ASHESI UNIVERSITY

LOW-COST VEHICLE DRIVING ASSISTANCE SYSTEM

CAPSTONE PROJECT

B.Sc. Electrical & Electronic Engineering

Stewart Tatenda Maposa Mangezi

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ASHESI UNIVERSITY COLLEGE

LOW COST VEHICLE DRIVING ASSISTANCE SYSTEM

CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University College in partial fulfillment of the requirements for the award of Bachelor of Science degree in Electrical & Electronic Engineering.

Stewart Mangezi

2020

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

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Candidate's Name:

STEWART TATENDA MAPOSA MANGEZI

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Date: 29/05/2020 ………………………………………………………………………………………………

I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University College.

Supervisor's Signature:

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Supervisor's Name:

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Date: ………………………………………………………………………………………………

Acknowledgments

Firstly, I would like to express my sincere gratitude to my supervisor, Dr. Stephen Kofi Armah, for the continuous support, encouragement, and academic advice during this capstone project. His guidance and immense knowledge greatly edified to my research and writing of this my capstone project.

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Abstract

The project intends to increase vehicle operator awareness with the integration of a Low-Cost Driving Assistance system in older car models. Situational awareness during driving significantly reduces the number of road traffic accidents, as proved by literature. A 4-wheel mobile robot is used as the plant representing a vehicle for easier and rapid prototyping. The plant is controlled by a Raspberry Pi3 to achieve the desired control choice as well as do all required computational processes. Image processing using a retrained Resnet50 neural network is adopted for road traffic signs. A 54% accuracy rate for image recognition is recorded. The wheeled mobile robot is successfully modeled and deemed unstable while the circuit is simulated and works as expected.

Table of Content

List of Tables

List of Figures

List of Abbreviations

WMR – Wheeled Mobile Robot

SIVD – Safe InterVehicle Distance

RTA – Road Traffic Accident

Chapter 1: Introduction

This chapter introduces the project background and thereby defines the problem to be addressed by the project. It goes further to outline the motivation for doing the project before highlighting the problem statement as well as the project functional and technical requirements based on the problem statement. Stakeholders are also identified. Also, a conceptual solution proposal and justification are outlined as drawn from the project functional and technical requirements. The chapter is tied up with the project objectives, as drawn from the conceptual solution proposal.

1.1 Background

"At least 15,000 people are injured and almost 2,000 killed every year in road traffic accidents (RTAs)," Traffic Safety Council of Zimbabwe (TSCZ). For example, in 2018, two buses, collided, and 47 people were killed as a result [1]. Most road traffic accidents (RTA) can be attributed to a human fault [2]. Some human causes include speeding, driving under the influence of drugs and/or drugs, driver fatigue, driver distraction, violation of regulations, driver attitude, and non-road worthy vehicles certified via corrupt means. Other factors include increased motorization, poorly maintained roads, weather, and animals crossing roads [3]. However, the driver's response is more likely to avoid an RTA when other systems may have failed, given there is still controllability of the vehicle.

Human reaction time is crucial as it is a significant factor that determines whether the accident can be avoided or not through human intervention. If one is under the influence of alcohol, drugs, distractors like emotional stress, physical pain, and mental dispositions, then their reaction time further increases such that they take longer to react to the situation, which of course, increases the possibility of an RTA [4]. This means the human reaction is critical in the eventuality of an accident since it could help evade severe injury or the accident itself, while on the other hand, the human reaction may increase the possibility of the happening of the accident.

According to IPMZ, ‘accidents are caused-they do not happen,’ as such causes can be identified and eliminated [2]. When extended to RTAs, then it can be noted that causes of RTAs can be identified, eliminated, or controlled to ensure minimal damage. RTAs cause loss of property, human life, infrastructure, and other associated effects of RTAs.

1.2 Motivation

Phoebe Maposa, my aunt, died in a car accident. The police report suggested that the accident was due to human limitations. Hapson Maposa, my uncle who was driving at the time of the accident, could not see the trailer of a jackknifed haulage truck that was crossing the road in time. It was too late to take evasive action, and the human delay leads to an accident that killed my aunt.

It is estimated that by 2020, RTAs will be one of the primary causes of injury and death in Zimbabwe due to the increased acquisition of vehicles while less is done to carter for the increasing road traffic population [3]. Therefore, it is of utmost importance that RTAs are reduced or eliminated to ensure human health and life are safeguarded as well as property. This problem can be solved using the various skillsets, scientific, and engineering knowledge acquired in the course of study. The solution must be a sustainable solution to reduce or eliminate the RTAs in Zimbabwe so that people do not get injured or perish on the Zimbabwean roads as my uncle and aunt did. Safer roads for all traffic users are can, therefore, be realized on Zimbabwean roads and subsequently on world roads.

1.3 Problem Statement

The Zimbabwean populate needs a low-cost solution that helps reduce or eliminate RTAs by reducing human error, employing better warning systems, setting speed envelops, and avoiding collisions, which thereby improves driver situational awareness, provides collision avoidance and improve motor vehicle control for the very cars they are currently using.

1.4 Objectives

1.4.1 Main Objective

This project aims to create a Low-Cost Vehicle Driving Assistance System that employs the use of sensors and a processor to assess the environment where a vehicle is and thereby give the operator relevant information about the environment so that the vehicle operator has increased situational awareness. That will, in turn, lower the risk of a road traffic accident as the driver is more prepared to take action at the right moment, which addresses the problem highlighted in the problem statement.

1.4.2 Specific Objectives

I. Design and Build a smart, efficient, reliable Low-Cost Vehicle Driving System based on the project requirements.

II. Model all parts of the system in software like Matlab and Proteus to optimize their performance.

III. Select the cheapest components that meet the project requirements to build the system.

IV. Test subsystems and compare the results with the requirements for the project.

V. Test the solution build by combining subsystems and compare results with requirements.

VI. Conclude and report on the findings

1.5 Stakeholder Identification

The main stakeholders for the project were identified from the problem statement as the Zimbwaean Vehicle Operators & Users. Other stakeholders are from Ashesi University

Computer Science and Engineering Department, including my capstone supervisor Dr. Stephen Kofi Armah. Table 1.1 shows the various stakeholders, inputs, and outputs from the project.

Table 1.1: Stakeholder Identification

Stakeholder	**Project Inputs** **(what the project gives to stakeholder)**	**Project Outputs** **(what the project gets from stakeholder)**
Zimbabwean Vehicle Operators & Users	Safer road travels through a system that reduces RTAs by increasing driver awareness, improve vehicle performance, and improved operator-vehicle communication.	Information on the problem, feedback on proposed solutions and prototypes, as well as general support towards achieving the project goals.
Ashesi University Computer Science & Engineering Department	Knowledge resource base from as they have access to all the information and knowledge gathered.	Support with resources in the form of funding, guidance from supervisors and faculty, access to labs, and university equipment.
Dr. Stephen K. Armah	Skills and knowledge through active participation in the design and building process.	Supervision, guidance, knowledge.
Stewart T. M. Mangezi	Experience, practical knowledge, exposure to fields of research, and study.	Knowledge, a functional system as a solution.

1.6 Project Requirements

The problem statement was broken down into specifics needs coupled with the justification of the need in the form of a requirement. The requirements were subdivided into functional and technical requirements, as shown in Table 1.2 and Table 1.3, respectively. The functional requirements elaborate on the problem statement by addressing the needs of the stakeholders and justifying the need to address the need. The technical requirements draw upon the functional requirements for the system to be built as the solution to the problem defined in the project.

Table 1.2: Functional Requirements

ID	Project Level Requirement	Notes/Rationale:	Stakeholder addressed
PR01SF	Avoid collisions with objects on the road	Reduction or elimination of RTAs	Vehicle Operator
PR02SF	Communicate using visual and audio signals to alert the driver of possible hazards	Helps increase operators' awareness	Vehicle Operator
PR03SF	Alert authorities or emergency services in case of collision	Reduce the risk of death from delayed assistance	Vehicle Operator
PR04SF	Read the signs on the sides of the road and respond accordingly with the right action	Data gathering for decision making	Vehicle Operator
PR05SF	Control can be overridden by vehicle operator when they see it fit, and the overriding should be done with relative ease	This ensures the human operator has greater control	Vehicle Operator
PR06SF	Notify operator when seatbelts are not worn, or steering is not held	Ensures operator is still in control	Vehicle Operator
PR07PS:	The system shall utilize onboard power (battery on the car)	Eliminates the need for external power or extra power sources	Stewart T. M. Mangezi
PR08TT	Ashesi University and other engineers may get to understand, use, and utilize the technology developed.	Facilitate learning, allow room for improvement	Ashesi University
PR09OR	The system must work reliably, fast and accurately, all the time irrespective of environmental conditions (road, weather, area, etc.)	Operators will rely on the system, so it should perform at its best all the time.	Vehicle Operator

PR10SD	System to operate for as long as the vehicle is operational from the day of installation.	Ensure long operational life	Vehicle Operator
PR11SI	System easy to install and remove as well as it is compatible with onboard systems	No significant adjustments needed to retrofit solution onto the vehicle	Stewart T. M. Mangezi & Vehicle Operator

Table 1.3: System technical requirements

ID	Parent Requirement	System Level Requirement	Notes/Rationale:
SR01	PR01SF	SIVD overshoot <10%	Minimize the overshoot error
SR02	PR01SF	SIVD steady state error <10%	Minimize the steady-state error
SR03	PR01SF	System rise time <0.5s	Ensure quick response
SR04	PR04SF	Optical sensor to recognize images (road signs) with a range > 500m	Read signs at a further distance
SR05	PR01SF	Distance from obstacle sensors with a range > 500m	Recognize obstacles accurately at a distance
SR06	PR09OR PR01SF	Signal processing and decision making done in time <50ms	Recognize obstacles accurately at a distance
SR07	PR06SF	Visual and audio displays that are informative yet not distractive	Increase vehicle operator awareness
SR08	PR07PS	Control system power rating	Minimize power requirements

1.7 Proposed Solution & Justification

A solution (control system) that takes input from the driver, system (vehicle) and environment, process the information and determines the action to take as well as a warning to give to the driver so that the driver is aware of what is going on within the system (vehicle) and the environment as shown in Figure 1.1. The human driver should be able to override this protocol with relative ease. The system must meet the requirements given in the requirements section.

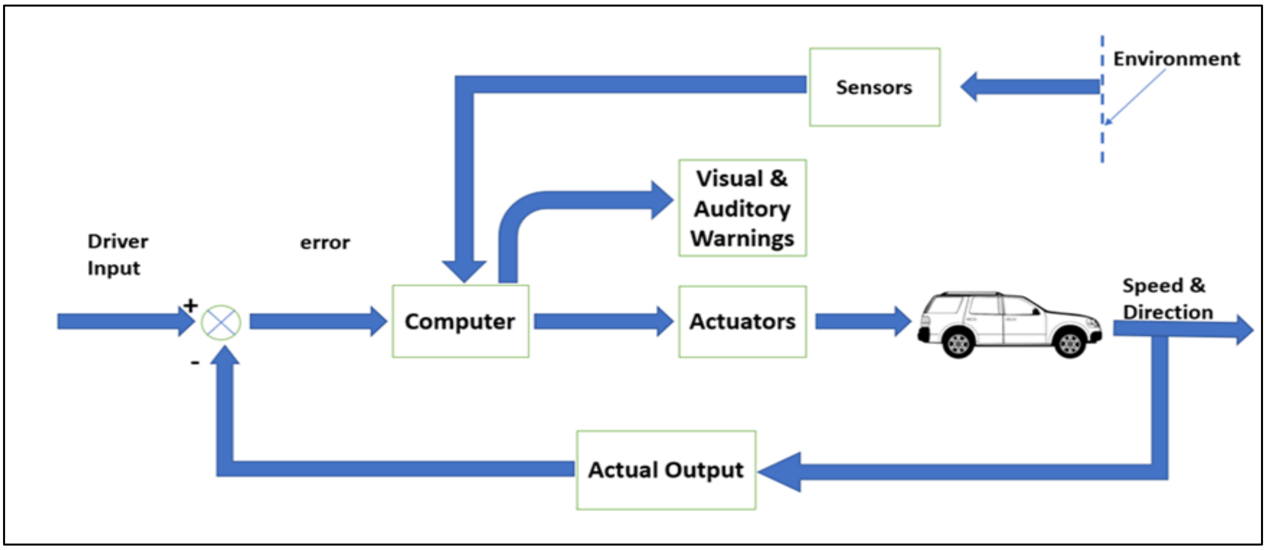

Figure 1.1: Proposed solution

The solution is expected to give each driver improved situational awareness and reduced human error. The vehicle the ability to detect any possible hazards then respond accordingly. Thus, more control is given to the driver and even more to the vehicle. RTAs can, therefore, be reduced even if the other factors leading to RTAs are not significantly changed. Time and financial investment to getting the solution operational in the field are expected to be lower compared to building new road infrastructure. The technology can also be improved and used in the manufacturing of safer vehicles in Africa. More importantly, the solution is within the scope of some Engineering students in their final year and professional engineers in the field. There is room to improve the solution further since anyone interested in the field could easily take it one and perfect the solution. Since the solution can be implemented locally, with local expertise, then the solution is favorable compared to the alternative solutions.

1.8 Project Scope

The project aims to deliver a working prototype of a Low-Cost Driving Assistance System build based on undergraduate Electrical and Electronic Engineering as well as research and guidance from Ph.D. researchers. As a student capstone project, this project is limited by the funding availed by the student as well as support form the student as well as support from the university. The project is to be completed within two academic semesters for submission. Hence any further research required outside the time constraint will be done after the submission of this project. There are additional project constraints that may emerge during the project, including but not limited to the shortage of resources, unavailability of better simulation software, limited student skills in machining and designing, knowledge capacity, and other unforeseen constraints. The project assessed that the solution required could be an engineering solution. The project writeup assumes some knowledge in engineering and science. Overall the project is a resource, time, and knowledge constrained. Thus, more detailed and in-depth research and analysis may not be done in this project.

Chapter 2: Literature Review & Related Work

This chapter is a literature review chapter as well as a discussion of related work. Work that has already been done is introduced, as well as what differentiates the related work form the project work outlining the uniqueness of the project work.

2.1 Literature Review

Several papers were reviewed during research on this topic. However, only a few reviews are written in this paper focusing on the main concepts and ideas for the research. For clarity, the literature review is split into subheadings that address either problem identification, audio signal collection, video signal collection, system modeling, or control methods considered. Each of the subheadings has each paragraph summarizing and critiquing the paper while the last paragraph summarizes and concludes on the whole subheading.

2.1.1 Problem Identification Papers

"Road Traffic Accidents in the Department of Irrigation: Empirical Evidence from The Midlands Regional Office, Zimbabwe" sought to examine the causes and impact of road traffic accidents in the Department of Irrigation Midlands Region [2]. The paper uses a descriptive survey method to examine the causes and impact of road traffic accidents. The study (both secondary and primary findings) showed that accidents are mainly a result of human error and, therefore, can be prevented [2]. The study recommends, among other things, continuous training of drivers in the Department, top management commitment to accident prevention, avoiding driving under the influence of alcohol, and grounding all unroadworthy vehicles [2]. However, the study doe does not discuss technical solutions that may help reduce human error or any ideas to improve the vehicles, so they increase driver awareness. Thus, the focus is on improving the human through training and providing a conducive working environment as a proposed solution to reduce RTAs. From this study, it can be concluded that human error is the major cause of road for the Department, which may be extrapolated to the whole of Zimbabwe.

"ROAD TRAFFIC ACCIDENTS IN ZIMBABWE, INFLUENCING FACTORS IMPACT AND STRATEGIES" examines the response to RTA in the event of RTAs which lead to the increased number of deaths on the Zimbabwean roads [3]. The Safe Systems Approach framework was adapted with some components from the Commission of Social Determinants of Health [3]. The study shows RTAs are as a result of reckless driving, violation of traffic laws, damaged vehicles, bad roads [3]. The study suggests that the Zimbabwean government must review basic legislation for road safety, enforce existing road safety laws, put a stop to corruption and improve data collection and recording, public transport should be improved, as well as establish universal national health insurance to improve access to health care. However, the paper the study does not address the need to improve vehicle performance and reaction.

"Reaction time of drivers who caused road traffic accidents" examines the reaction time of selected drivers who had been involved in an RTA and those who had not been involved. The human factor is the single cause of road traffic injuries in 57%, and together with other factors in more than 90% of all road traffic accidents [4]. The study creates experiments that test reaction time and has the test and control partake in the exercise then analyses the reaction time results statistical. The study showed those car drivers who caused road traffic accidents to have longer reaction time (both simple and choice reaction time), but as the tasks were more complex, that difference was statistically less visible [4]. Paper uses quantitative methods and statistics to validate the hypothesis, which gives it strong experimental backing. Paper does not examine how the age of the operator affects the reaction time. But most importantly, the study brings bare that human reaction time is slower as the situation gets complex, and therefore making the situation less complex could improve the reaction time, therefore, reduce the risk of an RTA.

From the above literature review, it can be shown that human error is the major cause of RTAs. The improvement of human reaction time and situational awareness may, therefore, reduce human error, thereby minimizing the risk of RTAs. Noting human error is the major cause of RTAs, is also an avenue that encourages the exploration of eliminating or limiting the human input in the vehicle operation process.

2.1.2 Visual Signal Papers

"Robust on-vehicle real-time visual detection of American and European speed limit signs, with a modular Traffic Signs Recognition system," presents a robust visual speed limit signs detection and recognition systems for American and European signs [5]. Study employees modular traffic signs recognition architecture, with a sign detection step based only on shape-detection (rectangles or circles), which makes the systems insensitive to color variability and quite robust to illumination variations. Instead of global recognition, the system classifies (or rejects) the speed-limit sign candidates by segmenting potential digits inside them, and then applying a neural network digit recognition [5]. The global sign detection rate was around 90% for both (standard) U.S. and E.U. speed limit signs, with a misclassification rate below 1%, and not a single validated false alarm in >150 minutes of recorded videos. The system processes in real-time videos with images of 640times480 pixels, at ~20 frames/s on a standard 2.13 GHz dual-core laptop.

Strength of paper: Employs a visual recognition system that is independent of color but focusses on the numbers within the sign. That allows it to be universally applicable to most regions in the world. The study does not discuss the methods that could be employed to recognize other signals like shapes within the sign, which may be varying (e.g., rail crossing signs, pedestrian crossing, stop signs etc.).

2.1.3 Distance of separation Signal Collection Papers

"Obstacle Detection and Collision Avoidance for a UAV With Complementary Low-Cost Sensors," demonstrates an innovative and simple solution for obstacle detection and collision avoidance of unmanned aerial vehicles (UAVs) optimized for and evaluated with quadrotors [6]. The study employs low-cost ultrasonic and infrared range finders for the design, implementation, and parametrization of the signal processing and control algorithm for the collision detection and avoidance system [6]. The UAV was capable of distance-controlled collision avoidance [6]. The solution created and explore by the study is cheap and straightforward; the key to making affordable solutions for budget-constrained projects. Tests conducted by the study give readable quantitative data, plus the experiments can be easily replicated. Both dynamic and stationery obstacles were used for tests to monitor the response, which was vital in validating the solution. However, the was a need for much signal filtering since the input signals were too noisy.

2.1.4 System Modeling Papers

Summary (Goal): “Model Predictive Control of Wheeled Mobile Robots” is a book that explores the dynamic modeling and control of wheeled mobile robots (WMR) applying model predictive control (MPC) [7]. The book uses a mathematical modeling approach to achieve the results with the use of MATLAB for the numerical methods to solving the equations. All models are linearized so that analysis of the models in MATLAB is simplified. The book analyzes the non-feasible active set method (NF-ASM) and the Fletcher Active Set Method (FL-ASM). Since the book is based on Ph.D. research, most of these methods and analysis are outside the scope of my studies. However, the modeling of the WMR system is useful for this study as needed for the modeling of the 4-wheel mobile robot used for the study of this paper.

2.2 Related Work

Drawing from the literature reviewed and other sources, it was identified that there was work that there are other solutions that have been implemented in an attempt to solve the problem identified in Chapter 1.3 of the project writeup existing solutions were identified. The project solution was also differentiated from any similar solutions by specifying what the project achieves differently from similar solutions.

2.2.1 Existing Solutions

Existing solutions that are currently being implemented or are under development were summarized in Table 2.1 below. The solutions were laid out so that the project could be designed to meet the requirements yet to be addressed with the existing solutions with the solutions as a reference.

Table 2.1: Existing Solutions

Solution	**Description**	**Why it is not Satisfactory**
a. Graduated driver licensing system	After the acquisition of the driver's license, a driver is restricted to areas and time they drive, and the limits are removed as the driver gains more experience.	• Does not improve the driver's situational awareness • Car performance does not improve • Roads and infrastructure are still the same
b. Vehicle inspection	The Vehicle Inspection Department of Zimbabwe inspects vehicles for roadworthiness. The inspections are done periodically to ensure consistency.	• Does not improve the driver's situational awareness • Car performance does not improve (Just insures it is standard) • Roads and infrastructure are still the same • Some motorist may evade these authorities • Bribery may sway the final decisions made
c. Education and	Training of all road users through various	• Car performance does not improve • Roads and infrastructure are still the same

information supporting road users	standardized training throughout Zimbabwe. Make more information available both on the road through signs and markings as well as through other forms like media.	• Human limitations still hinder the actual response during situations, e.g., human response time
d. Legislation and enforcement of road rules	1. Setting speed limits – restrict traveling speeds in various parts of the roads and areas. 2. Drinking driving laws – discourage the driver from driving while intoxicated 3. Motorcycle helmet law – ensures motorcyclist are protected in the event of a collision 4. Seat belt law – drivers and passengers are to have seat belts strapped on when care is in motion.	• Does not improve the driver's situational awareness • Drivers may not perceive the road signs as some are not visible or hidden in grasses or unkempt roadsides • Car performance does not improve • Roads and infrastructure are still the same • Enforcement is limited and hindered by things like corruption • Does not eliminate risk but does well to limit damage in the eventuality of an RTA
e. Promoting alternative transport	Her government tries to convince the population to switch to other modes of transportation like bicycles and trains.	• The train system in Zimbabwe is limited by the routes that have rail lines. Most areas are not connected by rail; hence they have no other alternative, but the road for longer distances as bicycles is limited in range. • Available trains are old diesel and coal engines which are very slow and breakdown multiple times

		• Constructing a new rail system with faster trains to connect the whole currently is very expensive. With the country's economic situation, it is almost impossible to achieve. • People still enjoy the convenience and control offered by the use of their motor vehicles
f. Building shorter, broader and safer routes	Improvement of the existing road network in the country by widening roads, resurfacing with asphalt and building newer shorter routes. Reduces pressure on the currents road network.	• Does not improve the driver's situational awareness • Car performance does not improve • Human error induced accidents are still realized despite the new road network.
g. Restriction to engine performance	This limits the engine performance that the road vehicles are given. The maximum speed and power an engine will give the vehicle is limited to ensure no drive can excessively speed.	• Does not improve the driver's situational awareness • Car performance does not improve (It is just limited in speed and maximum power) • Roads and infrastructure are still the same
h. Daytime running lights	Vehicle operators are to switch on the light when they travel during the day to increase visibility.	• Does not improve the driver's situational awareness (Lights may improve that of the other driver who is seeing the lights) • Car performance does not improve • Roads and infrastructure are still the same

i. Collision avoidance systems	System of sensors and processors to improve vehicle performance by making decisions based on the sensor information.	• Roads and infrastructure are still the same • Systems are currently in new models of cars being released. Thus those with older models do not enjoy these improvements. • The current technology is too expensive to retrofit in older models; new cars with the technology are also exorbitantly expensive. • Technology is highly guarded as intellectual and cooperate property such that Zimbabwe must pay a substantial amount to get the rights to use the technology.
j. Semi-autonomous and autonomous vehicles	Improved version of collision avoidance. Controllers have better algorithms that enable decision making that mimics humans such that cars can drive themselves even with the human on standby for intervention. This reduces human error and helps improve reaction time, plus driver situational awareness. (Best possible solution on the market)	• Roads and infrastructure are still the same • Systems are currently in new models of cars being released. Thus those with older models do not enjoy these improvements. • The current technology is too expensive to retrofit in older models; new cars with the technology are also exorbitantly expensive. • Technology is highly guarded as intellectual and cooperate property such that Zimbabwe must pay a considerable amount to get the rights to use the technology. • Systems are very complex and expensive, such that the common Zimbabwean would buy two ex-Japanese cars for just the price of one lidar system.

The best solution would be a combination of the solutions mentioned above in Table 2.1. There is a holistic improvement of the whole transportation system such that reduces the traffic on the road, improves the road network, improves vehicle operator situational awareness, improves vehicle performance, reduces or eliminate human error and the general quality of vehicle on the road. However, this is not feasible to implement in one go, in a short-term period of 5 years due to the cost and complexity involved.

However, the idea is how to borrow from all the ideas and create a solution that is more effective in terms of both cost and functionality. The system would be feasible to apply to the nation of Zimbabwe and subsequently could be adopted by other nations in sub-Saharan Africa.

Chapter 3: Methodology

This chapter outlines the methods that were followed in the development of the Low-Cost Driving Assistance System. There is a central focus on the processes followed in identifying the plant to be used for modeling. The plant was selected to represent a motor vehicle best so as to do rapid prototyping before integrating the solution to actual cars.

3.1 Plant Used for Modeling

For purposes of this project, sensors will be acquired, control system built, and tested on a Wheeled Mobile Robot (WMR) testbed, as shown in Figure 3.1.

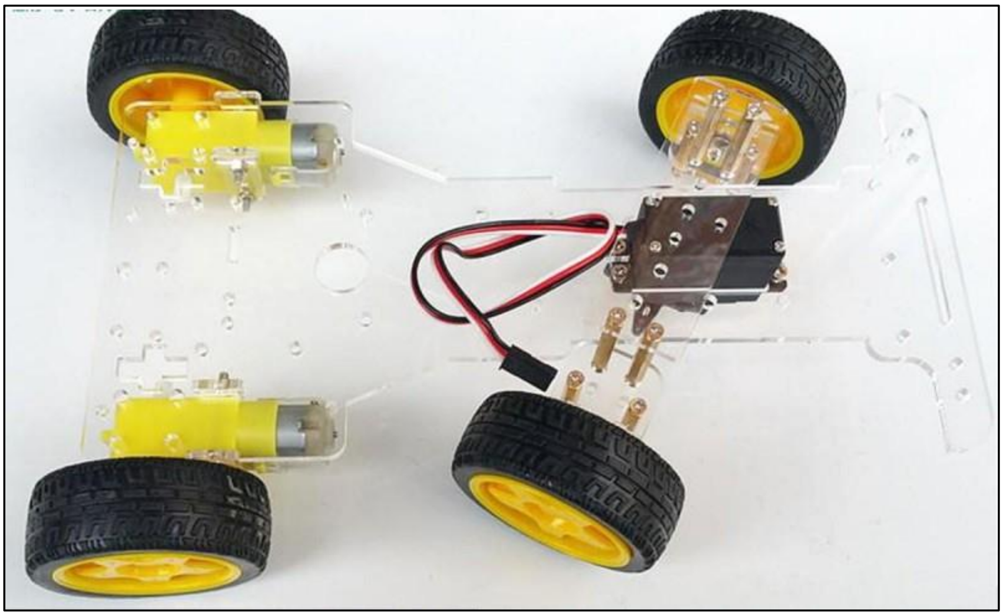

Figure 3.1: DIY WMR Chassis Kit

The WMR, DIY Steering Engine 4 wheel 2 Motor Smart Robot Car Chassis Kit is shown in Figure 3.1, has the following specifications:

- Chassis Material: 3mm Acrylic
- Length: 26.5cm
- Width: 18.5cm
- Wheelbase: 14.8cm
- Max operating speed: 0.6m/sec
- 2 x High Power DC Motor with Operating Voltage: 3-6V DC
- 2 x 20 line encoder disc for the motor
- 4 x Wheels of Tyre Diameter: 6.6cm

The vehicle system is prototyped using a WMR so that testing, modeling, and building can be done more rapidly with relative ease before the system is built and configured for the actual system (vehicle). Testing will be done by matching the initial system response of the WMR system before the installation of the control system and the response after the installation of the control system. Results were analyzed statistically and used in decision making, and validation or rejection of the hypothesis can be done. The proposed solution is represented, as shown in Figure 3.2.

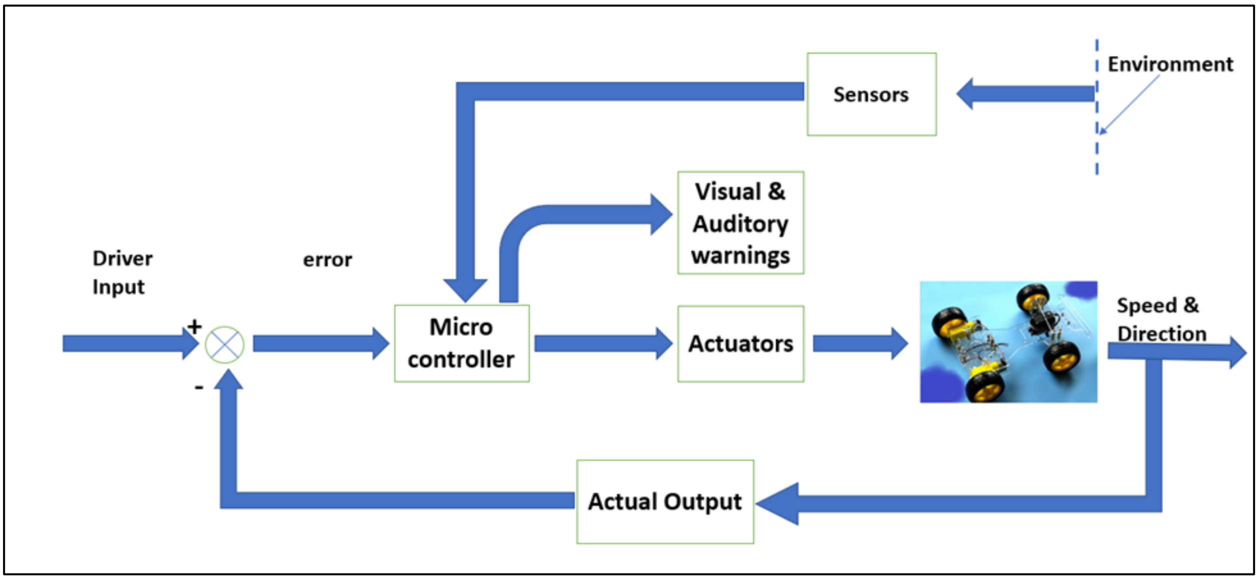

Figure 3.2: Proposed prototype model for the solution

3.2 System Control Loop

From the prototyping solution in Figure 3.2, a system control loop was designed to give a representation of the system, as shown in Figure 3.3. The system acquires information from the environment and sends it to the processor. Afterward, the processor then decides to display relevant information to the vehicle operator as well as send actuating signals to the system actuators as required. The control loop shown in Figure 3.2 is a summary and process flow resemblance of the system.

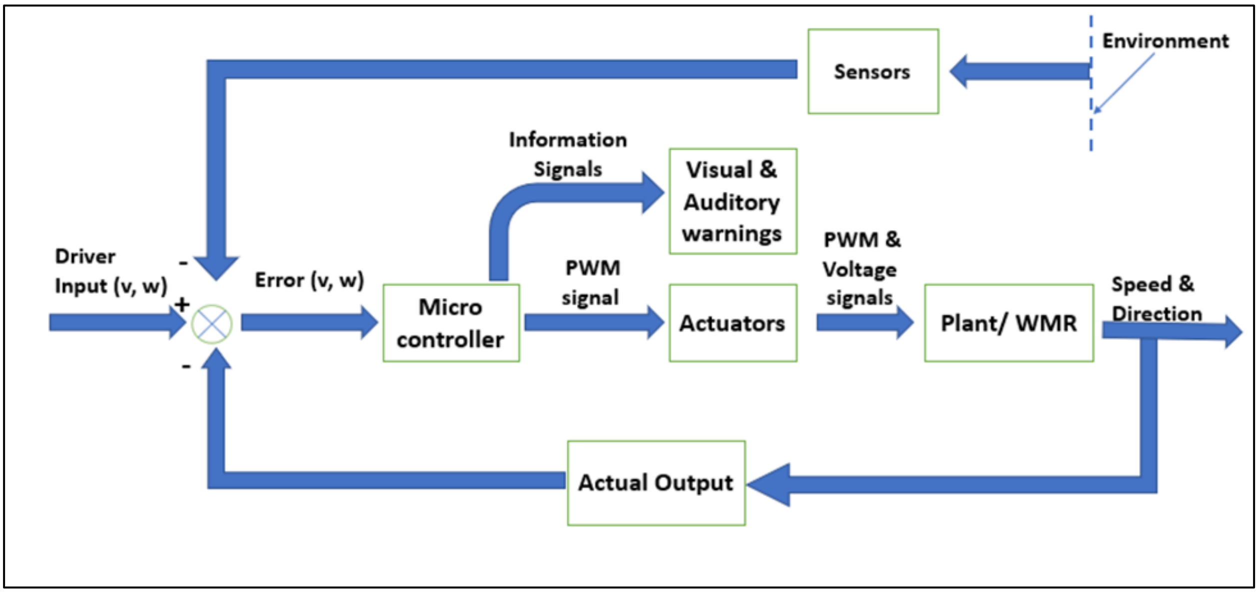

Figure 3.3: System Control Loop

3.3 WMR Kinematic Model

Based on the components selected to build the plant, the plant model was deduced into kinematics models. The WMR can be represented, as shown in Figure 3.4, where the front wheels are steered using Ackermann steering [7]. The center of rotation of the car's chassis lies on the line passing through the rear wheels at the intersection with the perpendicular bisectors of the front wheels. To define the configuration of the car, we ignore the rolling angles of the four wheels and write q = (∅, x, y, φ), where (x, y) is the location of the midpoint between the rear wheels, ∅ is the car's heading direction, and φ is the steering angle of the car, defined at a virtual wheel at the midpoint between the front wheels [7]. The controls are the forward speed

v of the car at its reference point and the angular speed w of the steering angle.

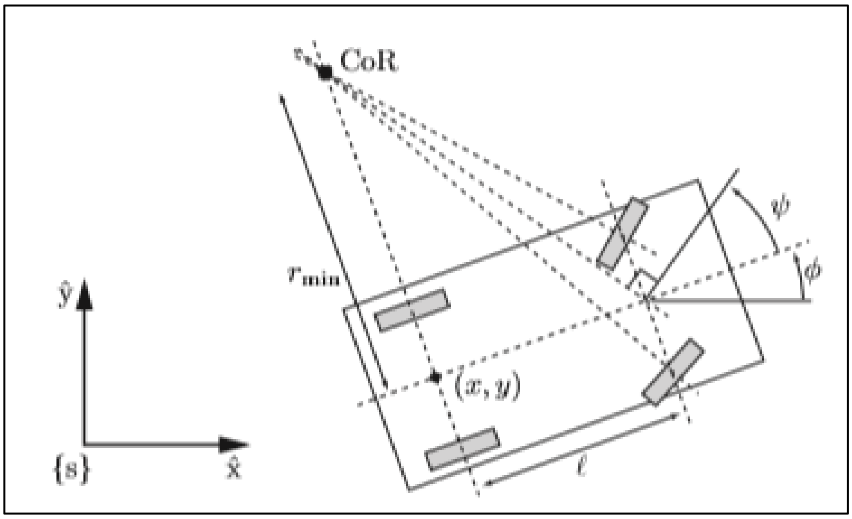

Figure 3.4: WMR Kinetic Model Diagram

The car's kinematics are:

$$\dot{q} = \begin{bmatrix} \dot{\emptyset} \\ \dot{x} \\ \dot{y} \\ \dot{\varphi} \end{bmatrix} = \begin{bmatrix} (tan\varphi)/l & 0 \\ cos\,\emptyset & 0 \\ sin\,\emptyset & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ w \end{bmatrix} \quad (1)$$

Where

$\emptyset \rightarrow heading\ angle$

$(x, y) \rightarrow\ locationof\ midpoint\ between\ rear\ wheels$

$\varphi \rightarrow steering\ angle\ of\ the\ WMR, [-\varphi_{max}, \varphi_{max}], .: \varphi_{max} > 0$

$v \rightarrow forward\ speed\ of\ WMR, [v_{min}, v_{max}]$

$w \rightarrow angular\ speed\ of\ the\ steering\ angle, [-w_{max}, w_{max}], .: w_{max} > 0$

$l \rightarrow wheel\ base$

Assuming the steering control is the angle of steering, not its angular velocity, steering is then no longer part of the configuration, and the Canonical nonholonomic robot model can be used [8]. This assumption is justified if the steering rate limit w_{max} is high enough that the steering angle can be changed nearly instantaneously by a lower-level controller [7]. In this case, it is eliminated as a state variable, and the car's configuration is simply q =(∅,x,y). We use the control inputs (v,w), where v is still the car's forward speed, and w is now its rate of rotation [7]. These can be converted to the controls (v, φ) by the relations in Equation (2) [8].

$$v = v \quad (2)$$

$$\varphi = tan^{-1}\left(\frac{lw}{v}\right) \quad (3)$$

Thus, the kinematic model Equation (1) is simplified as

$$\dot{q} = \begin{bmatrix} \dot{\emptyset} \\ \dot{x} \\ \dot{y} \end{bmatrix} = G(q)u = \begin{bmatrix} (tan\varphi)/l & 0 \\ cos\,\emptyset & 0 \\ sin\,\emptyset & 0 \end{bmatrix} \begin{bmatrix} v \\ w \end{bmatrix} \quad (4)$$

The rate of change of position equations of the system, as implied by Equation (4) are represented by Equations (5) & (6).

$$\dot{x} = vcos\emptyset \quad (5)$$

$$\dot{y} = v\sin\emptyset \quad (6)$$

Chapter 4: Analysis & Design

In this chapter, the analysis of various systems required was done either from the model in Chapter 3 or from existing information in the literature. Components and software were compared and selected based on criteria drawn from the project requirements. The selected software and components were then used in the design of circuits and programs to be used to create the Low-Cost Driving Assistance system.

4.1 Component Selection

Given the information from Figure 3.3, components to be used in the system were selected from a list of available and usable components. Pugh charts were used as the metric for the component selection for each category from sensors, actuators, and the display unit, as shown in the tables below.

Firstly, the best type of obstacle detection sensor most suitable for this application was selected, as shown in Table 4.1.

Table 4.1: Pugh Chart to select an obstacle detection sensor.

		BASELINE	WEIGHT	Infrared	Ultrasonic	Lidar
CRITERIA						
Distance		0	5	1	1	1
Whether		0	3	-1	1	0
Cost		0	5	1	1	-1
Mass		0	3	1	1	-1
Ease of use		0	4	1	1	-1
Speed		0	5	1	-1	
Result			25	19	15	-7

The infrared method of obstacle detection was best and selected for use. For this application, the SHARP GP2Y0A710K0F IR Distance Sensor was selected. For experimental proof, the Ultrasonic sensing technic was also selected, and the JSN-SR04T waterproof ultrasonic distance sensor was picked over the SR04 ultrasonic sensor.

Secondly, the microcontroller selection was made; however, keeping in mind the need to have image processing, as shown in Table 4.2. Raspberry Pi3 was selected over the FRDM-KL25Z and the ATMEGA328. The reason was to do with the image processing as the Raspberry Pi3 has more processing power to handle the image processing faster than the other 2 controllers.

Table 4.2: Pugh Chart to select microcontroller.

				OPTIONS		
		BASELINE	WEIGHT	FRDM-KL25Z	ATMEGA328	RASPBERRY Pi3
CRITERIA						
Cost		0	3	1	1	0
Mass		0	3	1	1	0
Ease of use		0	3	1	1	1
Speed		0	5	0	0	1
Power used		0	3	1	1	0
Functionality		0	5	0	0	1
Result			22	13	13	16

Table 4.3 shows the Pugh chart used to select the speed detection method to be applied for the WMR. The LM393 depends on the encoder to measure the angular speed of the rotating wheel. It is accurate when no slip is assumed, however, inaccurate when there is slip as expected in the real world. Thus, it scores less for functionality compared to the MPU-6050 inertial measurement unit that depends on measuring the acceleration, and then from integration, the speed of the body can be calculated. The MPU-6050 has better accuracy in slip conditions and thus its selection for use in the project. It was later noted that the two measuring methods could be used to check slip using their different speed values as referral points. From this, the microcontroller can be used to hint the vehicle operator to react accordingly to the slip level, especially when it is too high. The high slip indicates low friction, which may be a result of the bad road surface, i.e., slippery wet road, icy road. Such surfaces pose a threat to safety, and thus, the vehicle operator should be notified of the situation as it improves awareness of the danger from the slippery road surfaces.

Table 4.3: Pugh Chart to select speed sensor

		BASELINE	WEIGHT	MPU-6050	LM393	
CRITERIA						
Cost		0	3	1	1	
Mass		0	3	1	1	
Ease of use		0	3	0	1	
Speed		0	5	1	1	
Power used		0	3	1	1	
Functionality		0	5	1	0	
Result			22	20	18	

The Raspberry Pi3 touch screen was selected as the desirable display to use for the WMR as it allows both output and input functionality. The touch screen improves the human/machine interface; thereby, it is favorable. Table 4.4 shows the Pugh chart used to select the display.

Table 4.4: Pugh Chart to select display.

				OPTIONS		
		BASELINE	WEIGHT	Touch Screen	LED SETUP	LCD Display
CRITERIA						
Cost		0	3	-1	1	0
Mass		0	3	1	1	1
Ease of use		0	3	1	1	1
Speed		0	5	1	1	1
Power used		0	3	0	1	0
Functionality		0	5	1	-1	0
Result			22	14	13	12

Other components were selected for their compatibility with the chassis of the vehicle or with the Raspberry microprocessor. This was done to simplify the building process and to put the focus on building the control system for the WMR. The Raspberry Pi microprocessor requires a Motor Shield Motor Driver Board for Raspberry Pi (MOTOR SHIELD) so that the Raspberrypi can control motors of the WMR.

4.2 Component List

- 4-wheel robotic chassis (includes 4 wheels, 2 dc motors, 2 encoder discs, servo motor)

- MPU-6050 inertial measurement unit
- L293d Motor driver
- Raspberry Pi 3
- Raspberry Pi camera
- LM393 speed sensor and Encoder disk
- SHARP GP2Y0A710K0F IR Distance Sensor for Arduino
- JSN-SR04T waterproof ultrasonic distance sensor
- Piezo Buzzer PS1240
- Motor Shield Motor Driver Board for Raspberry Pi - MOTOR SHIELD
- 9v dc battery
- 5v, 2.5A power supply

The control loop flow diagram with the components is represented in Figure 4.1.

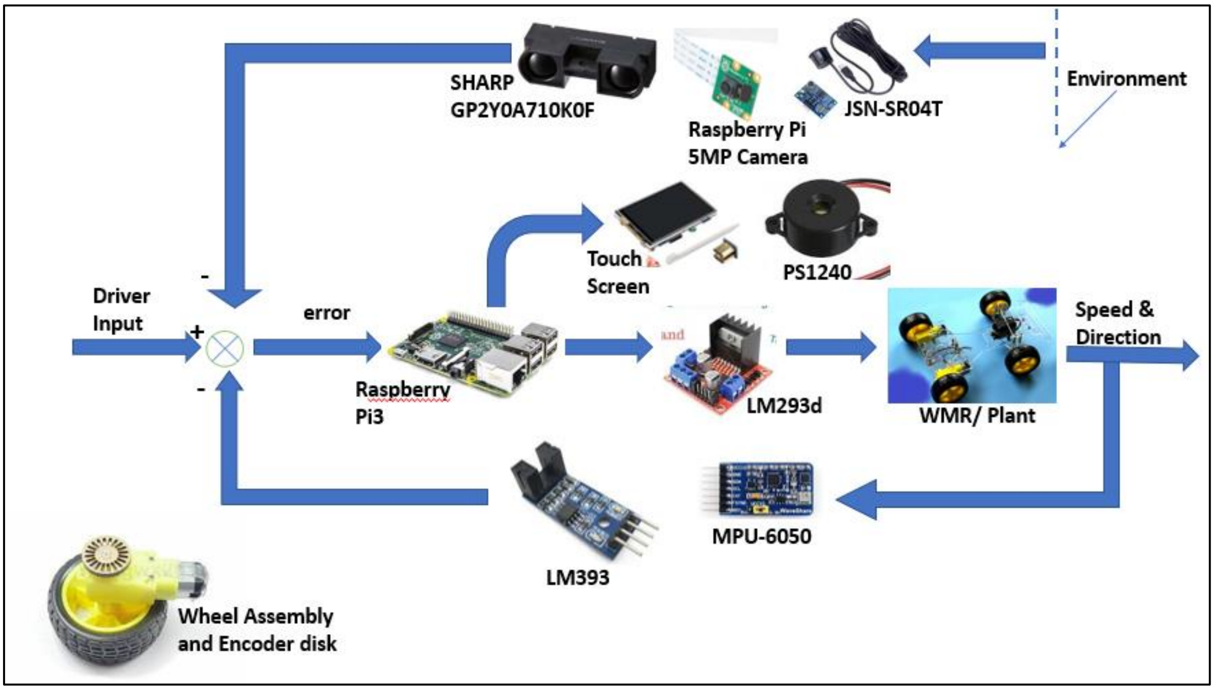

Figure 4.1: WMR control loop.

4.3 Circuit Schematics

Proteus was used to draw and simulate the circuit connection for the Low-Cost Driving Assistance System. The circuit design was used in the implementation process during the building of the project as it was used a circuit blueprint.

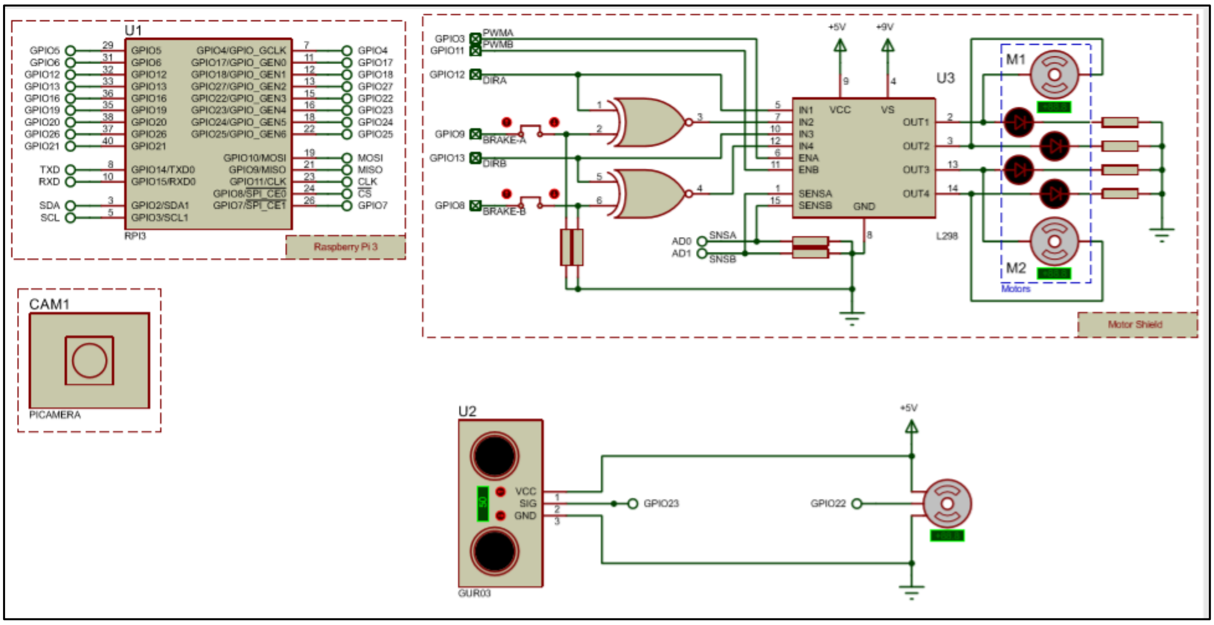

Figure 4.2: Low-Cost Driving Assistance System Circuit Schematic

4.4 Image Processing

A pretrained MATLAB deep neural network, ResNet-50 model, was retrained using images of the 30km/hr, 60km/hr, 80km/hr, stop, and deregulation signs shown in Figure 4.3.

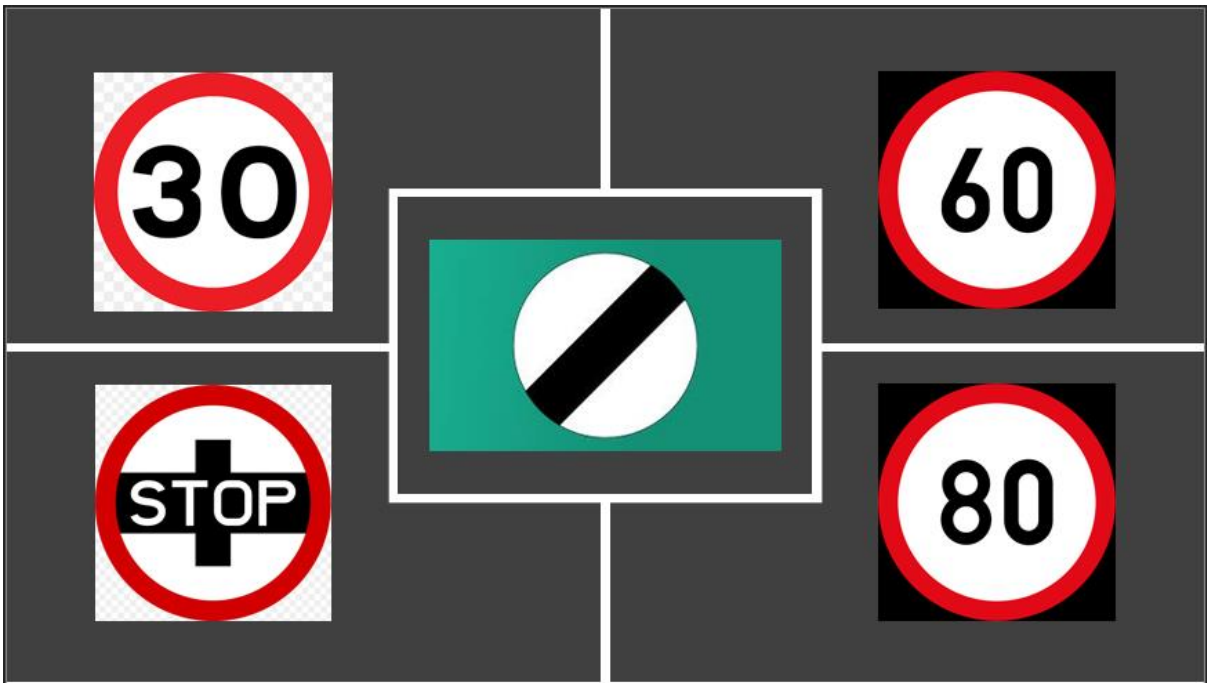

Figure 4.3: Traffic signs classified by the retrained ResNet50 model

Listing 1 in Appendix A shows the MATLAB code that was used to retrain the RasNet50 mode so that it can classify the road traffic signs shown in Figure 4.3. The road traffic sign images were obtained online from ImageNet.org [11]. The convolutional network layers in the RasNet50 model adjusts adjusted by weight values on the nodes of the network layers so that the network can classify road traffic signs [12, 13].

ResNet50 was selected over other pre-trained neural networks like GoogleNet based on speed and accuracy. Accuracy is vital as the correct classification of a road sign is paramount to providing accurate and reliable information to the driver. However, the information must come in time to ensure the vehicle operator has real-time information flowing in so that driver awareness is improved. Since the vehicle is in motion and the camera is acquiring real-time images to be processed for any traffic sign, the speed at which it takes the image must be fast to ensure real-time information is given to the vehicle operator. Figure 4.4 shows a comparison of pre-trained networks by MATLAB using a GPU. Resnet50 model has an accuracy greater than 70%, yet the relative response time is under 2 seconds and thus the best compromise amongst the other respective pre-trained networks.

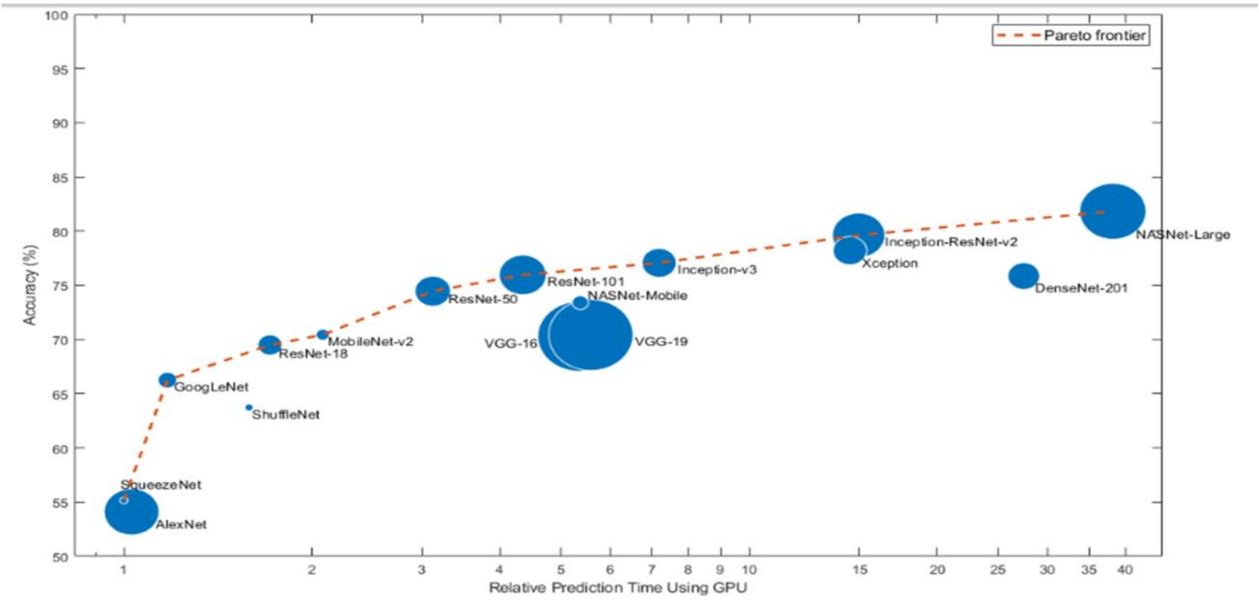

Figure 4.4: 'Relative prediction time vs. accuracy' comparison of pre-trained networks

4.5 Simulink Models

The systems were modeled in Matlab Simulink for computer simulation. Figure 4.5, Figure 4.6 and Figure 4.7 show the Simulink models derived from the mathematical modeling, obstacle avoidance as well as image processing. The models were simulated, and the results were recorded.

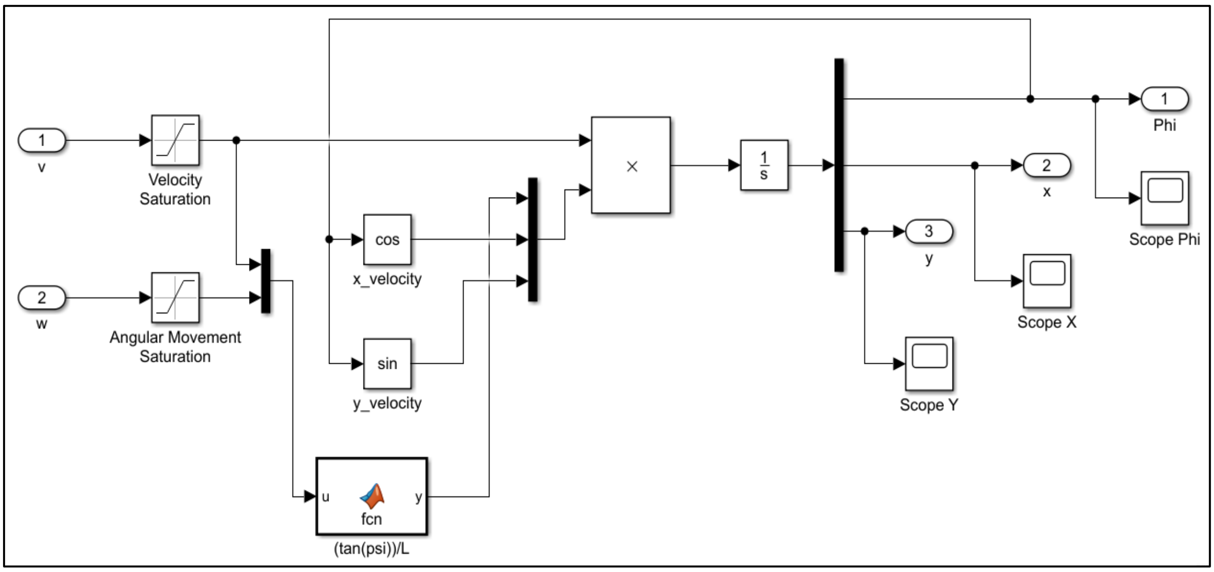

Figure 4.5: WMR Chassis Model

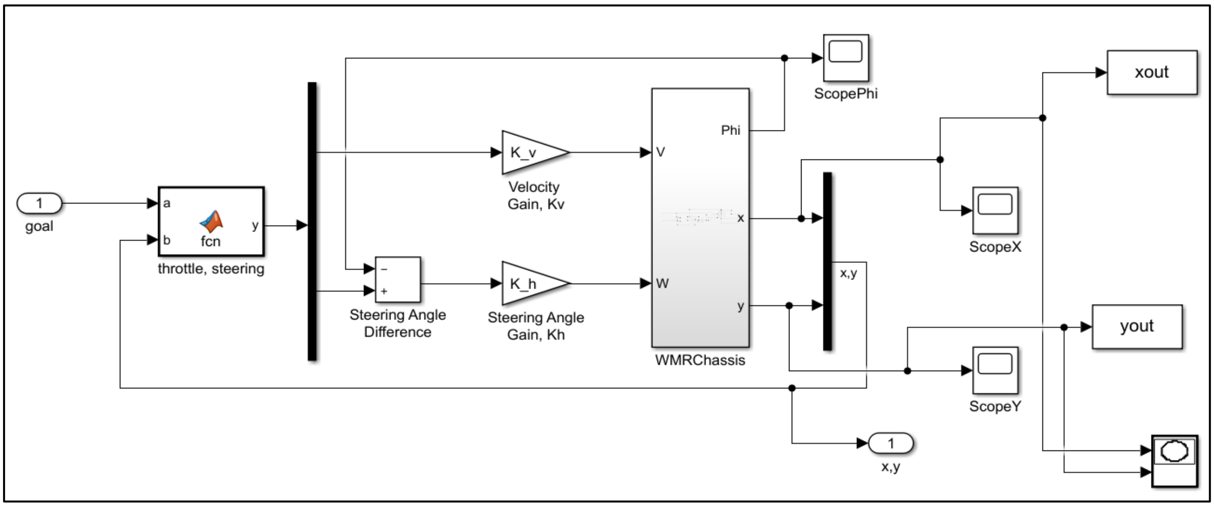

Figure 4.6 Move to a Point

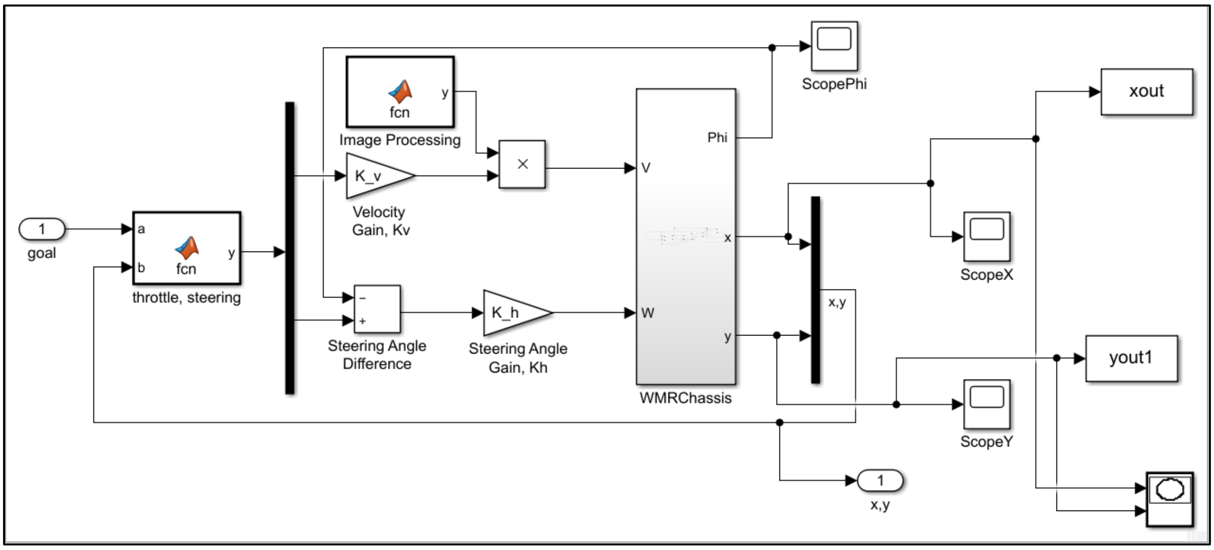

Figure 4.7: Driving Assistance System on a WMR Chassis Simulink Model

When the system in Figure 4.7 is running, the velocity of the WMR is limited by the speed restriction from the image processing. Image processing processes the images from the environment then feeds these to the image processing neural network with inturn classifies the image before outputting the classification in real-time to the system so its response accordingly.

Chapter 5: Implementation

This chapter discusses the implementation of various designs and models, as shown in the previous chapter. Here, embedding the software onto the microcontroller, assembling the WMR, and testing are discussed in detail. The chapter highlights how the subsystems were tested before they were all amalgamated to function as a single system.

5.1 Embedding Software onto Raspberrypi 3

Simulink's Embedded coder was used to embed Simulink blocks onto a Raspberry Pi B+ [15]. C code was generated and embedded on to the microprocessor, raspberry pi B+. The microprocessor then ran the software indigent of the computer used to embed the software onto the Raspberrypi.

5.2 Assembling WMR Chassis

The WMR arrived from a supplier in China as a set that required assembling before use as a WMR. The model was assembled, and the dimensions were measured and recorded for use during the modeling stage.

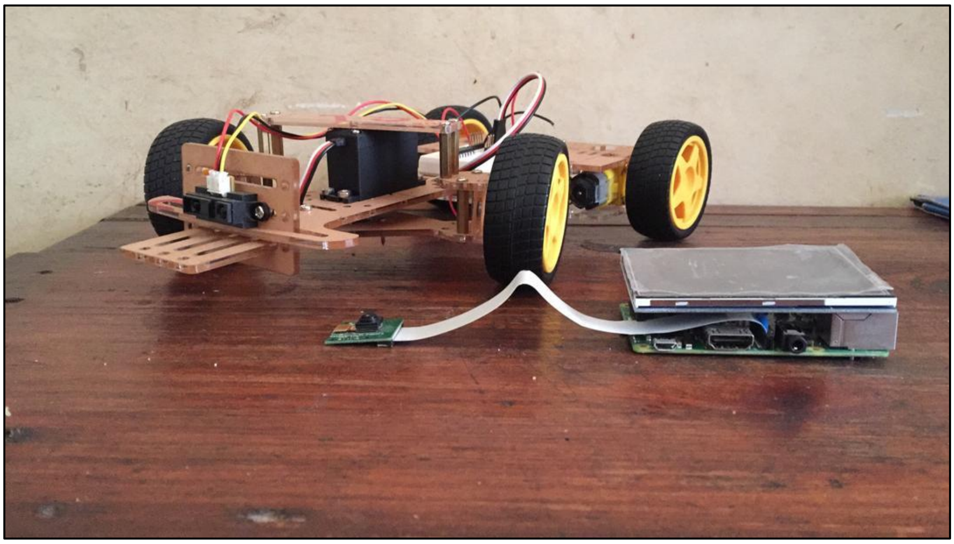

Figure 5.1: Assembled DIY WMR Chassis Kit

Figure 5.1 shows the assembled WMR kist used for this project. The plant description was discussed in Chapter 3.1 in detail.

5.3 Testing of Systems

The traffic sign classification code was run on a Raspberrypi microprocessor with the ribbon camera connection, as shown in Figure 5.2. Printed images with road traffic signs and some without road traffic signs were placed in front of the camera in random groups of 10 images, and the classification done by the system was recorded.

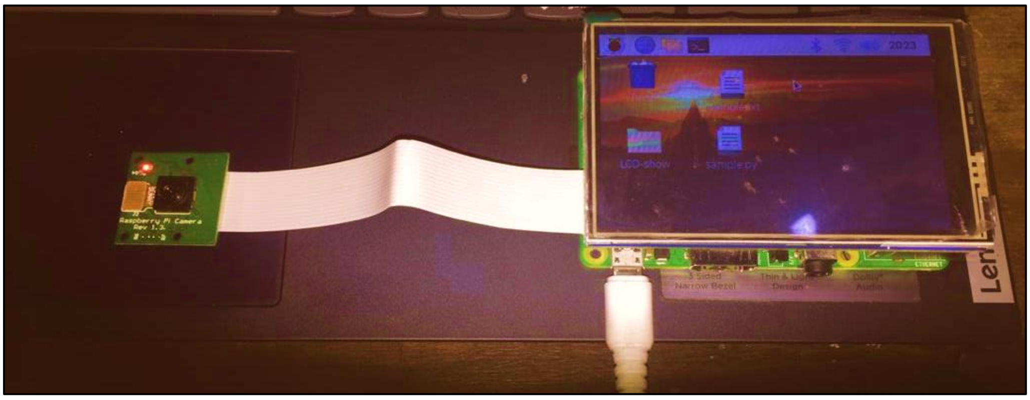

Figure 5.2: Raspberrypi B+ with ribbon camera connected

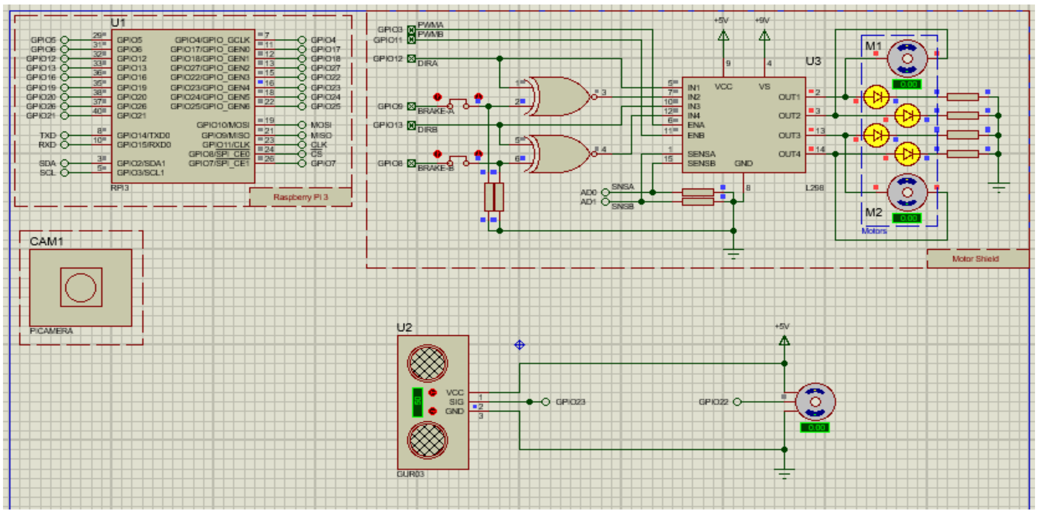

Figure 5.3: Low-Cost Driving Assistance System Proteus Simulation

The Proteus circuit in Figure 5.3 was simulated in Proteus to test the circuit. The observations were noted and recorded from the Proteus simulation.

Chapter 6: Results & Discussion

The results are discussed in this chapter. These recorded from the various tests held in the preceding chapters. The results are reviewed and discussed in sets of group analysis. Groups were classified from the different tests conducted like Matlab and Simulink tests, and Proteus results.

6.1 Matlab & Simulink Results

Simulink models were run. Their X and Y coordinate information was captured by graphs to assess the stability of the WMR from the models.

6.1.1 Simulink Results

Figure 6.1 and Figure 6.2 show the X direction and Y direction output when the chassis is given a goal (1, 8). This goal is beyond the saturation point for nonholonomic WMR. The WMR Chasis saturate, and the X settles at 1 while Y settles at 0.25.

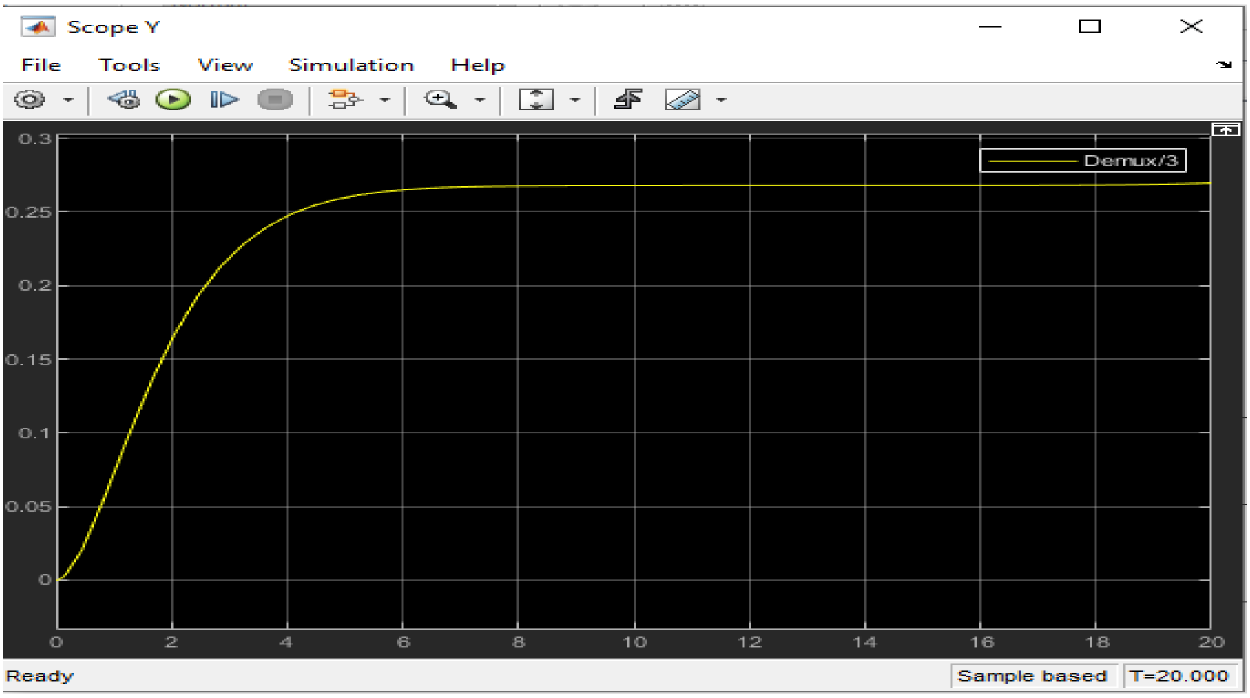

Figure 6.1: WMR Chassis Y Output

The limitation in Y is because a nonholonomic 4-wheel WMR cannot physically make such a wide-angle turn without slipping with a short X-direction movement relative to X. The turn angle will be greater than 15° thus the system saturates.

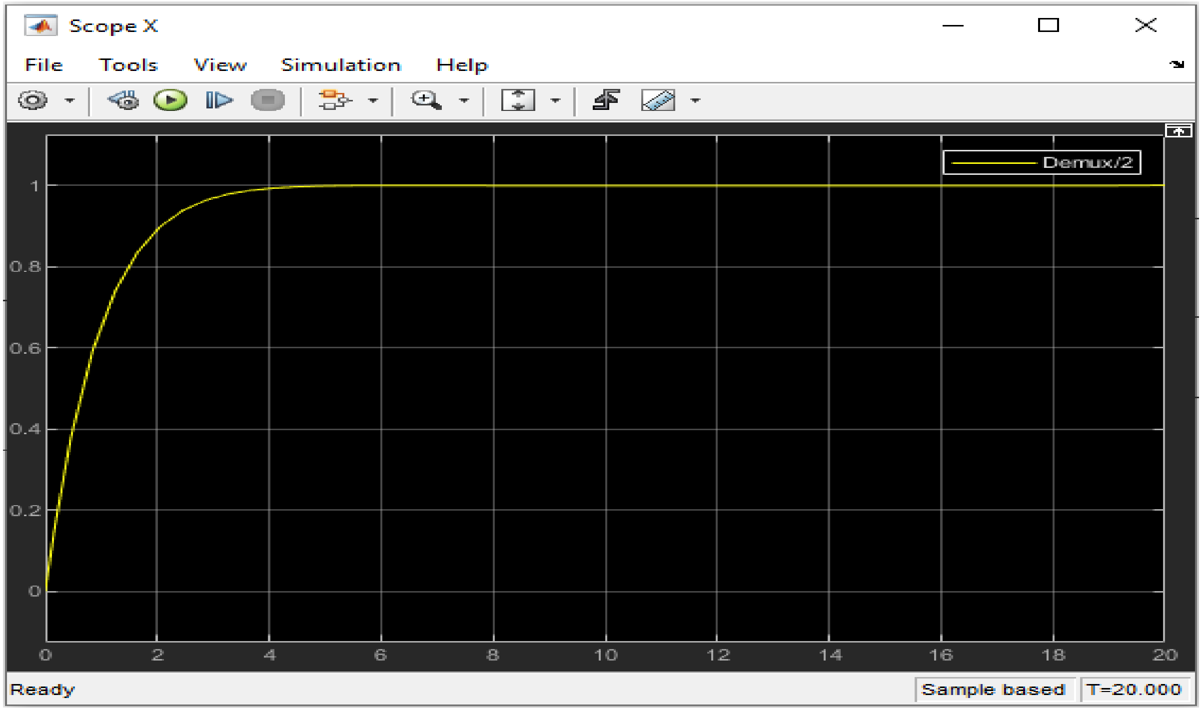

Figure 6.2: WMR Chassis X Output

During modeling, however, the slip was considered insignificant, so the model behavior exhibits no slipping of the wheels. In all other tests, the system showed that it was stable, although it has a large steady-state error for the Y value. For all values such that the turn angle is small (atan(X/Y)) and Y is significantly shorter than X then the WMR can make such turn and rest at the goal with stability thus the results were not regarded for this study that was seeking only when the system is unstable, or there is a significant steady-state error to see if control is needed.

Figure 6.3 and Figure 6.4 show similar results for the WMR move to a point model, as shown in Figure 6.1 and Figure 6.2. The system is stable but with significant steady-state error for Y, whose steady-state value is off by over 7m.

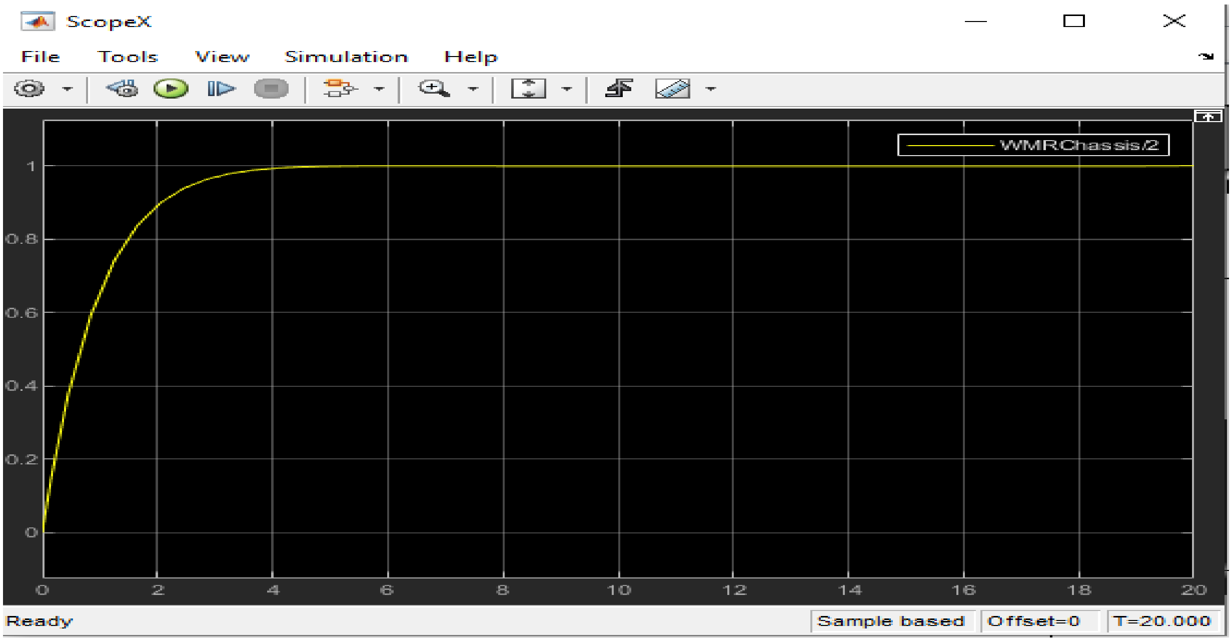

Figure 6.3: WMR Move to a Point X Output

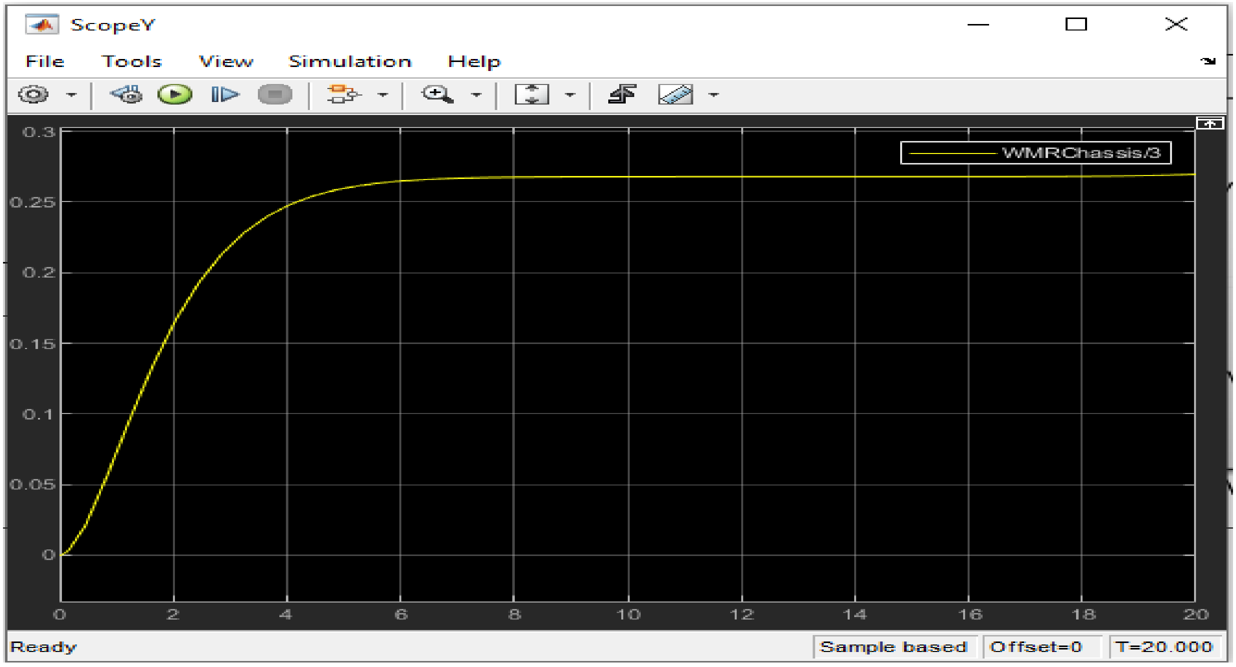

Figure 6.4: WMR Move to a Point Y Output

However, the system becomes unstable for both X and Y when the speed regulation is added as read by the traffic sign recognition block in Simulink, as shown in Figure 6.5 and Figure 6.6. The signal from the traffic signal block, which uses the code in Listing 3 causes a disturbance that destabilizes the whole system. The rise time is 3.67s for the Y output and 1.76s for the X output.

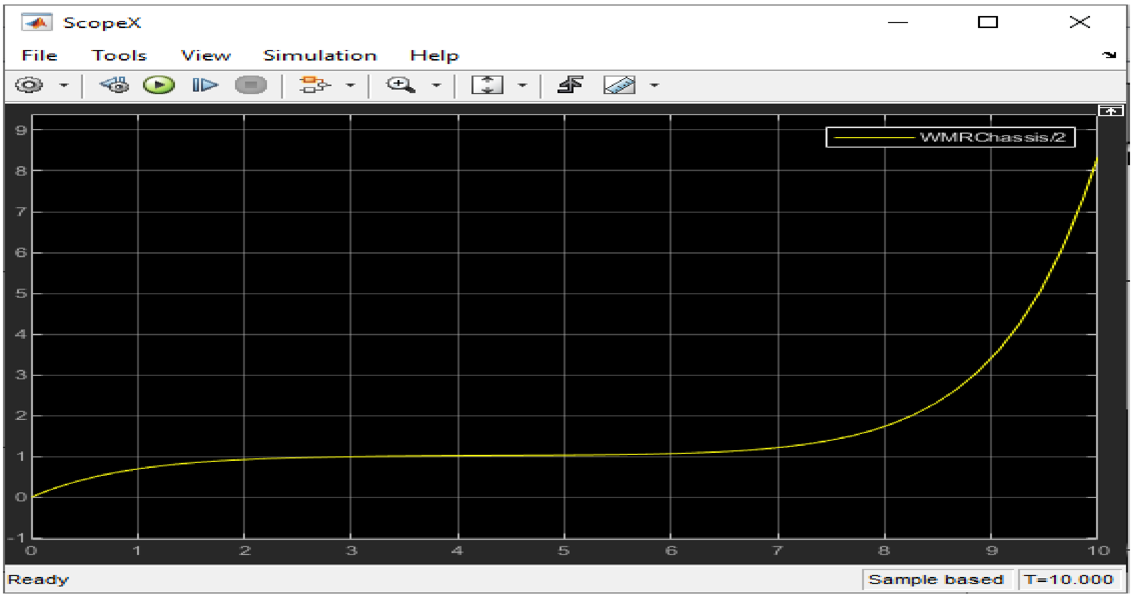

Figure 6.5: WMR Move to a Point X Output with Speed Regulation

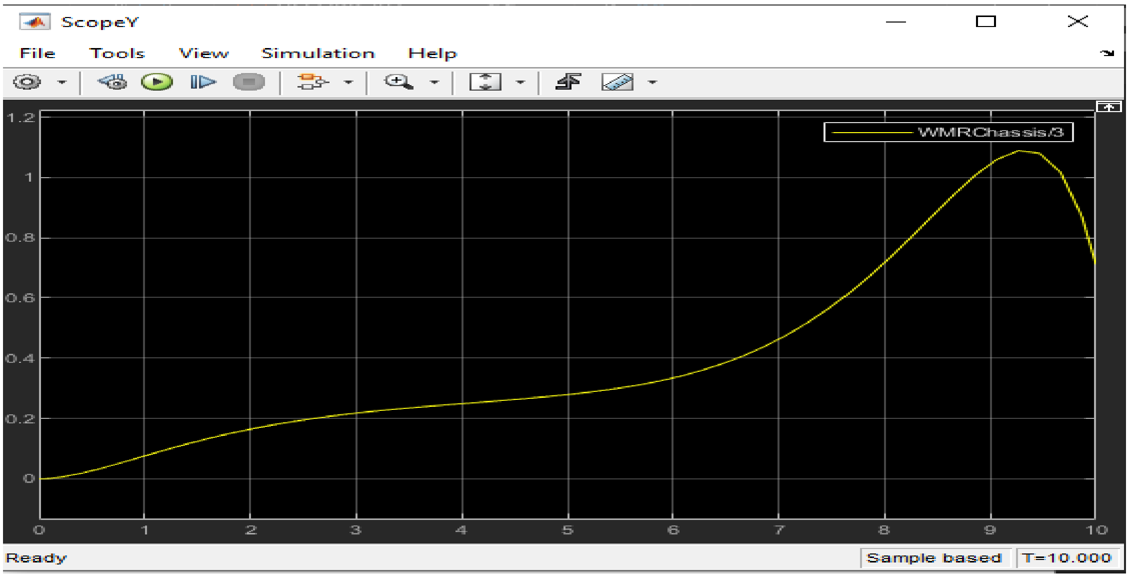

Figure 6.6: WMR Move to a Point Y Output with Speed Regulation

6.1.2 Matlab TrafficNet Results

The trained Resnet50 neural network was used to create the TrafficNet neural network, which was purposed to classify traffic road signs. TrafficNet neural network had an 80% success at classifying the test set traffic signs during the final training phase. The TrafficNet neural network showed that it had 80% from the testing part of code in Listing 1 in Appendix A.

6.1.3 Matlab with Raspberrypi Image Processing Results

The testing code in Listing 2 was embedded onto a Raspberrypi B+ microprocessor. The test results from five tests that were done with random images are presented in Table 6.1. The average accuracy recorded from the five tests was 54%. This was relatively low compared to the accuracy rate predicted for TrafficNet. However, it should be noted that real-time images the system was not receiving from the Raspberrypi Ribbon Camera were not as clear nor of quality as those used to train the system. Thus the TrafficNet fell short in an attempt to classify images in real-time correctly.

Table 6.1: Real-Time Image Processing Results

Test	Correct Classification	Total	Percentage Accuracy (%)
1	6	10	60
2	7	10	70
3	5	10	50
4	4	10	50
5	5	10	50
Average			54

6.2 Proteus Simulation Results

The circuit was simulated, and it compiled. The motors responded to the PMW output from Raspberrypi microprocessors in the simulation. Speed control was achieved by varying the GPIO pin output PMW. The observation served to acknowledge the functionality of the electrical connections that were designed in the circuit schematic.

Chapter 7: Conclusion, Limitations & Futureworks

Most of the build was not completed; hence many of the tests required to validate the solution were not tested. However, from the tasks and tests that were completed, a conclusion on the plausibility of the solution can be made, and suggestions for future work. With further testing on actual road vehicles, a strong argument will be made to whether or not the system can meet the requirements for use on actual road vehicles. The solution is suitable for low-cost applications with the relatively cheap material required for a complete build.

7.1 Solution suitability

Not enough evidence has been gathered to validate the solution validity, and thus the simulation results will be referred to for validation.

I. WMR system was not stable when used with road traffic signs detection systems and had no steady-state values as the graphs kept overshooting.
II. The rise time was greater than the required 0.5s
III. No control system was build and implemented to stabilize the WMR robot.
IV. The image recognition system build based on the retrained Resnet50, TrafficNet, can detect and classify real-time road traffic signs but with very low accuracy of 54%.
V. Visual and audio signals were not built nor tested together with the system.
VI. Low-cost components were found and selected for the project; however, not all of them were delivered by the supplier for the system.
VII. All parts of the system were successfully modeled and tested in software.

Although most of the requirements and objectives seem not to be met, it is essential to note that the most significant part of recognizing the road traffic signs and alerting the system to improve awareness was done. The accuracy needs improvement as well as the response time, but it was met.

7.2 Limitations

During the execution of the project, several limitations hindered the completion of the project and the meeting of objectives. Some of the limitations are listed below:

- Unavailability of an Nvidia Graphics Card during the project. Therefore there was not an Nvidia GPU required for deep learning by deep learning neural networks in Matlab to create a faster characterization network.
- COVID-19 epidemic greatly affected the entire project. Components ordered from China were not delivered with the order for the raspberry pi motor shield being canceled by the supplier. Campus closed down, and with it went lab access for fabrication as well as developing.
- Some of the components like battery packs, power supplies were left on campus during the hast departure from campus. Some components broke during transit from Ashesi University to the homes.
- Lost a considerable amount of support from stakeholders like my Supervisor and colleagues because of the physical separation brought by the COVID-19 Pandemic.
- Series of power cuts and the resulting poor internet services from service providers hindered research and collaboration online significantly.

7.3 Future Works

The project brought up new areas that need more research as well as completion. Further work is required to evaluate with more data, the suitability of the solution as well as try out the solution in the real world. The focus of the future work is to complete the remaining tasks, meet objectives and improve the processes used in developing the solution to create a better solution

1. Use an Nvidia Graphics Card powered computer for developing the traffic sign recognition system.
2. Complete the WMR chassis build up with all components. Thus, orders will be placed for all the orders canceled.
3. Use advanced sensors for improved accuracy and, thereby, implementation of solution on motor vehicles for testing.
4. Build a control system to stabilize the WMR as well as improve steady-state error before use in the project.
5. Do more research into neural networks and image processing to better improve the accuracy of the TrafficNet neural network that was built in this project.
6. Include more road traffic signs into the TrafficNet neural network.

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Appendices

Appendix A

Listing 1: MATLAB code used to retrain ResNet50 model to classify road traffic signs

```
%% Low-Cost Driving Assistance System
% By STEWART T.M MANGEZI:
% 'Capstone: RasNet50 Retraining'


outputFolder = fullfile('Signs'); %load path of data set to variable
outputFolder
rootFolder = fullfile(outputFolder, '101_ObjectCategories'); %load path of
categories folder to variable rootFolder

categories ={'deregulatory','eighty','sixty','stop','thirty',’no_sign’}; %
These are the categories to be used to train the Convolutional Nueral
Network

imds = imageDatastore(fullfile(rootFolder,categories),
'LabelSource','foldernames'); %IMDS, image data store to manage data
(location of images, name, value )

table = countEachLabel(imds); %check the number of images in levels
minSetCount = min(table{:,2}); %find lowest number of images to get minimum
image number to use acrossboard

imds = splitEachLabel(imds, minSetCount,'randomize'); % modify data store
to have same number of images
countEachLabel(imds); %to chech if they are the same view answers for
anypart

deregulatory = find(imds.Labels == 'deregulatory', 1);
eighty = find(imds.Labels == 'eighty', 1);
sixty = find(imds.Labels == 'sixty', 1);
stop = find(imds.Labels == 'stop', 1);
thirty = find(imds.Labels == 'thirty', 1);
no_sign = find(imds.Labels == 'no_sign', 1);

% figure(1)
% subplot(2,2,1);
% imshow(readimage(imds,airplanes));
% subplot(2,2,2);
% imshow(readimage(imds,ferry));
% subplot(2,2,3);
% imshow(readimage(imds,laptop));


net = resnet50(); %Loading resnet50 with image net data set already
pretrained and giving it a variable

% figure(2)
% plot(net)
% title ('Atchitecture of Resnet50')
% set(gca, 'YLim', [150 170]); %resizing figure to have better view,
```

```
net.Layers(1);  %view input layers, basical input dimensions
net.Layers(end); %view total number of layers
numel(net.Layers(end).ClassNames); % number of layers

[trainingSet, testSet] = splitEachLabel(imds, 0.3, 'randomize'); %dividing
the dataset into test and training images randomly

imageSize = net.Layers(1).InputSize; %This it to get the image size

augmentedTrainingSet = augmentedImageDatastore(imageSize, trainingSet,
'ColorPreprocessing', 'gray2rgb');
augmentedTestingSet = augmentedImageDatastore(imageSize, testSet,
'ColorPreprocessing', 'gray2rgb'); %resizing and conditioning the data set

w1 = net.Layers(2).Weights; % weight of convolutional layer number 2
w1 = mat2gray(w1);

% figure(3)
% montage(w1)
% title('Second Convolutional Layer Weight')

featureLayer = 'fc1000';
trainingFeatures =activations(net, augmentedTrainingSet, featureLayer,
'MiniBatchSize', 32, 'OutputAs', 'columns');

trainingLabels = trainingSet.Labels;
classifier = fitcecoc(trainingFeatures, trainingLabels, 'Learner',
'Linear', 'Coding', 'onevsall','ObservationsIn', 'columns');


testFeatures = activations(net, augmentedTestingSet, featureLayer,
'MiniBatchSize', 32, 'OutputAs', 'columns');

predictLabels = predict(classifier, testFeatures, 'ObservationsIn',
'columns');

testLabels = testSet.Labels;

confMat = confusionmat(testLabels, predictLabels);
confMat = bsxfun(@rdivide, confMat, sum(confMat,2));
mean(diag(confMat)) %accuracy
trafficNet = net;
save trafficNet
%---------------------------------testing--------------------------
newImage1 = imread(fullfile('test101.jfif'));
ds1 = augmentedImageDatastore(imageSize, newImage1, 'ColorPreprocessing',
'gray2rgb');
imageFeatures1 = activations(net, ds1, featureLayer, 'MiniBatchSize', 32,
'OutputAs', 'columns');
predictLabelImage1 = predict(classifier, imageFeatures1, 'ObservationsIn',
'columns');
sprintf('The loaded image belongs to %s class',predictLabelImage1)

newImage2 = imread(fullfile('test102.png'));
ds2 = augmentedImageDatastore(imageSize, newImage2, 'ColorPreprocessing',
'gray2rgb');
```

```
imageFeatures2 = activations(net, ds2, featureLayer, 'MiniBatchSize', 32,
'OutputAs', 'columns');
predictLabelImage2 = predict(classifier, imageFeatures2, 'ObservationsIn',
'columns');
sprintf('The loaded image belongs to %s class',predictLabelImage2)

newImage3 = imread(fullfile('test103.jfif'));
ds3 = augmentedImageDatastore(imageSize, newImage3, 'ColorPreprocessing',
'gray2rgb');
imageFeatures3 = activations(net, ds3, featureLayer, 'MiniBatchSize', 32,
'OutputAs', 'columns');
predictLabelImage3 = predict(classifier, imageFeatures3, 'ObservationsIn',
'columns');
sprintf('The loaded image belongs to %s class',predictLabelImage3)

newImage = imread(fullfile('test104.png'));
ds = augmentedImageDatastore(imageSize, newImage, 'ColorPreprocessing',
'gray2rgb');
imageFeatures = activations(net, ds, featureLayer, 'MiniBatchSize', 32,
'OutputAs', 'columns');
predictLabelImage = predict(classifier, imageFeatures, 'ObservationsIn',
'columns');
sprintf('The loaded image belongs to %s class',predictLabelImage)

%-----------------------------Testing Using Live Images in Real Time with
Raspberry pi and pi camera-----------------------------------------------
---------------------

mypi = raspi('192.168.137.81','pi','@#Maposa123'); %Setting up raspberry pi
camera = cameraboard(mypi, 'Resolution','1280x720');
inputSize = net.Layers(1).InputSize(1:2);
h = figure;

while ishandle(h)

    im = snapshot(camera);
    image(im)
    im = imresize(im,inputSize);

    newImage = snapshot(camera);
    ds = augmentedImageDatastore(imageSize, newImage, 'ColorPreprocessing',
'gray2rgb');
    imageFeatures = activations(net, ds, featureLayer, 'MiniBatchSize', 32,
'OutputAs', 'columns');
    predictLabelImage = predict(classifier, imageFeatures,
'ObservationsIn', 'columns');
    sprintf('The loaded image belongs to %s class',predictLabelImage)


    label = predictLabelImage;
    title({char(label)});
    drawnow
end
```

Listing 2: MATLAB code used to test the trafficNet model to classify road traffic signs

```
%-----------------------------Testing Using Live Images in Real Time-------
----------------------------------------------------------------

mypi = raspi('192.168.137.169','pi','@#Maposa123');
camera = cameraboard(mypi, 'Resolution','1280x720');
load('trafficNet.mat')
net = trafficNet();
inputSize = net.Layers(1).InputSize(1:2);
h = figure;
SpeedLimit = 5;

while ishandle(h)

    newImage = snapshot(camera);
    ds = augmentedImageDatastore(imageSize, newImage, 'ColorPreprocessing',
'gray2rgb');
    imageFeatures = activations(net, ds, featureLayer, 'MiniBatchSize', 32,
'OutputAs', 'columns');
    predictLabelImage = predict(classifier, imageFeatures,
'ObservationsIn', 'columns');
    sprintf('The loaded image belongs to %s class',predictLabelImage

end
```

Listing 3: MATLAB Function Simulink Block for Image Processing

```
%-----------------------------Image processing Matlab function-------------
----------------------------------------------------------

mypi = raspi('192.168.137.169','pi','@#Maposa123');
camera = cameraboard(mypi, 'Resolution','1280x720');
load('trafficNet.mat')
net = trafficNet();
inputSize = net.Layers(1).InputSize(1:2);
h = figure;
SpeedLimit = 5;

while ishandle(h)

    newImage = snapshot(camera);
    ds = augmentedImageDatastore(imageSize, newImage, 'ColorPreprocessing',
'gray2rgb');
    imageFeatures = activations(net, ds, featureLayer, 'MiniBatchSize', 32,
'OutputAs', 'columns');
    predictLabelImage = predict(classifier, imageFeatures,
'ObservationsIn', 'columns');
    sprintf('The loaded image belongs to %s class',predictLabelImage)

    if predictLabelImage == "deregulatory"
        SpeedLimit = 5;
    elseif  predictLabelImage == "eighty"
        SpeedLimit = 4;
    elseif predictLabelImage == "sixty"
        SpeedLimit = 3;
    elseif predictLabelImage == "thirty"
        SpeedLimit = 2;
    elseif predictLabelImage == "stop"
        SpeedLimit = 1;
    end

end
```