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Paramount Automotive Rear-End Collision LIDAR Warning System

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ABSTRACT
There have been several advancements in the automotive industry in the area of advanced driver assistance systems where radar and mono-cameras have been used to increase driver safety and driver awareness through feedback resulting from gathered data of vehicle surroundings. Rear-end accidents are the most common type of vehicle-to-vehicle accident and if advanced warning systems that alert the driver of a danger approaching from the rear were in place, there would be a great reduction in loss of life and reduction in damage costs. LiDAR technology is the most feasible way to implement rear-end warning alert systems due to its accuracy in obtaining measurements and resistance to noise from adverse weather conditions and other environmental factors. This paper presents a high-performance rear-end warning collision alert system that implements a Garmin Lite V3 LiDAR sensor and minicomputer to convert distance and velocity measurements. Communication is established serially using I2C, to alert the host vehicle driver of an imminent danger approaching from behind. The system was successfully implemented on a standard mid-sized sedan under speed and distance conditions common to most rear-end collisions. The system provided accurate results in most of the trials and maintained stability and accuracy during testing conditions.

Keywords – ADAS, LiDAR, RADAR, Driver Safety, Rear-End Warning Collision

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I. INTRODUCTION

There are no doubts that rear-end collisions are common and they come with a lot of health and financial burden. These collisions account for 29% of all police-reported crashes in the United States, which equates to approximately 1.8 million annually [1]. The technology involved in making vehicles safer to operate has been advancing at a rapid rate in recent years and with the advent of self-driving vehicles, there has been an even greater emphasis on ensuring the safety of passengers. LiDAR sensors use a simple method of transmitting a laser signal and awaiting a reflection from an object in the signal path. By calculating the time delay between the transmitting and receiving the signal, a LiDAR sensor can calculate the distance. With a few more manipulations velocity can also be obtained [2]. In the past couple of decades, LiDAR has played a massive role in autonomous and semi-autonomous vehicle application for navigating environments [3]. It is even used by scientists at NASA and ecologists to learn more about space and different ecosystems, respectively [4, 5]. Whether it’s recognizing lane obstacles or tracking endangered tree populations, LiDAR has proven a capable asset in many applications. Although autonomous vehicles can make powerful use of LiDAR sensors, there are also non-autonomous vehicles that can implement them to provide a safer environment for the driver and passengers. All of those state-of-the-art safety features in modern day cars can prove very costly, but if there was a way to make a relatively cheap module that can be affixed onto any vehicle, new or old, that would improve vehicle safety, it can revolutionize the automotive industry. The main components of the LiDAR system are a transmitter and a receiver, an optical analyzing system to process the input data and a computer that can act based on the data received. Using these components, an external device can be planted in a vehicle that would provide a warning system for imminent dangers; especially the threat of rear-end accidents. The rest of this paper is organized as follows: section 2 discusses rear-end ADAS technologies. Sections 3 and 4 provide a detailed system overview description and implementation of the developed system. Section 5 describes system design limitations. Sections 6 and 7 present the test conditions and experimental results. At last, Section 8 concludes the paper.

II. REAR-END ADAS TECHNOLOGIES

Before we move onto specific types of Advanced Driver Assistance Systems (ADAS) technologies, we must first categorize active-safety systems, meaning systems that intervene before the accident actually occurs, into two distinct types. Pre-crash systems prepare the vehicle for collision directly before the accident with the intention of lessening the consequences of the accident while driving assistance systems to support drivers in critical driving situations, returning them from a critical driving situation into a controlled one. To effectively mitigate an imminent collision or to warn the driver of a critical situation, the sensor on the rear of the vehicle should be able to fulfill some requirements. The sensor should ideally have a field of view of 180° and be able to detect objects as clearly as possible. Also, it should have immunity to adverse weather conditions. In addition to that, the main factors that are taken into consideration when determining the best sensors are, their ability to obtain information regarding the distance to the host vehicle, relative velocity, object width, lateral position and time to collision [6, 7, 8]. Currently, there are three main systems that are able to sense for obstacles in front or in the rear of the vehicles that can provide alerts or execute a maneuver to avoid a collision. The following is a brief highlight of those different systems that can provide insight on where the proposed system fits and its advantages and disadvantages.

1.1 Mono Camera

A video system is a seemingly antiquated technology that utilizes a grayscale capture of an object that is then used to extract information regarding its shape and appearance. There are significant drawbacks to this method because of increased sensitivity to adverse weather conditions and its ability to detect objects is not as robust as its LiDAR and RADAR counterparts [9]. However, when this method is coupled with distance measurements from a LiDAR or RADAR sensors in a process called “sensor fusion”, there is a massive improvement in the gathered data.

1.2 Radar

There are two main types of RADAR distance measuring sensors, the pulse RADARs and the continuous-wave RADAR. This type of sensor has the flexibility in that it can calculate velocity using the Doppler Effect which is a trait LiDAR sensor do not possess [10]. The former method sends out a single pulse and calculates the distance using time-delay methods. Furthermore, the velocity can be measured using a differentiation of this distance. Continuous-wave RADARs transmit continuously, and the distance measurement is calculated using frequency information. These methods cause inaccuracies due to the fact that the combinations of distance and velocity measurements must be taken when extracting this information from the differences in frequencies [11]. In terms of scanning methods, an antenna mounted on a mechanical swivel is used to scan at different steps but because of the high costs for such a device, it is rarely found in the market. Instead, a cheaper a method, referred to as the multi-lobe method, is commonly used but results in inaccurate lateral positions and cannot be used to extract object width from the scan.

1.3 Lidar

A more promising approach to get information on incoming objects is using LiDAR, which is an optical sensor containing a laser diode for the transmitter and photodiode for the receiver. There are two methods for retrieving information from a LiDAR scanner. Multi-beam sensors use arrays of transmitting and receiving elements to cover different angle segments and the scanning LiDAR sensors that use a mechanical swivel that sends out a single beam at each angle step [9, 12]. LiDAR is a much more reliable distance measurement tool for both lateral position and to retrieve the width of the object and it measures the distance directly using the equation below where c is the speed of light (~299,792,458 meters/second) and t is the time of flight of the laser beam.

$$\mathbf{D = (c*t) /2}$$

The only real limitation LiDAR has in comparison to RADAR is the inability to directly calculate velocity as RADAR uses the Doppler Effect. In the coming sections, we will explain how a LiDAR sensor was integrated in the system to sense the dangers of rear-end collisions.

III. SYSTEM DESCRIPTION

As previously mentioned, many accidents are caused by a lack of focus on the road and texting while driving. The proposed device is a pre-crash warning system that would alert the driver of the host vehicle of an imminent crash by issuing a warning sound. We have seen that LiDAR is one of the most effective methods for driver-assisted cruise control and based on this, the design chosen for this system will also utilize a LiDAR sensor. The system uses the Garmin LIDAR Lite V3 range finding module to calculate distance and velocity from time-of-flight of the near-infrared signal. The LiDAR was interfaced with a Raspberry Pi that took the distance and velocity readings as inputs and entered a decision matrix to determine whether or not to activate the signal to the speaker. The LiDAR module device mounts to the rear bumper of the vehicle to be in an optimal position for scanning. It was supplied with 5V DC signal supplied from the in-vehicle cigarette lighter receptacle and a Foval brand 150W Car Power Inverter to accommodate the Raspberry Pi’s power supply. If a velocity 25 km/h or less is recorded along with a distance less than 20 meters the warning will come in the form of a 1 KHz sine tone (3 V_{P-P}) coming from the speaker, which is connected to one of the GPIO pins of the Raspberry that would sound for 5 seconds. This can be done by switching the output of GPIO4 on the Raspberry Pi "On" and "Off" at a frequency of 1KHz. Figure 1 below introduces a system flow diagram.

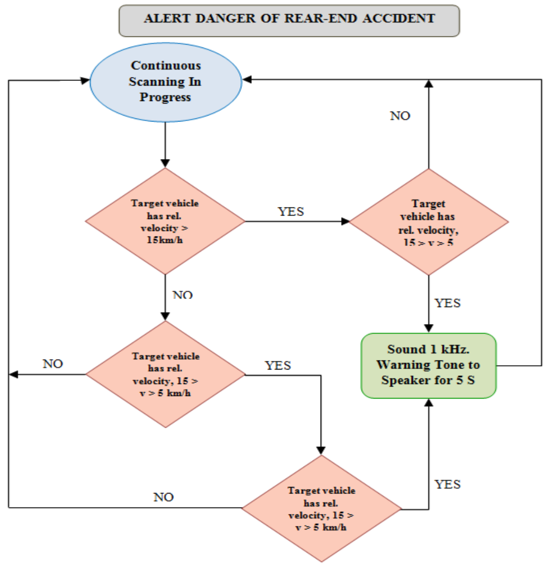

Fig. 1: System Flow Diagram

IV. SYSTEM IMPLEMENTATION

The computing power is centered in the Raspberry Pi 3 Model B mini-computer which contains a Quad Core 1.2GHz Broadcom BCM2837 64bit CPU and 1GB RAM and more importantly, a 40-pin extended GPIO. Using this module may seem like overkill but it was chosen due to its versatility and potential in expanding the project should the need arise. The ports used on the Pi were the SDA and SCA ports, GPIO4 port and the 5V power supply and ground pins. In later iterations of the project, there may be a need to utilize some other GPIO ports to provide more feedback warning to the driver if there are dangerous situations such as text display output. The LiDAR LITE V3 by Garmin is a compact device that utilizes a proprietary time-of-flight calculation method. It transmits a 905 nm signal at 1.3 watts to a target object and receives the reflected signal and calculates distance and velocity. The device first sends out a signal directly from the transmitter to the receiver to reference a "zero" time-delay. Then to begin the actual measurement, the device sends out a signal and once the signal reflects off an object within range, depending on the distance of the object the result is stored at a specific location depending on that distance. The next measurement of that same distance is stored at that same location and summed with the previous result. Once these results reach a pre-determined peak value, a distance is measured. If that peak value is not reached, no distance is measured for that specific location.

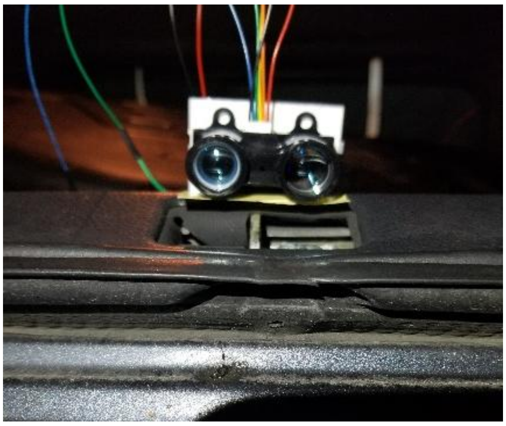

Fig. 2: Front View of Sensor Placement in vehicle

Fig. 3: 1KHz Sine Tone Speaker

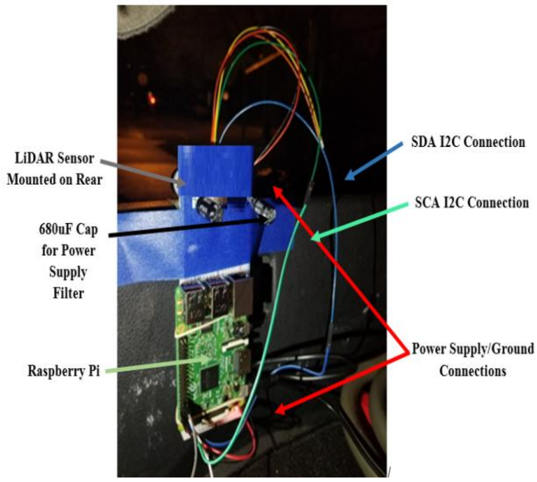

Fig. 4: Complete System Implementation

V. SYSTEM DESIGN LIMITATIONS

Using the LiDAR Lite V3 LiDAR module with this system has provided valuable data but it does have some limitations. A major one is that the sensor has a maximum range of 40 meters when taking measurements. Such a sensor will still able to give the drivers a reasonable reaction time but, an increased range would be preferred for this kind of implementation. In addition, this sensor gathers data using a reflected signal; it will be hindered by surfaces covered in a liquid due to the absorption or refraction of the near-infrared beam. Rain or snowy environmental conditions can impact the device performance. The actual sensor in the vehicle must be protected against weather conditions such as rain, fog, etc. Finally, at distances greater than 1 meter, the LiDAR unit has an accuracy of ±2.5 cm which may be a source of minor errors in the readings.

VI. TEST CONDITIONS

According to German GIDAS data (German In-Depth Accident Study), most of the vehicle-to-vehicle single rear-end collisions occurred on urban roads. Because of this fact, testing was conducted in an urban road in an attempt to replicate the worst-case scenario as evident from the GIDAS data. It was also mentioned in the same study that the difference in speed between the vehicles at the time of the collision was less than 15 km/h in more than 70% of 496 randomly sampled rear-end collisions involving personal injury [13, 14, 15]. In our test, the speeds that were tested ranged from 5 km/h to 25 km/h. The testing scenario had a host vehicle stationary while the target vehicle was approaching at the different velocities specified in the chart in Table 1. The target vehicle started at a distance of 5 meters from the host, although the LiDAR Module has a range limit of 40 meters, to ensure that the target would be moving at the appropriate velocity for each of the trials. Once the target vehicle began accelerating towards the host vehicle and reached the appropriate distance and velocity, the acquisition began and the state of the tone was verified and recorded. A total of 10 trials were performed on both sunny and cloudy days. The experimental data are presented in table 1.

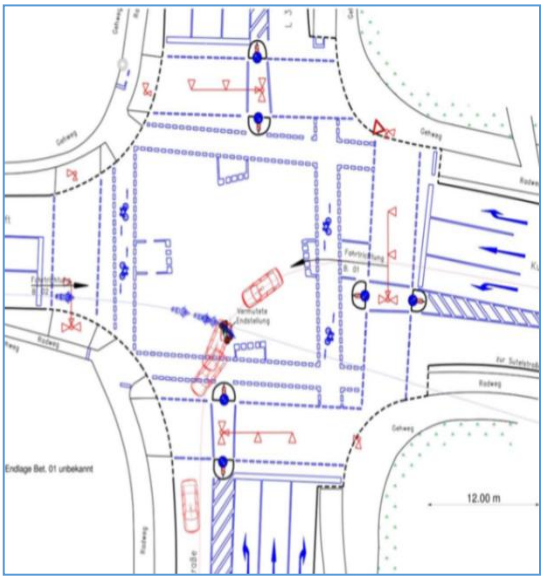

Fig. 5: True to scale drawing for GIDAS study

Table 1: Testing conditions where distance, velocity were varied

Trial	Distance	Velocity	Weather Conditions	Tone	Result
1	5 m	5 km/h	Overcast	Yes	PASS
2	8 m	10 km/h	Overcast	Yes	PASS
3	10 m	15 km/h	Overcast	Yes	PASS
4	15 m	20 km/h	Overcast	Yes	PASS
5	20 m	25 km/h	Overcast	No	FAIL
6	5 m	5 km/h	Overcast	Yes	PASS
7	8 m	10 km/h	Overcast	Yes	PASS
8	10 m	15 km/h	Overcast	Yes	PASS
9	15 m	20 km/h	Overcast	Yes	PASS
10	20 m	25 km/h	Overcast	No	FAIL

VII. TEST RESULTS

As seen from the table, the system was effective in issuing a warning signal once the condition for both the target vehicle velocity and target vehicle distance were met 80% of the time for both clear and overcast conditions. The only two cases where the warning signals were not issued, when the distance was 20 meters and the speed was 25 km/h for both cloudy and clear conditions. Upon revisiting the test method, it becomes clear that the chosen distances for trials were very close to the limits of the decision matrix. To overcome this issue is to increase the limit in the program. In addition, the accuracy tolerance in the LiDAR module ± 2.5 cm can help reduce many false triggers or "no tone" scenarios.

Other criteria that have been tested were the compactness and feasibility of this system. The device was mounted in the rear of the host vehicle. It has been determined that there must be a fixture designed to create a more secure environment protecting the LiDAR and rest of the system. The footprint of the system was small and can be easily affixed to any location in the vehicle trunk that has no path obstruction.

VIII. CONCLUSION

There is no doubt that human errors play a major role in all traffic accidents. With the advancement of technology, especially in the automotive industry, there is a great opportunity to make vehicles safer. Since rear-end collisions are one of the leading types of vehicle collisions, preventing this will not only prevent injury and loss of life but also save money in property damage. Of all the sensor options that could have been implemented, LiDAR has proven to be the most accurate and resilient in the face of adverse weather conditions. This paper discussed the rear collision avoidance system that is comprised of a LiDAR sensor mounted above the bumper of a vehicle that issues a warning tone to a speaker stationed in the cabin in front of the driver.

Multiple experiments with the system have been tested with promising results. Further tests may be conducted to prove out the resistance of the system against adverse weather conditions. We may also need to improve the mounting structure to reduce the possibility of damage to the device and protection from security concerns. The former was evidence of the concept that could be implemented with some minor modifications that were demonstrated through a practical prototype.

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