1. Location of radars mounted.

ABSA system uses a couple of identical SRR-209 radars from Continental Corp. Typically under bad weather, the driver often unable to notice the presence of other vehicle in the blind-spot region. For this reason the radar is chosen because it can perform well under any bad weather such as heavy rain, haze, or fog, unlike vision-based camera. On the other hand, vision-based camera must consider daytime and nighttime leading to much more complicated algorithm [7]. If using a sensor that cannot perform well under bad weather, it will defeat the main purpose of the ABSA system. Table 1 shows the specifications of the SRR-209 [4] and based on the performance of the radar, the detection region is designed. When the radar detected an object, the radar will output its relative velocity, radar cross section value, and polar coordinates using distance range and azimuth angle. The initial output of the object detected by the radar is in polar coordinates therefore to design the detection region the polar coordinates need to be converted into Cartesian coordinates (x, y)so that it is easier to pinpoint the locations of the object detected for calibration

Table-1. Continental SRR-209 characteristics [4].

Parameter	Value
Distance Range (m)	1 - 50
Azimuth Angle (degree)	±75°
Elevation Angle (degree)	±6°
Cycle Time (ms)	38
Radar Frequency Band (GHz)	24.05 - 24.25

The objective of ABSA system is to alert the driver when vehicles presence especially in the blind-spot region at any sides of the host vehicle is detected. Blind-spot region is a region where the driver unable to monitor because it is located at the side and rear of the vehicle which is out of eye sight. Even with the help of rear mirror and side mirror, still it is unable to give the driver a clear sight of the blind-spot region. This blind-spot region is the most important region to the driver for evaluation so that the driver can decide whether it is safe to change lane or not. Occasionally, even with the help of side mirror, the driver can be deceived and assuredly thinking that there is no presence of other vehicles thus leading to the causes of unwanted accidents. Therefore, with the help of ABSA system, such accidents can be avoided by alerting the driver of the presence of vehicle in the blind-spot region and confidently with such information contributes to the driver's decision making. The detection region of ABSA system is designed based on the Blind Spot Monitoring System (BSMS) by SEA International as guidelines for surface vehicle recommended practice [5]. Figure-2 shows the detection region according to Blind Spot Monitoring System (BSMS) as ISO compared to the ABSA system.

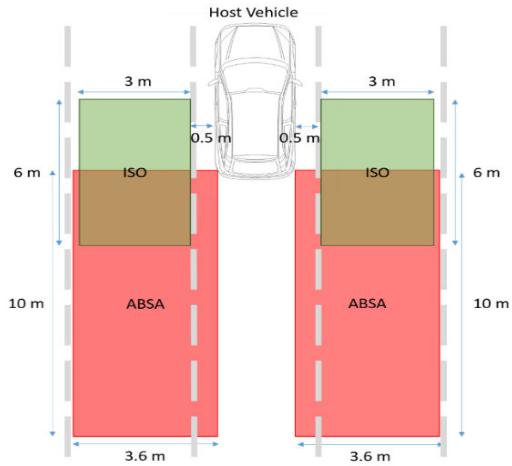

Figure-2. ABSA system and ISO detection region comparison.

As shown in Figure-2, ABSA system detection region is different and larger than the ISO's detection region. Even though ABSA system does not cover the whole recommended region but it is sufficient as the rear of the target vehicle is still can be detected. ABSA system is designed to detect up to ten meters for the system to be able to classify the target vehicle's type. However, the classification of vehicle's type is not covered in this paper. Based on the ABSA system detection region, the threat assessment algorithm is developed to fulfil all the ISO's standard recommendations. The detection region is then divided into two regions. The first region is called alert region and second region is warning region as shown in Figure-3.

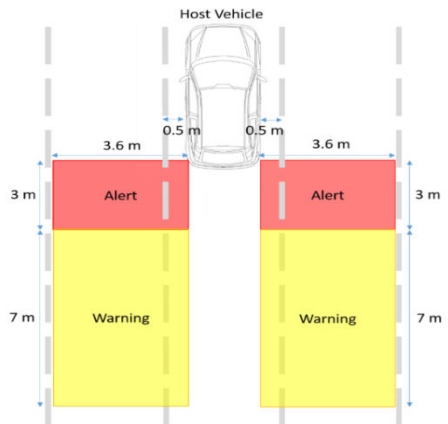

Figure-3. ABSA system's alert and warning regions.

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Each region gives a different pattern of warning signal to the driver. When a target vehicle is detected within warning region, the LED will start blinking and once the target vehicle entered the alert region, the LED will turn on constantly. If there are two target vehicles detected and each vehicle is within each region, the priority will be given to the alert region. The LEDs are located at both ends of the host vehicle's dashboard as shown in Figure-4. With different types of warning signals the driver can locate the current location of the incoming target vehicle

Figure-4. Location of LED installed.

Collision warning algorithm

As previously mentioned earlier in introduction, ABSA system encompasses of two major algorithms which consisted of collision warning algorithm and collision avoidance algorithm. Collision warning algorithm is the process of alerting the driver of the presence of the other vehicle in blind-spot region after these conditions are met. The first condition requires the object detected by the radar to be a target vehicle within the detection region. Target vehicles are of any highway licensable vehicles, considered larger than 125 cc motorcycle while pedestrians, pedal-cyclists or motor vehicles less than 125 cc engines will be considered as optional targets. The second condition, the detected target vehicle must be moving in the same direction as the host vehicle. Therefore, any object coming from opposing direction, stationary, including parked vehicles, roadside furniture and appurtenance will be ignored by the ABSA system thus it will not produce any warning signals to the driver. These unwanted objects are called non-targets [5]. Initially the radar will detect any object including the non-targets objects therefore the radar output must undergo the filtering process. The main problem is to differentiate between the incoming vehicle from the opposite direction and the same direction. The opposite direction includes vehicles which move slower than the host vehicle. It will be a huge distraction to the driver if the ABSA system keeps giving warning whenever the driver takes over other vehicle or vehicle from opposite lane passing by the host vehicle. Fortunately, the radar uses Doppler Effect to measure the relative velocity of the object detected. Relative velocity output from the radar will be the solution for this problem. Doppler Equation as shown in Equation 1

$$f' = \frac{Vo - Vs}{Vs} f \qquad (1)$$

Where

f' is the apparent frequency.
f is the real frequency.
v_o is the velocity of host vehicle.
v_s is the velocity of target vehicle.
v is the velocity of sound or light in medium

The relative velocity is the differences between the velocity of the host vehicle, v_o and the velocity of the target vehicle, v_s as shown in Equation 2. The polarity of v_o and v_s depends on the direction of the vehicle.

$$Vr = Vs - Vo \qquad (2)$$

Where

v_o is the velocity of host vehicle.
v_s is the velocity of the target vehicle.
v_ri s the relative velocity of target vehicle to the host vehicle.

When the detected object is approaching the radar, the polarity of the relative velocity is positive and negative polarity when the object is moving away from the radar. By using this simple finding, any object with relative velocity below 0 will be filtered out from radar detection simultaneously filtered out any static objects, such as parked vehicle and roadside furniture when the host vehicle is moving forward. Relative velocity 0 indicates that the target vehicle is in same speed with host vehicle and the system will warn the driver

Collision avoidance algorithm

The other algorithm is called collision avoidance algorithm used to trigger the active system, which overrides the steering control to prevent collision. This evasion control will be taken over by the Steering Intervention system. This system is triggered when an active signal is given by the ABSA system under these conditions. First condition is when target vehicle is detected in alert region. Second condition is the lateral distance between host vehicle and target vehicle is below 1 meter and decreasing. This occurs when the host vehicle is trying to enter potential collision lane as shown in Figure.5. Third condition is when the turn signal is turned on by the driver. Once all the conditions are met, ABSA system will send the active signal to Steering Intervention system and trigger the evasion control by steering the host vehicle back to the center of its original lane.

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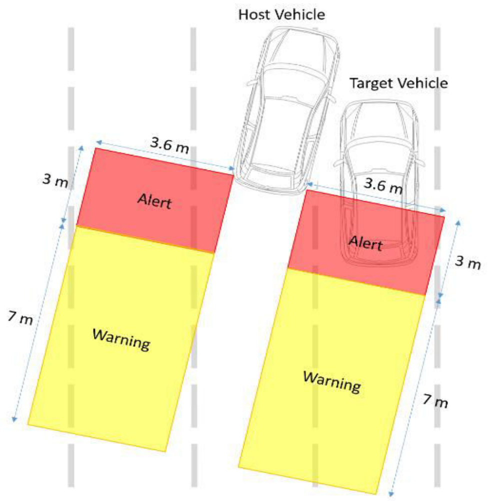

Figure-5. Host vehicle trying to change lane.

Threat assessment flowchart

Both algorithms are combined into one threat assessment algorithm and its flowchart is shown in Figure-6. The ABSA system will only be activated if the host vehicle's speed is 35km/h and above.

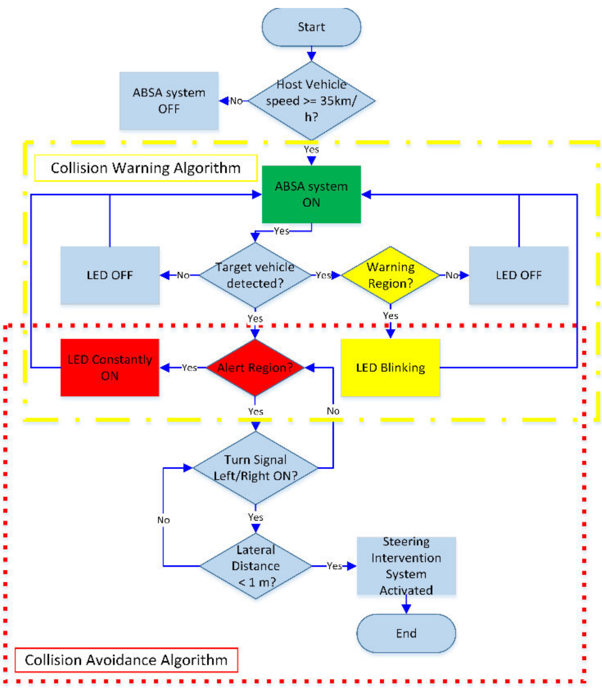

Figure-6. ABSA system's threat assessment algorithm flowchart.

EXPERIMENTAL SETUP

Based on the flowchart in Figure-6, several experiments have been conducted on Proton Tanjung Malim's test track to test the robustness of the threat assessment algorithm. The test is divided into four type of situations as follows: Target vehicle overtaking host vehicle, host vehicle overtaking target vehicle, host vehicle having the same speed with target vehicle and collision avoidance algorithm test. All the tests will be conducted with different vehicle speed. The threat assessment algorithm will be validated based on the alert, warning and active signals given by the system. Therefore, the signals will be recorded in each test, with other parameters such as the coordinates, relative velocity and radar cross section value. Figure 7 and 8 show how the tests are conducted on the test track and the views from the host vehicle and target vehicle.

Figure-7. Testing in progress from target vehicle's view.

Figure-8. Testing in progress from host vehicle's view.

EXPERIMENTAL RESULTS

The test results are tabulated according to each situation.

Target vehicle overtaking host vehicle

Table-2. Target vehicle overtaking host vehicle results.

	Velocity(km/h)		**Alert signal**	**Warning signal**	**Active signal**
	HV	*TV*			
1	40	60	✓	✓	×
2	60	80	✓	✓	×
3	80	100	✓	✓	×

Table-2 shows the test results for target vehicle overtaking host vehicle situation and the results are promising. The target vehicle will come from behind to overtake host vehicle with relative velocity 20km/h. The LED starts to blink when the target vehicle entered warning region, then it is constantly activated when the target vehicle entered alert region, lastly the LED turned off right after the target vehicle has successfully overtook the host vehicle.

Host vehicle overtaking target vehicle

Table-3. Host vehicle overtaking target vehicle results.

	Velocity(km/h)		**Alert signal**	**Warning signal**	**Active signal**
	HV	**TV**			
1	60	40	×	×	×
2	80	60	×	×	×
3	100	80	×	×	×

Table-3 shows the test results for host vehicle overtaking target vehicle situation. When the host vehicle overtakes target vehicle, it is expected that the ABSA system will not give any signals because the relative velocity of the target vehicle has negative polarity.

Host vehicle having the same speed with target vehicle

Table-4. Host vehicle having the same speed with target vehicle.

	Velocity(km/h)		**Alert signal**	**Warning signal**	**Active signal**
	HV	**TV**			
1	40	40	✓	✓	×
2	60	60	✓	✓	×
3	80	80	✓	✓	×

Table-4 shows the test results for host vehicle having the same speed with target vehicle situation. At same speed the results show the anticipated results as well. When the target vehicle is detected in alert region and warning region, the ABSA system responded and gives warning signals.

Collision avoidance algorithm test

Table-5. Collision avoidance algorithm test.

	Velocity(km/h)		**Alert signal**	**Warning signal**	**Active signal**	**Steering feedback**
	HV	**TV**				
1	40	40	✓	×	✓	✓
2	60	60	✓	×	✓	✓
3	80	80	✓	×	✓	✓

Table-5 shows the collision avoidance test results. This test is the most dangerous test as the host vehicle will approaches the target vehicle with turn signal is activated. The host vehicle will keep approaching the target vehicle until the lateral distance is below 1 meter so that ABSA system will trigger the active signal to the Steering Intervention system and then initiate the autonomous steering control to avoid the collision. Despite the dangerous actions, all the results met the expectations.

CONCLUSIONS AND FUTURE WORKS

In this paper, an effective threat assessment algorithm for Active Blind-Spot Assist system has been proposed. The proposed ABSA system uses only two radars that were installed at the back of experimental vehicle and the algorithm is fully based on the radar's output. Moreover, this algorithm is designed only for straight movement. For future works, the threat assessment algorithm will be improved for cornering movement. This demands more parameters are needed such as steering angle and vehicle's yaw rate to be included

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