DEBRE BERHAN UNIVERSITY

COLLEGE OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

DEGREE OF MASTER OF SCIENCE IN MOTOR VEHICLE ENGINEERING

MASTER THESIS

By: Nigusie Yihalem

AN AUTOMATED BRAKING SYSTEM FOR ACCIDENT PREVENTION IN LIGHT PASSENGER VEHICLE

July 2020

AN AUTOMATED BRAKING SYSTEM FOR ACCIDENT PREVENTION IN LIGHT PASSENGER VEHICLE

By: Nigusie Yihalem

A Thesis in Partial Fulfillment of the Requirements for the Degree of Master of Science in Motor Vehicle Engineering

Presented to College of Engineering

Department of Mechanical Engineering

Debre Berhan University

Supervised By: Dr. B. Dayal

DEBRE BERHAN, ETHIOPIA

July 2020

DECLARATION

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have dually acknowledged and refereed all materials used in this work. I understand that no adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the university and can also evoke penal action from the sources which have not been properly cited or acknowledged.

____

Signature

____

Name of the student

____

Date

By: Nigusie Yihalem

Approval Sheet

Approved by Board of Examiners:

____________________	____________	____________
Advisor	Signature	Date
____________________	____________	____________
External Examiner	Signature	Date
____________________	____________	____________
Internal Examiner 1	Signature	Date
____________________	____________	____________
Internal Examiner 2	Signature	Date
____________________	____________	____________
College Dean (Director)	Signature	Date
____________________	____________	____________
Department Head	Signature	Date

ABSTRACT

Reducing the number and worthiness of traffic accidents is a declared target and policy of most governments. It is clearly stated the traffic accident worthiness and their main cases in Ethiopia. Since dependence on driver reaction is the main cause of road accidents, it would be advisable to replace the human factor in some driving related tasks with automated solutions. To automate a vehicle, it is necessary to control the actuators of a car, i.e., the steering wheel, accelerator, and brake. The design and implementation of an automated braking system has been conducted with a component of a solenoid, intelligent LiDAR automotive based sensors, buzzer and LED light driver warning components, allowing the microcontroller to execute the preloaded well programmed code to stop the car as per the programmed stopping distance. It is assembled in conjunction with the original hydraulic brake system circuit for the sake of robustness and to permit the two systems to halt the car independently. This system is proposed and developed for light passenger vehicle TOYOTA HIACE Commuter 2007 four speed automatic transmission. Implementing and usage of this automated braking system have reduced the vehicles stopping distance from 143.524m to 113.577m with vehicles highest speed and maximum load it can experience. It observed that the new automated braking system reduced the stopping distance of the vehicle by 30m at maximum speed (152km/h) and maximum vehicle load (3905kg) compared to the existing conventional hydraulic braking system. As a result, this thesis contributes to efforts of increasing road safety and minimizing collision by reducing stopping distance of light passenger vehicle. It also reduces the enormous human lives lost and massive destructions of countries property presently around 24.42%. This study also provides a new theoretical and analytical basis for design and application of an automated braking system.

Keywords: Intelligent transportation and traffic safety; automated braking and driving; fatality and injury.

ACKNOWLEDGEMENT

First of all, I would like to thank almighty GOD for giving me everything. I would also like to thank my thesis advisor Dr. B. Dayal of the Motor Vehicle Stream at Debre Berhan Univerisity. The door of Dr. B. Dayal office was always open whenever I ran into a trouble spot or had a question about my research. He consistently allowed this paper to be my own work, but steered me in the right direction whenever he thought I needed it.

I would also like to thank the experts who were involved in the accomplishment for this research work: Dr. Jamir, Dr. Anand, Mr. Kaleab and Mr. Joefel. Without their passionate and positive participation and inputs, the work of this thesis study could not have been successfully conducted.

Finally, I must express my very profound gratitude to my spectacular parents, to mechanical engineering staff members and to my classmates for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of research and writing this thesis. This accomplishment would not have been possible without them.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURES

Abbreviations

RTA……………………………..……. Road traffic accidents

LIDAR………………………………. Light detecting and ranging

WHO…………………………….……. World Health Organization

EM…………………………..……….Electromagnetic

LED…………………………………. Light-emitting diodes

GPS…………………………..…….Geographical position sensor

INS…………………………………Inertial navigation system

ABS ………………………..…….Antilock Braking System

AEB…………………………..…….Automatic emergency brake

RPM…………………………..…….Revolution of vehicle tire

IR……………………………..…….Infrared

KE…………………………..……….Kinetic energy

Acronyms

S_s…………………………..……….Stopping distance

S_b…………………………..……….Braking distance

S_r…………………………..……….Reaction distance of the vehicle

V_v…..Speed of the vehicle

t_r…………………………..……….Reaction time of the driver

S_B…………………………..…..…Braking distance

g…………………………..…..….Acceleration due to gravity

F…………………………..……...Force generated by the plunger

N…………………………..…….Number of turns of coil in the electromagnet

I……………………………..……...Current supplied trough the coil

A_p………………………………..…Plunger cross sectional area

L_c…………………………...……..Length of coil wire

d_1………………………………..…Outer diameter of bobbin

d_2…………………………...……..Inner diameter of bobbin

a…………………………..…….…Acceleration

V…………………………..……..Speed

t…………………………...……...Time taken

t_b…………………………...……..Braking time of the vehicle

F_b…………………………...……..Braking force of vehicle

m_v……………………………...….Gross mass of the vehicle

a_v…………………………...…..….Acceleration of the vehicle

m_v…………………………..……..Mass of the vehicle

F_f…………………………...…..….Force of friction in newton which is equal to braking force

E_{th}………………………………..…Thermal energy produced by the brakes

R_{aspect}……………………..……..Tire aspect ratio

H_{tire}…………………………...…..Tire height

W_{tire}……………………………..…Tire Width

D_{tire}…………………………...…..Tire diameter

D_{rim}…………………………...…..Tire rim diameter

Greek Letters

μ…………………………...…….Coefficient of friction of asphalt road

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Every movement of human being in the world depends on vehicle transportation. This human need opens the incremental growth of passenger vehicles in a country. It is obvious that as the crowdedness of the vehicle increases the road traffic accident also increase. Many accidents caused by ignoring right of way, driving on the wrong side of the road, inappropriate speed, and insufficient distance from other vehicles and so on might have been prevented had the vehicles been able to brake faster.

The occurrence of traffic accidents is a very serious matter which points toward traffic safety. Around 1.24 million major or minor road traffic accidents occur annually on the world's roads, which makes road traffic injuries the eighth leading factor for death all over the world, mainly the prominent cause for death of young people aged between 15-29 years. [1] Road traffic accidents (RTAs) are huge public health and development problems. Every year nearly 1.3 million people lose their lives on the road and as many as 50 million others are injured. [2] Globally RTA fatalities remain more or less constant since 2007; yet, in many developing countries the rates are increasing. Especially Africa faces the highest annual rate of road fatalities in the world 27 per 100,000 population. [3] The following figures figure 1.1 and figure 1.2 are a record of worthiness of traffic accidents in Ethiopia.

Figure 1.1: Light passenger vehicle crash with bus in Ethiopia [4]

Ethiopia as many African countries is facing enormous road safety crisis. Each year thousands of road users are killed and the majority of them are economically active population. [5]

According to the estimate of the World Health Organization (WHO), the prevalence of road traffic fatality in Ethiopia for the year 2013 was 25.3 per 100,000 population and the rate is among the highest in the world. [3]

Vehicle accidents might be a consequence of rash driving, driving under influence, fatigue etc. Most of these can be mapped down to a single cause, driver's inability to hit the brakes at right time.

Figure 1.2: Light passenger vehicle crash worthiness in Ethiopia [6]

Any accident involving in commercial vehicle result not only in economic loss of the goods transported but also loss of life. Therefore, in vehicle safety systems, the braking system is one of the most important parts to be considered and needs skillful advancement. Since the brake system of the vehicle are highly sensitive to maintenance, periodic maintenance and inspection procedures have to be settled and implemented.

Some drivers are careless thus, drive a vehicle out of their profession like driving a vehicle after taking an alcohol or chat and also communicate with each other using mobile or within a cabin as well as out of the cabin through the window. Some traffic accidents also occurred when the obstacle is out of sight especially around densely traffic area, at parking stations and during reversing. The numbers of peoples who are dead during vehicle accidents were also large as compared to the other causes of death.

The traffic accident is increasing as vehicle production is increasing. All these problems combine together resulted in traffic accidents that everyone has seen today like property damage, personal injury, or even death. [7] Thus discussed magnitude of traffic accidents on both human lives and properties are clearly tabulated in both table 1.1 and table 1.2 in both crashes by collision type and crashes by vehicle type in a country of Ethiopia.

Table 1.1: Crashes magnitude by collision type [8]

Description	**Crashes**			
Collision Type	**Fatal Crashes**	**In %**	**Injury Crashes**	**In %**
Head on collisions	604	4.98	608.98	4.48
Rear end collisions	333	2.74	335.74	4.16
Broadside collision	284	2.34	286.34	2.85
Sideswipe collision	260	2.14	262.14	2.72
Rollover	2,105	17.34	2122.34	17.17
Collision with pedestrian	**5,894**	**48.55**	**5942.55**	**53.16**
Fall from vehicle	1,024	8.43	1032.43	6.46
Collision with animals	609	5.02	614.02	4.23
Collision with roadside parked vehicle	219	1.8	220.8	4.49
Collision with road side objects	370	3.05	373.05	1.43
Collision with terrain	233	1.92	234.92	0.07
Others collision	100	0.82	100.82	0.74
Unknown collisions	105	0.86	105.86	1.04
Total Collisions	**12,140**	**100**	**12240**	**100**

Table 1.2 Crashes magnitude by vehicle type [8]

Description	**Crashes**			
Vehicle Type	**Fatal Crashes**	**In %**	**Injury Crashes**	**In %**
Cycle and Motorcycle	451	3.71	1258	4.27
Automobile and Land Cruiser	1204	9.92	5606	19.03
Commercial Vehicle	5780	47.61	11124	37.77
Minibuses and Buses	**4191**	**34.52**	**10569**	**35.88**
Earth Moving Vehicles	183	4.54	248	0.84
Rail	2	0.02	5	0.02
Animal Draw Cart	48	0.40	126	0.43
Other Vehicles	70	0.58	173	0.59
Unknown Vehicles	211	1.74	345	1.17
Total Collisions	**12,140**	**100**	**29454**	**100**

In case of light passenger vehicles, the crash worthiness becomes more and more because of the weak and lightness of vehicles body and the lack automatic active braking and controlling system to be installed on it. The number of transport vehicles are described in numerical value of the literature. It is clearly stated the minibuses in Ethiopia are 70.78% greater than the number of buses. [8] And also in passenger vehicles the driver runs to make more trip in a day. So as to achieve more trips per a day the driver puts a choice of driving faster than the road, the vehicle weight and other related parameters offered to ride the vehicle in safe. This crash worthiness increases exponentially in our country Ethiopia. Active safety has a lot of significance in avoiding such tragedy.

The traffic accident is not only taking lives it also has a negative impact on countries economic growth. The table 1.3 provided below depicts that budget of Ethiopia from $2007/08 - 2017/18$ and economic lose due to road traffic accident. As clearly organized in the table 1.3 provided below Ethiopia loses from yearly budget in a range of $0.3\% - 2\%$ in the past eleven year. As organized in the table 1.3 the annually road traffic accidents; in the past eleven year in average Ethiopia loses around 0.9% of budget due to road traffic accident. [9]

Table 1.3: Budget lose due to road traffic accident in Ethiopia from 2007/08 - 2017/18 G.C. [9]

Ethiopia Fiscal Year	**Total Cost Road Traffic Accident in billion birr**	**Ethiopia Budget in billion birr**	**Lose of Budget due to Road Traffic Accident in percent (%)**
2007/08 G.C (2000E.C)	0.9	43.95	2.0
2008/09 G.C (2001E.C)	1.1	53.9	1.7
2009/10 G.C (2002E.C)	1.6	64.5	1.4
2010/11 G.C (2003E.C)	1.8	77.2	1.2
2011/12 G.C (2004E.C)	2.3	117.8	0.8
2012/13 G.C (2005E.C)	2.9	137.8	0.7
2013/14 G.C (2006E.C)	3.4	159.5	0.6
2014/15 G.C (2007E.C)	4.3	178.6	0.5
2015/16 G.C (2008E.C)	4.9	223.3	0.4
2016/17 G.C (2009E.C)	5.9	274.3	0.3
2017/18 G.C (2010E.C)	7.1	320.4	0.3
TOTAL	36.3	1651.25	9.8
Average	3.3	150.11	0.9

1.2 Problem Statement

In Ethiopia, road traffic accidents pose a huge development and health problem which takes millions of lives and damages assets in millions of birrs every year. Even if high level political commitment and immediate actions and decisions have been taken it can't curb this growing problem. As try to show the magnitude of crash, the vehicle type involved in crash and causes of the crash in the table 1.1; the light passenger vehicle involves in huge percent and the pedestrian type crash also takes the huge percent from the total rode traffic accidents in Ethiopia. This numerical value clearly directs the brake system performance light passenger vehicles doesn't offer an automatic braking during non-activeness of the driver.

Most of the accidents can be avoided if proper braking is applied in right time. Therefore, a great deal of consideration should be given to improve the braking system of light passenger vehicle in Ethiopia since their contribution to fatal crashes is high. This thesis proposes a new automatic braking control system to work jointly with the original for obstacles of front, side and rear. This option allows increasing of safety because the braking system decreases stopping distance to reduce the collision. Indeed, with automated braking system vehicles the road will be safer, the journey more comfortable, and traffic jams minimized.

1.3 Objectives

1.3.1 General Objective

The general objective of the thesis study is to design an automated braking system for accident prevention on light passenger vehicle.

1.3.2 Specific Objectives

The specific objectives of this thesis work include:

- ❖ Material selection, numerical calculation and integration and synthesis of various components of braking system.
- ❖ Programming and coding of the braking system with the real time vehicle data.
- ❖ Result, discussion and analysis keeping in view with the numerical data.
- ❖ Testing and implementation.

1.4 Scope of the Study

The scope of this thesis work is extending from to designing, programming of microcontroller and prototyping of automated braking control system for light passenger vehicles.

1.5 Limitation of the Study

The limitations of this thesis study are the time availability for extending the detail work of the thesis since the other courses are not finished on a time when it was planned. Plus, to the time availability for doing the thesis work; the other and main limitation is the material and equipment availability on a time of demand since the materials are less available and imported from aboard and also there is no a way of paying the price of materials and equipment for importing aboard in online market. It is a limitation for finding the exact data of existing stopping distance of light passenger vehicles in the official sites, journal, books and articles.

1.6 Significance of the Thesis

The traffic accidents which are caused by light passenger vehicle are increasing from day to day in Ethiopia as stated and tabulated in the introduction parts. Therefore; this thesis study will help to reduce the accidents caused by the delay of driver reaction to brake and the brake stopping distance since it is automatic. So that it will reduce the huge distraction of road traffic accident in both human lives and properties.

It also reduces the value of capitals to maintain the damaged vehicle and importing a new vehicle since the whole vehicles price to import is too expensive so that it will save more foreign currency in national level.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Automatic Braking Control Systems for Automotive

Alfred Eckert et al., (11-0111) proposes a system titles as “Emergency Steer & Brake Assist”. This paper presents an approach to systematically combine longitudinal braking assistance and its complementary lateral dynamics into an integral advanced driver assistance system for collision avoidance or mitigation. The system assists the driver during emergency brake and/or steer maneuvers based on driver input, physical aspects and surrounding sensor information. The robust detection of the surrounding and the analysis of the driving situation play a major role regarding the discrimination of a hazard situation from normal driving. The level of assistance is based on the ability and robustness of the sensor to display the picture of the real surrounding and driving situation. The discussed system approach assists by preconditioning the chassis for the oncoming brake and/or evasion maneuver and in the case of an emergency evasion maneuver initiated by the driver gives a recommendation utilizing steering torque overlay to help the driver to steer along a calculated optimized trajectory. [10]

Garima Agrawal et al., (2017) warranted that safety the vehicles by using Automatic Braking System with Distance Adjustment. This paper deals with auto braking system used in automobiles to sense an imminent collision with another person, vehicle or obstacles; or a danger such as high brakes or by applying the brakes to slow the vehicle without any driver input. The researcher proposes the automatic braking system using two modes. As stated in the paper, in collision avoidance, the collision is avoided by the automatic braking, but the driver will not be warned in this type of system. It also stated that there is a chance of wrongly interpreting signals especially in the case of radar or lasers. There is a threshold safe distance calculated by the system and if the driver fails to respond even when the vehicle crosses that region, then only brakes will be applied automatically. The main components also described well and it is stated that the objective of the system is to reduce the speed or stop the vehicles automatically when the ultrasonic sensors sense collision with another person, vehicle or obstacles. [11]

Rupesh Kumar et al., (2017) warranted that safety the vehicles by using Anti-lock and Automatic Braking system (AABS) Technology. The researcher uses an ultrasonic type sensor so as to controls the speed of the vehicle by continuously monitoring the distance of the obstacle or any other vehicle ahead and checking the speed of the vehicle in concern using wheel speed sensors. The main components used for such system development are an Arduino board, ultrasonic sensors, Hall Effect sensors, and motors. Here the Hall Effect and ultrasonic sensors are used to measure the speed of the vehicle and detect the obstacle in front direction only and initiating automatic braking. The principle of the study setup is; if the speed of the vehicle is above a set velocity for a predefined safety distance, then the microcontroller system performs the actuating mechanism to bring back the vehicle to a safe speed thereby minimizing the chances of accidents in forward direction only. [12]

Chaithra M et al., (2016) develops a vehicle control system based on an automatic electronically actuated control automotive braking system for automobiles is titled as “Automatic Braking System for Automobiles Using IR Sensor”. This vehicle braking system consist an Infrared transmitter and receiver circuit used to detect the obstacle and the vehicle in front of the system holder vehicle. The project work facilitates an electromagnetic braking system using solenoid. The final proposed embedded system module includes a microcontroller with solenoid and sensor. This study provides total safety in the negligence of the driver in the emergency situation which can reduce the loss of human lives and invaluable wealth and properties. [13]

P. Balashanmugam et al., (2013) introduces an electrical based automotive control system for braking actuation titled as “Fabrication of High-Speed Indication and Automatic Pneumatic Braking System”. Here as similar to the above the researcher uses a sensor with receiver and transmitter type so as to actuate the braking system of the automotive by a medium of air working fluid with the principle of pneumatic type braking system. The researchers also describe the main components have been used for development and the advantage disadvantage of the system of air braking. Pneumatic operation technology is very essential and important for any technicians or engineers to get a better knowledge of the pneumatic system, air-operated valves, and others. In this project, current is used to make effective action of brake-in rotating wheel and the braking arrangement is in a wheel as a model. [14]

Naim Sidek et al., (2018) share out with designing and implementing of Intelligent braking system by combining the concepts of mechanical and electronics engineering. It also explains the benefits of various parts and why they are used for developing the proposed system plus the main characteristics of the selected components. The braking system is developed based on IR sensor input data with regard to vehicles real data of speed and weight. The advantages of automatic emergency braking system over conventional braking system are well explained with different point of views and considerations. The future will bring autonomous steering to prevent head-on collisions and run-off-road crashes which are often very serious, or even fatal. [15]

Ping Fan Jin et al., (2015) have proposed an autonomous vehicle controlling mechanism with a title of “Design of unmanned vehicle advanced braking system using smart motor”. The researchers have tried to show the existing autonomous vehicle controlling systems specially which is concerned with vehicle braking system and the researchers are try to describes the conventional vehicle controlling systems related to braking system and that of the autonomous vehicle braking system components and working principles. Tin this study paper the researchers are mainly focused on design of autonomous vehicle advanced braking system using DC smart servo motor torque controller. The mechanism used in this study paper is connecting the vehicle brake pedal with DC servo smart motor. The researchers also develop the vehicle longitudinal control model using LabView2012. [16]

V. Milanes et al., (2010) have proposed a vehicle braking system with a title of “Electro-Hydraulic Braking System for Autonomous Vehicles”. This paper presents the design and implementation of an electro-hydraulic braking system consisting of a pump and various valves, allowing the control computer to stop the car. The researcher develops the system without using neither normal sensors nor intelligent automotive sensors. As stated in the article the system is design and developed by using hydraulic flow control valves which can be operated by an electrical signal. The paper clearly forwards the components used and the working principle of the new proposed braking system. The system is assembled in conjunction with the original circuit for the sake of robustness and to permit the two systems to halt the car independently. The integration of newly proposed electrohydraulic braking system and antilock braking system also discussed in the paper. [17]

Sanket Thorve et al., (2016) validated an automatic braking system based on an electronically actuated automotive control system. The proposed system consists two main mechanisms, primarily it consists an automatic braking system for vehicle brake actuation the secondly the pneumatic bumper system for energy absorption in case of front crash. The researcher selects the infrared type sensor to sense the vehicle coming from the front and sends a signal to the engine through relay control to stop working of the engine. The limit switch activates the pneumatic bumper system and brake to reduce the damage or pre-crash safety to the vehicle. The system used for a four-wheeler vehicle and heavy vehicles. The limitation was the researcher did not put any consideration of wheel locking and steering locking when the engine becomes off. Rather than wheel and steering locking, the system has no offer to prevent an accident from the rear side of a vehicle. The system also has few limitations in crowded traffic condition since the bumbler is actuated on the signal of IR sensor mounted in front of the vehicle. [18]

Chetan Tembhurkar et al., (2018) concentrated to describe the basic automotive active safety systems which are currently in production like traction control (TC), brake assist (BA), electronic stability control (ESC) and electronic brake-force distribution (EBD) functions and future systems that are currently in development and advancement progression. The researcher proposes a system which can operate automatically with the help of ultrasonic sensor which are mounted for forward traffic and obstacle detection with the combination of air brake system circuit and some modification in the traditional braking system that can alert the driver in a front collision and self-energizing applying of the brake of the vehicle automatically in highly emergency and critical situation. [19]

Sourabh et al., (2017) develops an automotive control and braking system based on an electronically actuated and microcontroller controlled braking system titled as "Automatic Brake for Hills Station". The researcher proposed the usage of an IR transmitter and Receiver type sensors with combination of micro controller, Control Unit, Pneumatic braking system. As stated in the article the IR sensor is used to detect the obstacles where by the vehicle goes on. As proposed by the researcher if there is an obstacle or obstacles in the vehicle driving path, the IR sensor senses the hills obstacles and giving the control signal to the microcontroller for activating the vehicle braking system. The mechanism has been proposed so as to stop the vehicle using brake system which prevents from rolling backward when the vehicle is moving in the uphill roads.

The development of the study has two phases. The first one was designing of ratchet and pawl mechanism, frame, shaft, etc. is done and in the second phase sensor selection and interference is done. Ratchet and pawl mechanism have been fabricated and assembly with sensor interface is tested. [20]

2.1.1 Summary of literature

Most of the above researchers have proposed the way of improving braking efficiency by using a braking and control system of automatic braking system works with integration of automatic bumper system, clutch and automatic braking system to reduce the accidents related with automotive brake system and also to notice the hazard-ness of the driving path or road. On the other hand, some of other researchers are studied mainly to increase braking efficiency by an electronically actuating solenoid valve system with the integration of existing disc brake with a cylinder.

But almost of all the researchers have proposed their system for only forward crash warning and crash avoidance braking system which means the researchers didn't consider the crash caused by cornering and reverse driving. The researcher had proposed the automatic obstacle detection system and automatic bumper and braking system to operate using only a front ultrasonic and IR type sensors which did not offered a graphical vehicle surrounding image. Because of the non-matured efficiency of existing vehicle braking system, a huge distraction of wealth and a worthy die of humans are recorded in each year and each country by traffic accident. This huge distraction of wealth and human lives loss gets much in light passenger vehicles the braking distance and braking performance needs to optimized since the distraction of human lives and wealth are huge as try to show in the table 1.1. Therefore, braking with the integration of microcontroller, sensors, and an additional electromagnetic solenoid valve is found which can improve the braking efficiency by inducing magnetic force on the solenoid plunger and push the brake fluid to activate the vehicle brake system. Therefore; integration of microcontroller and LiDAR intelligent automotive sensors together with the existing conventional vehicle braking system can prevent the collision and enhance the reduction of accidents in light passenger vehicles during forward, corner and reverse driving.

2.2 Electromagnetic Actuator Technology

Many of the devices familiar in everyday life rely for their operation on the forces exerted by magnetic fields on electric currents. The force on the current can produces a torque and this torque is utilized in motors, solenoids and like devices. Magnetic fields due to currents also give rise to forces between current carrying wires, then the force induced is used for different electro mechanical applications. [21]

Electromechanical systems are involved in many applications. Many actuating principles were previously proposed but the highest value of the ratio between the actuating energy volumes of actuator is provided by the electromagnetic actuation, with different design solutions. The electrodynamic interaction is produced between magnetic materials and electric current carrying coils and is preferred for its strength, polarity and range of displacements at macro-scale. These properties recommend them for laser technology used in systems for measurements, sensors, macro-scanners, macro-mirrors with adjustable focalization and correctable aberrations, etc.

The electromagnetic (EM) actuators have complex structures and complicated driving electronics but can develop high forces at any scale and can be used at resonance or far from it. The electromagnetic actuator type is based on the tendency of magnetic circuits to attain to the minimum potential magnetic energy or the interaction force between a magnetic field and a current-carrying wire [20]. The classical electro-dynamic actuators are similar to voice-coil actuators, widely used at macro-scale.

Actuators (also called as power transducers) are electrical devices that transform input energy (control variable) to output mechanical work (acting variable). An actuator which works based on the electromagnetic principle for energy conversion is called as electromagnetic actuators. Electromagnetic actuators convert electrical and mechanical energy into one another. The energy conversion takes place in the so-called air gap which separates the stationary member (stator or fixed contact) and moving member (rotor or moving contact) of the actuator. [23]

A special type of actuator is the electromagnetic actuator. Control variable of this actuator is electric current and acting variable is forcing interaction and its effects. The principle of transformation in these actuators is based on force interaction in a magnetic field. Electromagnetics actuators are used in many applications (from small devices for a very precise control of position to quite powerful units such as drives of rods in nuclear reactors). [24]

The solved actuator consists of two basic parts electric and magnetic circuits. The electric circuit is formed by a cylindrical coil wound fixed on the frame. The magnetic circuit is formed by the shell and movable core. Movable core is placed on the axis of the actuator and can move freely in it. To reduce the friction force between the moving core and shell as well as to prevent their mutual impact the core is placed in a nonmagnetic sliding tube. The current in the coil produces magnetic field that gives rise to the Maxwell force which acts on the ferromagnetic core. [25]

2.3 Vehicle Braking System

For the movement of the motor vehicle, the vehicle must be guided by sufficient powered electric motor or an internal combustion engine. In case of fuel powered type vehicles, the vehicle has the ability of converting fuel energy into heat energy which means conversion of chemical energy into thermal energy by means of combustion.

To move a vehicle, an internal combustion engine must convert its heat energy to mechanical energy. This mechanical energy goes from the engine to the driving wheel tires by means of a system of connecting rods, shafts and gears. The final factor that moves a vehicle is the amount of traction its tires have on the road surface.

Traction is the ability of a tire to grip the road surface on which it rolls. The vehicle's acceleration rate depends on the power the engine develops and the amount of traction the tires have on the road surface.

Friction is the force which resists movement between two surfaces in contact with each other. To stop a vehicle, brake shoe linings are forced against the machined surfaces of the brake drums, creating friction. This friction produces heat.

The engine converts the energy of heat into the energy of motion - the brakes must convert this energy of motion back into the energy of heat. Friction between brake drums and linings generates heat, while reducing the mechanical energy of the revolving brake drums and wheels. The heat produced is absorbed by the metal brake drums, which dissipate heat by passing it off into the atmosphere. The amount of heat the brake drums can absorb depends on the metal thickness of which they are made. When enough friction is created between brake linings and drums, the wheels stop turning. The final factor that stops a vehicle is not the brakes, but the traction between tires and road surface. [26]

After the combustion of chemical energy into thermal energy the thermal energy should be converted into mechanical energy for the movement of the vehicle. This mechanical energy transferred to the vehicle's wheel tire by a means of a harmonized combination of different components of the vehicle like connecting rods, shafts and gears. The other main factor which enables the vehicle to move is the amount of traction or friction that the vehicle's tire have with the road it rolls.

Traction is the resistance between the tire and the ground in reaction to torque being exerted by the wheel axle under engine power. Traction is also mean by the ability of a vehicle tires to grip the road surface on which it rolls. The vehicle's acceleration rate depends on the power of the engine develops and the amount of traction that the tires have on the road surface.

Friction is the force which resists movement between two surfaces in contact with each other. The engine converts the energy of heat into the energy of motion, the brakes must convert this energy of motion back into the energy of heat. To stop the vehicle, brake shoe /pads/ linings are forced against the machined surfaces of the brake drums /wheel/, creating friction. This friction produces heat.

A brake system is one of the most important controlling systems of the vehicle with the combination of some interactive parts. Braking system is the device which brings the moving vehicle into rest by converting kinetic energy of the vehicle to frictional energy in terms of heat energy which is dissipated to atmosphere. Brakes helps to slow down or stop the vehicle in the shortest possible time as per the driver requisite and also at the time of driving down the hill and to obtain a better traction control in different terrains. The electromagnetic braking system, servo braking system, mechanical braking system, hydraulic braking system, ABS brakes, etc. are some braking system categories that are in use.

2.4 Hydraulic Brake System

Hydraulic braking system works on the principle which is based on Pascal's principle which states that "confined liquid transmits pressure without loss in all direction". According to this law when the pressure is applied on a fluid will travel equally in all the directions hence the uniform braking action is applied on all four wheels. A hydraulic braking system transmits brake pedal force to the wheel brakes through pressurized fluid, converting the fluid pressure into useful work of braking at the wheels. [19]

In a hydraulic braking system, the braking force is directly proportional to the ratio of the master cylinder cross sectional area to the disc or drum brake wheel cylinder cross sectional areas. Therefore, these cylinder diameters are appropriately chosen to produce the desired braking effect. The wheel cylinder cross sectional areas of the front and rear disc and drum brakes respectively may be chosen to produce the best front-to-rear braking ratio. [27]

The hydraulic brake system contains an input cylinder called the master cylinder, and four output cylinders, one for each wheel brake. When the driver presses on the brake pedal, force is applied to the pushrod and to the master cylinder. The pistons inside the master cylinder move forward, pushing on the fluid. Since the fluid cannot be compressed, the pressure on the fluid increases.

Secured to the master cylinder are brake fluid lines. The fluid that is under pressure by the pistons can exit the master cylinder via these brake lines, which eventually connect to the output pistons at the wheel brakes.

Some of the fluid will leave the master cylinder via the brake lines. These lines are very small in diameter compared to the size of the master cylinder pistons. This is to maintain the pressure on the fluid. At the front brake there is a hydraulic output, in this case, a disc brake caliper. The caliper has a single piston that is much larger than the master cylinder pistons. This is because we need to increase the force this output piston can apply. Since the output force is increased, the total movement of the piston is decreased. The force of the output hydraulic cylinder piston is given by equation 2.1.

$$F = P * A \dots\dots\dots\dots\dots\dots\dots\dots\dots (2.1)$$

Where: F = is force of the output piston

P = is the fluid pressure forward by line

A = is output piston area

2.4.1 Vehicle Stopping Distance

The distance required to stop a vehicle depends on its speed and weight in addition to the factors of energy, heat, and friction coefficient between the vehicle tire and road.

The braking distance is the distance that a vehicle travels while slowing to a complete stop. The braking distance is a function of several variables. First, the slope (grade) of the roadway will affect the braking distance. If the vehicle is going in a direction of uphill, gravity assists the vehicle in attempts to stop and reduces the braking distance.

The stopping distance (S_s) is the reaction distance plus the braking distance, which is shown in the following equation.

$$Stopping\ distance\ (S_s) = reaction\ distance\ (S_r) + the\ braking\ distance\ (S_b)$$

$$S_s = S_r + S_b \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.2)$$

2.4.2 Vehicle Reaction Distance Because of Driver Delay

The reaction distance is the distance that the driver travel from the point of detecting a hazard until the driver begin to braking or swerving. The reaction distance is affected by:

- The car's speed (proportional increase):
    - ✓ 2 x higher speed = 2 x longer reaction distance.
    - ✓ 5 x higher speed = 5 x longer reaction distance.
- Driver's reaction time.
    - ✓ Normally 0.5–2 seconds.
    - ✓ 45 - 54-year olds have the best reaction time in traffic.
    - ✓ 18 - 24-year olds and those over 60 have the same reaction time in traffic.

The reaction distance can be decreased by anticipation of hazards and preparedness. At the same time the reaction distance can be increased by the necessity of decision-making (for example, between braking and steering out of the way), alcohol, drugs and medication and tiredness.

Therefore, the reaction distance can be mathematically expressed in equation 2.2 like below.

$$S_r = \frac{V_v * t_r}{3.6} \dots\dots\dots\dots\dots\dots\dots\dots\dots..(2.3)$$

Where

S_r = reaction distance of the vehicle (m)

V_v = speed of the vehicle (km/hr)

t_r = reaction time of the driver (sec)

2.4.3 Vehicle Braking Distance

The braking distance is the distance that a vehicle travels while slowing to a complete stop. Braking distance refers to the distance a vehicle will travel from the point when its brakes are fully applied to when it comes to a complete stop. It is primarily affected by the original speed of the vehicle and the coefficient of friction between the tires and the road surface, and negligibly by the tires' rolling resistance and vehicle's air drag. The type of brake system in use only affects trucks and large mass vehicles, which cannot supply enough force to match the static frictional force. [28]

The braking distance is affected by:

- The vehicle's speed (quadratic increase; "raised to the power of 2"):

- ✓ 2 x higher speed = 4 x longer braking distance.
- ✓ 3 x higher speed = 9 x longer braking distance.

- ➢ The road (gradient and conditions).
- ➢ The load of the vehicle or the vehicle carries.
- ➢ The brakes (condition, braking technology and how many wheels are braking).

The braking distance is expressed mathematically in equation 2.3 like bellow.

$$S_B = \frac{{V_v}^2}{2 * \mu * \mathrm{g}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (2.4)$$

Where:

S_B = Braking distance (m)

V_v = Velocity of the vehicle before applying brake (m/s)

μ = Coefficient of friction of asphalt road

g = acceleration due to gravity (m/s^2)

2.5 Design Concepts of Electromagnetic Brake System

Without a proper braking system, it is impossible to operate an automobile. Braking systems allows a vehicle to stop or slow down by applying only a small force on the brake pedal. Whatever it is, from bicycles to aero plane, every vehicle which are in use must have a proper braking system. Recently, most of the automobiles have brakes on its 4 wheels to ensure safety while driving. Among the four, brakes located on the front wheels play an important role in stopping the car.

Electricity and magnetism are inextricably linked, and the development of fundamental principles of electromagnetism parallels the evolution of modern industrial society. Individual electric charges immersed in an electric field or moving through a magnetic field experience electromagnetic force. The electric force on a charged particle is proportional to, and along the direction of, the electric field. The force generated by a magnetic field on a charged particle is in the direction determined by the right-hand rule perpendicular to the plane defined by the particle's velocity and the direction of the magnetic field. [24]

In general, electromagnetic actuators have many advantages such as fast response, simple control, and low manufacturing cost compared with the other actuators.

2.5.1 Electromagnetism and Its Principle

Magnetism cannot be efficiently transmitted over any great distance on account of leakage. The practical method is to transmit a current of electricity through a wire, and then convert its energy into magnetism at the point where the attraction is desired.

This is accomplished by winding spirals of insulated wire around the magnetic material which is to be magnetized. Such a device is known as an Electromagnet, and upon the passage of an electric current through the winding, the magnetic material behaves similarly to a permanent magnet of the same general form, with the exception that, if the magnetic material has but little coercive force, the magnetism will practically disappear upon the discontinuation of the electric current through the winding. [29]

2.6 System Components and System Design

The function of the braking system is to retard the speed of the moving vehicle or bring it to rest in a shortest possible distance whenever required. The vehicle can be held on an inclined surface against the pull of gravity by the application of brake. Brakes are mechanical devices for increasing the frictional resistance that retards the turning motion of the vehicle wheels.

The analysis and design of automotive brake systems draw mainly upon the physical laws of statics, dynamics, and heat transfer. In most cases practical engineering equations are used to determine braking performance and thermal response in a variety of braking situations.

The analysis and design of a brake system begin with an analysis of the brake torque or force produced by the wheel brakes. Therefor an automated hydraulic brake system consists of two main components. These are:

- ❖ The conventional hydraulic brake components and
- ❖ The electronic components.

2.6.1 Conventional Hydraulic Brake Components

The hydraulic braking system uses hydraulic fluid (commonly brake oils containing glycol ethers or diethylene glycol) to transmit the force applied on the brake pedal to the final drum shoes or disc caliper to stop the moving vehicle. The major components in the hydraulic brake system circuit are connected fluid-filled master cylinder and slave cylinders. When the driver applies force on the brake pedal, the fluid in the master cylinder is pushed to the slave cylinder through the connected brake lines. When fluid enters into the slave cylinder, the piston rod will move outwards and create the friction that makes the wheels to stop. This is the principle of hydraulic brake working. [26]

Hydraulic brakes use the physical principle of equal pressure to all locations. The schematic of this principle is illustrated in figure 2.1 below. The piston to the left pressurizes the fluid with a given force. The forces exerted on each of the eight pistons to the right is equal to the force on the left piston since all piston cross sections are identical. However, the stroke of each of the eight pistons is only one eighth of the stroke at the left piston. [30]

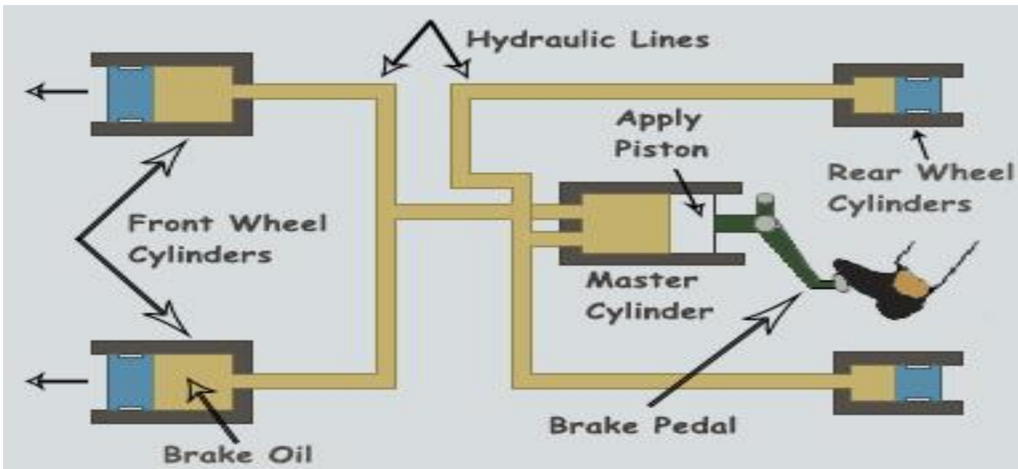


Figure 2.1: Simple schematic diagram of hydraulic system principle. [30]

The basic components of conventional hydraulic braking system and their functions are listed and described below. [31]

Brake Fluid Container: Ordinary oil will compress meaning it won't be able to transfer that pressure. You will lose brakes and you won't be able to stop. Air can compress as well, so it is mandatory to bleed the brake system while replacing some components, including the brake oil and brake oil container. Almost all containers have wiring leading to the top so they can detect when the brake fluid is below the minimum.

Brake Pedal: To slow down or stop the movement of a vehicle, the driver will apply force on a pedal. This component where the driver presses with his/her foot is called the brake pedal. It is connected to the master cylinder through a mechanical cord or linking rod. [30]

Brake Booster: is used to increase the pressure of the pedal and improve stopping power. It uses a vacuum from the engine meaning the engine must run in order to have brakes. That's why it is never a wise idea to turn off the car while going downhill. The driver will literally lose the brakes. This is a dangerous situation in which it can cause an accident. The brakes may barely work, but this depends on a car.

Master Cylinder: An important unit of every braking system that converts the applied force on the pedal to hydraulic pressure. The basic functions of master cylinder include developing pressure, equalizing the required pressure for braking, preventing contaminants like air and water, etc. Master cylinder components are housing, reservoir, piston, rubber cup, pressure check valve and more. [30]

Wheel cylinder: Wheel cylinders are responsible for converting hydraulic pressure to mechanical pressure used for pushing brake shoes towards the drum. The stepped wheel cylinder and the single-piston wheel cylinder are the two major categories of wheel cylinders.

Brake Lines & Hoses: Brake lines or hoses are used for transferring high-pressure fluid between different components. In these two, brake lines are rigid and are constructed using double wall steel tubing. Whereas the brake hoses are flexible that can be moved. [30]

Brake Fluid: Brake fluids are the medium that transfer pressure to the wheel cylinders. Low freezing point, water tolerance, lubrication, non-corrosiveness, proper viscosity and high boiling point are the required properties for hydraulic brake fluids.

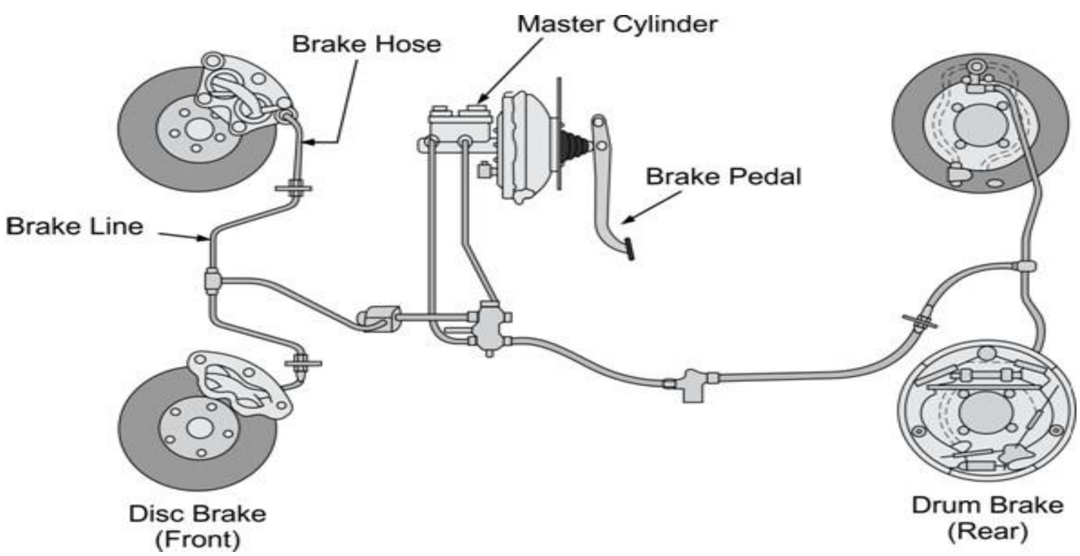


Figure 2.2: Conventional hydraulic brake system Components (23)

2.6.2 Electronic Components

Electrohydraulic brake systems are the combination of electronics and hydraulics to create a more versatile brake system. The electronics provide control flexibility, while the hydraulics supply the power. Electrohydraulic braking offers many advantages over traditional hydraulic braking systems. These advantages can be exploited to provide improved system performance and greater comfort for the operator.

Therefore, the main and most common components that are integrated to the conventional brake system components to make an automated braking system are:

- Microcontroller
- LiDAR sensor
- Relay module
- Solenoid
- Breadboard
- Buzzer
- LED lights

A. Micro-Controller

Microcontrollers are widely used in embedded systems and make devices work according to our needs and requirements. The microcontroller tells the memory, arithmetic/logic unit and input and output devices how to respond to a program's instructions. There are many versions of Arduino boards introduced in the market like Arduino Uno, Arduino Due, Arduino Leonardo, and Arduino Mega, however, most common versions are Arduino Uno and Arduino Mega. But for this thesis study it has been selected Arduino Uno as a microcontroller unit. Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller. [33]

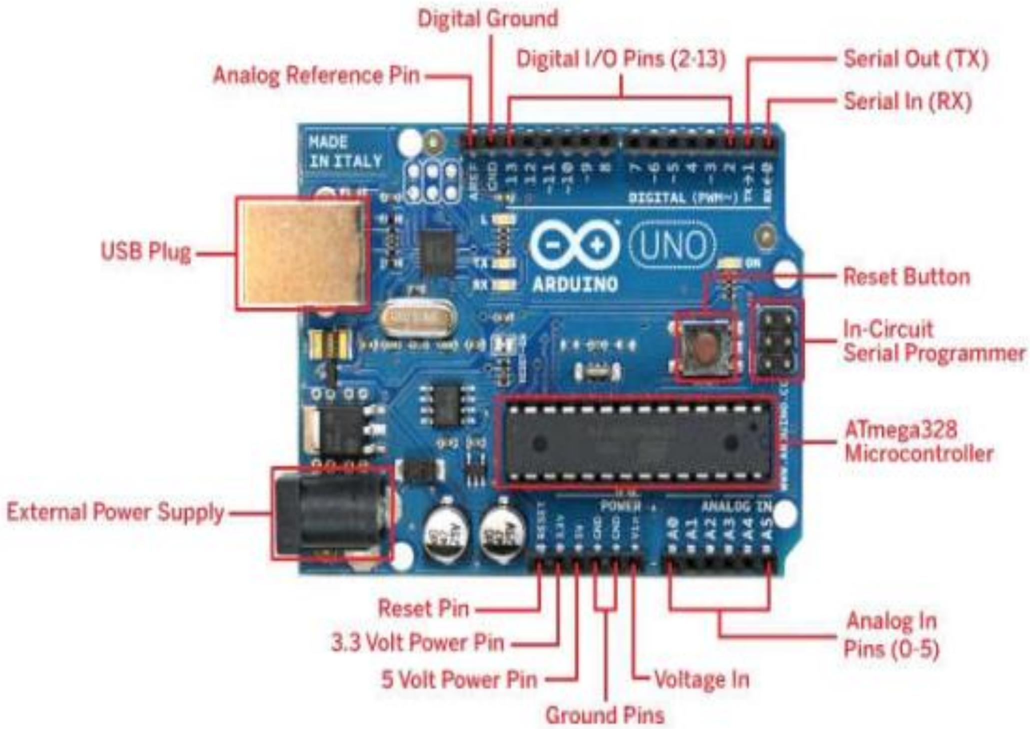


Figure 2.3: Arduino Uno microcontroller. [33]

Arduino also simplifies the process of working with microcontrollers, but it offers some advantage and interested amateurs over other systems.

Inexpensive: Arduino boards are relatively inexpensive compared to other microcontroller platforms. The least expensive version of the Arduino module can be assembled by hand.

Arduino sheets can read simple or advanced information signals from various sensors and transform it into a yield, for example, actuating an engine, turning LED on/off, associate with the cloud and numerous different activities also, the Arduino IDE utilizes a streamlined rendition of C++, making it less demanding to figure out how to program.

Dissimilar to most past programmable circuit sheets, Arduino does not require an additional bit of equipment (called a software engineer) keeping in mind the end goal to stack another code onto the board. It can basically utilize by USB link.

At last, Arduino gives a standard shape factor that breaks the elements of the miniaturized scale controller into a more available bundle. [34]

Cross-platform: The Arduino Software (IDE) runs on Windows, Macintosh OSX, and Linux operating systems. Most microcontroller systems are limited to Windows.

Simple, clear programming environment: The Arduino Software (IDE) is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well.

Open source and extensible software: The Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries.

Open source and extensible hardware: The plans of the Arduino boards are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending it and improving it. Even relatively inexperienced users can build the breadboard version of the module in order to understand how it works and save money.

B. Sensor

Sensors are vital and play important roles in this application, hence they need to be wisely distinguished and selected. Their task in this system is to measure the distance between two cars and their speed. In the realm of distance or range sensor, there are several types of sensors with distinctive features and characteristics. Each of them has their own strengths and weaknesses and is being used in different domains. For example in brake application, ultrasonic sensor is not very good since it is sensitive to drafts and high frequency ambient noise that come from the radiator. The same also applies to infrared sensor and in addition, its effectiveness is reduced at high ambient temperature. The diffuse reflective photoelectric sensor is suitably used in the collision avoidance system since it can be integrated in brake system; the modulated infrared light source provides immunity to ambient light. [35] In this thesis study the use of LiDAR sensor to measure distance of the two cars or obstacles are considered. As far as cost and accuracy are concerned, LiDAR sensor suits better in sensor selection for this application. Its sensing range is typically up to 200 meters ahead and it is not very expensive. [36]

LiDAR Sensor

LIDAR (light detecting and ranging) appears to be the best solution for these challenges. The technology has already proven its accuracy and reliability in ADAS applications. Moreover, LIDAR’s increasing power and portability are being embraced as it is integrated into new, exciting functions like 3D mapping and car-surround sensors.

Light detection and ranging, or LIDAR, is a remote-sensing technology that uses pulsed laser energy (light) to measure ranges (distance). Engineers and earth scientists use LIDAR too accurately and precisely map and measure natural and constructed features on the earth's surface, within buildings, underground, and in shallow water. It has broad applications in many industries such as engineering and public safety. [37]

The actual calculation for measuring how far a returning light photon has travelled to and from an object is expressed by:

$$Distance = \frac{Speed\ of\ Light\ x\ Time\ of\ Flight}{2}$$

Often deployed in down-looking systems in the air or oblique geometries in ground systems, a LIDAR system includes a laser source, a scanner, and a GPS receiver. During a LIDAR survey, an active optical sensor transmits laser beams toward a target while moving along or rotating across defined survey routes or fixed objects.

The laser energy is reflected by the target and is detected and analyzed by receivers in the LIDAR sensor. The receiver records the precise time from when the laser pulse left the system to when it is returned to the sensor. Using precise pulse time, the range distance between the sensor and the target may be calculated. [37]

When combined with the positional information from GPS or an inertial navigation system (INS), these distance measurements are transformed into measurements of three-dimensional points that define the reflective target in 3D space.

Lidar point data including laser time range, laser scan angle, GPS position, and INS information is post processed. It is then compiled into highly accurate georeferenced xyz coordinates by analyzing the laser time range, laser scan angle, GPS position, and INS information.

Laser pulses return to the sensor from different reflective surfaces located above and on the ground. A single emitted pulse may return as one or more reflections. The first returned pulse is very important, as it marks the highest or tallest reflective surface. First returns can include treetops, building roofs, and vehicle tops. If no other reflective surfaces are encountered, a single first return may represent the earth's surface.

Therefore, TF03 180m IP67 LiDAR have been selected. TF03 is high speed LiDAR, It contains two versions with 100m and 180m. TF03 includes compensation algorithms for outdoor glare and other interference, so it works normally under strong light environment and rain, fog and snow conditions.

Figure 2.4: TF03 IP67 LiDAR sensor. [37]

C. Relay Module

A relay is an electrically operated switch that can be turned on or off, letting the current go through or not, and can be controlled with low voltages, like the 5V provided by the microcontroller pins. The relay is also the device that open or closes the contacts to cause the operation of the other electric control. It detects the intolerable or undesirable condition with an assigned area and gives the commands to the circuit breaker to disconnect the affected area. Thus, protects the system from damage. [38]

It works on the principle of an electromagnetic attraction. When the circuit of the relay senses the fault current, it energizes the electromagnetic field which produces the temporary magnetic field.

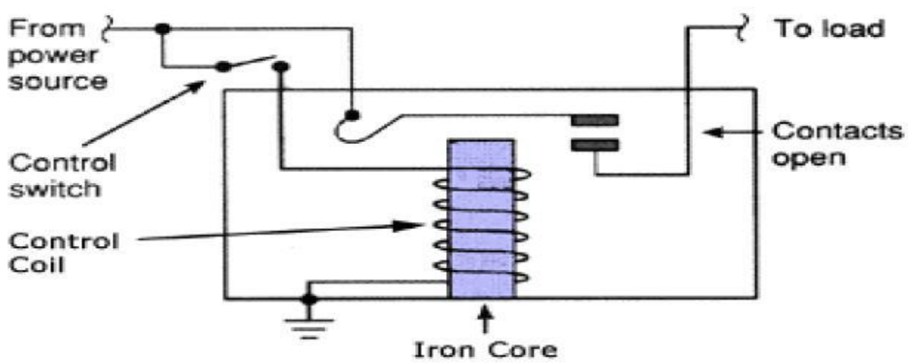


Figure 2.5: Simple schematic presentation of relay circuit. [38]

This magnetic field moves the relay armature for opening or closing the connections. The small power relay has only one contacts, and the high-power relay has two contacts for opening the switch.

D. Solenoid

Solenoid is the generic term for a coil of wire used as an electromagnet. It also refers to any device that converts electrical energy to mechanical energy using a solenoid. The device creates a magnetic field from electric current and uses the magnetic field to create linear motion. [23]

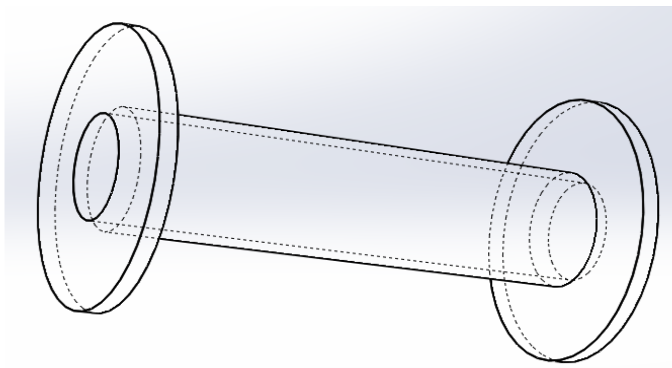


Figure 2.6: Solenoid 3D model developed by SOLIDWORKS

E. Buzzer

A buzzer or beeper is an audio signaling device which may be mechanical, electromechanical, or piezoelectric (piezo for short). Typical uses of buzzers and beepers include alarm devices, timers, and confirmation of user input.

Figure 2.7: Driver warning buzzer. [39]

Generally, there are two common types of buzzers that are commonly available. One of them is a simple buzzer which when powered will make a continuous beep sound, the other type is called a readymade buzzer which will look bulkier than this and will produce a Beep. Beep. Beep. Sound due to the internal oscillating circuit present inside it. [39]

F. LED Lights

An LED lamp or LED light bulb is an electric light for use in light fixtures that produces light using one or more light-emitting diodes (LEDs). LED lamps have a lifespan many times longer than equivalent incandescent lamps, and are significantly more efficient than most fluorescent lamps. There are three basic colored LED in product. But for this study work it has been selected to use only one yellow type LED light warning. [40]

Figure 2.8: Yellow LED warning light. [40]

The long leg is typically positive, and should connect to a digital pin on the Arduino board. The short leg goes to GND; the bulb of the LED will also typically have a flat edge on this side.

G. Breadboard

A breadboard is a rectangular plastic board with a bunch of tiny holes in it. These holes let you easily insert electronic components to prototype (meaning to build and test an early version of) an electronic circuit, like this one with a battery, switch, resistor, and an LED (light-emitting diode).

The connections are not permanent, so it is easy to remove a component if mistakes are made, or just start over and do a new project. This makes breadboards great for beginners who are new to electronics. [41]

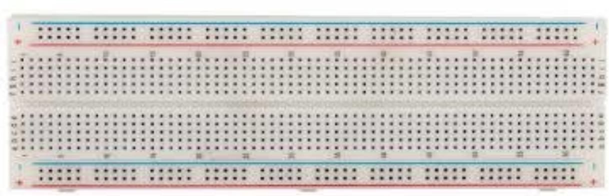


Figure 2.9: Breadboard for customizing the connection. [41]

2.6.3 Working Principle of Automated Braking System

There are technologies to detect obstacles and prevent frontal vehicle accidents. Besides this it also gives an alert to the driver to take actions relating to vehicle braking. But the forward obstacle detection and forward vehicle crash preventive system is not much enough and well matured to decrease the massive loss of economy and human lives. Therefore, it is found to integrate the solenoid valve, microcontroller, LiDAR sensors and other driver warning for developing the automated braking system. This thesis study is mainly concerning on enhancing the existing work by introducing automatic brakes with distance adjustment, which would get its input from the intelligent automotive type sensors which will be install in all sides of the vehicle, which will then apply the brakes automatically and prevent from collisions exist than before.

The automated braking system monitors vehicles, pedestrians, and objects in the path of the vehicle based on the distance, speed, and time which are programmed and loaded on the microcontroller. When the potential for a collision is detected, a warning is activated and sent to the driver for taking actions regarding to vehicles speed braking or vehicles driving path. In this study work, the automated brake system is considered to be activated and energized at a moment when the vehicles engine key turned on. The system also gets a sustainable power supply to the whole system and continuous to operate with regard to the vehicles longitudinal speed. When the vehicle starts moving either forward or backward direction within or without side turning, in the sensor unit, the installed LiDAR sensor senses the presentences of obstacle in the vehicles longitudinal path and its distance where it drives through. The microcontroller analysis the input obstacle distance by sensors and the vehicles instant speed inputted by vehicles speed sensor.

Then after analyzing of the input speed and input obstacle existing distance, the micro controller recognizes energizing or non- energizing of electrohydraulic solenoid valve assembly based on the code program it was loaded.

If there is no obstacle in a path, the receiver of LiDAR sensor circuit will not receive any signal and the solenoid valve remains closed. In contrast, if there is an obstacle(s) that can be detected by the installed LiDAR sensors then with instant of time the sensed signal directed to the microcontroller as an input signal and instantly the microcontroller sends an output signal to the relay module to energizing and instantly actuates the buzzer and yellow LED light which can alarm the driver to apply the brake and notice that the automated braking system will be intervene.

If the driver applies the brake system and reduce the vehicle speed, the microcontroller goes to execute the new vehicle instant speed and obstacle existing distance relation. In contrast, if the driver does not apply brake the microcontroller for time it coded and after the waiting time left it energizes and instantly actuates the solenoid assembly and activates the longitudinal motion of the solenoid plunger within instant of time. When the electrohydraulic solenoid is electrically energized, a magnetic field is created which pushes the plunger to outwards the center of the coil, this action pushes the brake booster extension rod which can activate the whole assembly of vehicle hydraulic brake system which can instantly directs the hydraulic fluid to the final brake components and applies braking.

During braking of this automated brake system, the situation of a brake will be held if the obstacle does not leave the path where the vehicle goes and the path which can allow the vehicle can pass in the direction of vehicles path. After the obstacle is removed from the vehicle path, the solenoid plunger will not be energized and it will back to the former position. Finally, the brake returner spring pulls the solenoid plunger which results returning of the compressed fluid in the wheel cylinder backward to brake master cylinder and reservoir.

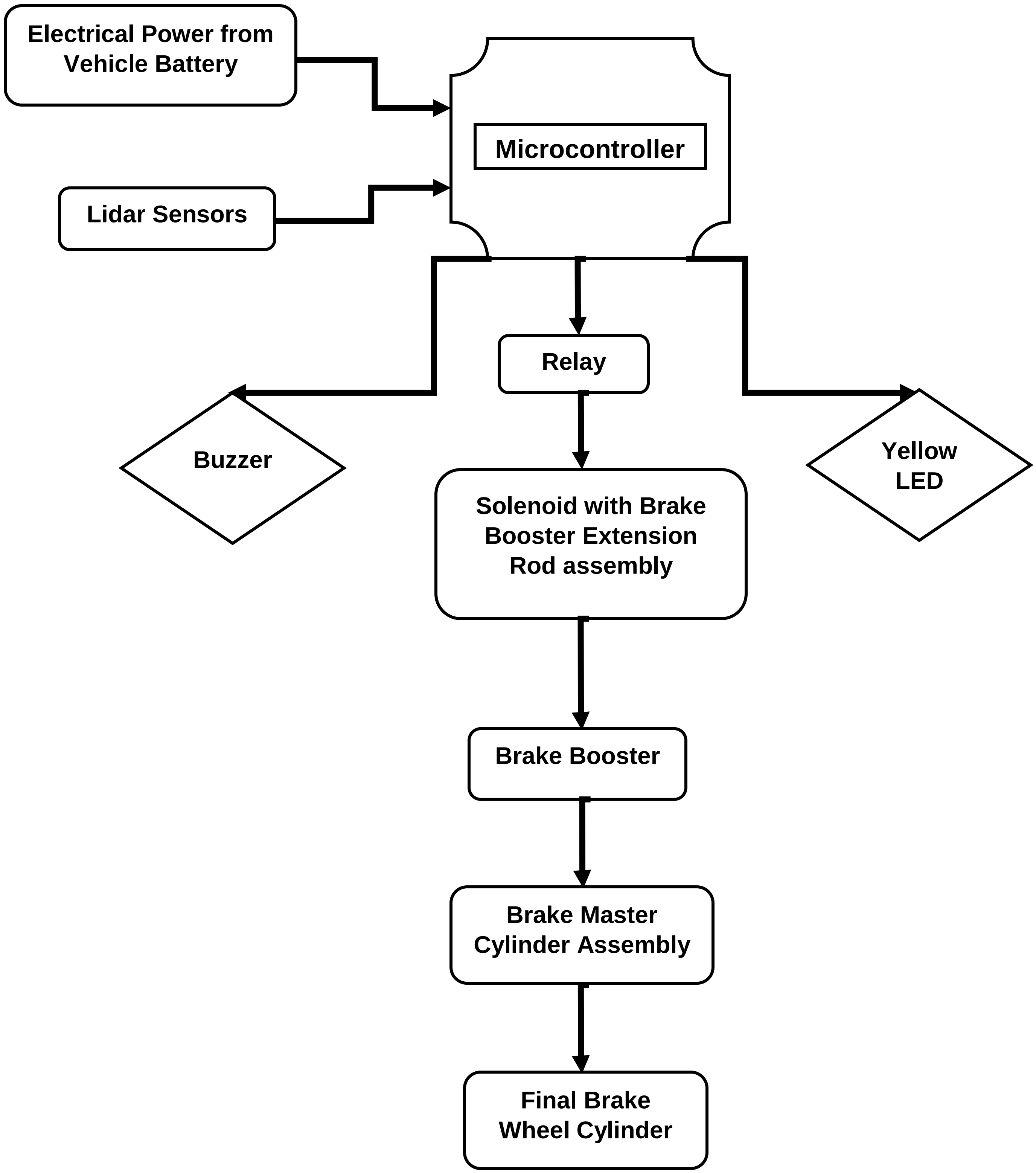


Figure 2.10: Schematic presentation of automated brake system working principle.

CHAPTER THREE

3. METHODS AND MATERIALS

3.1 Methods

This thesis work is concerned with the development and way of implementation of automated braking system for vehicles with design and analysis selected vehicle of TOYOTA Hiace Commuter 2007 model 4(four) speed automatic type transmission. The studying of this thesis work follows the following main basic scientific and engineering procedures.

- Data collection and organization.
- Material selection.
- Solenoid component system design.
- Programming the system using Arduino software.
- SOLIDWORKS modeling
- Draw circuit diagram using Proteus software
- Implementation and representation of the prototype.

The overall method to accomplish this thesis study is provided in the figure 3.1 below which shows the basic flow of methods and approaches for this thesis study work. The thesis began with research and planning. This is done in order to identify the suitable component needed for hardware implementation and circuits.

The proposed approaches for completing this thesis study is proposed to follow the following methodology from starting to finalized the study work.

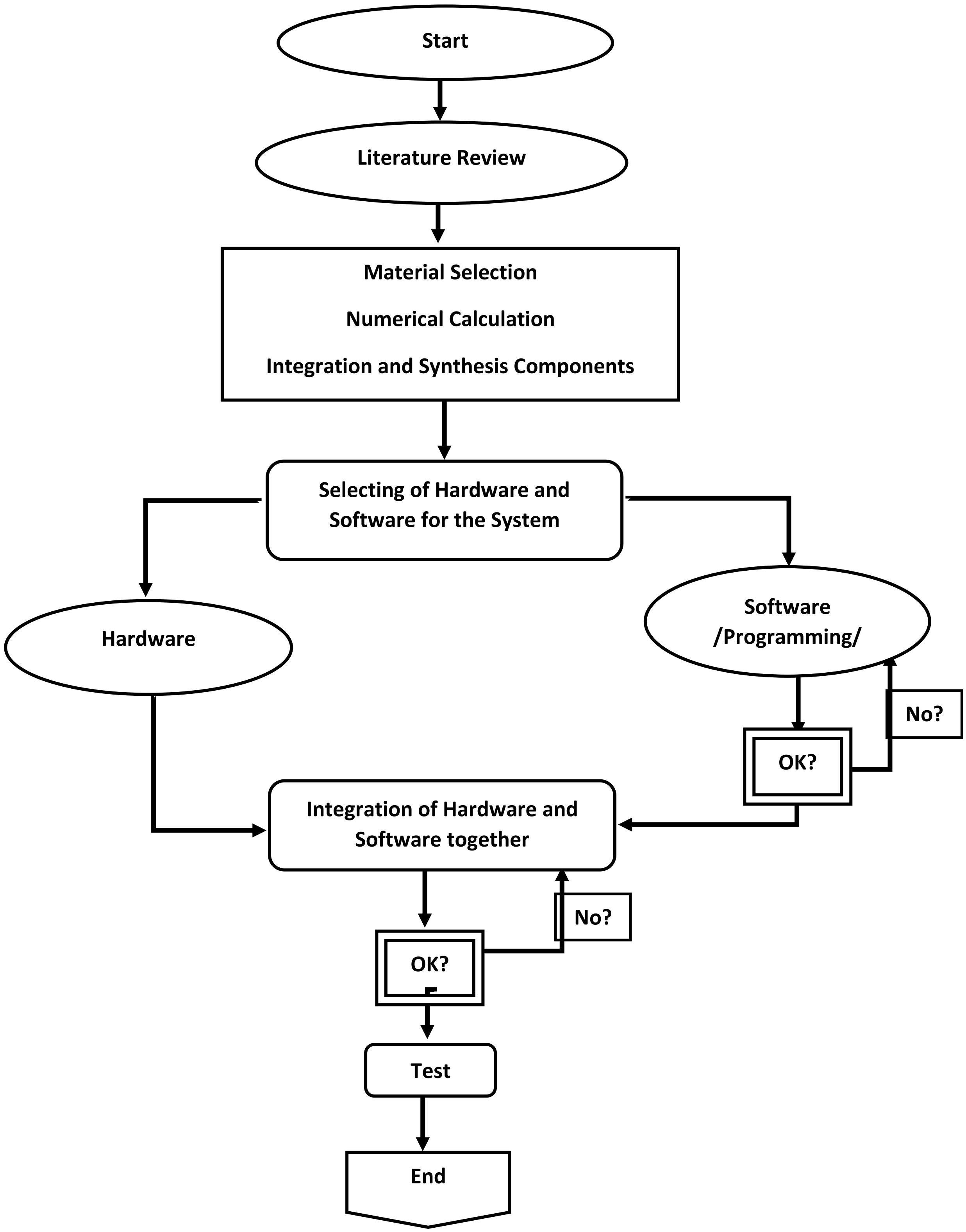


Figure 3.1: Methodology flow chart of the thesis study

3.1.1 Data Collection and Data Organization Methods

To organize and collect relevant data, vehicle type selection comes first. Therefore, by referring different companies and dealer's official website with the relevant literatures and study papers, TOYOTA HIACE COMMUTER 2007 model vehicle has been selected for accomplishing this thesis study work. The selection of TOYOTA HIACE COMMUTER 2007 vehicle model is done since almost of all relevant vehicle specification data are available and the vehicle model is in the range of light passenger vehicle category which is compatible with this thesis study work.

After selection and specifying of vehicle model, data collection was proposed and held on. The method of data collection used for this thesis work is only primary and secondary method of data collection. The primary data collection method was gathered by interviewing the correspondent technicians, drivers, mechanics and related persons who are already engaged with vehicle maintenance, inspection and related tasks. The secondary data collection method, were the internet, books, articles, seminar etc. The required and general data and specifications of TOYOTA HIACE Commuter 2007 automatic type transmission that are used for this thesis are presented in the table 3.1 provided below.

An engine of TOYOTA HIACE Commuter 2007 has a four-speed automatic type transmission. The following table 3.1 shows the selected vehicle general specifications and its parameters with its conventional brake system assembly specifications.

Table 3.1: Selected vehicle specifications and parameters [44]

Vehicle Parameters	*Measuring Unit*	*Numerical Value*
Curb Weight	Kg	1,800
Gross Weight	Kg	2,600
Overall Height	mm	2,285
Overall Length	mm	5,380
Overall Width	mm	1,880
Maximum Speed	Km/hr.	152
Rolling Resistance Coefficient	------	0.8
Vehicle battery ampere	A	50
Vehicle recommended tire specification	--------	P215|70R16

3.2 Materials for Components

The main objective of vehicle braking system is to convert the kinetic energy of the vehicle into thermal energy, thus allowing the vehicle to decelerate or comes to stop.

So as to overcome this specifically goal all the brake system components should design and analyzed with respect to the conventional standards. Therefore, this automated braking system is designed as an electro-hydraulic system with microcontroller, solenoid, sensors and those conventional hydraulic brake system components.

3.3 Material Selection for Components

Selection of a proper material for the machine component or system design is one of the most important steps in the process of machine design. The best materials are some which will have serve the desired purpose at minimum cost and can stand with time. Therefore, to design the proper components, the following properties of materials are considered.

- Strength
- Durability
- Machinability and
- Weld-ability

The most factor which should be in consideration for selection of materials for machine components in machine design are:

- Availability of the material
- Suitability of the materials for the working conditions and
- The cost of the material.

3.3.1 Material Selection for Solenoid Components

Solenoids are the basic electromagnetic actuation device for electromechanical equipment. No matter which types of solenoids, electrical solenoids or hydraulic solenoids, they all share the same basic solenoid structure, which includes a wound solenoid coil and the solenoid armature kit, which is also known as solenoid iron core.

Solenoid iron core includes solenoid armature tube, sealing compound, and solenoid plunger. Among these components' solenoid plunger is the final actuating component, when the solenoid coil has been electrified, the magnetic field is created, and the solenoid iron core is magnetized so that the plunger can move to trigger the device.

And when the electricity has been cut off, the magnetic field disappeared, the solenoid iron core becomes un-magnetized immediately, and the solenoid plunger is return to its previous position. [42]

There are many metallic materials that can be magnetized, such as steel, cobalt, nickel, etc. Normally, carbon steel is the traditional magnetizable material, except for 304 stainless steel, other steel types can be magnetized. To make solenoid iron core, the most suitable material is soft iron, not steels. When the steels are magnetized, they will keep the magnetic permanently, even after the electricity has been cut off, the magnetized steel cannot demagnetizing. Therefore, if the solenoid armature assembly is made of steels, its magnetism cannot be controlled by the current size, which means it lost the main features of solenoid.

Therefore the material selection should be done for bothe solenoid bobbin and solenoid plenger. The solenoid plunger spring should not be take into consideration since the brake returner spring can substitute the action of solenoid plunger returner spring work. The table 3.2 provided below shows the selected material and its properties.

Table 3.2: material properties for solenoid plunger and solenoid bobbin

Component	***Material grade***	***Yield Strength***	***Ultimate strength***	***Elastic modulus***
Solenoid plunger	AISI 4140 alloy steel	620MPa	827MPa	204.7743$*\mathbf{10^3}$ KPa
Solenoid Bobbin	AISI 4140 alloy steel	620MPa	827MPa	204.7743$*\mathbf{10^3}$ KPa

3.4 Design and Analysis of Automated Brake System Components

It is known that the hydraulic braking system transmits brake foot pedal force to the wheel brakes through a harmonized combination of different brake system components with the working fluid medium of pressurized fluid, converting the fluid pressure into useful work of braking at the wheels. With this operation the conventional braking system has only hydraulic mechanical system. But in this study work, the ongoing brake system has two main system components. These brake system components are:

- Hydraulic mechanical parts which exists in the usual hydraulic brake system and
- Electronically actuated component parts.

From literatures and vehicle guide web sites it is stated that the force applied on the brake pedal is in the range of minimum 20pound and maximum of 120pound and it is also stated that the gap between the brake booster and the pedal pivot point is in the range of 163.6mm to 173.6mm. Therefore, the designing and analysis of the solenoid component should be over the range and value of average brake pedal force because the brake returner spring applies a resistance on the developed brake system since the solenoid is designed to place between the brake pedal and brake booster assembly.

3.4.1 General Design Consideration

Design of this automated braking system is preceeded based on the selected vehicle model which is TOYOTA Hiace Commuter 2007 specification. Therefore so to design and analyzing of the titled automated braking system mechanism, it is mandatory to consider the selected vehicle general specifications and its conventional brake system assembly specifications.

3.4.2 Design of Solenoid

It is previously stated that the solenoid is a coil of wire wrapped around the cylindrical bobbin structured component used to convert electric current in to magnetic fields for generating a mechanical linear motioned force for a pre-set objective on the principle of magnetic induction. When the wrapped coil is powered, the solenoid generates magnetic field lines that close at the plunger. This induces a load and causes the plunger to move. When there is no current, the plunger remains in its position and is released. The plunger is then returned to its original position by means of external forces (spring, weight, lever, etc.).

3.4.3 Design Parameters of Solenoid

The design and analaysis of solenoid can be preceeded by specifying the main and considerable parameters for the whole of solenoid system design including solenoid bobbin and solenoid plunger. The table 3.3 data are the main and basic parameters which are taken into consideration to design the solenoid part of the automated braking system.

Table 3.3: Selected vehicle brake component specification and solenoid component specifications taken from Addis Ababa MOENCO Company and web browsing. [44]

Parameters	***Abrivation***	***Numerical Value***
Brake booster and foot pedal gap length (mm)	L_b	163
Solenoid plunger length (mm)	L_p	60
Length of solenoid (mm)	L_S	60
Brake booster extention rod diameter (Plunger dia) (mm)	$d_{pr}=d_2$	12
Outer diameter of bobbin (mm)	d_1	18
Copper coil diameter (mm)	d_c	1
Brake pedal force (N)	F_b	410

Based the above given parameters the 3D model of solenoid bobbin or cylinder has been developed using SOLIDWORKS software. The 3D developed model also provided here in figure 3.2 below.

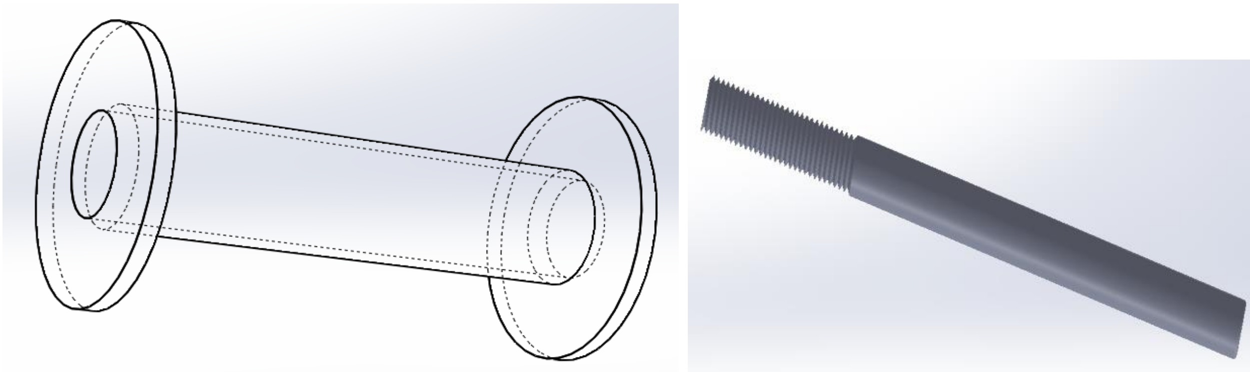


Figure 3.2: SOLIDWORKS 3D model of Solenoid bobbin (Left) and Solenoid plunger (Right).

3.4.4 Design and analysis of Solenoid plunger

Solenoids convert electrical energy into force and motion. When the coil is energized with electric current an electromagnetic force is created around the coil. In this solenoid plunger design it has been selected a conventional linear actuator type solenoid which consists of a plunger, magnetic circuit housing, and a coil.

Linear actuating solenoid is an electromagnetic based solenoid that converts electrical energy into a mechanical pushing or pulling force or motion.

Linear solenoids basically consist of an electrical coil wound around a cylindrical tube with a Ferro-magnetic actuator or “plunger” that is free to move or slide “IN” and “OUT” of the coils body. An electric power is positioned around the plunger. As soon as the coil is electrically energized a magnetic field is created which pushes the plunger to outwards the center of the coil, this action pushes the master cylinder piston assembly and generates hydraulically pressure inside the brake system assembly. The resistivity of copper wire is $1.68 * 10^{-8}$ohmmeters.

In this automated braking system, the booster extension rod is taken to be a solenoid plunger by only changing the material that is used before in the conventional braking system into alloy steel AISI 4140 as stated in the above provided material selection and property table.

Since the solenoid plunger is specified in size, material and diameter the main thing will preceded here is testifying or determining the number of turns that can be wrapped around the solenoid bobbin for producing or generating the specified mechanical foot brake pedal force which is numerically 400N.

Therefore, the mechanical linear type force that can be generated by the plunger a linear actuated solenoid can be describe in mathematical expression in equation 3.1. [43]

$$F = \frac{(N * I)^2 * \mu * A_p}{2 * \sigma^2} \dots\dots\dots\dots\dots\dots\dots (3.1)$$

Where

F = force generated by the plunger

N = number of turns of coil in the electromagnet

I = current supplied trough the coil

μ = magnetic permeability of air $4\pi * 10^{-7} H/m$

A_p = plunger cross sectional area

σ = size of air gap (mm)

Here the force generated by the solenoid plunger is equal to the brake pedal force which is 400N. But in this automated braking system development the solenoid assembly is consider to place between the brake foot pedal and brake booster cause the space availability is ranging from 163.6mm to 173.6mm. [51]

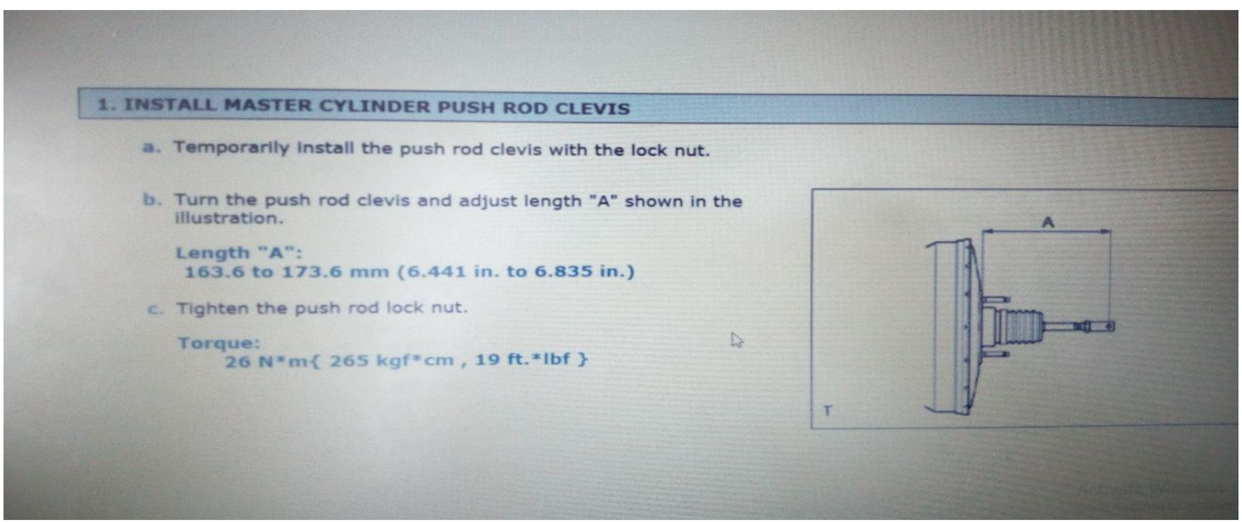


Figure 3.3: Brake booster and brake foot pedal gap distance from MOENCO Addis Ababa. [44]

Therefore, the returner spring of the brake system applies a resistance on the motion of solenoid plunger. Therefore, for designing of solenoid system it is better and recommendable to take +10N on foot pedal force.

Therefore, using the above solenoid plunger force equation, the number of turn that produces a force of 400N on the plunger can be determined by equating for number of turn (N), the number of turns of coil wire over the bobbin to generate a force of 410N (400+10) is defined as:

$$N = \sqrt{\frac{2F * \sigma^2}{I^2 * \mu * A_p}}$$

Where

$$A_p = \frac{\pi {d_2}^2}{4}$$

Where

d_2 = Solenoid plunger diameter which is equal with brake push rod diameter

Therefore, substituting values for determined and specified equation variables and solve for number of turns (N);

$$N = \sqrt{\frac{2 * 410 * 0.1^2 * 10^6}{50^2 * 4\pi * 10^{-7} * \frac{\pi * 12^2}{4}}}$$

$$= \sqrt{\frac{640 * 10^7}{48361.061 * 144}}$$

$$\boldsymbol{N = 919.03 turn \cong 920 turn}$$

From the above mathematical expression, the number of turns of coil around the solenoid bobbin has to be determined to 920turns, therefore the length of the coil that can be turned or wrapped around the solenoid bobbin can be calculated using the mathematical expression in equation 3.2.

$$L_c = \pi * \left(\frac{d_1 + d_2}{2}\right) * N \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.2)$$

Where

L_c = Length of coil wire (m)

d_1 = Outer diameter of bobbin (mm)

d_2 = Inner diameter of bobbin (mm)

Substituting the corresponding value in to the equation coil wire length wrapped around the solenoid bobbin and solve for coil wire length;

$$L_c = \pi * \left(\left(\frac{18+12}{2}\right) * 10^{-3}\right) * 920$$

$$= 3.14 * \left(\frac{30}{2}\right) * 920 * 10^{-3}$$

$$\boldsymbol{L_c = 43.34m \cong 43.5m}$$

There is a difference between the initial current to drive the solenoid to its new position and the current to hold it there.

3.5 Software System Code Programming of Automate Braking System

System programming is an essential and important feature and foundation in any automation system development and always involves to accommodate changes in the hardware system. System programming involves designing and writing computer programs that allow the system hardware to interface with the programmer and the user, leading to the effective execution of the pre-set goal on the automated system.

Therefore, the code which are used for monitoring the automated braking system can be generated using a compatible software of automation called Arduino software. The developed code could have integrated and assimilate the braking time, stopping distance and vehicle speed of the vehicle where it is assembled. Therefore, before developing the code program for automated braking system, the vehicle parameters of which braking time, stopping distance and related parameters should be first determined using analytical mathematical calculation based on brake science, engineering principle and procedure.

3.5.1 Vehicle Braking time

Braking time is the time it takes a vehicle to stop from the time the brake is first applied until the vehicle actually stops. The braking time can be expressed mathematical by integrating the following equation of motion.

$$a = \frac{dV}{dt}$$

Where

a = Acceleration (m/s^2)

V = Speed (m/s)

t = Time taken (sec)

Using the above defined acceleration equation; by integrating velocity of vehicle per acceleration of vehicle will provide the vehicle braking time. Here some assumptions about coding of automated braking system should be forwarded. The code should be written for the maximum braking time which is calculated using the parameters of the vehicle. Here the maximum braking time is ensured when the maximum loaded vehicle is driven at a maximum speed that the vehicle can experience.

Therefore, equating the above equation of motion which is given by a form of acceleration motion of equation for time taken and integrating both sides will give the time taken to accomplish the motion of travel.

$$\int dt = \int \frac{dV}{a_v}$$

$$t = \frac{V}{a}$$

Defining time taken as braking time of the vehicle (t_b), speed as speed of the vehicle (V_v) and acceleration as acceleration of the vehicle (a_v) will define as:

$$t_b = \frac{V_v}{a_v}$$

And more than 200 years ago Sir Isaac Newton defined and wrote the basic law relating force of an object to its acceleration as follow.

$$F = m * a$$

Therefore, the force applied to stop the vehicle which means the braking force of the vehicle can be expressed as:

$$F_b = m_v * a_v$$

Where

F_b = Braking force of vehicle (N)

m_v = Gross mass of the vehicle (kg)

a_v = Acceleration of the vehicle (m/s^2)

Equating for acceleration of the vehicle:

$$a_v = \frac{F_b}{m_v}$$

Therefore, by merging the two above expressed equations of motion and braking force; and substituting equation of acceleration in time equation and solving for braking time is given by equation 3.3.

$$t_b = \frac{V_v * m_v}{F_b} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(3.3)$$

And from equation of motion it is possible to find the distance travelled by an object if the time taken is determined.

$$S = ut - {}^{1}\!/_{2} * a * t^2$$

By substituting the variables using appropriate vehicle parameters, then the stopping distance that is travelled by the vehicle for the above braking time can be mathematically expressed as:

$$S_s = V_v * t_b - {}^{1}\!/_{2}\, a_v * {t_b}^2$$

Where

S_s = Stopping distance of vehicle (m)

V_v = Speed of the vehicle before brake applying (m/s)

t_b = Braking time taken to stop the vehicle (Sec)

a_v = Acceleration of the vehicle (m/s^2)

Then by substituting acceleration by its expression of mas of the vehicle and braking force, the stopping distance mathematical expression becomes:

$$S_s = V_v * t_b - {}^{1}/_{2} * \frac{F_b}{m_v} * {t_b}^2$$

It is possible to integrate the signal of speed sensor of the vehicle to the system by using two phase cable in to the automated braking system and the vehicle tachometer. This reduces the task and the system parts which can be installed for the system of automatic braking system. Therefore, the speed range of braking distance distributing and recognizing can be fetched from vehicles conventional speed sensor.

For the well-being-ness of the passengers or drivers or cargos the braking system of the vehicle should be safe and offer appropriate braking performance. So as to experience this type of braking performance in automated type braking system the speed of the vehicle should be ranged starting from parking speed to high speed of the vehicle stated in the vehicle specification since the braking distance of the vehicle is decidedly depends on vehicles linear speed. Therefore, the vehicle speed range distribution is done with numerical distance of $18km/hr$ up to $72km/hr$ and $24km/hr$ for greater than $72km/hr$ for this automated braking system is as follow.

Table 3.4: Vehicle speed distribution for code programming of automated braking system.

Linear Vehicle Speed in Km/hr.	***Equivalent Linear Vehicle Speed in m/s.***
Greater than 144	Greater than 40
121 to 144	33.578 to 40
97 to 120	26.878 to 33.3
73 to 96	20.278 to 26.6
55 to 72	15.278 to 20
37 to 54	10.278 to15
19 to 36	5.278 to 10
6 to 18	1.667 to 5
Less than 5	Less than 1.389

From the above braking distance equation, it is stated that the braking force of the vehicle is in variable form. It is known that brake system works on the principle of friction.

When a moving element is brought into contact with a stationary element, the motion of the moving element is affected. This is due to frictional force, which acts in opposite direction of the motion and converts the kinetic energy into heat energy.

Therefore, so as to determine the variable stated as braking force it is better to first determine the kinetic energy that the vehicle experiences when the brake is applied.

Therefore, the energy present in an object in motion (kinetic energy) is given by the following equation:

$$KE = {}^{1}/_{2} * m_v * V_v{}^2$$

Where

KE = Kinetic energy ($Joule$)

m_v = Mass of the vehicle (kg)

V_v = Speed of the vehicle (m/s)

From this equation, and assuming the mass of the object is constant, it is clear that in order to remove the kinetic energy from the system, the speed must be brought to zero. [35]

The selected vehicle for this study work has a vehicle mass of $2600kg$ and it also has passenger seat capacity of 15 seat excluding of driver and ministrant. It is also stated that the vehicle has a maximum speed of $152km/hr$ which is equal to $42.2m/s$. Therefore, using such above stated and tabulated vehicle specifications and parameters with including $200kg$ cargo capacity.

And using average mass of passengers as $65kg$ per person, the induced kinetic energy can be calculated as:

$$KE = {}^{1}/_{2} * m_v * V_v{}^2$$

$$= {}^{1}/_{2} * \big(2600 + 200 + (65 * 17)\big) * 42.2^2$$

$$= 0.5 * 3905 * 1780.84$$

$$\boldsymbol{KE = 3,477,090.1J = 3,477.09KJ}$$

This induced kinetic energy is equal to the work done by the braking force of the vehicle which means $KE = 3{,}477.09KJ = W$.

3.6 Vehicle Stopping Distance

The distance required to stop a vehicle depends on its speed and weight in addition to the factors of energy, heat and friction.

The brake power required to stop a vehicle varies directly with its weight and the “square” of its speed. For example, if weight is doubled, stopping power must be doubled to stop in the same distance. If speed is doubled, stopping power must be increased four times to stop in the same distance. When weight and speed are both doubled, stopping power must be increased eight times to stop in the same distance. [28]

It is stated that the stopping distance of any vehicle is highly depends on the reaction time and braking time. This automated braking system mainly aims to experience short stopping distance by eliminating the reaction time of the driver for applying brake. In designing of this automated braking system, it will be considered different speed ranges of the vehicle up to its uppermost speed. The selected vehicle speed ranges considered in this design work are: at $152km/h,$ $144km/h, 120km/h, 96km/h, 72km/h, 54km/h, 36km/h, 18km/h \ and \ 5km/hr$.

3.6.1 Vehicle Braking Distance

Braking distance refers to the distance a vehicle will travel from the point when its brakes are fully applied to when it comes to a complete stop. It is primarily affected by the original speed of the vehicle and the coefficient of friction between the tires and the road surface and negligibly by the tires' rolling resistance and vehicle's air drag. The type of brake system in use only affects trucks and large mass vehicles, which cannot supply enough force to match the static frictional force.

It is very difficult to achieve reliable calculations of the braking distance as road conditions and the tires’ grip can vary greatly. The braking distance may for example be 10 times longer when there is ice on the road. [45]

Within general circumstance when the vehicle is supported with an automated braking system and assumed that the vehicle experiences its maximum speed of drive 152km/hr, the braking distance of the vehicle in this circumstance can be calculated by using the following mathematically expressed using equation 2.4.

$$S_B = \frac{V^2}{2 * \mu * \text{g}}$$

Where

S_B = Braking distance (m)

V_v = Velocity of the vehicle before applying brake (km/hr)

μ = Coefficient of friction of asphalt road

g = Acceleration due to gravity (m/s^2)

Substituting numerical values into equation and computing for braking distance (S_B) of the vehicle will result:

$$S_B = \frac{\left(\frac{152}{3.6}\right)^2}{2 * 0.8 * 9.81}$$

$$= \frac{1782.716}{15.696}$$

$$\boldsymbol{S_B = 113.577m}$$

3.6.2 Vehicle Reaction Distance Due to Driver Delay

Reaction distance is how far your car travels in the time it takes the driver to react to a hazard and step on the brake. Braking distance is how far your car travels from the time the brakes are applied until it comes to a complete stop. Reaction distance is also mean by the distance traveled between the moment you mentally perceive a hazard and the moment you physically hit the brakes. It takes the average person half a second to think and another half a second react and apply the brakes. Therefore, using the maximum speed that the vehicle can experience, the reaction distance that the vehicle can travel before brake applying can be calculated using equation 2.3.

$$S_r = \frac{V_v * t_r}{3.6}$$

Where

S_r = reaction distance of the vehicle (m)

V_v = maximum speed of the vehicle (km/hr)

t_r = reaction time of the driver (sec)

Substituting the numerical values instead of variables and compute for reaction distance will give:

$$S_r = \frac{152 * 0.7}{3.6}$$

$$\boldsymbol{S_r = 29.556m}$$

Here it shows that the vehicle travels about $30m$ when the obstacles or pedestrians are in front risk without applying brake by means of hesitating of the driver for applying brake. Therefore, by using automated braking system, reaction distance resulting from drivers reaction time delay can be eliminated not reduced.

Here the means of eliminating of reaction distance during automated braking system is because of automatically applying of brake as it senses an obstacle.

3.6.3 Vehicle Stopping Distance

Stopping distances include the distance travelled while the driver notices a hazard and applies the brakes (thinking distance), and while the vehicle comes to a full stop from its initial speed (braking distance). Total stopping distance is the combined distance of reaction distance and braking distance.

Therefore, the mathematical description of total stopping distance of the vehicle is given by using equation 2.2.

$$S_s = S_r + S_b$$

Where

S_s = Total stopping distance of the vehicle (m)

S_r = Reaction distance of the vehicle (m)

S_b = Braking distance of the vehicle (m)

Substituting the numerical values form the above calculation and computing for total stopping distance of the vehicle (S_s):

$$S_s = 113.577 + 29.556$$

$$\boldsymbol{S_s = 143.133m}$$

This $S_s = 143.133m$ value is the total stopping distance that the vehicle will travel to experience full stop ($V_v = 0m/s$) when it drives in a speed of $152km/hr$. Therefore, based on the above scientifically calculation and analysis, if the vehicle is offered by automated braking system its total braking distance will be decreased from $143.133m$ to $113.577m$.

Let's see the distribution of braking distance (S_b), reaction distance (S_r) and total stopping distance (S_s) of the vehicle in the table 3.5 below with the normal conventional installed braking system by range the speed of the vehicle starting from $5km/hr$ to its maximum speed of $152km/hr$.

Table 3.5: Analytical calculated stopping distance, braking distance and reaction distance at different vehicle speed.

	Vehicle Speed (km/hr)								
Distance(m)	152	144	120	96	72	54	36	18	5
S_b	113.577	101.937	70.789	45.305	25.484	14.335	6.371	1.593	0.865
S_r	29.556	28	23.334	18.667	14	10.5	7	3.5	1.258
S_s	143.133	129.937	93.123	63.972	39.484	24.385	13.371	5.093	2.354

From the above mathematically calculated tabulated data of table 3.5, it is clearly revealed the three distance parameters are unswervingly depends on the vehicles speed. As try to show clearly the proportionality of the vehicle distance parameters and vehicle speed is linear. When the vehicle speed decreases the distance parameters also decrease in linear way.

The main objective of this thesis study is reducing the total stopping distance as much as possible by a scientifically way of eliminating the reaction distance in which the driver delays to apply brake when the obstacle is there. Therefore, the design and analysis of this automated braking system will be preceded with stopping distance of $S_s = 113.577m$.

It is stated that friction braking is the most commonly used braking method in modern vehicles. It involves the conversion of kinetic energy to thermal energy by applying friction to the moving parts of a system. The friction force (braking force) resists motion and in instant it generates heat, gradually as per the foot force applied it bringing the velocity of the vehicle to zero.

Therefore, the energy absorbed as thermal energy because of contact frictional force taken from the system is given by equation 3.4.

$$E_{th} = F_f * S_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.4)$$

Where

E_{th} = thermal energy produced by the brakes ($Joules$).

F_f = force of friction in newton which is equal to braking force (N).

S_s = stopping distance in meter (m).

Applying conservation of energy to the above kinetic energy and thermal energy equations, the thermal energy produced must equal to the kinetic energy dissipated:

$$KE = E_{th}$$

$$1/2 * m_v * V_v^2 = F_f * S_s$$

From the above thermal energy equation, it is described that the frictional force generated on vehicle brake wheel is the same as braking force of the vehicle (F_b).

The braking force is defined as the force required on the vehicles wheel that can slows or overcome full stop the car when the driver operates the brake pedal. Therefore, substituting the braking force in the place of frictional force and compute for braking force will give equation 3.5.

$$1/2 * m_v * V_v^2 = F_b * S_s$$

$$F_b = \frac{m_v * V_v^2}{2 * S_s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

From this equation it can be seen that increasing the velocity or mass of an object means the applied braking force must be increased to bring the object to a stop in the same distance.

Therefore, the braking force required in case of automated braking system for the selected vehicle with a maximum speed and maximum loaded weight can be calculated as follow.

$$F_b = \frac{m_v * V_v^2}{2 * S_s} = \frac{KE}{S_s}$$

$$= \frac{3{,}477.09 * 10^3}{113.577}$$

$$\boldsymbol{F_b = 30{,}614.386N = 30.614KN}$$

When a force is applied to the brake of the vehicle, there is work done by the friction between the brakes and the wheel. This reduces the kinetic energy of the vehicle, slowing it down and causing the temperature of the brakes to increase.

3.7 Vehicle Speed Ranging with Maximum Vehicle Load Capacity

In starting of the vehicle, the longitudinal speed of the vehicle is zero and through gradual gear selection and accelerate pedal positioning the vehicle experiences a speed greater than $0m/s$. For simplifying the design and analysis part of this automated braking system, the vehicle considered to start its movement at $5km/hr$ $(1.389m/s)$ minimum speed and varying up to $152km/hr$ $(42.22m/s)$ maximum speed.

It is clear that as the vehicle speed increases both braking time and stopping distance are increase exponentially. In contrast as the vehicle speed decreases both braking time and stopping distance also decrease with direct proportionality. Therefore, using the vehicles maximum speed $(152\text{km/hr} \ /42.222\text{m/s}/ \ )$ and maximum loading capability including passenger (17) and cargo load $(3905kg)$ the braking time and total stopping distance of the vehicle can be calculated as follow. In the above analysis part of braking time of the vehicle, the mathematical expression of the braking time is given by previously discussed equation 3.3.

$$t_b = \frac{V_v * m_v}{F_b}$$

$$= \frac{42.222 * 3905}{30{,}614.386}$$

$$\boldsymbol{t_b = 5.385sec}$$

And using the calculated braking time for maximum vehicle speed and maximum vehicle load $(t_b = 5.385sec)$, the total stopping distance of the vehicle can be calculated using the mathematical expression of:

$$S_s = u_v * t_b - {}^1\!/_2 * \frac{F_b}{m_v} * {t_b}^2$$

$$= (42.222 * 5.385) - \left(\frac{30{,}614.386 * 5.385^2}{2 * 3905}\right)$$

$$= 227.391 - 113.670$$

$$\boldsymbol{S_s = 113.721m}$$

Therefore, by ranging the vehicle speed starting from $5km/hr$ to its maximum speed of $152km/hr$ the distribution of braking time and total stopping distance of the vehicle with automate braking system is tabulated as the table 3.6 provided below.

Table 3.6: Analytical calculated vehicle braking time and stopping distance at different speed with automated brake system.

	Vehicle Speed (km/hr)								
	152	144	120	96	72	54	36	18	5
***Braking Time**(sec)*	5.385	5.102	4.251	3.401	2.551	1.913	1.275	0.637	0.354
Stopping Distance (m)	113.577	101.937	70.789	45.305	25.484	14.335	6.371	1.593	0.675

This above table 3.6 organized and analyzed data are an input data for the programing of the automated braking system.

Moreover, the above analyzed tabulated date the programming of the automated raking system is assumed to put $40cm$ safety factor for only front obstacle detection. For left and right side turning, without the intrusion of vehicles speed, only parking clearance distance of $40cm$ is maintained.

It is also known that the vehicle speed which is equal to $5km/hr$ is a usual vehicle parking speed. Considering this vehicle speed specification, the vehicle speed less than $5km/hr$ is not considered for this automated braking system design.

3.8 Block Diagram of Software System Programming of Automated Braking System

For developing precise and accurate automated braking system, the code program should be developed on a software which are so companionable. The code program also should have a capability of integrating the input commands with the brake system hardware components so as to harmonize the working of braking system components.

The speed sensor of the vehicle counts the revolution of the vehicles wheel since it is designed to work on the principle of magnetic induction type hall effect wheel speed sensor. The Hall Effect wheel speed sensor works based on magnetic induction principle on a toothed wheel with the clearance of air gap. The Hall Effect sensor has three terminals of reference voltage terminal, ground terminal and signal terminal which are connected to anti-lock brake system computer, negative of the battery terminal connection and signal terminals respectively.

The sensor has an internal transistor which can produce an electrical signal of 5V with the rotation of vehicle wheel on the principle of magnetic induction method. Therefore, so as to develop the program first it is mandatory to change the vehicles linear velocity to wheel rotation. The conversion of linear velocity to wheel rotation is done as like below.

The selected vehicle has a recommendable tire specification of P215|70R16 which can be interpreted as p stands for passenger vehicle, 215 stands for width of tire in mm, 70 stands for aspect ratio of the vehicle in % and 16 stands for tire rim diameter in inches. Therefore, using this tire data let's find the tire diameter starting from equation 3.6.

$$R_{aspect} = \frac{H_{tire}}{W_{tire}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(3.6)$$

Where

R_{aspect} = Tire aspect ratio in %

H_{tire} = Tire height in inches

W_{tire} = Tire Width in inches.

Therefore, by substituting the values in the place where the variables are assigned and computing for height of the tire:

$$0.70 = \left(\frac{H_{tire}}{215/_{25.4}}\right)$$

$$H_{tire} = 0.7 * 8.46457$$

$$\boldsymbol{H_{tire} = 5.925in}$$

Using the above calculated vehicle tire height and specified tire rim diameter, the vehicle tire diameter can be mathematically defined by using equation 3.7.

$$D_{tire} = (2 * H_{tire}) + D_{rim} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(3.7)$$

Where

D_{tire} = Tire diameter in inches

D_{rim} = Tire rim diameter in inches.

$$D_{tire} = (2 * 5.925) + 16$$

$$= 11.850 + 16$$

$$\boldsymbol{D_{tire} = 27.850in = 70.739cm}$$

Therefore, the vehicle tire rotation for the linear speed range which is specified from 5km/hr to 152km/hr can be calculated as follow using equation 3.8.

$$V_v = D_{tire} * RPM * 0.001885 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.8)$$

Where

D_{tire} = Tire diameter in cm
V_v = Vehicle speed in km/hr
RPM = Revolution of vehicle tire in rpm.

Therefore, substituting the values of vehicle maximum speed and above calculated tire diameter values in to equation 3.8 and equivalently computing for RPM variable:

$$152 = 70.739 * RPM * 0.001885$$

$$RPM = \frac{152}{70.739 * 0.001885}$$

$$= \frac{152}{0.133343015}$$

$$\boldsymbol{RPM = 1,139.917rpm = 1,140rpm}$$

And for minimum programmed linear vehicle speed of 5km/hr, the vehicle tire rotation will become:

$$RPM = \frac{5}{70.739 * 0.001885}$$

$$\frac{5}{0.133343015}$$

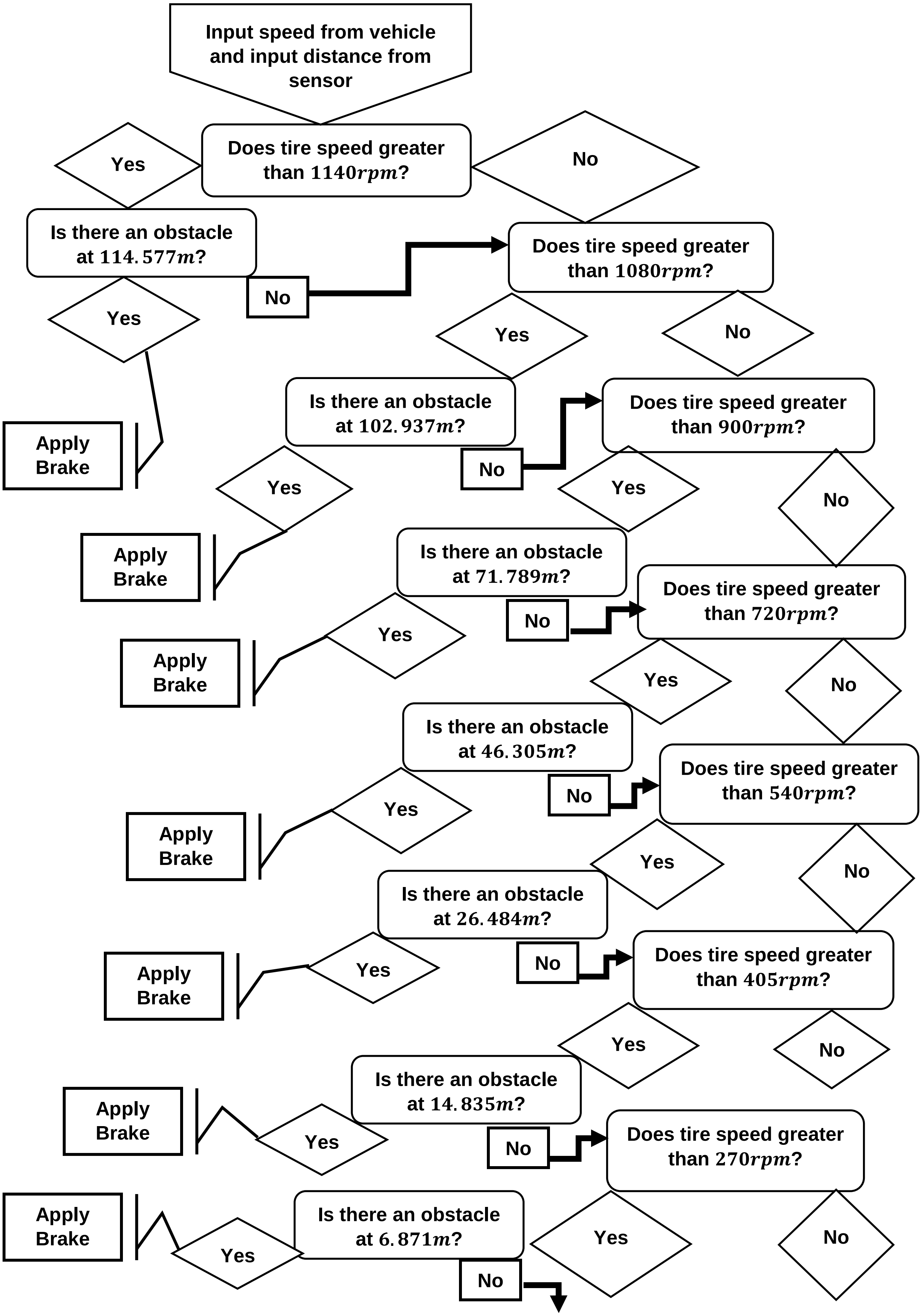
$$\boldsymbol{RPM = 37.497rpm = 38rpm}$$

With the same procedure the other linear vehicle speed corresponding vehicle tire are calculated and tabulated like the table 3.7 provided below.

Table 3.7: Vehicle linear speed and vehicle tire rotation

Vehicle linear speed (Km/hr)	5	18	36	54	72	96	120	144	152
Vehicle tire rotation (rpm)	38	135	270	405	540	720	900	1080	1140

Therefore, using the above table 3.7 linear vehicle speed and vehicle tire rotational speed of tabulated data of the vehicle with automated brake system, the code program of this automated braking system can be developed based on the following figure 3.4 block diagram expression. For safe warning and alerting of the driver it has been considered a forward sensing distance of 100cm for speed ranging from 72km/hr up to 152km/hr peak speed, 50cm sensing distance for vehicle speed ranging from 36km/hr to 71km/hr and 30cm sensing distance for vehicle speed ranging from 6km/hr to 35km/hr.



Input speed from vehicle and input distance from sensor
Does tire speed greater than 1140rpm?
Yes
No
Is there an obstacle at 114.577m?
Yes
No
Apply Brake
Does tire speed greater than 1080rpm?
Yes
No
Is there an obstacle at 102.937m?
Yes
No
Apply Brake
Does tire speed greater than 900rpm?
Yes
No
Is there an obstacle at 71.789m?
Yes
No
Apply Brake
Does tire speed greater than 720rpm?
Yes
No
Is there an obstacle at 46.305m?
Yes
No
Apply Brake
Does tire speed greater than 540rpm?
Yes
No
Is there an obstacle at 26.484m?
Yes
No
Apply Brake
Does tire speed greater than 405rpm?
Yes
No
Is there an obstacle at 14.835m?
Yes
No
Apply Brake
Does tire speed greater than 270rpm?
Yes
No
Is there an obstacle at 6.871m?
Yes
No
Apply Brake

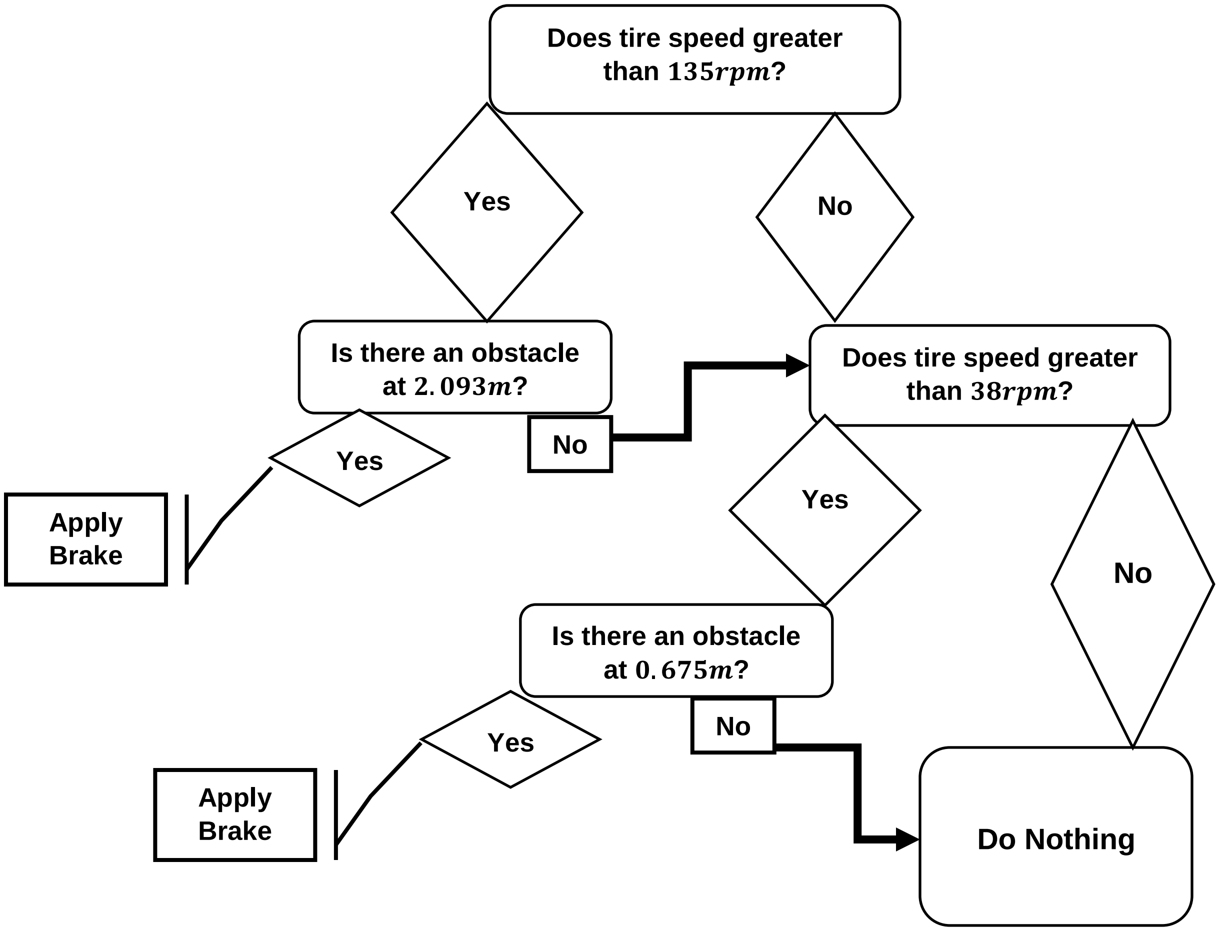


Figure 3.4: Flow chart of automated braking system programming

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Automated Braking System Result Data

The automated braking system code programming as shown in the flow chart above, it is developed based on vehicle speed and scientifically calculated braking distance, therefore it can work in any traffic flow condition and at any moving speed of the vehicle. The scientifically designed and analyzed electrohydraulic solenoid and its components was held based on scientifically procedure and way so as to fix between the vehicle booster and brake foot pedal lever by using the brake booster extension rod as a solenoid plunger. The components of solenoid assembly are developed on SOLIDWORKS software in both 3D and 2D draft as provided in the following figure 4.1 as bellow.

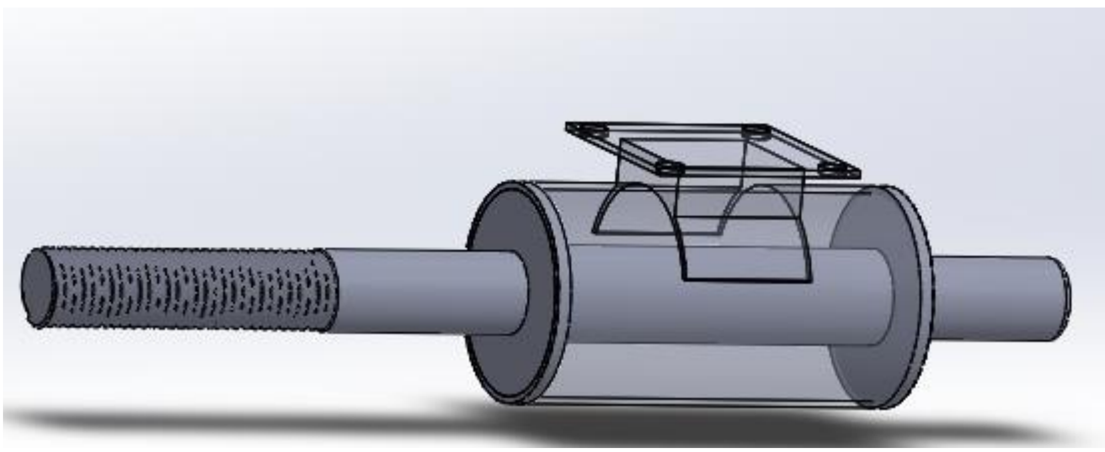


Figure 4.1: Assembly 3D drawing of designed solenoid using SOLIDWORKS 2018

The above figure 4.1 shows the proposed solenoid assembly which has been designed based on scientific principle, law and procedures for the automated brake system assembling of TOYOTA HIACE Commuter 2007 model. The designing and analyzing of this automated braking system sub component solenoid assembly starts with analytical calculation results from different governing equations stated in the document above. In the numerical calculation and designing of this solenoid assembly different parameters are determined in both mathematical equations and numerical values and results. From those results the numbers of turns of a solenoid assembly is the first and vital results which can determine and sets vital effect on designing and performance of electrohydraulic solenoid. It is clearly analyzed that the magnitude of the electromagnetic turn of the solenoid required to produce a mechanical force which is equal to the foot brake pedal force that can be produced by the driver is determined to be 920.

On the processes of electrohydraulic solenoid assembly design different theories and principles are considered and applied for the determination of components and its appropriate size which have a capability of execution of the required electromagnetic motion in the final assembly of an automated braking system for its pre-stated objectives. Furthermore, in the analytical calculation result provided in table 4.1 shows that the proposed automated braking system affords a lessening of stopping distance of the vehicle at maximum speed and maximum load condition with numerically value of 113.577m as shown in the table 4.1 provided below. It also calculated and analyzed the braking time of the vehicle with a condition of maximum vehicle speed and maximum loading capacity of the vehicle which results 5.385sec for the full braking of the vehicle with the condition stated above.

Table 4.1: Automated braking system designed and analyzed data

Determined Parameters	**Acquired Results**
Number of turns of solenoid valve ($\boldsymbol{N}$)	$\mathbf{920}$ turns
Length of coil wire ($\boldsymbol{L_c}$)	$\mathbf{43.5}\boldsymbol{m}$
Forces of produced by solenoid ($\boldsymbol{F_s}$)	$\mathbf{410}\boldsymbol{N}$
Plunger diameter ($\boldsymbol{d_p}$)	$\mathbf{12}\boldsymbol{mm}$
Kinetic energy ($\boldsymbol{KE}$)	$\mathbf{3,477.09}\boldsymbol{KJ}$
Maximum speed-load braking time ($\boldsymbol{t_b}$)	$\mathbf{5.385}\boldsymbol{sec}$
Maximum speed-load stopping distance ($\boldsymbol{S_s}$)	$\mathbf{113.577}\boldsymbol{m}$

As stated in the component description of automated brake system, the sensors selected for this thesis study work is LiDAR sensors which can be mounted in the four direction of the vehicles body for the full detection of obstacles around and near by the vehicle. The selected LiDAR sensor have a capability of detecting obstacles up to 180m which can suit with the selected vehicles specifications and parameters regarding to vehicles stopping distance. The braking distance is determined from the speed of the vehicle which is sensed by the vehicles conventional speed sensor and a safety factor of 100cm distance for car speed from 72km/hr to 152km/hr and 50cm distance for car speed from 6km/hr to 71km/hr has been added for obstacle detection and braking as an allowance.

4.2 Comparison of Conventional Braking system and Automated Braking System with Stopping Distance

It is clearly stated and discussed the direct proportionality of vehicles speed, vehicles load and vehicles stopping distance.

As vehicles speed and load increases with the same manner vehicles stopping distance also increase rapidly. This stopping distance increment is very high and huge in the case of conventional hydraulic braking system and it is clearly tabulated above. But in case of the newly proposed and developed automated braking system type the vehicles stopping distance is slowly increases compared to the existing ones. In same way as the vehicle speed is decreased, the existing braking system stopping distance is slowly decreases but the newly developed braking system stopping distance is rapidly decreases compared to the existing one as shown in table 4.2 provided below.

This decrement of stopping distance of the vehicle is achieved by eliminating of drivers delay time and by continuously scanning of vehicles nearby obstacles and by analyzing of vehicles speed and obstacles distance regarding to vehicles location. The table 4.2 provided below shows the sensing distance and vehicle stopping distance when the vehicle experiences an automated braking system.

Table 4.2: Vehicle speed, sensing distance and stopping distance correlation in automated braking system.

Vehicle Speed (km/hr)	Vehicle sensing distance (m)	Vehicle stopping distance (m)
$\mathbf{152}$	$\mathbf{114.577}$	$\mathbf{113.577}$
$\mathbf{144}$	$\mathbf{102.937}$	$\mathbf{101.937}$
$\mathbf{120}$	$\mathbf{71.789}$	$\mathbf{70.789}$
$\mathbf{96}$	$\mathbf{46.305}$	$\mathbf{45.305}$
$\mathbf{72}$	$\mathbf{26.484}$	$\mathbf{25.484}$
$\mathbf{54}$	$\mathbf{.835}$	$\mathbf{14.335}$
$\mathbf{36}$	$\mathbf{6.871}$	$\mathbf{6.371}$
$\mathbf{18}$	$\mathbf{2.093}$	$\mathbf{1.593}$
$\mathbf{5}$	$\mathbf{0.675}$	$\mathbf{0.675}$
Below $\mathbf{5}$	Not detected	……..

As try to show in the table 4.1 provided below the vehicle with automated brake system have an adequate advantage with regarding to stopping distance reduction than the vehicle was. As written in the correlation table 4.3 provided below when the vehicle moves with a speed of 5km/hr it takes 2.354m to stop the vehicle with the previously installed conventional hydraulic brake. But in a vehicle with automated brake system for a speed of 5km/hr it takes only 0.675m which is almost one third of the conventional took. Taking another speed condition which is 54km/hr it takes 24.385m with conventional type brake and 14.335m with automated type brake system.

In the same way when the vehicle travels with a speed of 120km/hr it took 93.123m in conventional type brake in contrast it takes 70.789m in automated type braking system.

Table 4.3: Comparison of conventional and automated braking system performance using stopping distance.

Vehicle speed (km/hr)	Conventional stopping dis (m)	Automated stopping dis (m)
$\mathbf{152}$	$\mathbf{143.133}$	$\mathbf{113.577}$
$\mathbf{144}$	$\mathbf{129.937}$	$\mathbf{101.937}$
$\mathbf{120}$	$\mathbf{93.123}$	$\mathbf{70.789}$
$\mathbf{96}$	$\mathbf{63.972}$	$\mathbf{45.305}$
$\mathbf{72}$	$\mathbf{39.484}$	$\mathbf{25.484}$
$\mathbf{54}$	$\mathbf{24.385}$	$\mathbf{14.335}$
$\mathbf{36}$	$\mathbf{13.371}$	$\mathbf{6.371}$
$\mathbf{18}$	$\mathbf{5.093}$	$\mathbf{1.593}$
$\mathbf{5}$	$\mathbf{2.354}$	$\mathbf{0.675}$

So as to generalize the comparison of the previously installed conventional hydraulic braking system performance with the newly proposed and developed automated braking system based on stopping distance it takes with the same speed, the automated braking system have a capability of decreasing stopping distance of the vehicle with 19.73% than the exciting type braking system. The figure 4.2 provided below shows the relationship clearly.

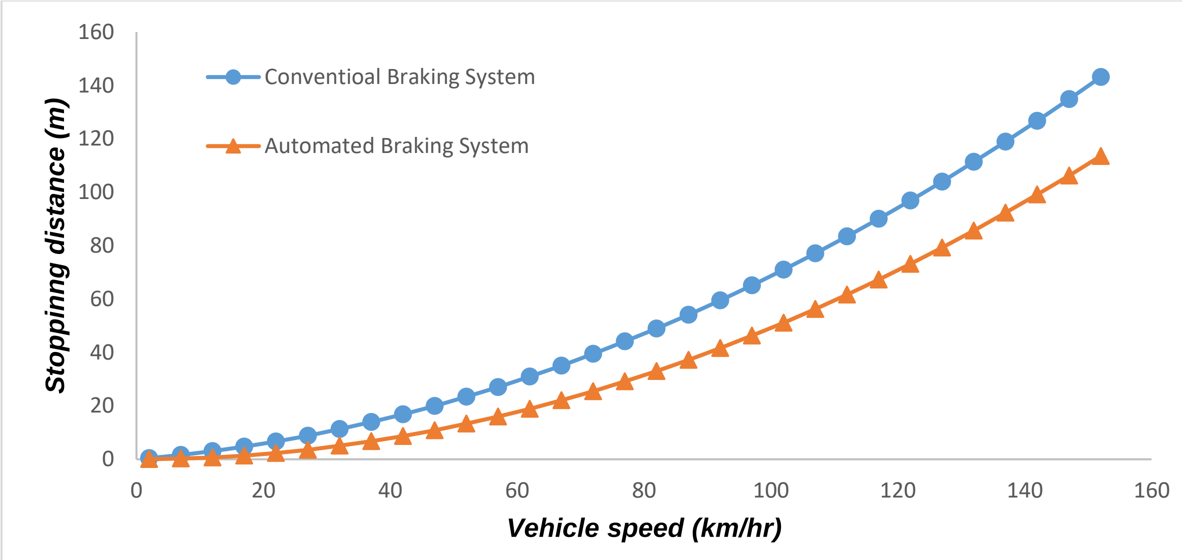


Figure 4.2: Comparison of existing braking system stopping distance and automated braking system stopping distance according to vehicle speed.

4.3 Braking Time and Stopping Distance of Automated Braking System

As stated in the design and analysis part, the vehicle is considered in ranging starting from a parking speed of 5km/hr up to vehicles maximum speed of 152km/hr. the analysis of this automated braking system done when the vehicle has a forward, reverse or curve motion of travel with a minimum speed of 5km/hr. Using vehicles speed range, the analysis results stopping distance difference and braking distance difference which makes the vehicle decelerate within an interval of time as shown in table 4.4 provided below. The figure 4.3 provided below clearly shows the correlation between vehicle speeds, braking time and stopping distance of newly proposed and developed automated braking system. So as to justify in word description, in the vehicle with automated braking system, as the vehicle speed increases, vehicle braking time and stopping distance increase slowly in contrast as the vehicle speed decreases both vehicles braking time and stopping distance decrease rapidly. This vehicle speed, braking time and stopping distance correlation is clearly organized on the figure 4.3 provided below. So as to generalize it is clearly visible that the vehicle speed is directly proportional to both braking time and stopping distance.

Table 4.4: Vehicle braking time and stopping distance of automated brake system.

	Vehicle Speed (km/hr)								
	152	144	120	96	72	54	36	18	5
T_b (sec)	5.385	5.102	4.251	3.401	2.551	1.913	1.275	0.637	0.354
S_s (m)	113.577	101.937	70.789	45.305	25.484	14.335	6.371	1.593	0.675

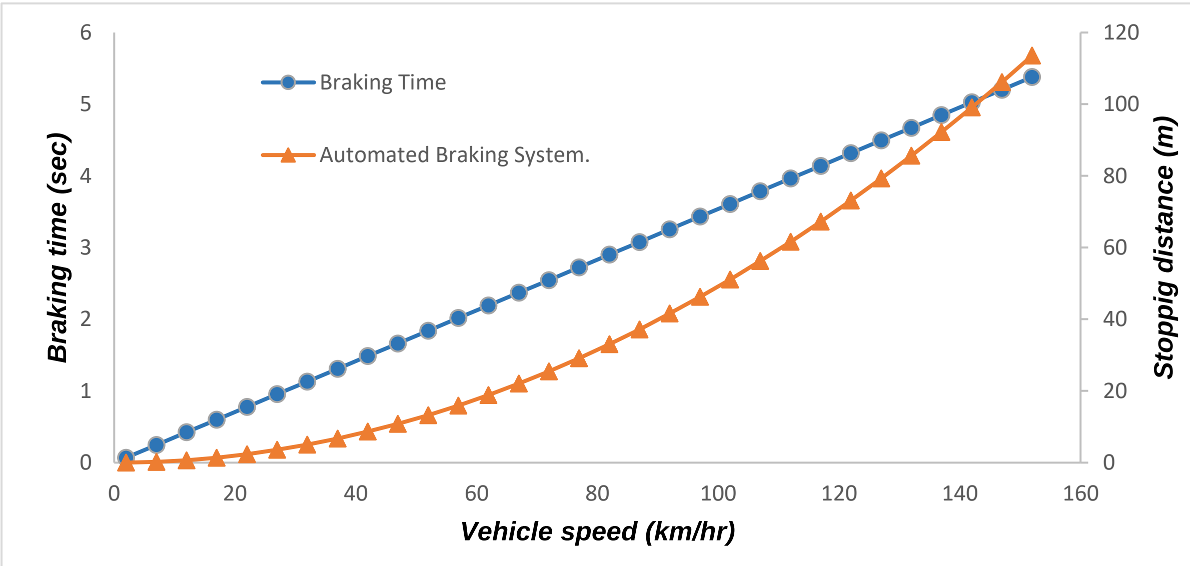


Figure 4.3: Braking time and stopping distance relation with vehicle speed.

4.4 Automated Brake System Component Operating Conditions

The whole components of the proposed automated brake system were discussed briefly in the previous chapters of this thesis work. So as to describe components operating conditions it is better to consider the automated brake system as at rest and at working condition. Therefore, the components of the automated brake system are considered in two different operating conditions; one in normal operating conditions and other in braking conditions. This condition of the brake system components are described in the table 4.5 provided below.

Table 4.5: Component operating condition in automated braking system.

Component List	Normal Driving Condition	Braking Condition
Relay switch	Open	Closed
Warning LED (Red)	Off	Light
Warning buzzer	Off	Ringing
Solenoid plunger	Pulled	Pushed

4.5 Prototyping and Representation of the Electronic System for Automated Braking System

The actual real vehicle data automated braking system components listed in the table 4.5 provided above and their operating conditions also stated in a simplified way. Implementation of this automated braking system on the real vehicle is restricted by financial problem. Taking this and related problem in consideration prototyping and representing the system and working principle of automated braking system on electric robot car been a solution. Therefore, in prototyping and representing of this automated braking system using electric robot car the solenoid is not proposed to be in use. This is because in electric robot car motor driving, braking can be applied by simple cutting off the electric connection of the motor since the inertia of mass is almost negligible.

Therefore, the prototyping and representation assembly of this automated braking system on electric robot car can be accomplished as follow.

- Fix microcontroller (Arduino UNO) and breadboard with breadboard holder plate with screw set using screw driver.
- Take robot main chassis and fix DC motor on it using motor screw set.
- Fix caster wheel on chassis using caster screw set.
- Fix microcontroller (Arduino UNO) and breadboard holding plate with chassis using screw set.
- Fix DC battery to chassis using hot glue, screw and nut.
- Fix rubber wheel to the DC motor.
- Attach DC motor driver shield to the microcontroller (Arduino UNO).
- Connect the two left DC motor in one and the two right side DC motors in one.
- Connect the combined left and right-side DC motors with the DC motor driver shield output pins.
- Connect the four sensors to the microcontroller (Arduino UNO), to 5V and ground pins using jumper wires.
- Connect IR receiver, LED light and buzzer to the microcontroller (Arduino UNO).
- Detail connection of sensors to microcontroller (Arduino UNO):
  - Front Ultrasonic sensor:

    V_{cc}---------------5v

    Trig--------------A0

Echo-------------A1

GND-------------GND

- Left side Ultrasonic sensor:

  V_{cc}---------------5v

  Trig--------------A2

  Echo-------------A3

  GND-------------GND

- Right side Ultrasonic sensor:

  V_{cc}-----------------5v

  Trig---------------A4

  Echo-------------A5

  GND-------------GND

- Back Ultrasonic sensor:

  V_{cc}---------------5v

  Trig--------------13

  Echo-------------12

  GND-------------GND

- Detail connection of DC motor driver shield to Microcontroller (Arduino UNO):

  IN_1-------------Pin_4

  IN_2-------------Pin_5

  IN_3-------------Pin_6

  IN_4-------------Pin_7

- Detail connection of IR receiver to Microcontroller (Arduino UNO):

  Power pin-------------Pin_3

- Detail connection of Buzzer to Microcontroller (Arduino UNO):

  Power pin-------------Pin_11

- Detail connection of LED light to Microcontroller (Arduino UNO):

  Power pin-------------Pin_11

- Upload the code to (microcontroller) Arduino UNO microcontroller using compatible USB cable.
- Connect the power supply to microcontroller (Arduino UNO) using compatible device.

4.6 Graphic Presentation of Electronic System Circuit and Code Programming for Automated Braking System

This automated braking system for the implementation in light passenger vehicle are seriously depend on electrical system, component, electrical connection and electrical signal. Therefore, the electrical components and electrical signal connection should be developed professionally and follow electrical laws and procedures. The figures; figure 4.4 and figure 4.5 provided are developed electrical connections which are Proteus software based generated electrical connection as per the code programed on Arduino software. All the required components and their electrical connections are clearly provided in a visible manner for both prototype and real vehicle automated braking system in figure 4.4 and figure 4.5 respectively.

The equivalent code programs are also provided in the appendix parts of this paper for both prototype and real vehicle data automated braking system. The system circuit development and code programming of prototype automated braking system is developed using Infrared receiver.

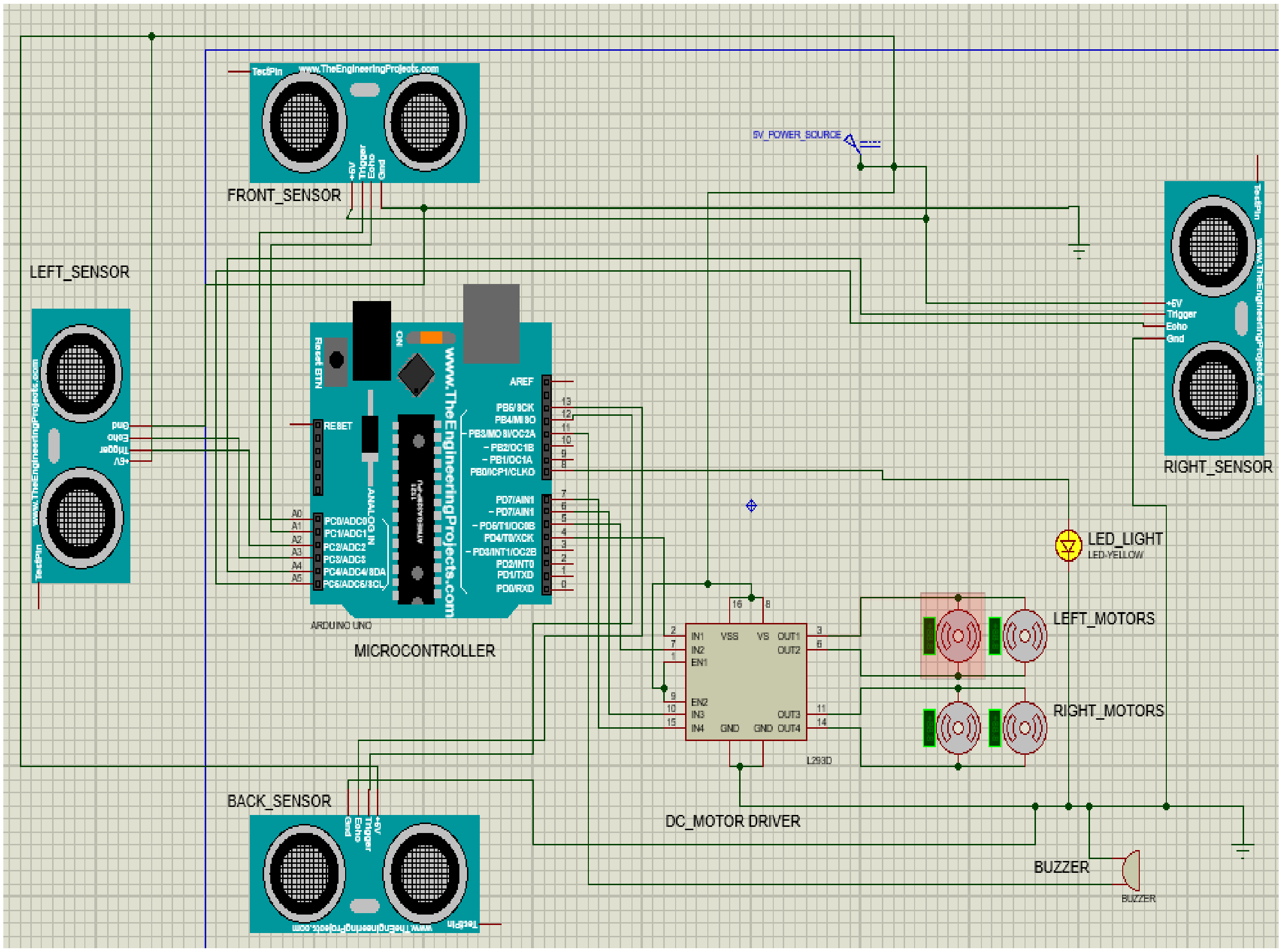


Figure 4.4: Schematic presentation of electrical connection of prototype using Proteus software.

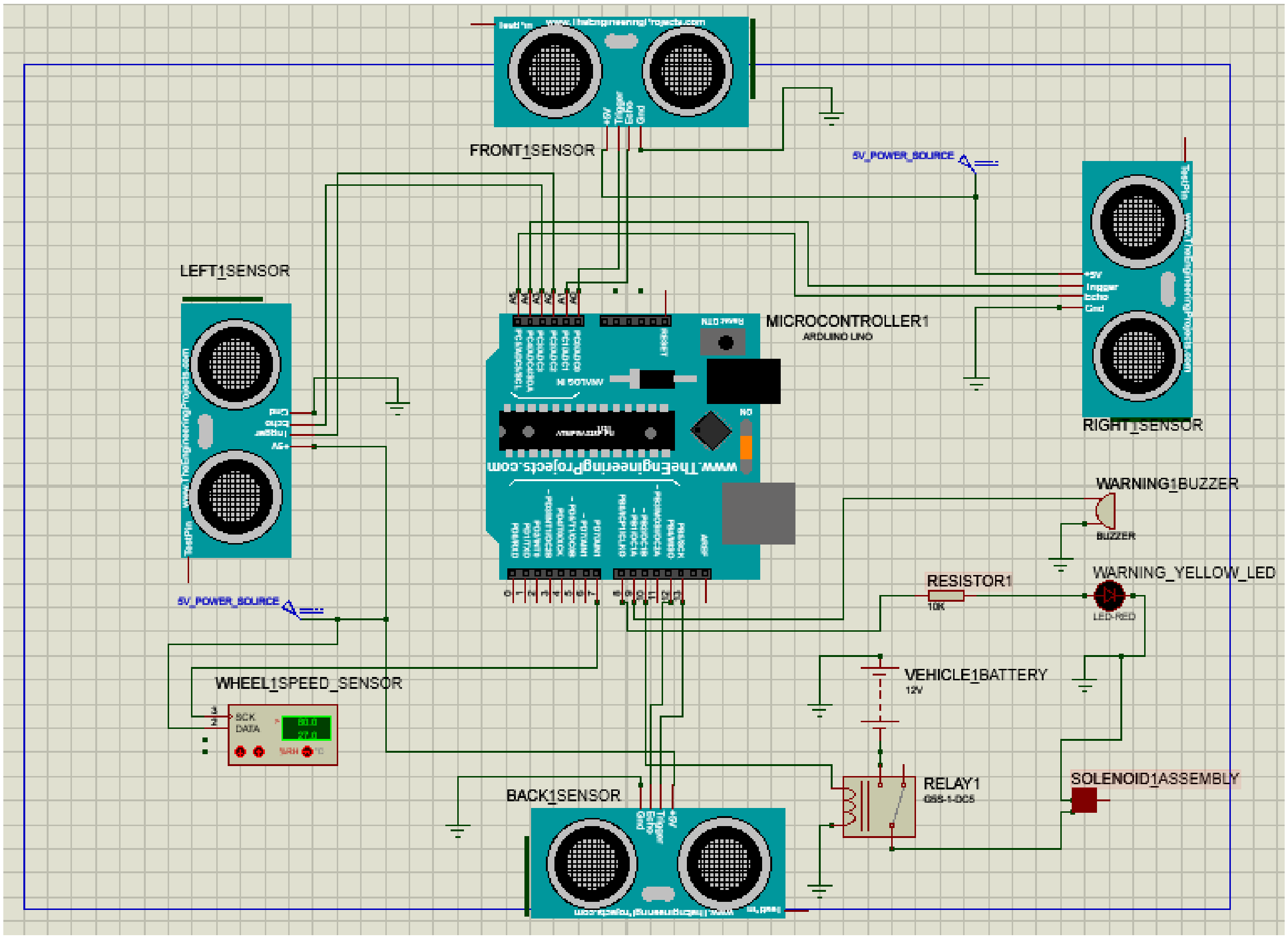


Figure 4.5: Schematic presentation of electrical connection of real vehicle data using Proteus software.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Summary

The internal algorithms for model components which helped through development of each system separately and interconnected them has been explained briefly and explicitly. Scenario development procedures and software tools functioning have also been brought into reader's knowledge briefly. Moreover, the limitations on these features and results discussions have also been provided.

5.2 Conclusion

This research work discusses through the preparation and advancements in the scenario development and model development for the automated braking system. Active safety features implementation is very important for now a day traffic environment where one can drive safely and comfortably. This thesis study presents the development and implementation of an automated baking system for accident prevention in light passenger vehicle, intended to use in vehicles where the drivers may not brake manually. This automated brake system has things which are neatly presented one can understand that the target is achieved exhaustively and efficiently, with a better electrohydraulic property from hydraulic principles and pre-stated specifications. The design and analysis part of the paper work executed based on scientific procedures and specifications. As shown in the design and analysis part of the document, the proposed solenoid plunger system can fit between the brake booster and brake pedal and have a capability of producing the required force to execute braking.

The new brake system is much better than that of the existing conventional brake system; based on scientifically calculated data, the stopping distance at maximum vehicle speed and at maximum vehicle load is $113.577m$ which is reduced $30m$ from the existing conventional brake system. It is also observed that the automated braking system is better than the manual braking system by reducing collision, so that it can be conclude to use automated braking system.

The components of the automated braking system such as; micro-controller, LiDAR sensor, LED, buzzer, relay and solenoid plunger can be easily replaced. The system is a realistic and less expensive system and it can be implemented in a simple way by modifying the foot brake pedal lever component of the conventional vehicles brake and also it reduces the requirements of additional driving skills of the driver.

5.3 Recommendation

Even though the thesis document, the developed system working principle and execution of the system have been clearly presented, it has been found mandatory to recommend in a more generalized way issues in this thesis work.

Such types of studies, on the fields related to automotive, have gorgeous contributions on the enhancement of the enfant automotive industries as per country context, yet very lack of clear directions and problem identification are basic limitations on running automotive related projects. So, it is recommended that subsequent pressure and fellow up are mandatory to the direction of automotive related topics and research works.

The system is programmed by relating the obstacle sensing distance with a large range of vehicle moving speed, but it is recommended that the speed of the vehicle and obstacle sensing distance can be in small range. The developed automated braking system can be integrated with any combination of wheel brake assembly of caliper and drum wheel brake. But it can be more efficient if it is integrated with a four-wheel caliper brake assembly. The developed automated brake system can offer best performance and it can substitute the speed tracker which is in action by Ethiopian Minister of Transportation.

The model is a good demonstration tool for anyone who wants to do research on automated braking system. The theoretical design and analysis compiled in this thesis work may be not in a best fashion so that it is recommended to follow and assess differently if possible finite element analysis is advisable for the solenoid assembly.

5.4 Future Work

In this study it is recommended to further study in a recent and futuristic way with the automotive trend follower. The developed braking system is considered to implement for the vehicle which are automatic type transmission system. The choosing of the automatic transmission type vehicle is so as to simplifying the design, analysis and system components since disengagement of clutch system is required if it is applied for manual transmission type vehicles. Therefore, extra studies should be carried on components of this automated braking system by considering the implementation of this system for vehicles with manual type transmission. It also recommendable for future study of the integration of this automated braking system and propeller shaft mounted electromagnetic retarder by using the same sensor signal and micro controller so as to overcome best performance of vehicle braking.

REFERENCES

1. W. H. Organization., 2015, "*More Than 270,000 Pedestrians Killed On Roads Each Year".*
2. Sleet D., et al., 2011, "*The Decade Of Action For Global Road Safety*"., J Safety Res.
3. World Health Organization., 2018, "*Global Status Report On Road Safety 2015*"., WHO Summary, Geneva.
4. Amhara Mass Media Agency Report.,2019, " https://ethiopianmonitor.com/2019/10/19/ten-killed-in-deadly-car-crash-in-northern-ethiopia/ ".
5. Ethiopian Federal Police Commission., 2017, "*Road Traffic Accident Report*. Addis Ababa, Ethiopian.
6. Etenesh Abera., 2018, "*AddisStandard*" http://addisstandard.com/news-at-least-24-killed-in-two-separate-car-accidents-in-amhara-and-oromia-regional-states/.
7. Getu S., et al.,2013, "*Characteristics of Police-reported Road Traffic Crashes in Ethiopia over a Six Year Period*"., Australasian Road Safety Research, Policing & Education Conference Brisbane, Queensland.
8. Girma G., et al., 2018, "*Prevalence Of Fatality And Associated Factors Of Road Traffic Accidents Among Victims Reported To Burayu Town Police Stations, Between 2010 And 2015*"., Journal of Transport & Health.
9. Debela D., 2019, "*Road Traffic Accident In Ethiopia From 2007/08-2017/18, (Since Ethiopia Millennium)*"., American International Journal of Sciences and Engineering Research; American Center of Science and Education, USA.
10. Alfred E., et al., 2011, "*Emergency Steer & Brake Assist*"., *A Systematic Approach For System Integration of Two Complementary Driver Assistance Systems*"., Continental AG, Germany.
11. Garima A., et al., 2017, "*Automatic Braking System with Distance Adjustment*"., J.Sci.Res.
12. Rupesh kumar., et al., 2017, "*AntiLock And Automatic Braking Systems*"., Proceedings of ASAR International Conference, Rourkela, India.
13. Chaithra M., et al., 2016, "*Automatic Braking System for Automobiles Using IR Sensor*"., International Journal of Advanced Research in Electrical.
14. P.Balashanmugam., et al., 2013, "*Fabrication of High Speed Indication and Automatic Pneumatic Braking System*"., International Journal of Engineering Trends and Technology.
15. Naim Sidek and Momoh Salami., 2018, "*Design of intelligent braking system*"., ResearchGate.
16. Ping Fan Jin., et al., 2015, "*Design of Unmanned Vehicle advanced braking system using smart motor".,* The 12th International Conference on Ubiquitous Robots and Ambient Intelligence-URAI; KINTEX, Goyang City, Korea.
17. V. Milanes., et al., 2010, "*Electro-Hydraulic Braking System for Autonomous Vehicles"*., International Journal of Automotive Technology.
18. Sanket Thorve., et al., 2016, "*Design and Implementation of Automatic Emergency Braking System".,* International Journal of Current Engineering and Technology.
19. Chetan Tembhurkar., et al., 2018, "*Design of Intelligence Braking System*"., IJIES.
20. Sourabh Santosh Joshi., et al., 2017, "*Design Of Automatic Braking System For Vehicles In Hill Station*"., IJIERT.
21. Chang-Woo Song and Seung-Yop Lee., 2015, "*Design of a Solenoid Actuator with a Magnetic Plunger for Miniaturized Segment Robots".,* Appl. Sci.
22. E. Purcell., 2011, "*Electricity and Magnetism".,* Second Edition, Cambridge Univesity Press.
23. MICO, Inc., 2010, "*Electrohydraulic Components: Electronic Pedals, Digital Valve Controllers, and Electrohydraulic Valves:* MICO, Inc.
24. E. B. Moullin., 1950, "*The Principles of Electromagnetism*"., Second Edition, Oxford at the Clarendon Press.
25. Daniel Comeaga., et al., 2018, "*Micro Electromagnetic Actuator: Static Behavior Constantin*"., MATEC Web of Conferences ICMSC.
26. Pankaj Mishra., 2020, "*What is Hydraulic Braking System and How It Works?*"., https://www.mechanicalbooster.com/2018/08/what-is-hydraulic-brakingsystem.html#:~:text=Hydraulic%20braking%20system%20is%20a,in%20order%20to%20achieve%20braking.
27. U.S. Department of Transportation., 2012, "*Automatic Emergency Braking System (AEB*)"., Research Report; National Highway Traffic Safety Administration.
28. SGI: Saskatchewan driver's licensing and vehicle registration., 2020, "*Air Brake Manual*"., https://www.sgi.sk.ca/air-brake/-/knowledge_base/air-brake/speed-weight-distance.

29. Paul Lorrain and Dale R. Corson., 1978, "*Electromagnetism Principles and Applications*"., Second Edition W.H.Freeman and Company, San Francisco.
30. Web Desk., 2019, "*Hydraulic Brake System*"., https://whyps.com/hydraulic-brake-system-components.
31. James Remfrey., et al., 2015, *Hydraulic Brake Systems for Passenger Vehicles: Handbook of Driver Assistance Systems*"., Springer, Switzerland.
32. Abinash Swain., 2020, "*How Does Hydraulic Brake System Work*'., http://gentorch.com/how-does-hydraulic-brake-system-work/.
33. Gajanan Koli., 2017, "*Intelligent Braking System using the IR Sensor".,* IJASRE.
34. Eriki Ananda. K., et al., 2018, "*Arduino Based Automated Braking Control System to Enhance the Safety at Low Light and Long Stressed Drive Conditions"*., IJMSME.
35. S . N.Sidek and M.J.E.Salami., 2000, "*Design of intelligent braking system*"., Researchgate.
36. Chris Woodford., 2020, "*Lidar".,* https://www.explainthatstuff.com/lidar.html.
37. Bluesky International Limited., 2020, "*How Does Lidar Work? The Science Behind The Technology.,* http://www.lidar-uk.com/how-lidar-works/.
38. Unnamed Author; ELECTGO., 2020, "*Relay:What Is A Relay, Its Function, Types And Relay Wiring;* https://www.electgo.com/what-is-a-relay/.
39. Bruce Rose., 2020, "*Buzzer Basics: Technologies, Tones, and Drive Circuits:*"., https://www.cuidevices.com/blog/buzzer-basics-technologies-tones-and-driving-circuits.
40. Wikipedia., 2020, https://en.wikipedia.org/wiki/Light-emitting_diode; Edited on 22 July 2020.
41. SparkFun Electronics., 2020, "*How to Use a Breadboard*"., https://learn.sparkfun.com /tutorials/how-to-use-a-breadboard/all.
42. Anyang Kaidi., 2020, "*Suitable Materials for Solenoid Iron Core*"., http://www.solenoidsupplier.com/solenoid-iron-core-materials/.
43. Richard S. Figliola and Donald E. Beasley., 2006, "*Theory and Design for Mechanical Measurements".,* sixth Edition.
44. TOYOTA Company., 2011, "*Repairing Manual"., TOYOTA HIACE Commuter* 2007; Addis Ababa, Ethiopia.
45. Fricke, L., 1990, "*Traffic Accident Reconstruction*: Volume 2 of the Traffic Accident Investigation Manual"., The Traffic Institute, Northwestern University.
46. Girma Gemechu., et al., 2018, "*Prevalence Of Fatality And Associated Factors Of Road Traffic Accidents Among Victims Reported To Burayu Town Police Stations, Between 2010 And 2015, Ethiopia".,* Journal of Transport & Health.
47. Sandeep Thorat., et al., 2016., "*Design and Implementation of Automatic Emergency Braking System.,* IJCET.
48. Josef Steinbaeck., et al., 2017, "*Next Generation Radar Sensors in Automotive Sensor Fusion Systems".,* ResearchGate, Conference Paper.
49. T. Peynot, J. Underwood, and S. Scheding., 2009, "*Towards Reliable Perception For Unmanned Ground Vehicles In Challenging Conditions".,* IEEE / RSJ International Conference on Intelligent Robots and Systems.
50. D V Tretsiak., et al., 2008, "*Research In Hydraulic Brake Components And Operational Factors Influencing The Hysteresis Losses".,* Journal of Automobile Engineering.
51. Val Schabinsky., 2020, *How Long Does It Take To Fully Stop A Vehicle".,* http://internationalclinicaltrials.com/vehicle-braking-time.html.
52. R. H. Rasshofer., et al., 2005, "*Automotive Radar and Lidar Systems for Next Generation Driver Assistance Functions*"., Advances in Radio Science, BMW Group Research and Technology, Hanauer, Munich, Germany.
53. Jack Erjavec., 2002, "*Automotive Brakes".,* THOMSON: Delmar Learning, google book.
54. Nonpublished Thesis Report by: Shenshen Shi., 2016, "*Automobile brake system"*.
55. Masters, G. M., 2004, "*In Renewable And Efficient Electric Power System Canada".,* John Wiley and SONS INC.
56. Theraja, B., 2005, "*A Textbook Of Electrical Technology*"., First Edition. Volume 1.

APPENDIXES

Appendix A: Code Programming for Prototyping of Automated Braking System

```
/// Prototyping_Automated_Braking_System ///

/// Thesis_Final ///_/// Nigusie_Yihalem ///

#include <IRremote.h>

#define irPin A5

IRrecv irrecv(irPin);

decode_results results;

int motorPin1 = 4; // pin 2 on L293D IC

int motorPin2 = 5; // pin 7 on L293D IC

int motorPin3 = 6; // pin 1 on L293D IC

int motorPin4 = 7;

int trigPin4 = 13;

int echoPin4 = 12;

int trigPin1 = 3;

int echoPin1 = 2;

int trigPin2 = 9;

int echoPin2 = 8;

int trigPin3 = 11;

int echoPin3 = 10;

#define LED A1

#define Buzzer A0

long duration, distance, FIRSTSensor,SECONDSensor,THIRDSensor, FORTHSensor;
```

```
void setup(){
Serial.begin (9600);
pinMode(trigPin1, OUTPUT);
pinMode(echoPin1, INPUT);
pinMode(trigPin2, OUTPUT);
pinMode(echoPin2, INPUT);
pinMode(trigPin3, OUTPUT);
pinMode(echoPin3, INPUT);
pinMode(trigPin4, OUTPUT);
pinMode(echoPin4, INPUT);
pinMode(LED, OUTPUT);
pinMode(Buzzer, OUTPUT);
digitalWrite(LED, LOW);

irrecv.enableIRIn();
  pinMode(motorPin1, OUTPUT);
  pinMode(motorPin2, OUTPUT);
  pinMode(motorPin3, OUTPUT);
  pinMode(motorPin4, OUTPUT);

}

void loop(){
```

```
SonarSensor(trigPin1, echoPin1);
FIRSTSensor = distance;
SonarSensor(trigPin2, echoPin2);
SECONDSensor = distance;
SonarSensor(trigPin3, echoPin3);
THIRDSensor = distance;
SonarSensor(trigPin4, echoPin4);
FORTHSensor = distance;
digitalWrite(LED, LOW);
digitalWrite(Buzzer, LOW);

//Serial.print("S1:");Serial.println(FIRSTSensor); delayMicroseconds(10);
//Serial.print("S2:");Serial.println(SECONDSensor);delayMicroseconds(10);
//Serial.print("S3:");Serial.println(THIRDSensor); delayMicroseconds(10);

if((FIRSTSensor <= 5))
{digitalWrite(LED, HIGH);
 digitalWrite(Buzzer, HIGH);
 digitalWrite(motorPin1, LOW); // set pin 2 on L293D low
 digitalWrite(motorPin2, LOW); // set pin 7 on L293D low
 digitalWrite(motorPin3, LOW);
 digitalWrite(motorPin4, LOW);
 delay(250);
```

```
 }
if((SECONDSensor <= 5))
{digitalWrite(LED, HIGH);
 digitalWrite(Buzzer, HIGH);
 digitalWrite(motorPin1, LOW); // set pin 2 on L293D low
        digitalWrite(motorPin2, LOW); // set pin 7 on L293D low
        digitalWrite(motorPin3, LOW);
        digitalWrite(motorPin4, LOW);
 delay(250);
 }
if((THIRDSensor <= 5))
{digitalWrite(LED, HIGH);
 digitalWrite(Buzzer, HIGH);
 digitalWrite(motorPin1, LOW); // set pin 2 on L293D low
        digitalWrite(motorPin2, LOW); // set pin 7 on L293D low
        digitalWrite(motorPin3, LOW);
        digitalWrite(motorPin4, LOW);
 delay(250);
 }
if((FORTHSensor <= 5))
{digitalWrite(LED, HIGH);
 digitalWrite(Buzzer, HIGH);
 digitalWrite(motorPin1, LOW); // set pin 2 on L293D low
        digitalWrite(motorPin2, LOW); // set pin 7 on L293D low
```

```
        digitalWrite(motorPin3, LOW);
        digitalWrite(motorPin4, LOW);
 delay(250);
 }
if (irrecv.decode(&results)) {
switch (results.value) {

case 3249185118:
        digitalWrite(motorPin1, LOW); // set pin 2 on L293D low
        digitalWrite(motorPin2, LOW); // set pin 7 on L293D low
        digitalWrite(motorPin3, LOW);
        digitalWrite(motorPin4, LOW);
        Serial.println("Motor: Stop");
delay(250);
break;
case 3249147378:
        digitalWrite(motorPin1, LOW); // set pin 2 on L293D high
        digitalWrite(motorPin2, HIGH); // set pin 7 on L293D low
        digitalWrite(motorPin3, LOW);
        digitalWrite(motorPin4, HIGH);
        Serial.println("Motor: Forward");
delay(250);
break;
```

```
case 3249163698:
        digitalWrite(motorPin1, HIGH); // set pin 2 on L293D high
        digitalWrite(motorPin2, LOW); // set pin 7 on L293D low
        digitalWrite(motorPin3, HIGH);
        digitalWrite(motorPin4, LOW);
         Serial.println("Motor: Reverse");
delay(250);
break;

case 3249180018:
        digitalWrite(motorPin1, HIGH); // set pin 2 on L293D high
        digitalWrite(motorPin2, LOW); // set pin 7 on L293D low
        digitalWrite(motorPin3, LOW);
        digitalWrite(motorPin4, HIGH);
        Serial.println("Motor: Right");
delay(250);
break;

case 3249196338:
        digitalWrite(motorPin1, LOW);
        digitalWrite(motorPin2, HIGH);
        digitalWrite(motorPin3, HIGH);
        digitalWrite(motorPin4, LOW);
        Serial.println("Motor: Left");
```

```
delay(250);

break;


}


irrecv.resume();

   }


}


void SonarSensor(int trigPin,int echoPin)

{

digitalWrite(trigPin, LOW);

delayMicroseconds(2);

digitalWrite(trigPin, HIGH);

delayMicroseconds(10);

digitalWrite(trigPin, LOW);

duration = pulseIn(echoPin, HIGH);

distance = (duration/2) / 29.1;

}
```

Appendix B: Code Programming for Automated Braking System of Real Vehicle Data

```
/// Real_Vehicle_Data_Program ///

/// Thesis_Final///_/// Nigusie_Yihalem ///

const int trigPin1 = A0;

const int ecoPin1 = A1;

const int trigPin2 = A2;

const int ecoPin2 = A3;

const int trigPin3 = A4;

const int ecoPin3 = A5;

const int trigPin4 = 13;

const int ecoPin4 = 12;

const int relay = 11;

const int buzzer = 13;

const int yellowlight = 7;

long duration;

int distance1;

int distance2;

int distance3;

int distance4;

int safetyDistance1;

int safetyDistance2;

int safetyDistance3;

int speeds;
```

```
void setup() {
Serial.begin(9600); // put your setup code here, to run once:
pinMode(ecoPin1, INPUT);
pinMode(trigPin1, OUTPUT);
pinMode(ecoPin2, INPUT);
pinMode(trigPin2, OUTPUT);
pinMode(ecoPin3, INPUT);
pinMode(trigPin3, OUTPUT);
pinMode(ecoPin4, INPUT);
pinMode(trigPin4, OUTPUT);
pinMode(relay, OUTPUT);
pinMode(buzzer, OUTPUT);
pinMode(yellowlight, OUTPUT);
}
void loop() {
// put your main code here, to run repeatedly:
digitalWrite(trigPin1, LOW);
digitalWrite(trigPin2, LOW);
digitalWrite(trigPin3, LOW);
digitalWrite(trigPin4, LOW);
delayMicroseconds(10);
digitalWrite(trigPin1, HIGH);
digitalWrite(trigPin2, HIGH);
digitalWrite(trigPin3, HIGH);
```

```
digitalWrite(trigPin4, HIGH);

delayMicroseconds(20);

digitalWrite(trigPin1, LOW);

digitalWrite(trigPin2, LOW);

digitalWrite(trigPin3, LOW);

digitalWrite(trigPin4, LOW);

/*calculate the time taken or duration of

the signal to reflect back to the receiver of the sensor as follows

*/

duration=pulseIn(ecoPin1, HIGH);

duration=pulseIn(ecoPin2, HIGH);

duration=pulseIn(ecoPin3, HIGH);

duration=pulseIn(ecoPin4, HIGH);

distance1=duration*0.034/2; //to change distance in to centimeter

distance2=duration*0.034/2;

distance3=duration*0.034/2;

distance4=duration*0.034/2;

safetyDistance1=distance1;

safetyDistance2=distance2;

safetyDistance2=distance3;

safetyDistance3=distance4;

Serial.print("distance1=");

Serial.println(distance1);

Serial.print("distance2=");
```

```
Serial.println(distance2);
Serial.print("distance3=");
Serial.println(distance3);
Serial.print("distance4=");
Serial.println(distance4);
Serial.println("cm");
Serial.print("speed=");
Serial.println(speeds);
Serial.println("rpm");
if(speeds = 1140)
{ if(safetyDistance1<= 11457.7 && safetyDistance2<= 30 && safetyDistance1<= 100)
{ digitalWrite(relay, HIGH);
delay(538.5);
digitalWrite(buzzer, HIGH);
digitalWrite(yellowlight, HIGH);
delay(100);
}
else{
digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(yellowlight, LOW);
delay(30);
} }
if(speeds >= 1080)
```

```
{ if(safetyDistance1<= 10293.7 && safetyDistance2<= 30 && safetyDistance1<= 100)
{ digitalWrite(relay, HIGH);
delay(510.2);
digitalWrite(buzzer, HIGH);
digitalWrite(yellowlight, HIGH);
delay(100);
}
else{
digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(yellowlight, LOW);
delay(30);
} }
else if (speeds>=900)
{if(safetyDistance1<= 7178.9  && safetyDistance2<= 30 && safetyDistance1<= 100)
{digitalWrite(relay, HIGH);
delay(425.1);
digitalWrite(buzzer, HIGH);
digitalWrite(yellowlight, HIGH);
delay(100);
}
else{digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(yellowlight, LOW);
```

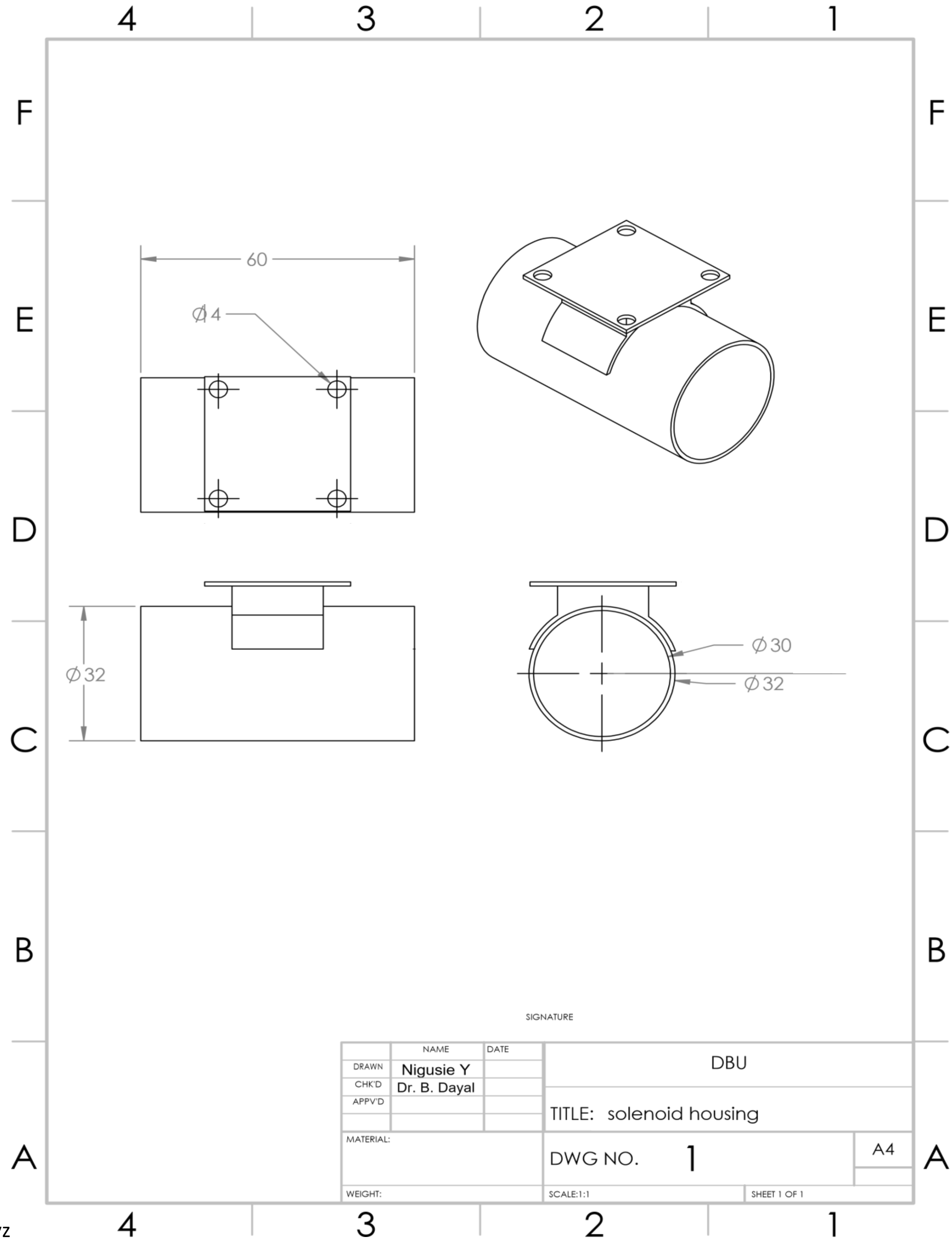
```
delay(30);

} }

else if(speeds>=720)

{if(safetyDistance1<= 4630.5  && safetyDistance2<= 30 && safetyDistance1<= 100)

{digitalWrite(relay, HIGH);

delay(340.1);

digitalWrite(buzzer, HIGH);

digitalWrite(yellowlight, HIGH);

delay(100);

}

else{

digitalWrite(relay, LOW);

digitalWrite(buzzer, LOW);

digitalWrite(yellowlight, LOW);

delay(30);

} }

else if(speeds>=540)

{if(safetyDistance1<= 2648.4  && safetyDistance2<= 30 && safetyDistance1<= 100)

{digitalWrite(relay, HIGH);

delay(255.1);

digitalWrite(buzzer, HIGH);

digitalWrite(yellowlight, HIGH);

delay(100);

}
```

```
else{
digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(yellowlight, LOW);
delay(30);
} }
else if(speeds>=405)
{if(safetyDistance1<= 1523.5  && safetyDistance2<= 30 && safetyDistance1<= 100)
{digitalWrite(relay, HIGH);
delay(191.3);
digitalWrite(buzzer, HIGH);
digitalWrite(yellowlight, HIGH);
delay(100);
}
else{
digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(yellowlight, LOW);
delay(20);
} }
else if(speeds>=270)
{if(safetyDistance1<= 687.1  && safetyDistance2<= 30 && safetyDistance1<= 100)
{digitalWrite(relay, HIGH);
delay(127.5);
```

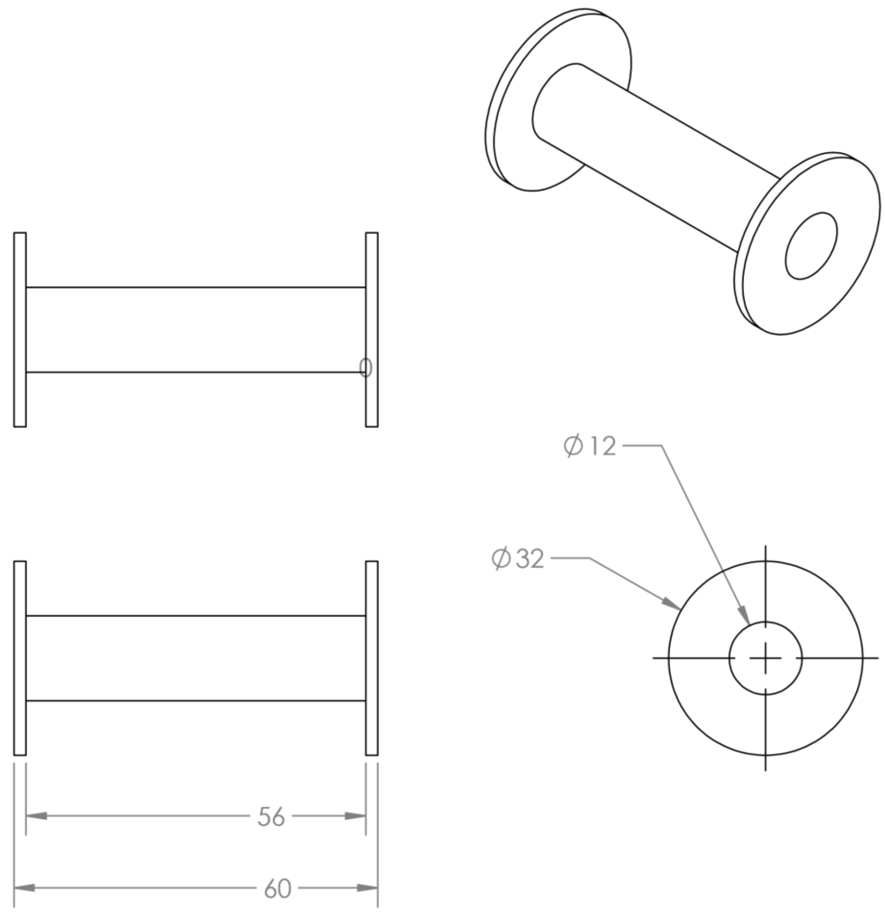
```
digitalWrite(buzzer, HIGH);

digitalWrite(yellowlight, HIGH);

delay(100);

}

else{

digitalWrite(relay, LOW);

digitalWrite(buzzer, LOW);

digitalWrite(yellowlight, LOW);

delay(20);

} }

else if(speeds>=135)

{if(safetyDistance1<= 189.3  && safetyDistance2<= 30 && safetyDistance1<= 100)

{digitalWrite(relay, HIGH);

delay(63.7);

digitalWrite(buzzer, HIGH);

digitalWrite(yellowlight, HIGH);

delay(100);

}

else{

digitalWrite(relay, LOW);

digitalWrite(buzzer, LOW);

digitalWrite(yellowlight, LOW);

delay(20);

} }
```

```
else if(speeds>=38)
{if(safetyDistance1<= 67.5  && safetyDistance2<= 30 && safetyDistance1<= 100)
{digitalWrite(relay, HIGH);
delay(35.4);
digitalWrite(buzzer, HIGH);
digitalWrite(yellowlight, HIGH);
delay(100);
}
else{
digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(yellowlight, LOW);
delay(20);
} }
else{digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(yellowlight, LOW);
delay(20);
}
Serial.println(distance1);
Serial.println(distance2);
Serial.println(distance3);
Serial.println(distance4);
}
```

Appendix C: Part Drawing and Assembly Drawing of Solenoid

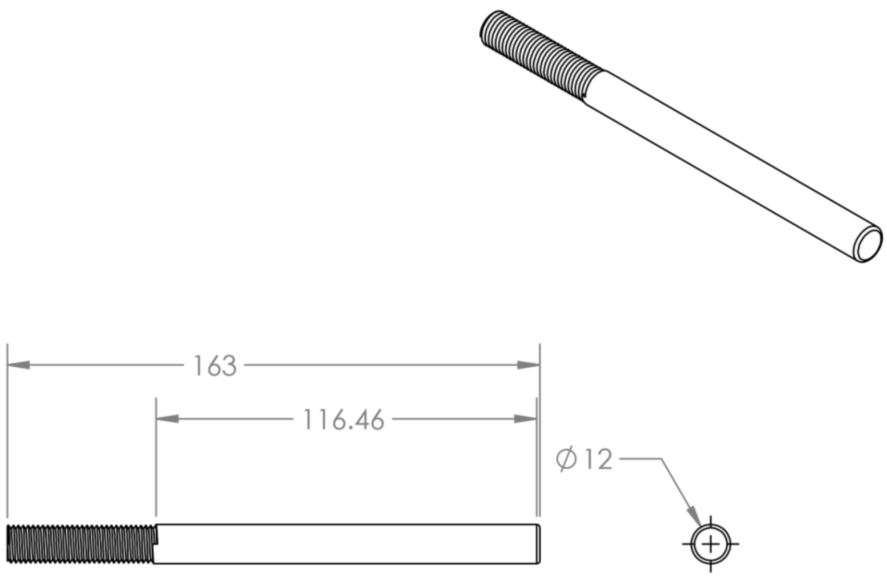


vz



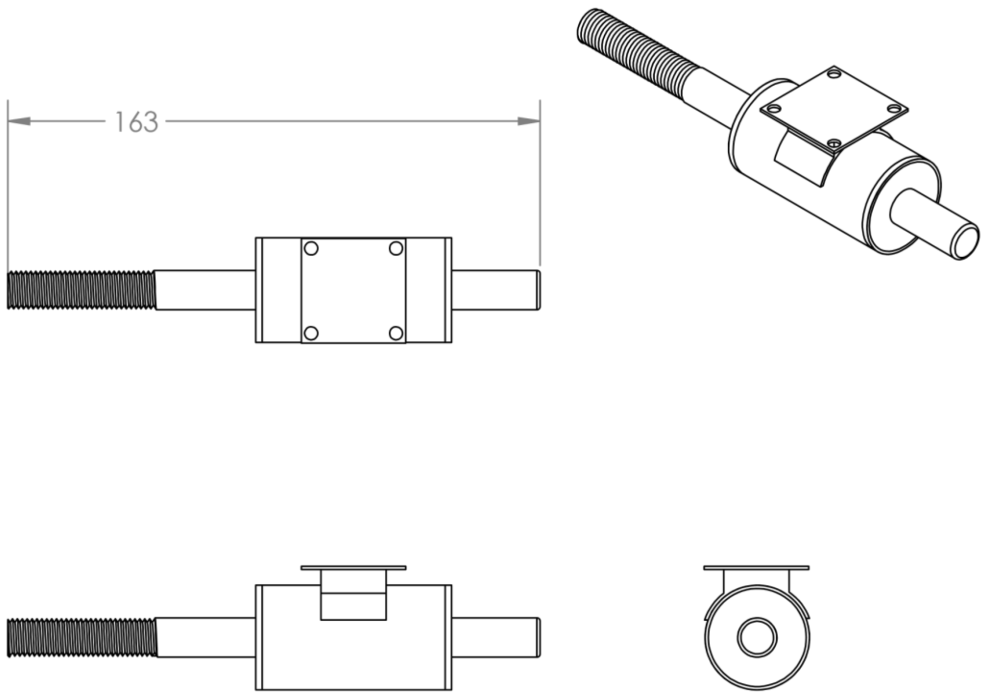
SIGNATURE

	NAME	DATE	
DRAWN	Nigusie Y		DBU
CHK'D	Dr. B. Dayal		
APPV'D			TITLE: solenoid bobbin
MATERIAL:			DWG NO. 2 — A4
WEIGHT:			SCALE:1:1 — SHEET 1 OF 1



SIGNATURE

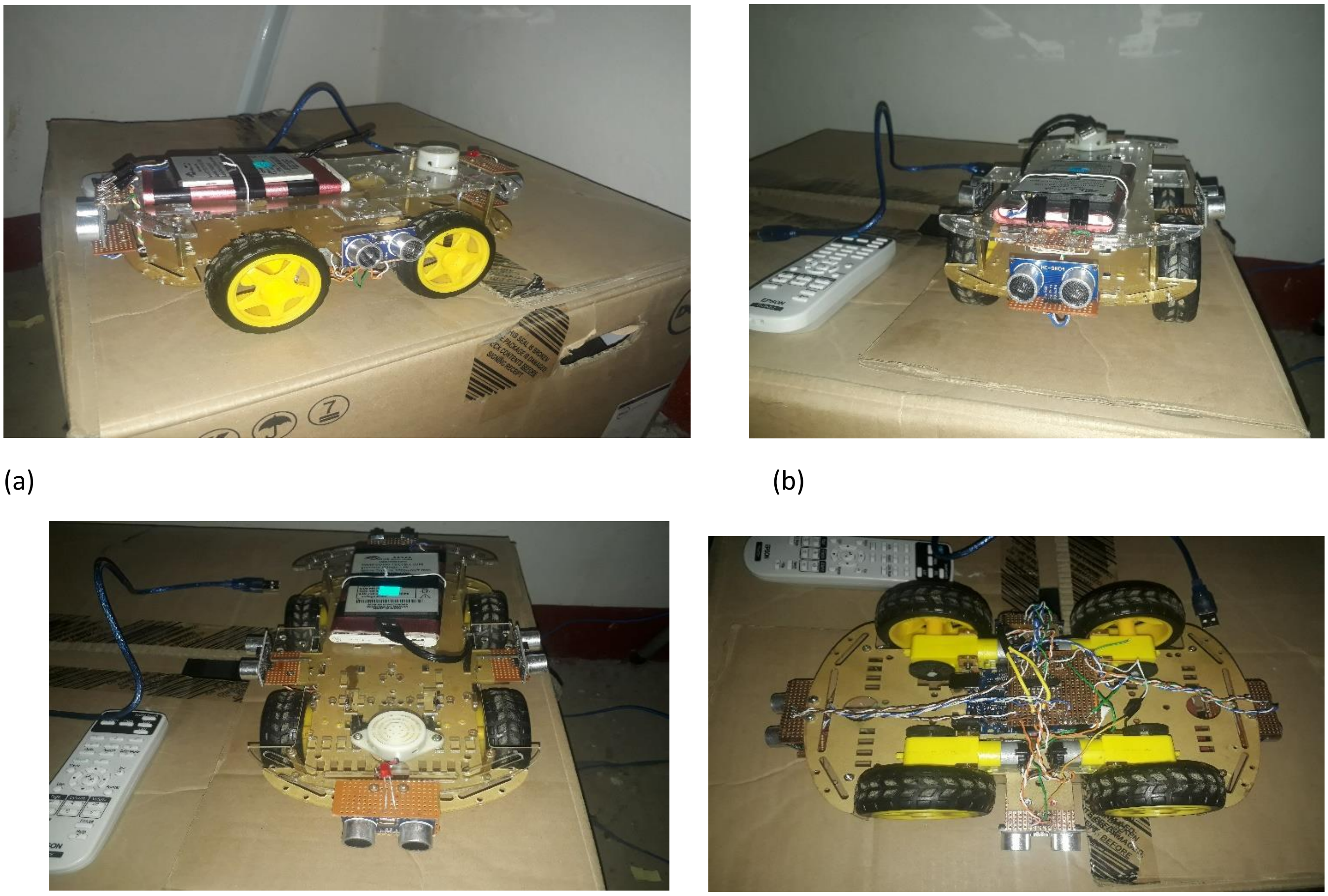
	NAME	DATE	
DRAWN	Nigusie Y		DBU
CHK'D	Dr. B. Dayal		
APPV'D			TITLE: solenoid plunger
MATERIAL:			DWG NO. 3 — A4
WEIGHT: 90			SCALE:1:2 — SHEET 1 OF 1



SIGNATURE

	NAME	DATE	
DRAWN	Nigusie Y		DBU
CHK'D	Dr. B. Dayal		
APPV'D			TITLE: solenoid assembly
MATERIAL:			DWG NO. 4 — A4
WEIGHT: 91			SCALE:1:2 — SHEET 1 OF 1

Appendix D: Figure of Prototype Generated by Mobile Phone



(a) (b) (c) (d)

Figure 6.1: Prototype figures (a) side view, (b) front top view, (c) back view, (d) bottom side view