

CHAPTER 3 – RESEARCH METHODS

3.1 Root Cause Analysis

3.1.1 Fishbone Diagram

Road accidents can be caused by several factors, to identify the potential causes of the problem fishbone diagram will be used as a problem analysis. The fishbone diagram ensured there is no stone remains unturned in the study of the road accident problem.

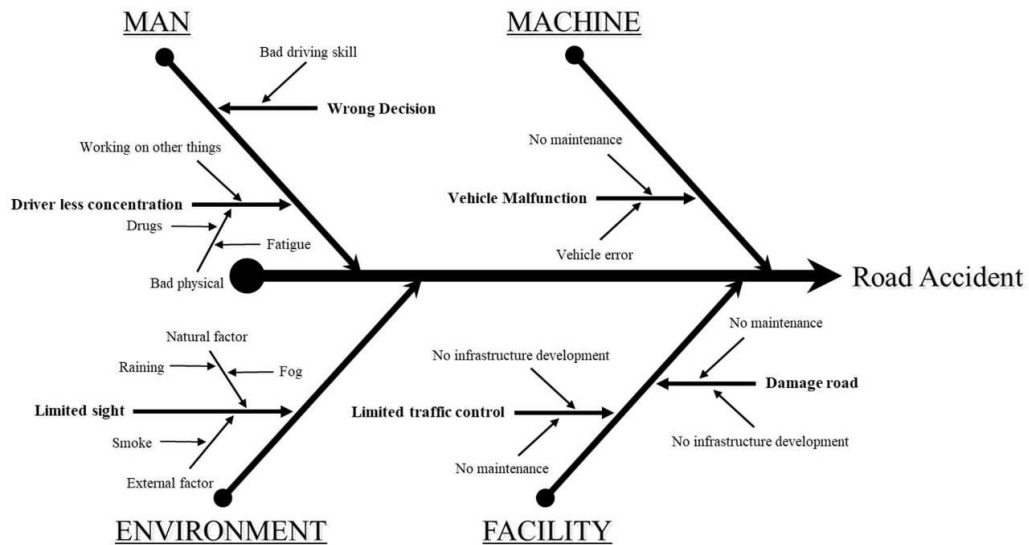


Figure 3.1 Road Accident Fishbone Diagram

From Figure 3.1, the fishbone diagram shows the 4 main categories for the root cause of the road accident problem, i.e.: man, machine, environment, and facility. Each category identifies potential causes as the root cause of the road accident.

- Man. Focus on the root cause from the driver's side, the potential causes in this category are bad driving skills, driver misfocused (working with other things), and driver bad physical condition.

- Machine. The potential cause triggered by the machine is related to vehicle malfunction that may be caused by lack of maintenance and system error of the vehicle design.
- Environment. Separate to the 2 main root causes, the environment can be impacted by natural factors (rain, fog, disaster) and external factors (smoke, etc.).
- Facility. This category identifies possible causes by the government organization such as the infrastructure eligibility and its maintenance.

3.1.2 Why-why Analysis

Road accident root causes have been defined in the fishbone analysis which is categorized into 4 main items. In further analysis of the root cause, it is necessary to make a why-why analysis of the root cause of the fishbone analysis. The why-why analysis is summarized in the Table 3.1.

Table 3.1 Road Accident Root Cause why-why Analysis

Problem	Category	Why 1	Why 2	Why 3	Root Cause	Weakness
Road Accident	Man	Driver less concentration	Working on other things (gadget or other tools)	-	Driver focus on other things during driving	People awareness
			Bad physical condition	Fatigue	Driver feels fatigue	People awareness
				Drugs or alcohol effect	Driver have drugs effect	People awareness
		Wrong decision	Bad driving skill	-	Driver bad driving skill	People awareness
	Machine	Vehicle Malfunction	Vehicle system error/ not function as standard	-	Vehicle system have abnormality function	Vehicle malfunction detection
			No maintenance	-	No maintenance on vehicle makes error during usage	Vehicle malfunction detection

	Environment	Limited sight	Natural factor such as bad weather (rain, fog)	-	Natural factor of environment	No detection
			External factor such as smoke	-	External factor of environment	No detection
	Facility	Limited traffic control	No infrastructure development yet	-	No infrastructure development yet	No detection
			No maintenance	-	No maintenance on facility makes error during usage	No detection
		Damage road	No infrastructure development yet	-	No infrastructure development yet	People awareness
			No maintenance	-	No maintenance on facility makes error during usage	People awareness

Why-why analysis mentions the root cause in accordance with the fishbone analysis root cause in the 4 categories, which are re-categories into the weaknesses of people awareness, vehicle malfunction detection, and no detection. So, it is decided the countermeasure based on the improvement of the weaknesses.

Table 3.2 Countermeasure Improvement of the Weakness Point

Problem	Weakness	Countermeasure	
		Corrective	Preventive
Road Accident	People Awareness	Self-awareness of physical condition, don't drive with bad physical condition	Additional system detection
	No detection	Additional infrastructure development	Additional system detection
	Vehicle malfunction detection	Additional system detection for malfunction	Vehicle maintenance

In conclusion, it is necessary to make an additional improvement to give detection for improving people's awareness and less detection issues. Based on the target improvement, the Vehicle Collision Warning System can fulfill the road accident problem improvement needed.

3.2 Overview of the Development Method

3.2.1 Research Methodology

The research methodology will emphasize a hands-on and practical approach to developing and validating driver assistance collision warning systems. It started with the thesis proposal acknowledged. In this stage, researcher will define the research problem, introduce the significance of the system, and specify the objective of developing the driver assistance system. After acknowledging the thesis proposal, researcher will conduct a literature review to learn about the existing vehicle safety system and the related technologies, then analyze the strengths and limitations of the current system to identify opportunities for improvement. Continue to the next step is system development, there are 4 steps to building a driver assistance collision warning system:

- System architecture and design
- Prototyping and implementation
- Testing and validation
- Iterative improvement

The first step to building a system is to design the overall architecture of the system, including hardware components, software modules, and decision-making algorithms. After the design has been built, it needs to implement the design into a system prototype based on the system architecture. With the intention to validate the prototype, research will continue to testing and validation by conducting controlled experiments to evaluate the performance of the developed system. The result of testing and validation will iterate with the system improvement, to enhance system performance and reliability. The final step of the research methodology evaluates the final iteration and analyzes the result. As the result, it will be a discussion of system strengths, limitations, and potential areas for improvement.

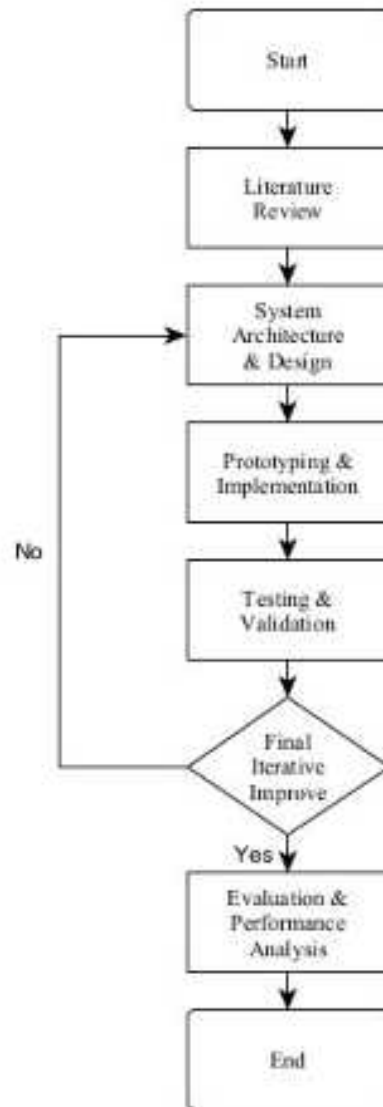


Figure 3.2 Research Methodology

3.2.2 V-Model Project Milestone

The research method that will be applied to the Vehicle Collision Warning System is the V-model project milestone. Compared to the other method, V-model provide more proper handling for support software integration [22]. This model is split the development stage into three parts, i.e.: design, implementation, and integration and qualification testing.

The letter “V” is a representation of the development flow with the left side of the “V” describing the requirement and specification, then the right side of the “V” representing the validation and testing process. The horizontal line from the left and right side of “V” is the project milestone, which verification must follow the requirement. The detailed flow process of the V-model is shown in Figure 3.3.

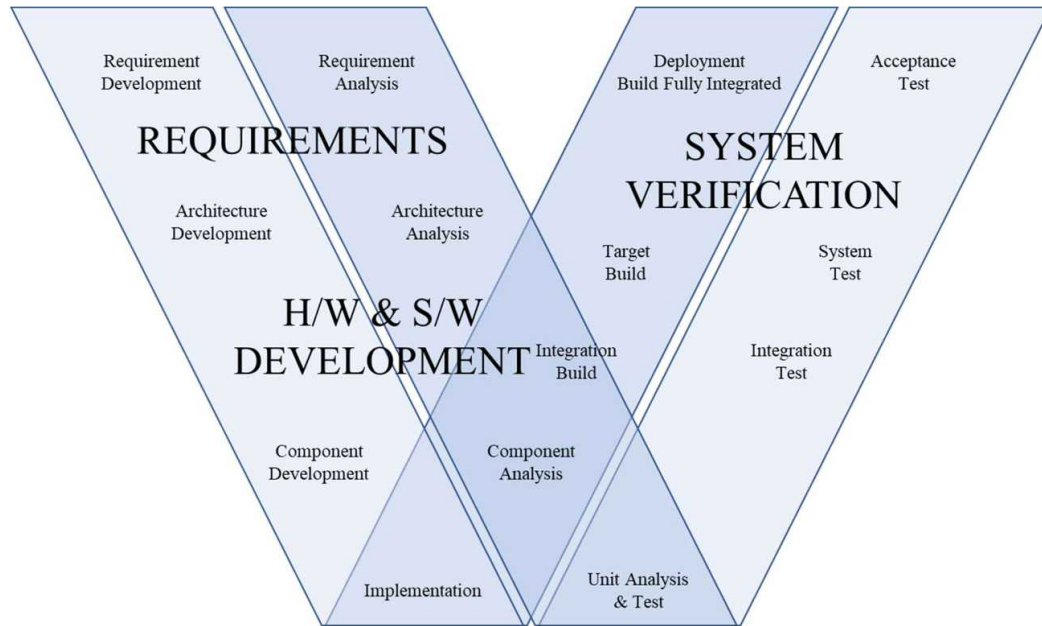


Figure 3.3 Research Method using V-Model

The V-model starts with the Requirements stage, defining the requirement of the system that will be developed and its architecture. This stage is also called the pre-development stage, which is the detailed requirement of the hardware and software that will be developed. Still on the left side of “V”, but research continuous to the main development stage, this stage is the Hardware and Software Development, starting to develop the product based on the requirements that are already set. Throughout the Hardware and Software Development stage, there are three phases of development. It begins with component development, followed by implementation and unit analysis, and finalizes with the integration of the component into the final system. Straightaway after the Hardware and Software Development stage, the process development going to the right side of the V-model, System Verification stage. As the “V” horizontal line is the relation between verification and requirement, the validation and testing should represent all of the requirements of the system.

3.2.3 Short Method Description

The development process of the driver assistance collision warning system, which is based on the V-model development method, will be explained in seven distinct phases.

- Step 1 – Requirement Development. This approach phase involves identifying the system requirements, it is important to clearly define the requirement in order to achieve the function and the feature of the system.
- Step 2 – Architecture Development. Through the block diagram, the architecture of the system will be designed. The architecture must consider the technical features and the requirement, it will set the design limit of technical architecture but still can fulfill the system requirement.
- Step 3 – Component Development. This step indicates the beginning of the main development stage, during which the actual designed of the hardware components and software of the system are developed.
- Step 4 – Unit Analysis & Test. This step is a trial event that validates the components. This is a confirmation of the prototype's function. During this stage, every single component will be calibrated as a single unit.
- Step 5 – Integration Test. System development generally occurs on a per-feature or per-component scale. To make a complete solution, each smaller system needs to be integrated into a single compiled that is tested as a single entity.
- Step 6 – System Test. The single system will be assembled into a complete system for testing. Testing will be validating the system based on the architecture design.
- Step 7 – Acceptance Test. This step is the final step to decide whether the system is fully worked or needs some other rework. Called as an acceptance test because the final test represents all of the system requirements designed.

3.3 Pre-Development Stage

The pre-development stage outlines the essential requirements for the process of system development. This stage is separated into two phases, Requirement and Architecture Development. During the Requirement Development phase, the primary objective is to collect essential system requirements that specifically address the intended input and

output of the system. Subsequently, in the Architecture Development, these requirements are transformed into an actual system design that conceptualizing the comprehensive framework and interaction of hardware and software components, ensuring that the system's design will fulfill the specified requirements.

3.3.1 Requirement Development

3.3.1.1 Variable Input

The driver assistance system strategically and functionally chooses three primary variables, which is distance to the next vehicle, relative speed, and time-to-collision, to effectively address the fundamental aspects of vehicle safety and dynamic response in real-time driving situations. Time-to-collision is a critical factor in determining the required brake action in order to avoid collision. The lower value of time-to-collision require significant action to safely brake. However, it is also critical to consider the distance to the next vehicle, as it impacts the duration and space accessible for suitable actions and response durations. A shorter distance to the next vehicle indicates a higher risk of collision, especially if the speed is high. By integrating these variables, the system can make decisions that are better informed and adapted to the specific context.

3.3.1.2 Warning Output

In the realm of international vehicle safety regulations, alongside various other international frameworks, the United Nations Economic Commission for Europe (UN ECE) holds a pivotal role. UN ECE contribute substantially to the process of developing vehicle regulations on vehicle safety, energy-efficiency and environmental and anti-theft performances. The UN ECE ensures that these regulations are not only comprehensive but also designed to be universally applicable, fostering a harmonized approach to road safety on a global scale. Standards and conventions developed in UNECE are used worldwide [23].

The United Nations Economic Commission for Europe (UN ECE) has developed a total of 163 regulations related to vehicle standards and regulations. Among these, there are two regulations specifically addressing warning and indication systems for vehicles.

The warning and indicator can be divided into two categories: audible warnings, which provide instant alerts by sound, and visual warnings, which make individuals aware within the field of viewpoints.

1. Regulation No. 28 Audible Warning Device

Audible warning devices, operated by direct current or compressed air, which are intended for fitting to motor vehicles with the exception of motor cycles. The audible warning device shall emit a continuous and uniform sound; its acoustic spectrum shall not vary substantially during its operation [24].

2. Regulation No. 121 Hand Controls, Tell-tales, and indicators

There are 3 visual indications category mention in the UN R121: Control, Tell-tale, and Indicator. ‘Control’ means that hand-operated part of a device that enables the driver to bring about a change in the state or functioning of a vehicle or vehicle's subsystem. ‘Tell-tale’ means an optical signal that, when alight, indicates the actuation or deactivation of a device, a correct or defective functioning or condition, or a failure to function. ‘Indicator’ means a device that shows the magnitude of the physical characteristics that the instrument is designed to sense [25].

Based on the UN ECE regulation, this research will utilize a Buzzer as audible warning and the control symbol as visual warning. The specifics of the cautionary indication displayed in the Table 3.3.

Table 3.3 Warning Indication Output

No.	Item	Control Symbol	Function	Illumination Color
1.	Emergency Brake		Warning for an emergency brake demand when system has detected an imminent forward collision	Yellow
2.	Brake		Warning for taking action for braking: light brake, moderate brake, significant brake	Green, Yellow, Red

3.3.1.3 Decision-Making Concept

The vehicle collision warning system developed in this research is a system that acts as a driver assistance to prevent or mitigate collisions by providing warnings to the driver. The system utilizes distance and relative speed to make decisions based on the data.

Distance and relative speed are important variables in a vehicle collision warning system to calculate the time-to-collision and decide on the appropriate warning output. The Ministry of Transportation of the Republic of Indonesia (Kemenhub RI) states that the safe driving distance is 3 seconds from the vehicle in front of us when we advance our vehicle, this time interval provides maneuvering space for drivers to stop, change lanes, or come to a sudden halt.

As the objective of the research, the vehicle collision warning system will be applied on the toll road in Indonesia. The Indonesian Ministry of Public Works and Public Housing (PUPR) through Toll Road Business Entities (BUJT) mention that “apart from having to "Keep a Safe Distance" from other vehicles, there is also a time calculation formula to minimize and avoid the danger of accidents, known as the "3-second rule". Table 3.4 shows the system decision with the guidance of the 3-second rule.

Table 3.4 System Decision Guidance

No.	Time-to-Collision (sec)	Actuator	
		LED Emergency Brake	Buzzer
1.	> 3	Off	Off
2.	$2 > \text{TTC} \leq 3$	Amber	Off
3.	≤ 2	Amber	On

The vehicle collision warning system should consider the fact that the guidance should be adjusted based on variative conditions. Based on the consideration of the facts, the developed driver assistance system will be built as a kinematics and perception algorithm to make decisions. The Kinematics algorithm approaches the specified target value as either true or false in a strict sense (follows 3-second rule guidance from education campaign from the Toll Road Business Entities, The Ministry of Public Works and Public Housing), meanwhile, the perception algorithm depends on the system calculation by Fuzzy Logic to give the suggestion of the brake action based on

the distance to next vehicle and the relative speed. The vehicle collision warning system decision approach is shown in Figure 3.4. On the other side, Figure 3.5 shows the Fuzzy decision tree.

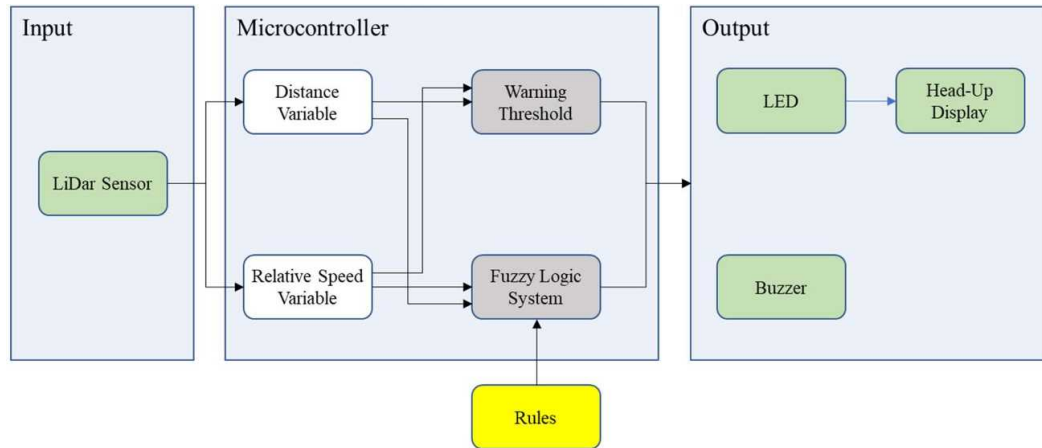


Figure 3.4 Decision Approach Block Diagram of Driver Assistance Collision Warning System with Kinematics and Perception Algorithms

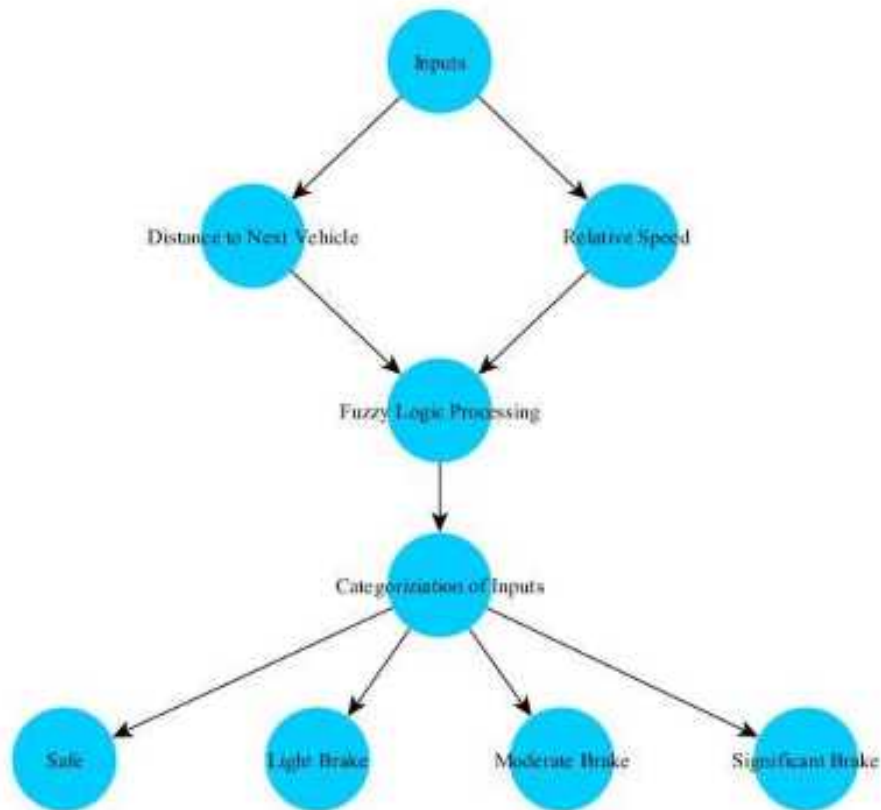


Figure 3.5 Fuzzy Decision Tree for Collision Warning Decision

The inputs consist of the Speed of the vehicle and the distance to the next vehicle. The inputs involve Fuzzy Logic Processing, which evaluates the collective risk by considering the current relative speed and distance. The outcome of the process is the classification of inputs into four distinct categories, each corresponding to a distinct level of braking action needed:

- Significant Brake: indicates a severe danger that needs significant braking to rapidly reduce speed.
- Moderate Brake: represents a moderate risk which braking is required to maintain a safe distance.
- Light Brake: suggests a low risk, where minimal braking or just deceleration might be sufficient.
- Safe: signifies the safety condition when there is no collision risk.

3.3.2 Architecture Development

3.3.2.1 Block Diagram

The system to be developed utilize Optical Distance Measurement Sensor: LIDAR (Light Detection and Ranging) and two warning outputs: LED and Electric Buzzer. The sensor worked as the input that provides distance parameter then will be processed by the microcontroller. Once the input has been processed, the microcontroller will trigger the output based on the system calculation.

The system's output serves as a driver assistance, providing warning indications to the vehicle user. Rather than shifting vehicle parameters such as braking or speed limits, the system alerts the driver to potential collision risks, allowing them to maintain their driving experience without interruption. The warning output will be provided through a visual indication by an LED integrated with a head-up display, as well as an audible alert generated by a buzzer.

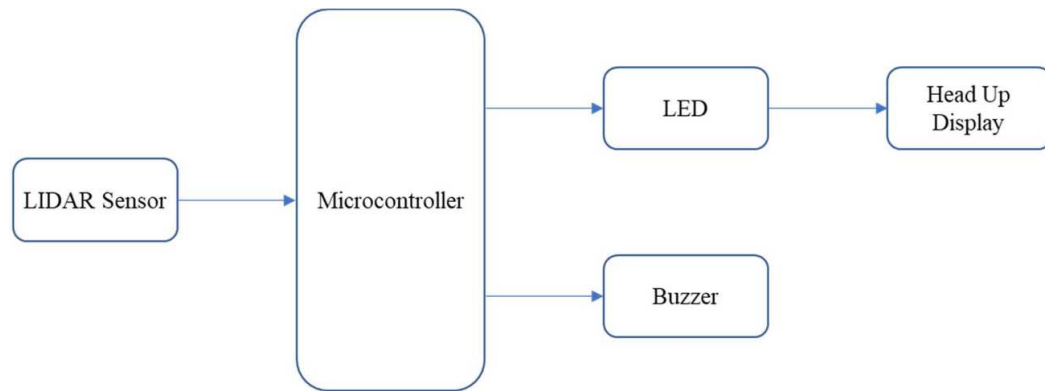


Figure 3.6 Collision Warning System Block Diagram

3.3.3 Components of the System

Components are the technological elements that construct the fundamental structure of the driver assistance system. The microcontroller Arduino Mega 2560 is essential to this system because to its potent performance and adaptability in managing complex computations and peripheral integration. The system utilizes the Garmin LIDAR Lite v3 sensor to monitor the distance to the car ahead and the vehicle relative speed is the result of the calculation from Arduino computation. To assist the driver for critical safety information to the driver, the system includes two types of actuators: a head-up display (HUD) that utilizes LEDs to give visual alerts, and an electric buzzer that emits auditory signals to immediately attract the driver's attention. Collectively, these components work together to optimize vehicle safety.

3.3.3.1 Controller

3.3.3.1.1 Arduino Mega 2560

The Arduino Mega 2560 is an ATmega2560-based microcontroller board featuring 256 KB flash memory, 54 digital pin I/O (of which 15 can be used as PWM outputs), 16 analog pin I/O, 4 UARTs (hardware serial interfaces), a USB connection, and a power jack [26]. Compared to predecessors, the Arduino Mega 2560 provides a larger capacity for memory and pins. This characteristic renders it a highly suitable option for projects that demand numerous inputs and outputs or more complex programming tasks.

This microcontroller is compatible with a wide range of communication protocols, such as I2C, SPI, and UART serial communications. This allows it to establish connections with a variety of sensors, actuators, microcontrollers, or computers. The USB connection not only enables programming from a computer but also functions as a convenient power source. The Arduino Mega 2560's open-source nature, to program the Arduino Mega 2560, it utilizes the Arduino Integrated Development Environment (IDE), a software tool that enables the writing, testing, and uploading of code to the board.

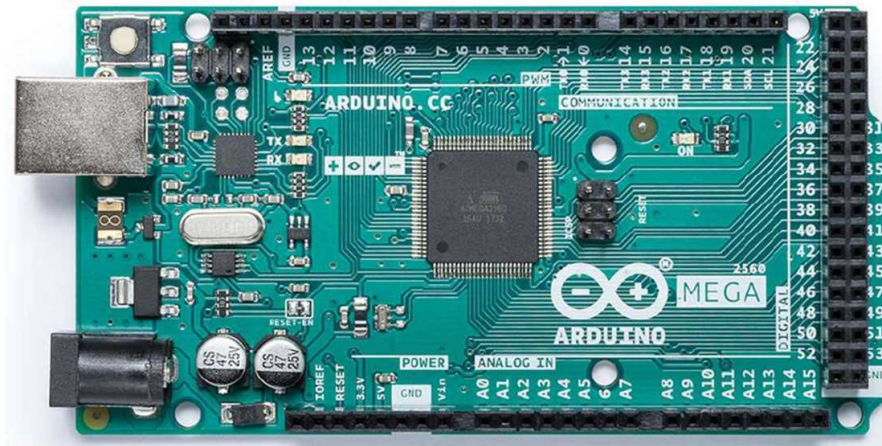


Figure 3.7 Arduino Mega 2560 Microcontroller [26]

3.3.4 Sensors

3.3.4.1 Optical Distance Measurement Sensor Garmin LIDAR Lite v3

The Garmin LIDAR Lite v3 is a compact, high-performance optical distance measurement sensor that uses laser technology to accurately measure distances from objects. LIDAR is a distance sensor that is essential for the implementation of ADAS [27]. This device measures distance by calculating the time delay between the transmission of Near-Infrared laser signal and its reception after reflecting off of a target [28]. This sensor performs well in its ability to promptly emit and perceive the reflections of laser pulses, allowing it to immediately measure distances to objects with excellent accuracy. The ability to measure quickly is essential for applications that rely on real-time data for effective operation, such as vehicle safety systems, where quick detection and avoidance of obstacles are crucial.

The LiDAR Lite v3 has the capability to accurately measure distances up to 40 meters, with a precision of ± 2.5 cm for distances below 5 meters and ± 10 cm for distances above 5 meters. Due to the quality of its build, it can function effectively under various environmental situations. The sensor utilizes either I2C or PWM communication protocols, providing versatility in its integration with microcontrollers, such as the Arduino Mega 2560.



Figure 3.8 Garmin LIDAR Lite v3

3.3.5 Actuators

3.3.5.1 Head-up Display

The Head-up Display (HUD) utilizes triple-color LEDs in red, amber, and green to provide an intuitive interface for displaying important driving information. It primarily emphasizes emergency brake and suggestion braking action alerts as visual warning. The HUD can be positioned on the upper section of the car's instrument panel, ensure that the symbols are within the driver's fundamental field of vision. The use of three distinct colors serves a crucial function, with red signifying a greater degree of risk in comparison to amber, while green represents the indicator of safety. The integration of this Heads-Up Display (HUD) into the vehicle's system requires synchronized it with the driver assistance system to accurately detect and display the appropriate warning.



Figure 3.9 Vehicle Collision Warning Head-up Display

3.3.5.2 Buzzer

The buzzer is a small auditory signaling device that operates at 4 to 8V DC and has a diameter of 12mm [29]. It is designed to emit a sound level of 85 dB, making it an excellent instrument for providing audible warnings in driver safety systems. The buzzer providing a consistent output that is ideal for real-time alerts, such as the overspeed and brake action warnings. The operating voltage requirement means it can be easily powered by standard electronic circuits, making it a versatile component for adding audible feedback to a variety of projects and systems. Its small size allows for easy integration into a wide range of devices, including vehicle safety systems, where space is often at a premium.

The operation of this buzzer relies on the utilization of a piezoelectric component that undergoes vibration upon the application of an electric current, thereby generating sound waves. The sound level of 85 dB is appropriately audible in noisy surroundings, so that warnings or notifications can attract attention without being excessively loud.



Figure 3.10 Buzzer

3.4 Calibration, Testing, and Validation

3.4.1 Calibration

Calibration is an essential step in the unit analysis and testing phase, where each individual component is examined and verified. Calibration purposes to ensure that the data collected is not merely raw, but transformed into precise, consistent, and comparable information. The vehicle collision warning system has two data from the sensors: distance and relative speed. Through calibration, the systems can be tuned to feature a natural driving behavior, which can increase the acceptance of driver assistance system by customers [30].

The calibration method for the vehicle collision warning system consists of two steps: firstly, verifying that the actuators (LED and Buzzer) respond correctly to the commands from the microcontroller to turn on or off, and subsequently, aligning the accuracy of the LIDAR sensor data with the actual distance.

3.4.2 Testing and Validation

Testing and validation of the vehicle collision warning system provide assurance that the methodology, data, and results align with the research objectives. Based on V-Model project milestone, the validation step requires checking the correctness of the temporal arrangement by extensively testing the implementation on the target [17]. There are three method of the testing within the phase: integration test, system test, and acceptance test.

- **Integration Test.** System development generally occurs on a per-feature or per-component scale. To make a complete solution, each smaller system needs to be integrated into a single compiled that is tested as a single entity.
- **System Test.** The single system will be assembled into a complete system for testing. Testing will be validating the system based on the architecture design.
- **Acceptance Test.** This step is the final step to decide whether the system is fully worked or needs some rework. This should include various environments like day (normal light), night (low light), and cover contaminant (fog, rain, dust).