ADAPTIVE CRUISE CONTROL

BASIC DESIGN

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
OSAMA KHAIR

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

NICOSIA, 2019

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OSAMA KHAIR: ADAPTIVE CRUISE CONTROLBASIC DESIGN

Approval of Director of Graduate School of
Applied Sciences

Prof. Dr. Nadire CAVUS

We certify this thesis is satisfactory for the award of the degree of Master of Sciences
in
Mechatronic Engineering

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I hereby declare that all information in this document has been obtained and presented accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original of this work.

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ABSTRACT

Almost every minute new motorway accident happens in our world, on average, some people die and others receive serious injury. It is important to work for reducing these accidents through preparing different automotive researches and suggesting some accident avoidance systems those can support the drivers to prevent accidents. Cruise Control mechanisms were created to enable the vehicles with steady speed along the road driving unless otherwise the driver deactivates this system via the brake pedal however, it does not help the driver to overcome any possible accident and therefore, it is necessary to adapt such system and integrate new components to assist in avoiding collisions the time that then cruise control is active. The aim of this thesis is to explain how to develope a cruise control mechanism that can work to prevent possible accident from front through creating a prototype-car that moves forward and able to turn left-right using small electric motors. This thesis will also explain the basic components of the Adaptive Cruise Control System (ACC) including camera, detection sensors, control unit and necessary operational programs. Moreover, this thesis presents a simulation program of ACC car running in the higher way. The simulation test and results will show the motion behaviors of an ACC car during the different driving conditions including no car in front case and the case where there is car in front. The motion of the prototype-car can be controlled in order to follow the front moving car (the target) without collision.

Keywords: Adaptive cruise control; Anti-collision; motion control; machine vision; control system.

ÖZET

Otoyollarda ortalama olarak dakikada bir kez trafik kazası olmaktadır. Bu kazaların bir kısmı ölüm veya ciddi yaralanmalar ile sonuçlanmaltadır. Kazaların oluşmasını önleyici araştırmalar yapıp konu ile ilgili sistemler geliştirmek son derece önemlidir. Hız sabitleyici sistemler araçların sabit hızla gitmesini sağlamak için tasarlanır. Genellikle sürücünün fren yapması ile sistem devre dışı kalır ve olası bir kazayı önlemek için katkı sağlamaz. Hız sabitleyici sistemleri geliştirip olası bir tehlike durumunda kaza önleyici tedbirlerin uygulanması önem taşımaktadır. Bu çalışmanın amacı önden çarpmalara karşı hız sabitleyici sistemlerin nasıl geliştirilebileceğini incelemek ve bu doğrultuda sadece öne doğru hareket edebilen ve sağa -sola dönüş yapabilen bir araba prototipi geliştirmektir. Çalışmada uyarlanabilir seyir kontrolu sistemlerde kullanılan kameralar, algılayıcılar, kontrol birimleri ve işlevsel yazılımlar gibi temel unsurlar açıklanmış ve uyarlanabilir seyir kontrolü donanımlı bir aracın otoyol seyri simülasyonu geliştirilen bir yazılım ile yapılmıştır. Simülasyonlarda söz konusu aracın önünde başka bir hedef araç olması veya olmaması gibi farklı durumlar incelenmiş ve aracın davranışı belirlenmiştir. Geliştirilen prototip aracın ise hedef araca çarpmadan hareketi sağlanmıştır.

***Anahtar Kelimeler**:* Uyarlanabilir seyir kontrolu; çarpışma önleyici; hareket kontrolü; yapay görme; kontrol sistemleri

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LIST OF ABBREVIATIONS

ACC: Adaptive Cruise Control

ECM: Engine Control Module

ECU: Engine Control Unit

ABS: Antilock Brake Systems

PWM: Pulse with Modulation

UHF: Ultrahigh frequency

AFH: Adaptive Frequency-Hopping

RF: Radio Frequency

TCM: Transmission Control Module

V: Velocity of vehicle A

W: Velocity of vehicle B

X: The required safe distance

T: Starting Time in seconds

XA: Starting Distance of the vehicle A

VA: Starting Velocity of the vehicle A

AA: Starting Acceleration of the vehicle A

XB: Starting Distance of the vehicle B

VB: Starting Velocity of the vehicle B

AB: Starting Acceleration of the vehicle B

CHAPTER 1

INTRODUCTION

1.1 Background

Adaptive Cruise Control (ACC) is an advanced improvement of the Cruise Control system that controls the vehicle speed. The idea of the Cruise Control goes back to 1948 when Ralph Teetor (Mechanical Engineer) decided to look at a system that able to control the speed of his car as he was feeling uncomfortable with his car that was driven by his lawyer who was kept accelerating and decelerating during driving (Anonymous, 2016).

The reason for researching ACC is to handle the situation at the time when a driver is not paying attention on highways as well as to give more driving comfort to the automobiles users. ACC acts as a collision avoidance system that is designed to reduce the number of accidents on the roadways however; still everyone need to treat driving seriously. ACC can be considered as a part of the safety systems on the cars.

It was recorded that 40,200-people killed from motor vehicle accidents in United States in 2016 (NSC, "Motor Vehicle Fatality Estimates" 2016), while in 2014 the number of serious injuries in the European Union has reached 203,000 (Adminaite et al., 2015). If the in-use vehicles were produced with a system that helps in saving lives during the emergency situation, it would have greatly decreased the number of those deaths and injuries.

Designing of ACC system required different hardware components to be connected and communicating together via the ACC electronic program. ACC program is installed in the main ACC Control Unit and supplies the required data to the other Control Units on the vehicle. The ACC components includes; Control Unit that carries the required operational program, suitable detection sensors, suitable cameras, and wires to connect the components together.

Cameras are now widely used for achieving different tasks such as, monitoring the driver's body posture, detecting abnormal roads conditions, detecting moving vehicles, in addition it works on dark vision to assist the drivers on seeing farther down the street and finding any object passing or animals may cause risky situation or an accident. Thermal cameras with some other sensors has a rapid possibility to detect and identify dangers in the street, and giving more driving safety for both passengers and pedestrians.

Vehicle detection sensors are often classified according to their location as intrusive and non-intrusive (Barbagli et al., 2012). Intrusive sensors are fitted to the pavement surfaces while the non-intrusive sensors can be fitted at different locations and able to detect a vehicle's movement and other related values such as vehicle speed and lane area.

1.2 Aims

This thesis will present the main electronic components of the cars, give some ideas about image processing system that used in automobiles for tracking vehicles, showing how to fit an ACC system to a prototype-car and studying the necessary hardware & software components. Moreover, this thesis presenting some simulation methods of two tacking vehicles (A & B), showing the tests results and analyzing the tracking conditions.

1.3 Outline

Chapter 2 of this thesis gives a general idea about automotive systems, chapter 3 explains the image processing system that is used to analyze the detected objects by the detection camera, chapter 4 introduce the required hardware components of the ACC prototype-car, chapter 5 shows the methodology of the ACC prototype-car system, chapter 6 presents the results and discussions, and chapter 7 gives the conclusion and future work of ACC.

CHAPTER 2

AUTOMOTIVE SYSTEMS

2.1 Overview

Automotive manufacturers are working hardly in order to produce vehicles with higher performance and efficiency. The efficiency of a vehicles' engine is the most important area that found different studies specially with changing of the environmental regulations from time to time, on the other hand there is a huge needs to save more fuel as possible from all vehilces types in order to use it as energy for some other perposes. (Sen and Zainul Abidin, 2007).

Modern vehicles are now computerized machines; this fact has large effect on the working principles of these vehicles, in the meantime automobiles users' requirements from society led to different developments in automobiles production. Thus, automotive became co-design of mechanics and control systems. (Uwe and Lars, 2005).

As the source of the power in each automobile is the engine, this part has received more updates and improvements. Modern engines use a computer program downloaded into the Engine Control Module (ECM) to ensure higher efficiency of the engine. The ECM collects the necessary data from some sensors attached to the engine then process them and send the required outputs to the relavant actuators on the Engine Supply System (Sen and Zainul Abidin, 2007).

Many modern automobiles are containing an automatic transmission that can select the desired gear ratio without external intervention. This type of transmissions generally uses hydraulic system to change the gears, this depending on the fluid pressure within the transmission assembly. (Moskalik, 2016).

Moreover, Antilock Brake Systems (ABS) is now widely used to prevent the automobiles' wheels from been locked up during braking. ABS contains electronic control system connected to the main hydraulic unit to regulate the brake fluid pressures using some electro-valves.

2.2 Engine Control Module (ECM)

Until 1969 the engines of the most vehicles were controlled through some combination of mechanical, pneumatic, or hydraulic systems. Then, in the 1970s, electronic control systems were introduced in some vehicles (Joao, F and Matos, S, 2010).

The Engine Control Module ECM (also called Engine Control Unit (ECU)) is the brain of the engine; it controls the whole engine operations. The input information, for example, speed, temperature, weight and pilot throttle are utilized to guarantee the required fuel flow for the given arrangement of information sources. ECM controls the working parameters, to provide the engine with all required information in order to manage the operation, along of these lines, they ensuring the engine against any possible damage. A microprocessor with a computer program can help in increasing of the engine life and safety (Sen and Zainul Abidin, 2007).

ECM comprises of an arrangement of sensors, a handling unit and an arrangement of actuators as expressed in Figure 2.1. The sensors occasionally measure the engine status and give contribution to the handling unit, which forms this information, takes some choice and drives the actuators as needs be. The actuators execute the orders got from the control unit. The handling unit works upon a control methodology to enhance the fuel infusion and start with the goal that it limits fuel utilization and emanations of poisons and expands the torque and power. It is the duty of the control unit to set the required calibration according to the engine condition. There are different control programs for setting the engine, everyone has advantages and disadvantages, this usually selected by the vehicle manufacture (Sen and Zainul Abidin, 2007).
Many parameters can be used as inputs for the ECM. Some of the most important are:

- Air flow volume.
- Air inlet temperature.
- Inlet-manifold absolute pressure sensor (MAP).

• Temperature of the coolant.
•Throttle angle.
•Amount of un-burnt Oxygen.
• Crankshaft position.
• Camshaft position.

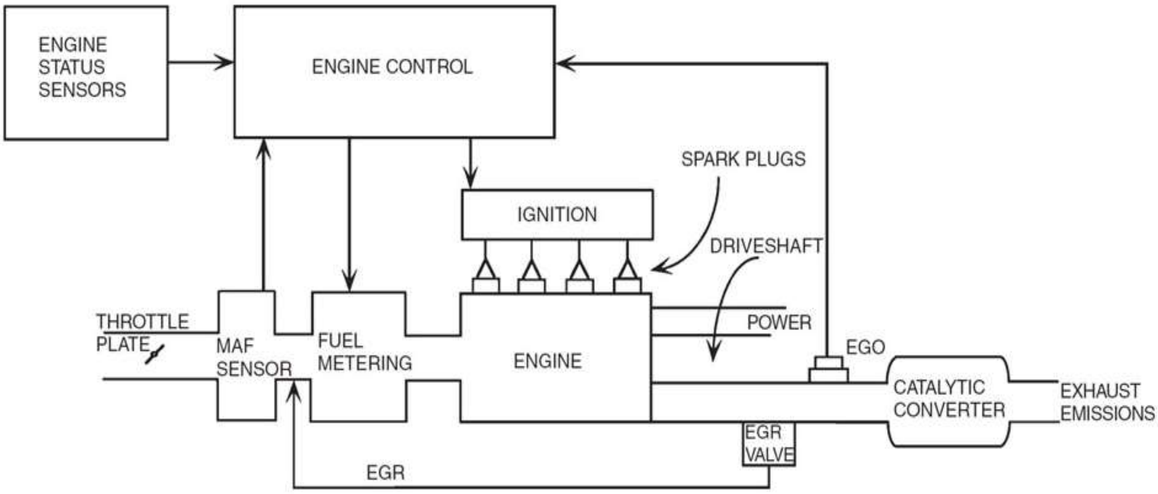


Figure 2.1: Engine functions and control

The main duty of the ECM is to control the fuel injection and ignition. The method of the control is described as following:

1- Injection: In order to ensure that the fuel is burned completely and correctly, the ratio of the air to the fuel that entering into the piston should be managed at a constant value, approximately 14.7 for Gasoline (Pradhan et al., 2012). This can be done via adjusts the opening time of every injector.

2- Ignition: In order to burn the fuel completely enough time is required, thus the spark has to start the fire instantly before the piston reaches the top point. Moreover, this parameter is also effective for the emissions control as the un-burnt fuel is pushed out by the pistons with some other components to the atmosphere creation air pollution (Ashok, 2015).

2.2.1 Overview about the input sensors

1. ***The Air Flow Sensor:*** There are many methods can be used in order to measure the air amount that pass into to the inlet-manifold, such as: vane system, the air flow sensor plate, and the heated film method.

2. ***Air Inlet Temperature Sensor:*** Air Intake Temperature Sensor is a gauge that measures the temperature of the passing air into the inlet-manifold. In general, the sensor contains a resistance works as temperature detector, the value of this resistance changes directly proportional to the temperature change.

The changeable resistance (CR) is connected with another constant resistor in series so that the voltage at this CR can be measured. In case the temperature rise, the resistance of the CR will rise too; and this makes the voltage across the resistance to rise. This change in value is then recorded by the ECM.

3. ***Manifold Absolute Pressure Sensor:*** MAP sensor is used for comparing the pressure of the inlet-manifold with the pressure of another specified vacuum (not the atmospheric pressure that may change).

The vacuum in a MAP gauge is separated from the inlet-manifold pressure by an elastic film. The film is connected to a strain gauge that able to convert the vacuum value to a voltage signals that is then sent to the ECM as a different in the voltage signal.

4. ***Coolant Temperature Sensor (CTS):*** Coolant temperature sensor is working basically as same as the air inlet temperature sensor. The data that received from CTS is processed by the ECM to control the amount of supplied fuel that injected by the fuel injectors.

The data that received from the CTS is also used by the ECM to switch ON/OFF the electric fan which used to reduce the temperature of the coolant inside the radiator.

5. ***Throttle Angle Sensor:*** The data of this sensor is used by the ECM to control the engine at the idle speed. This sensor is a rotary type that consists of a wiper blade and resistance coil. If the throttle is fully open the sensor transmits a 5V signal while it sends 0V when the valve is fully closed. The idle speed is controlled by a screw located on the throttle body.

6. ***The Oxygen Sensor:*** This sensor measures the amount of un-burned oxygen during the combustion process. The sensor produces signals with voltage from 0.15V to 1.3V when it is subjected to oxygen; this signal is transmitted to the ECM in order to control the fuel injection according to the calculated fuel ratio.

7. *Crankshaft Position Sensor:* Crankshaft Sensor is used to calculate the engine speed and the position of each cylinder on the mean time; it usually works using vanes move in between a stationary magnet and transducer.

8. *Camshaft Position Sensor:* This sensor provides the ECM with the required data about the Piston position from the TDC (Top Dead Center).

The ECM uses this data that received from the Camshaft Sensor to activate the actuators of the fuel injectors and the spark plugs.

This sensor has the same working principle of the Crankshaft Sensor in the except that instead of having vanes on the camshaft, a permanent magnet is attached on the camshaft gear (Ashok, 2015).

2.2.2 Engine actuators

1. *The Spark Plug:* Spark Plug is used to ignite the air-fuel mixture and create the required power. Basically, it works as following:

When the ECM receives the necessary data from the camshaft and crankshaft sensors, it sends electric current to the Ignition coil that produces a higher voltage up 25kV passes through the plug/plugs contact creating a spark.

2. *The Fuel Injectors:* Many engines use solenoid operated fuel injectors. When the ignition is turned ON, the ECM sends an electric voltage to the injectors allowing them to open in order to spray the pressurized fuel that received from the fuel tank via the supply line. (Sen and Zainul Abidin, 2007).

2.2.3 Electric vehicles:

The electric vehicles are the vehicles those operate with an electrical power source in which the electrical energy is transferred into mechanical energy in form of rotation using an electric motor; this rotation is then transmitted to the vehicles' wheels through the transmission system causing the required movement. The electric motors those used for electric vehicles are designed especially for this purpose. Electric vehicles may operate with AC or DC motors according to the designer.

The most efficient types of the electric vehicles are those supported with four motors.

Electric vehicles may work with only the electrical energy or with both electric motor plus gasoline engine as an alternative source of power on the vehicle. The main component of the electric vehicle is: battery, electric motor and controller, this can be explained according to the following diagram Figure 2.2 (Swaraj and Archana, 2017)

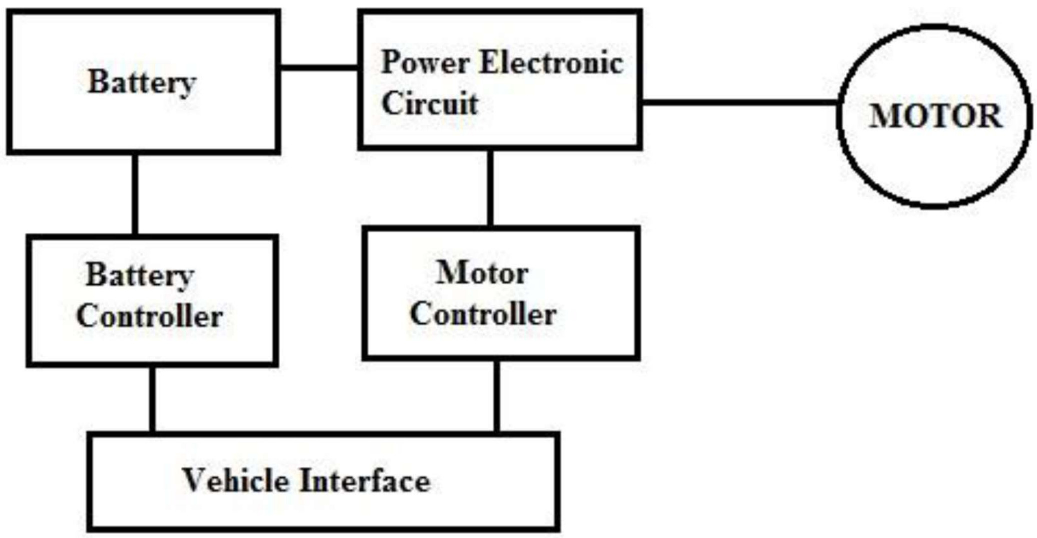


Figure 2.2: Electric vehicle main components

2.3 Gearboxes

2.3.1 Automatic gearboxes

Automatic gearbox is a transmission system that contains special devices to provide automatic gear ratios withoutexternal intervention from the driver. The number of the gears-ratios in the automatic gearboxes may vary according to the manufature design howerver, four forward gears and a reverse is the most popular automatic gearboes. Instead of a gearstick, the driver moves a lever called a selector. Most of modern automatic gearboxes contains parking position, neutral and reverse, drive, 2 and 1 on the selector options. The engine will only start if the selector is in either the park or neutral position. In park position, the drive shaft is locked so that the drive wheels cannot move. In most new gearboxs the brake pedal has to be pressed in order to shift the Gear Lever from the parking position to the other selection positions. This is a safety condition to prevent any sudden movement of the vehicle. (Denton, 2006).

Modern automatic gearboxes contain between three to six different gear ratios, also they may include ‘Economy’ or ‘Sport’ modes to increase the driving options. These types of gearboxes may have different names as same as *selectomati, tiptronic*, *multitronic* and *steptronic.* The gear selector lever usually fixed on the floor or within the steering wheel/column. Automatic Gearbox generally may consist of a torque converter and set of gears.

The main task of the torque converter is to transfer the engine torque to the wheels using some other supported components Figure 2.3. The basic idea of the torque converter can be stated as a rotating element that is driven by the engine and in the meantime a turbine that rotates the transmission parts (ROSPA, 2002).

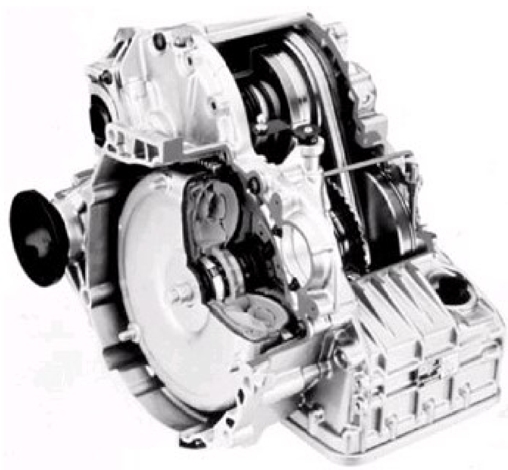


Figure 2.3: Cut section of automatic gearbox (ROSPA, 2002)

When the accelerator is pressed the speed of the rotating element of the convertor is increased, this forces the gearbox oil through the vanes of the turbine, making it rotate. Whenever there is an increase or decrease in the torque this will affect in gears changing ratio. Most the automatic gearboxes have the following selection options:

P = Park: locks the transmission system from the movement.

R = Reverse: Rear drive position.

N = Neutral: Gear free position

D = Drive: This is the forward moving gears ratio, usually consist of 1, 2, 3 & 4 is used for manual selection, while 'D' is used for normal driving condition that allows the Gearbox to make automatic adjustments according to the wheels speed, engine load and accelerator position (ROSPA, 2002).

Selecting the gear ratio is done according to the vehicle and gearbox control systems. Most modern automatic transmission has a control system prevents changing to a lower gear if the engine speed or the wheel speed are too high.

Many automatic gearboxes include manual selection gear ratios that makes it easier to control the vehicle speed during and after overtaking another vehicle on the road. However, when there is no need for flexible driving then shifting the gear lever to 'D' (Drive) is preferred.

Selecting higher gear ratio should match the driving circumstances, ex: selecting 3 in a 5-speed automatic gearbox can be suitable for urban driving while 4 can be used for non-urban roads.

For more safety it is advisable to press the brake pedal while shifting the gear lever from a position to another when the vehicle is stationary (ROSPA, 2002).

2.3.1.1 Overview about automatic transmissions

Manually selecting a preferred gear ratio can prevent wearing of the gearbox components, especially when it is necessary to change up and down between two gears.

Drive mode usually is more comfort as the gears changes is done without interfering of any external source (the driver).

Modern automatic gearboxes are designed to select the appropriate gear ratio according to the speed and throttle position, and they achieve the required task with higher performance. Manual intervention is always possible whenever it is required, this should be remembered during driving. (ROSPA, 2002).

2.3.2 Semi-automated gearbox

In order to reach customer satisfaction and increasing the driving choices, it was important to produce vehicles with technologies match most customer habits, the gearbox design is

one of these technologies.
Semi-automatic or robotized gearbox is a transmission that combines between manual and automatic transmission in one box. This type of gearboxes is manual gearboxes that supported with extra mechanism allowing it to shift the gears without need to any external intervention. However, still the manual changing of the gears is possible whenever the driver prefers. It is important to mention here that the Semi-automatic gearboxes are connected with the engine flywheel via a clutch system as the situation for all manual gearboxes, however shifting the gears and pressing the clutch bearing is done through actuators or robots attached to the gearboxes and controlled via electronic box that includes an operating program communicating with the other control units of the vehicle via data cables and wires. This solution gives more advantages including both economic and designed sides as the automatic transmissions have a complicated system. In some designs the command of gear shifting is done by control lever placed on the steering wheel, that allow managing of the transmission in safe manner (Automobiles Citroen, 2006)
Shifting the gears is much faster despite the presence of a clutch system with this type of gearboxes. Figure 2.4 describes the different components of these gearboxes and explaining its working principles (Automobiles Citroen, 2006).

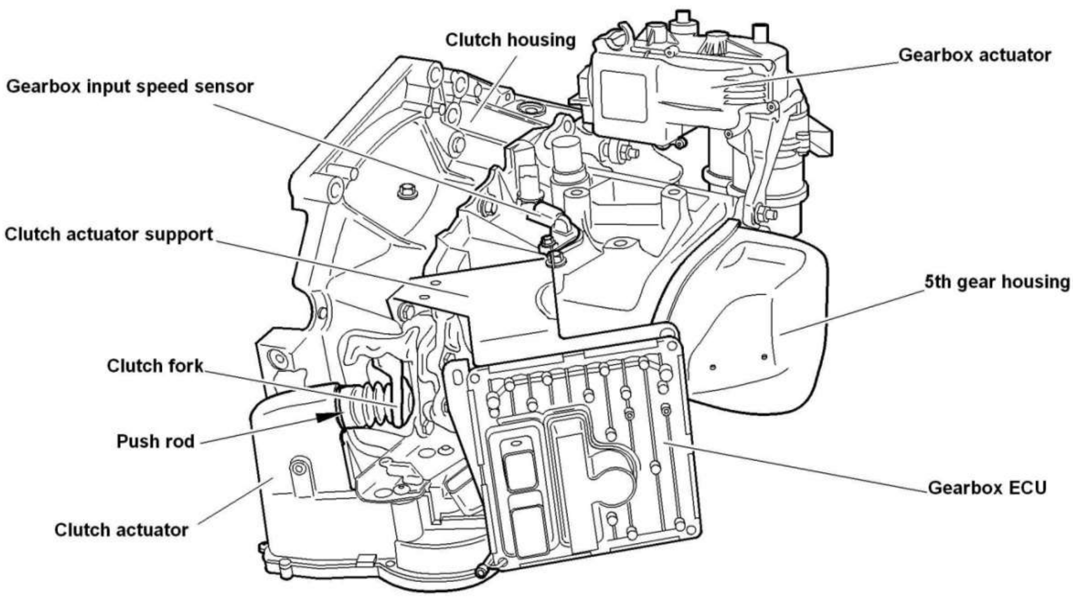


Figure 2.4: Semi-automated gearbox and its components

2.3.2.1 Clutch actuator

The clutch actuator Figure 2.5 required to open and close the clutch and adjust the clutch for wear (Automobiles Citroen, 2006).

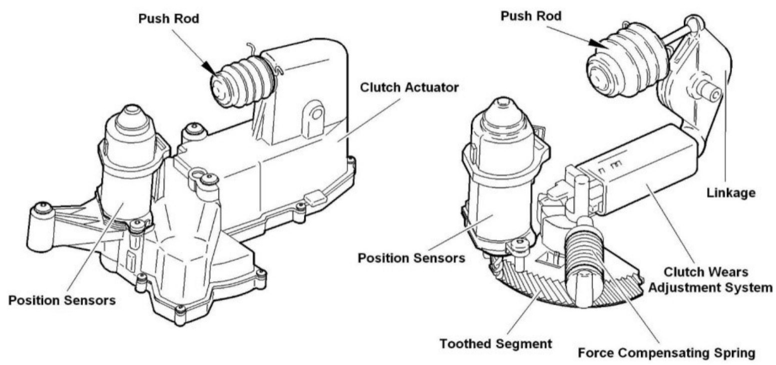


Figure 2.5: Clutch actuator

2.3.2.2 Gearbox actuator

Role: The gearbox actuator engages each gear using a rotational lever, this actuator includes two electric motors with integrated position sensors assisting in performing the required movements, as shown in Figure 2.6 (Automobiles Citroen, 2006).

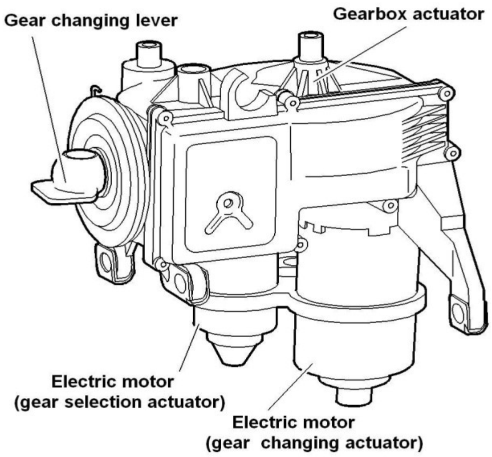


Figure 2.6: Gearbox actuator

Description:

The gearbox actuators consist of:

- The gear changing actuator.
- The gear selection actuator.
- The gearbox control unit: Required for controlling the gearshift operations.
- Some position sensors to supply the gearbox ECU with necessary signals while the electric motor rotates.

The sensors are located opposite a magnetic phonic wheel linked to the rotor of the electric motor (Automobiles Citroen, 2006).

2.3.2.3 Gearbox ECU

The roles of the ECU is following::

- Controlling the actuators for changing the gears electrically.
- Manages and performs the gear programs ("automatic" program).
- Stores the characteristics of the actuators (programming).
- It controls the control panel display.
- Communicates with the other Control Units via the network.
- Performs auto-diagnostics and implements emergency modes.

The gearbox ECU requires information from the following components:

- Gear selector unit.
- Paddles at the steering wheel.
- Brake pedal position Sensor.
- Clutch actuator position sensors.
- Selection actuator position sensors.
- Gear changing actuator position sensors.
- Gearbox input speed sensor. (Automobiles Citroen, 2006).

2.4 Anti-lock Braking System (ABS)

ABS refers to the brake system that is supported with an electrical and electronic devices in order to provide more safety during the braking at critical conditions. Most of the newly produced vehicles include ABS as a part of their brake system. ABS system is designed in order to prevent locking of the wheels during braking and provides a better braking performance. ABS does not usually activate in all braking conditions, but in fact it is designed to operate during the braking on a poor road surfaces, such as ice, snow, water, etc., or during emergency stops. (Derek and Allan, 2005).

2.4.1 Back history

The first appearance of ABS was in 1900s, it was designed for trains and then developed for jet airplanes. In the late 1960s, the automobiles producers began their implementation of ABS for luxury vehicles. The early design of ABS was using a fully mechanical technology, however, with appearance of the electronics technology, the automotive manufacturers decided to develop the ABS using electronics system for better performance from one side and in the other side to make the ABS smaller in the size. (Thomas and Dr. Gerd, 2002). Another advanced ABS was appeared in some automobiles in 1978while it was more popular in 1990 models. Nowadays ABS is fitted in most of the automobiles (Mehmet, 2015).

2.4.2 Basic function

The main aim of the ABS is to prevent locking of the wheels and thus maintains both, steering control and vehicle stability on the same time assuring time less braking distances. Any malfunction on ABS system or poor maintenance of the vehicle can lead to loss the braking control.

2.4.3 Working principle

Figure 2.7 shows general diagram of an automobile braking system with the Support of ABS. The force on the brake pedal is transferred via hydraulic fluid to the brake parts on the wheels. The force is increased via a servo that connected to the main hydraulic cylinder, and converts the brake force into pressure that transferred to brake components on the wheels. During the above process there is possibility that the wheels stop turning before the vehicle cut off its movement. This situation is called ‘locking up’ and means that the braking force was transferred inefficiently to the wheels and so a longer stopping distance is required (Thomas and Dr. Gerd, 2002).

ABS works in the same way but with more efficiency. Some electromagnetic sensors measure the speed of the wheels and detects whether it is locked up under braking or not. If the wheels got locked the brakes are released and reapplied in automatic way. Such process is done different times in order to prevent locking of the wheels and so avoiding any possible collision (Thomas and Dr. Gerd, 2002).

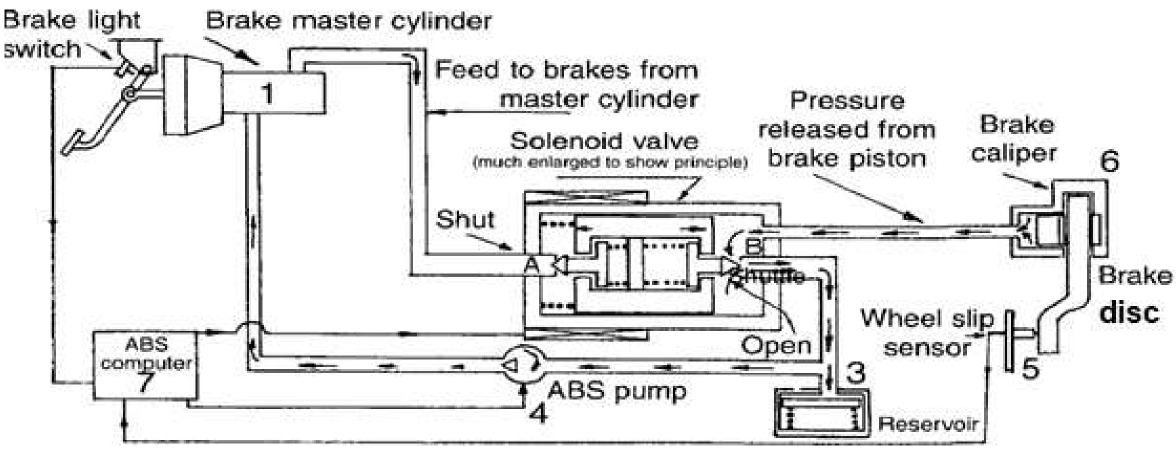


Figure 2.7: Simplified version of an ABS (Thomas and Dr. Gerd, 2002).

2.4.4 ABS components

ABS consist of some electronics and hydraulics systems including the following components:

- Wheels Speed Sensors: These sensors measure the wheel-speed and transmit necessary information to the ABS control unit.
- ABS Control Unit: It is an electronic device contains a computer program in order to controls operation of the ABS via receives data from the wheels speed sensors, determines whether the locked wheels, and sends the necessary command to the Hydraulic Unit.
- Hydraulic Unit (HU): It is a mechanical device that controls the fluid pressure inside the brake lines.
- Valves: These are placed in the brake lines and controlled by the hydraulic unit in order to regulate the fluid pressure (Thomas and Dr. Gerd, 2002).

2.4.5 The 3-Channel ABS versus & 4-channel ABS

3-channel ABS: This is referring to the brake lines those designed with 2 front separated pressure lines and only one rear pressure line. This type is cheaper and less complicated but it does not have enough safety as much as the 4-channel ABS.

4-channel ABS**:** This is referring to the brake lines those designed with 2 front separated pressure lines and also2 separated rear pressure lines, in this case the wheel speed can be measured in all four wheels separately therefore wheel lockup can be controlled in all four wheels separately (Thomas and Dr. Gerd, 2002).

CHAPTER 3

IMAGE PROCESSING

3.1 Introduction to Image Processing

The essential concept of image handling indicates the preparing of computerized image, became empty the clamor and with any classify of abnormalities sitting in an image use the advanced computer. The excitement or exception must creep the image each center its adjustment or center modification and still on. For scientific examination, a picture or image can be described as a two dimensional assimilation (x,y) with x and y are locative (plane) facilitates, and the adequacy of any match of capacity (x, y) is recognized as the power or deep scale of the picture by then. Whenever x, y, and its power assessment of f are all limited, separated contain, we call the image a computerized image. It is critical that an advanced image that is synthetic out of a limited number of strain, each of it has a particular area and esteem. These strains are called image strain, or pixels. The pixel is the extreme broadly utilized to express sub serve the components of a computerized picture (Urquhart, 1982).

Various systems have been created in Picture Handling amid the final four to five contracts. The greater part of the strategies is formed for upgrading pictures gotten from unnamed projectile, storage tests and military supervision aviation. Picture Handling structure is obtained to be plainly prevalent order to simplify the conductivity of dynamic work forcing the PCs, comprehensive the volume of store tool, representation propagation and so forth (Weiss, Y, 1999).

Current computerized invention has created it potential to lead multi-dimensional mark with frame that zone from basic advanced loop to harvest the border parallel of PCs. The goal of this observation can be separated in three classes:

- Image Handling image in → picture out.
- Picture Examination image in → assessment out.
- Picture Understanding image in → crowd on the principal ideas of image preparing.

Area does not permit us to create more than a pair of early on comments about image inspection. Image understanding requires an approach that contrasts on a very basic level from the subject of this record. Promote, it will limit it selves to two–dimensional (2D) image preparing albeit the greater part of the concept and procedures that are to be recorded can be prolonged out operative to at least three measurements (Weiss, 1999).

3.2 Digital Image Processing

Image processing is basically referring to the clear images those received from some applications such as military, medical, satellites, and security cameras. In this process the image is analyzed via several methods including sharpening edge enhancement, image enhancement, etc. The most of image processing technologies are treated with two dimensional images. Image processing is indicating the process in which the input is a picture or video while the output is a picture or main parameters expressing this picture (Zhou, 2010).

Two main methods are used for image enhancement: The first one works for images in frequency field while the other one works for image in spatial area. The frequency filed is implemented using Fourier series transformation on the other hand the one that works in spatial area is applied using the treatment of the individual pixels of the image.

In case the image is available with less equality, the relative characters mix unfinished binarization. It uses Power-Law Transformation to reduce the distribution of characters before thresholding that raise the distinction of the particle and guide to the preferred image segmentation. The Power-Law Transformation equation is given by $s=cr^\gamma$, wherever r and s square measure severally the input and output density, c and $\gamma$are positive. The indicator within the power-law equation (γ) is inform as gamma correctio (Zhou, 2010).

The MATLAB park for Matrix Laboratory was mentioned primarily to supply simple entrance to matrix software created and advanced by the LINPACK (linear system package) and with the EISPACK (Eigen system package) planner. The program has been commercially obtainable since 1984 and is now applied widely in most universities applications.

MATLAB is a suitable technique for solving the creative calculating problems.
MATLAB includes some progressing of data structure, as same as built-in marking, simulation, and debugging stuffs that allow it to be excellent programming software for different purposes and researchs (Gonzalez, 2004).

Flag handling refers to the science of arranging, testing and preparing of simples and computerized signals, and controls placing away, separating, and various operations on marks. These marks combine transmission signals, signals of voice or sound, signals of pictures, and all other marks etc. Out of each one in all these marks, the sector that arrangements with the type of marks that the data could be an image and therefore the yield is to boot an image is completed in picture making ready. because it name proposes, it manages the handling on photos. It is to boot isolated into easy image handling and therefore the advanced image making ready. The expression digital image process principally indicates to transformation of a couple-dimensional image by a digital computer. in an exceedingly floppy condition, it suggests digital process of any couple-dimensional knowledge. A digital image could be a disposition of true ranges incontestable by a restricted number of stings. the quality feature of Digital Image process procedures is its variation, repeatability and therefore the conservation of original knowledge accuracy. the various Image process techniques are:

- Image segmentation
- Image preprocessing
- Image classification
- Image enhancement (Zhou, 2010).

3.2.1. Image segmentation

Dividing the image to components is one amongst the opener ways in which in picture handling. a widely known technique that may be applied for image division is Thresholding. In Thresholding technique, a twin image is organized wherever all protest pixels had just one dim scale with all established pixels take additional - by and enormous pixels square measure showing "dark" and therefore the alternative established seems lightweight 'candid'. The preferred edge is that the one that chooses all the protest pixels and charts them to 'dark'.

completely different techniques for the programmed possibility of the limit are studied to ready to characterize the charting of the dark scale within the double set, we have a tendency to mention here the below equation {0, 1}:

$$S(x,y) = \begin{cases} 0 \; if \; g(x,y) < T(x,y) \\ 1 \; if \; g(x,y) \geq T(x,y) \end{cases} \quad (3.1)$$

which S (x, y) is that the calculable image division, g (x, y) is that the dim scale of the pel (x, y) and T (x, y) is that the limit Associate in Nursing stimulant at the directions (x, y). within the lower tough state T (x, y) is alter free and a regular for the whole image. It will be hand-picked, as an example, on the premise of the dim scale bar graph. At the purpose once the bar graph features a try of articulated maxima, that ponder dark scales of theme (s) and foundation, it's conceivable to decide on a solitary limit for the total image (Weiss, 1999).

Division of the images includes once in a very whereas not simply the segregation amongst things and therefore the foundation, in addition partition between varied districts.
the problems of image division and gathering keep extraordinary difficulties for laptop vision. Since the season of the form development in brain analysis (Wertheimer, 1938)], it's been complete that sensory activity gathering assumes a capable half in human visual per-1 caption. an intensive type of procedure vision problems may on a basic level build nice utilization of fragmented footage, were such divisions reliably and effectively estimable. as an example, middle level vision problems, as an example, stereo and movement estimation need a fitting district of support for correspondence operations. Spatially non-uniform districts of support may be distinguished utilizing division procedures. a lot of elevated quantity problems, as an example, acknowledgment and film ordering will likewise build utilization of division brings regarding coordinative, to handle problems, as an example, Figure-ground detachment and acknowledgment by elements.
While the previous few years have seen intensive improvement in eigenvector-based methods for image division (Weiss, 1999), these techniques square measure to ease back to be in any approach purposeful for a few applications. whereas their square measure other

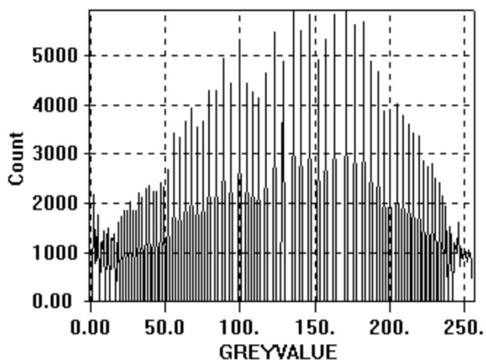
ways to manage image division that square measure terribly productive, these techniques by and enormous neglect to catch perceptually vital non-neighborhood properties of an image as talked regarding at a lower place. The division technique created here each catches sure perceptually essential non-neighborhood image qualities and is computationally a pair of effectives – running in O (n log n) time for an image pixel and with low consistent variables, and may keep running much speaking at video rates.

3.2.1.1 Local binarization using discrete convolution

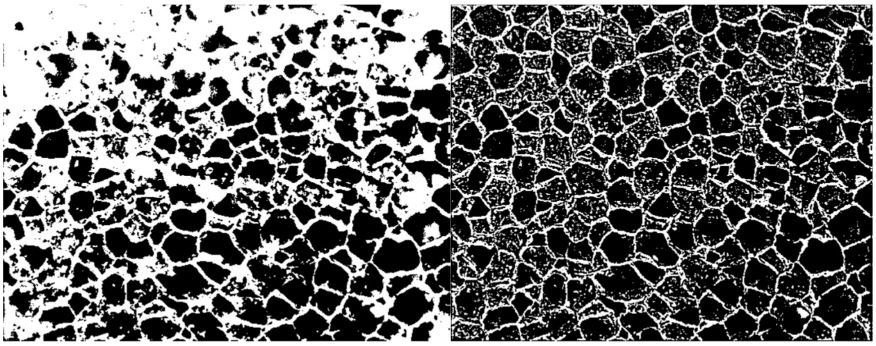
This method of binarization is used for implementation of the separate compilation refinement mechanism that make a modified image that's ready to be straightforward threshold victimization one because the verge quantity.
For resolution making close to a correct mathematical quantity of stricture p, the grade of affiliation among the most and also the in-volute footage is applied. it's careful as tracks:

$$r(p) = \frac{Cov(f, g(p))}{\sqrt{Var.Var(g(p))}} \tag{3.2}$$

Where f and $g(p)$ refers to the main gray scale image and the image involuted, correspondingly (Volodymyr et al., 1995).



a) Real picture b) The gray level histogram



c) Global thresholding d) Local thresholding

Figure 3.1 The 4 steps to the image binarization (Volodymyr et al., 1995)

3.2.1.2 Segmentation based on watershed transform

The technique for division in view of the utilization of borderer stripes was created in the system of scientific morphology. Look a picture which is a topographic roof, characterize the catchment bowls and borderer crosses as far as a contracting procedure. Envision that every bore of the roof is punctured which have a surface is dove in a mere with a consistent straight speed. This water step inside that openings surges of the roof. The minute that the surges stuffing two particular catchment bowls begin to combine, a barrage is raised with a specific end goal to forestall blending of the surges. The association of all barrages characterizes the watershed stripes of the picture. There are distinctive PC executions of watershed calculations. Fundamentally, they are able to be partitioned in two gatherings: calculations, which reproduce the overwhelming procedure and strategies going for immediate location of the watershed focuses (Salman, 2006)

3.2.1.3 Edge detection operators

Roberts edge detection: according to (Roberts, 1965) The Roberts operator implement easy, fast to calculate, 2-D locative inclination calculation on an image. It thus important areas of a rising locative gradient which often coincide to borders.

In judgment, the technique includes of a couple of 2×2 gyration covers first visor is easy the different alternate by 90°.

The value of convergent dimension can be presented by:

$$|G| = \sqrt{Gx^2 + Gy^2} \quad (3.3)$$

though typically, convergent dimension is calculated using:

$$|G| = |Gx| + |Gy| \quad (3.4)$$

Whose is the faster to enumerate.

The degree of direction of the border presenting elevation to the locative tendency (depend on the pixel of the grid orientation) is presented by:

$$\theta = arctan\left(\frac{Gy}{Gx}\right) - \left(\frac{3\pi}{4}\right) \quad (3.5)$$

Employing this visor, the convergent volumes presented by

$$|G| = |P_1 - P_4| + |P_2 - P_3| \quad (3.6)$$

Prewitt edge detection: The edge detection was developed by Judith M.S.Prewitt. Appreciation to the volume of the border Prewitt is in the right direction. Likewise, extraordinary angle edge identification needs a completely time weariness computation to discover the heading from the qualities in the x and y-bearings, the range border admission discovers the route particularly from the piece with the ultimate noteworthy answer.

Sobel edge detection: the Sobel system is utilized as a part of the picture preparing, particularly inside edge identification program. It is a separated separation director, registering an estimate of the angle of the image values work. Thus, the ingredient of the inclination might be detect employing the attached parataxis:

$$\frac{\delta f(x,y)}{\delta x} = \Delta x = \frac{f\left(x+d_{x,y}\right)-f(x,y)}{d_x} \tag{3.7}$$

$$\frac{\partial \mathrm{f(x,y)}}{\partial \mathrm{y}} = \Delta \mathrm{x} = \frac{\mathrm{f(x+dx,dy)-f(x,y)}}{\mathrm{dy}} \tag{3.8}$$

dx & dy range straight the x & y instructions correspondingly, in separated picture, only one can look at dx & dy is numbers of pixel through2 facts. dx = dy = 1 (pixel spacing) is that point at that pixel assortment are (i, j),

$$\Delta \mathrm{x} = \mathrm{f(i+1,j) - f(i,j)} \tag{3.9}$$

$$\Delta \mathrm{y} = \mathrm{f(i,j+1) - f(i,j)} \tag{3.10}$$

With a view to find the turnout of a propensity intermission, one could Figure the variation in the slope at (i, j). This able to be completed by detecting the attached dimension:

$$\mathrm{M} = \sqrt{(\Delta \mathrm{x})^2 + (\Delta \mathrm{y})^2} \tag{3.11}$$

Moreover, the orientation θ is presented by

$$\theta = arctan\frac{\Delta y}{\Delta x} \tag{3.12}$$

Processing the pseudo-convolution factor as presented.
Using this mask, the convergent dimensions presented by

$$|G| = |P_1 - P_4| + |P_2 - P_3| \tag{3.13}$$

Canny edge detection: According to (Canny, 1986) the fundamental objective of this Edge detection are the followings:

1- ***Elevated level of detection:*** have a depressed endurance of unsuccessful to realize the true edge points, and have a depressed endurance of false doing then on-edge points. Since jointly these endurances are lessening functions of the produce signal-to-noise rate, this standard coincides to maximizing signal-to-noise rate. So essentially, it haste's sign as numerous true border as potential.

2- ***Abnormal state of confinement:*** The call attention out as borders concentrates by the manager should to be adjacent conceivable to focal point of the genuine border.

3- ***Least reaction:*** the one reaction to outright edges. It is certainly caught the principal rule since from there are two reactions to a similar border, one of them has to be investigated not genuine (Canny, 1986).

3.2.2 Image preprocessing

In image preprocessing, the image data registered by a prospector on disciple confines errors recognized with geometry and brilliance appreciations of the pixels. Those mistakes are remedied employed proper scientific samples, whose are each clear or the volumes samples. Image improve is the adjustment of image in variable the pixel luminosity goodness to promote its visible impact. Image improve contains a collection of strategies that are applied to promote the visible occurrence of an image, or to modification through the image to a framework, which is more capable for epidermal or engine elucidation (Koprowsk, 2016).

3.2.3 Image classification

The recreation comes about verified that the planned controlling achieves improved with the combined broadcast vivacity metric from the most extreme quantity of recoils metric. The projected intention springs vivacity productive mode to evidence broadcast and augments the generation of total organization. By way of the performance of the projected control is broke down among two capacities in upcoming through a rare adjustment in plan examinations the implementation of the projected intention can be compared and additional vivacity productive control. We take applied petite organization of 5 centers, as number of centers expands the intricacy will increase. We can build the number of centers and break down the implementation (Ratan & Lozano-Perez, 1999).

3.2.4 Image enhancement:

In image enhancement we deal with the pixel of the picture and preparing it for improvement. Picture improvement includes a gathering of systems which are utilized to enhance the graphic entrance of a picture, or to change over the picture to a shape, that is more qualified for humanoid or engine elucidation. Isn't broad hypothesis of picture upgrade cause being broad standard for the nature of a picture. In this manner, diverse classes of strategies were created over the previous decades. The image enhancement is often used in medical and satellites systems (Vishwakarma, et al 2012).

CHAPTER 4

HARDWARE PART

4.1 Arduino (UNO/atmel 328)

Arduino Uno is a simple electronic device that designed for easy use, it is able to receive different types of input signals and resend them as preferred outputs. Arduino includes usually 14 advanced data/yield pins, 6of them possible to be applied for PWM (Pulse with Modulation) yields, there are 6 data sources, USB jack, power input, in addition to a reset button, all are included there, in other words the Arduino contains everything needed for a control device. Moreover, it can be connected to a computer via a USB cable (Ladyada.,2014). Shown in Figure 4.1.

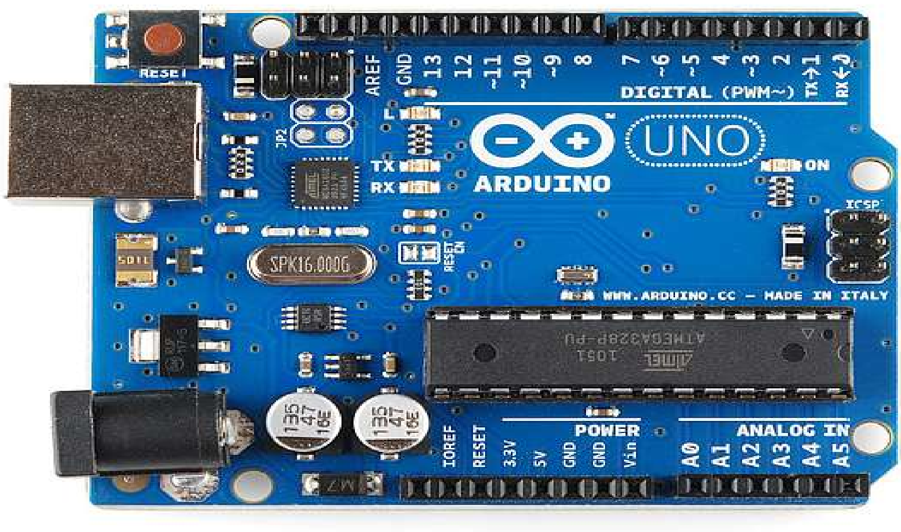


Figure 4.1: Arduino (UNO)

4.2 Servo-motor (SG90)

4.2.1 Overview

Servo-motor Figure 4.2 is an electric device that pushes or rotates an element of a machine with higher accuracy, this type of the devices can be used in different applications such as: house-electronics, toys, and aircrafts (Szottka, and Butenuth, 2011). Servo-motor will act as the steering motor of the prototype-car and so it is resposible of turing the wheels Left and Right.

Figure 4.2: Servo-motor (MG945)

4.2.2 Servo-motor and Arduino connections

Arduino digital PWM pin number 11 is connected to the input signal of the servo-motor, while a 12-volt battery is connected to voltage step-down Figure 4.3 for supplying servo-motor with 6 volts. See Figure 4.4.

To close the circuit, the ground of servo-motor is connected to the Arduinos' ground.

Figure 4.3: Voltages step-down

Hint: Arduino is supplied with 12 volt power device therefore, it can be connected directly to 12 volt battery. It is better to use PWM pins to control in Servomotors because these pins will give you high efficiency.

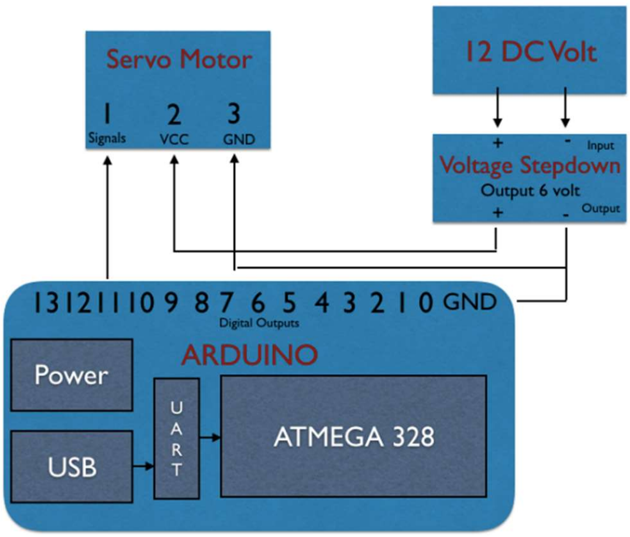


Figure 4.4: Connection between Arduino and servo-motor

4.3 Motor Driver

4.3.1 Overview

Motor driver is a small type of the electric amplifiers, it receives a control signal with low-current and resend it as a signal with higher-current (Yilmaz et al, 2016).

The driver is connected to DC-motor of the prototype-car to control the directions and speed of the prototype-car according to PWM. See Figure 4.5.

Figure 4.5: L298N Dual H-Bridge motor driver IC

4.3.2 Motor driver specifications

Drive section supply voltage Vs: +5V ~ +35V.
Drive section peak current Io: 2A.
Logical section of the supply pin area Vss: +5V ~ +7V.
Logical section of the operating current at range: 0 ~ 36mA.

4.3.3 Motor driver and Arduino connections

Arduino digital pins number 8 and 9 connected to motor drive input to control in DC motor direction (forward/ backward).
To control the speed of the car we connect PWM pin number 5 to enable pin of motor driver.
Supply 5 volt to motor driver from Arduino.
Supply 12 Volt to DC Motor through Motor Driver. See Figure 4.6.

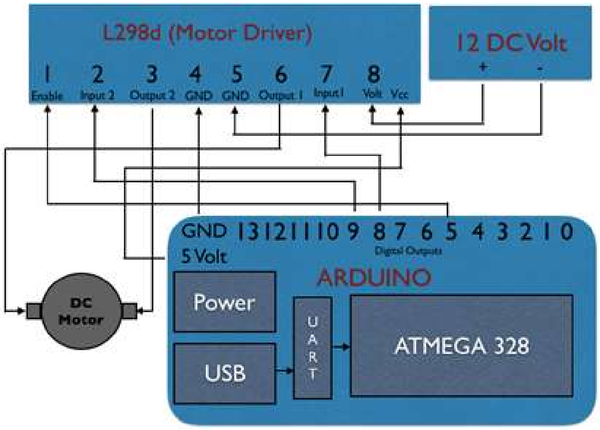


Figure 4.6: Connection between Arduino and Motor driver

4.4 Bluetooth Shield (hc-05)

4.4.1 Overview

Bluetooth is a wireless device that used for sending and receiving data among short distances via short-wave-length UHF (Ultrahigh frequency) radio-wave between 2.4 and 2.485 GHz. It can be connected with different devices, overcoming difficulties of concurrence. Bluetooth working as following: First it arranges the transmitted data in shape of packets, then transmits every packet in 1 of the 79 available channels, every channel of the Bluetooth has a bandwidth of 1 MHz that usually achieves 1600 hops each second, with Adaptive Frequency-Hopping (AFH) enabled. See Figure 4.7.

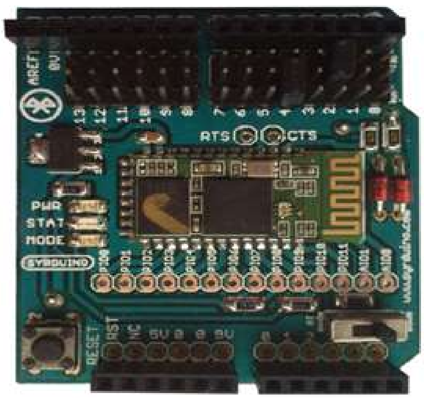


Figure 4.7: Bluetooth modul

Security: Bluetooth devices supplies security only among the radio network, from one device to all other devices.

There are three security standards:

1-Confidentiality 2-Authentication 3-Authorization.

Bluetooth in the future: Bluetoothcan be used instead of its competitors however, it has been developed to become an organizational structure for Personel Area Network (PAN).

in 2001 about 10 million Bluetooth devices were produced while in 2003 there were 70 million produced, this is show the rapid grawing in this technology.

Goals of the Bluetooth: Wireless standard (*unification*) for the interconnection of computing and communication devices, to be inexpensive and having short-range Wireless radios.

Piconets: A Bluetooth network is known as piconet (small net). A piconet can provide up to 8 stations, one of them can be defined as primary while the rest can be defined as secondary stations. All the secondary stations operate at the same time with the primary. It is important here to mention that a piconet can include only one primary station not more. The communication between the primary station and the other secondary stations can be one-to-one or one-to-many, as shown in Figure 4.8 (Kerekes and Leahy, 2006)

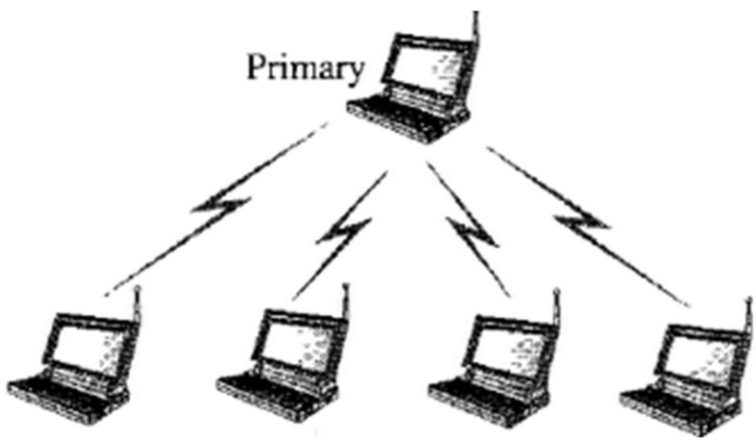


Figure 4.8: Piconet

despite that a piconet can include a maximum seven secondary stations however, it is possible to add more eight secondary stations in the parked state. This parked state works at the same time with the primary, but cannot communicate unless it is moved from this parked state.

4.4.2 Advantages and disadvantages

1. Advantages

The main advantage of of the Bluetooth technology that there are no wires or cables needed for the short-ranges data transfer. Bluetooth uses less power comparing with most of the other wireless technologies. As example, the Bluetooth technology Class 2 radio uses power of 2.5 mW.

2. Disadvantages

Easy to be intercepted as it uses greater range of Radio Frequency (RF), also it can only be used for short-range communications. Despite in fact that there are some disadvantages however, Bluetooth remains the best option to be used on fields those require short wireless system.

4.5 Camera

A true HD-quality video camera capable of recording at frame rate up to (30 fps) is connected to PC via USB. Shown in Figure 4.9.

Figure 4.9: Camera brand (A4TECH)

This camera was chosen because it has ability of recording at 30 fps.

4.6 Ultrasonic Sensors

Figure 4.10: Ultrasonic sensors

Ultrasonic distance sensors are a non-contact devoices to measure the distance between different objects. These types of sensors consist of two parts, one is the transmitter and the other is the receiver, they transmit and receive an ultrasonic sound (Figure 4.11). The basic principle of the ultrasonic sensors is that the transmitter part sends a sound signals with frequency over 18 kHz in the air with speed of 344 m/s (at around 20°C) while the receiver part receives the reflected signals from the target. The distance between the transmitter and the target simply calculated by considering the time required for the ultrasonic signals to reach the receiver from the transmitter, this can be done up to several meters.

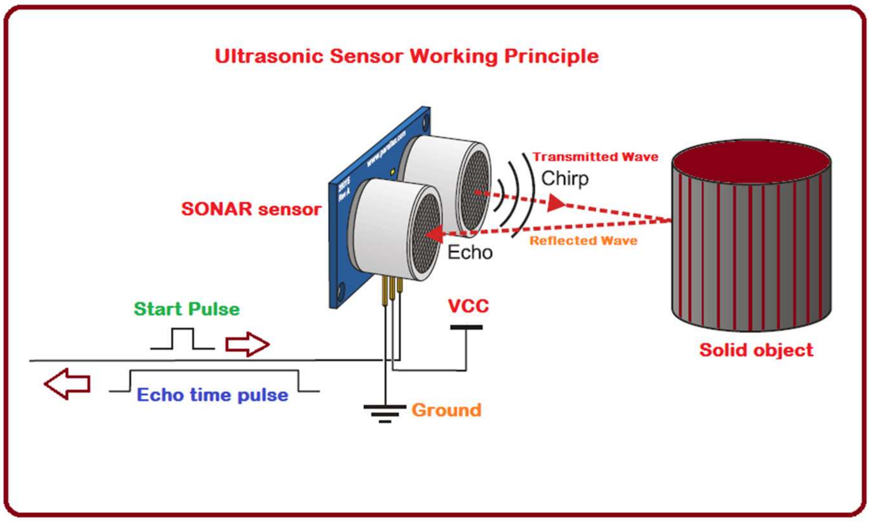


Figure 4.11: Ultrasonic sensor working principles

As nearly all materials able to reflect the sound waves, this makes the ultrasonic sensors are suitable for many tasks with excellence in the detection and measurement. Also, they can work well in dusty, dirty environments due to their use of sound waves. However, they may not perform well with little targets placed against huge backgrounds or targets same as foam batting as they are excellent for absorbing sound waves. (Michal et al, 2015).

1- Advantage

- Appreciated for the detection of transparent obstacles and liquids.
- Detection is independent from surface properties.
- Large detection range.
- Small and easy to fit.
- Simple operation.
- The direction can be either straight or 90°.
- High Accuracy.

2- Disadvantages

- Very sensitive for the temperature difference.
- Difficult to read the reflected waves from curved, soft, small and thin objects.
- Initial high cost.
- Can't be used for all Liquid types: Some liquids do not reflect the ultrasonic waves.

4.7 The Condidate Prototype-car

Figure 4.12 showing the car that will be used for implementing the ACC prototype-car, this car is a simple electrical car works with power source of 12 volt battery and connected to the Arduino and Motor driver, a 12 volt connected to voltage step down to supply servo-motor with 6 volt.

Figure 4.12: The candidate prototype-car

CHAPTER 5

METHODOLOGY

5.1 Procedures

Implementing of an adaptive cruise control on a prototype-car that able to maintain the safe distance between the ACC prototype-car and a car in front of it as shown in the example Figure 5.1. The ACC prototype-car should have possibility to accelerate or decelerate automatically according to the traffic and road conditions, for this purpose a software was developed to simulate the process of that prototype car.

Figure 5.1: Car with ACC following another and maintaining the safe distance

5.2 System Overview

This chapter presents a general overview of the ACC electrical diagram and explains the methods of implementing ACC system in a prototype-car, some more details will also be described in the following sections.

An external PC that includes the ACC MATLAB program together with Arduino acting as control unit of the ACC. On the other hand, same above PC is also carrying the simulation program that is used during the simulation tests those will be descripted in separate sections.

Figure 5.2 presenting the block control diagram of the prototype-car (Figure 5.3) while tracking another moving car in front, the control PC receives some input detection signals from the ultrasonic sensors and images from the camera (cam), then the PC processes those input signals and images in order to compare them with identified safe distance and take necessary actions to keep the prototype-car moving without hitting the car in front and stopping the prototype-car in the emergency cases.

The control MATLAB program (Appendix A) of the ACC prototype-car calculates the required values for servo-motor (controlling the prototype-car directions right-left) and DC motor (controlling forward backward) via the Arduino.
The communication between the PC and Arduino is done through the Bluetooth in the meantime the Arduino is connected to the other parts of the prototype-cars' network via some wires.

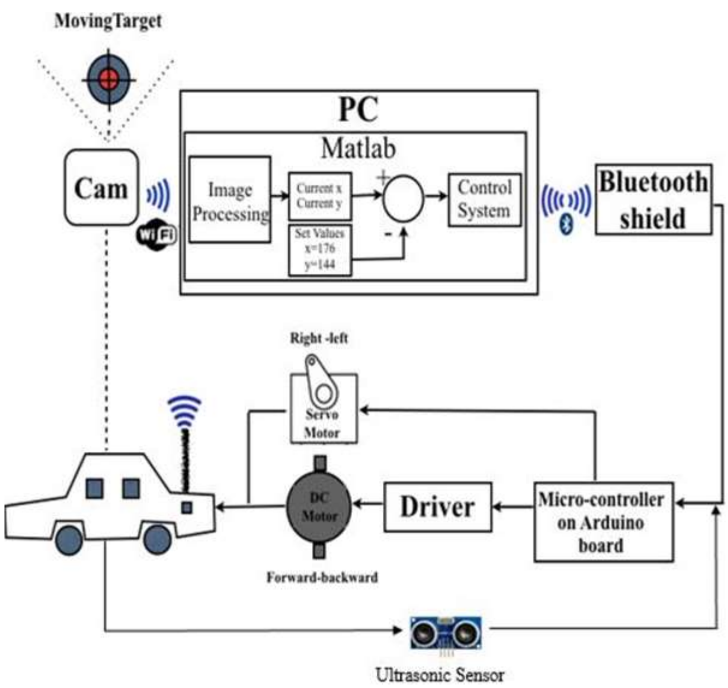


Figure 5.2: Block diagram of the prototype-cars' components

Figure 5.3: The ACC prototype-car after fitting the ultrasonic sensors

5.3 Software Components

5.3.1 MATLAB (v.2013b) on the PC

5.3.1.1 Processing of the input images

The process of the input images from camera starts by getting snapshots streamed with 352*288 pixels and RGB color frames at (30 fps). It is important to mention here that image processing operation in this ACC system require special environment during the ACC test. This test environment should not contain any part that has same color of the front target so that the system can focus on the color of the target as shown in Figure 5.4.

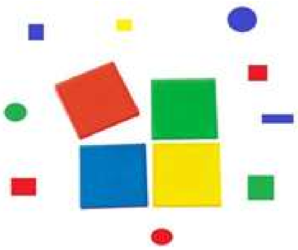


Figure 5.4: Snapshot

The image processing can be achieved in the following steps:

A- Create a grayscale image of the blue component image from the original image (snapshot).

B- Subtract the grayscale image from blue component image. See Figure 5.5.

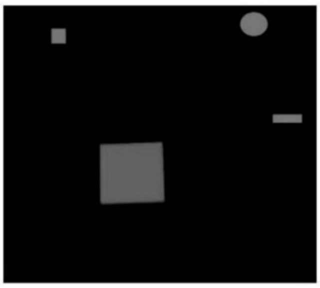


Figure 5.5: Subtracting the grayscale image from blue component

C- Convert the result into a binary image, based on a threshold: See Figure 5.6

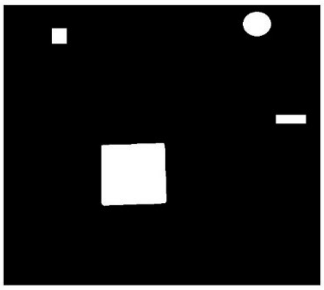


Figure 5.6: Convert to binary image

D- Remove small objects with less scale from binary image: See Figure 5.7

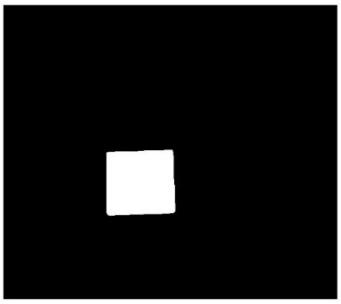


Figure 5.7: Removing objects those less than 400px

E- Label all the connected components in the image and set properties for each labeled region.

F- Display calculated properties on the original image: See Figure 5.8

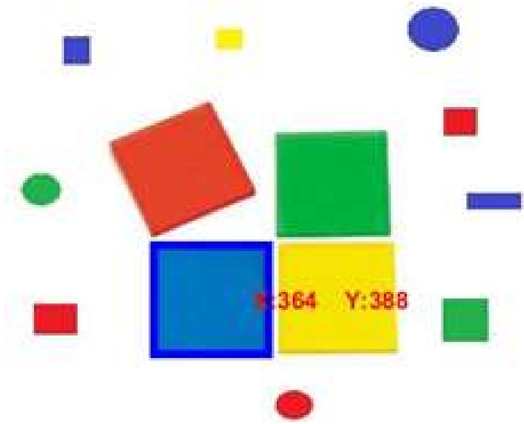


Figure 5.8: Label connected components in 2-D binary image
(At the end of image processing, we get the centroid [X, Y] of the target).

5.3.1.2 Controlling

A- Determine the center of the image that received from the target and adjust the driving components of the prototype-car using the servo-motor and DC motor.
B- Send the required control command to Arduino via Bluetooth.

5.4 Flow Chart of The ACC Prototype-car

Figure 5.9 shows the general software loop of the designed ACC prototype-car.

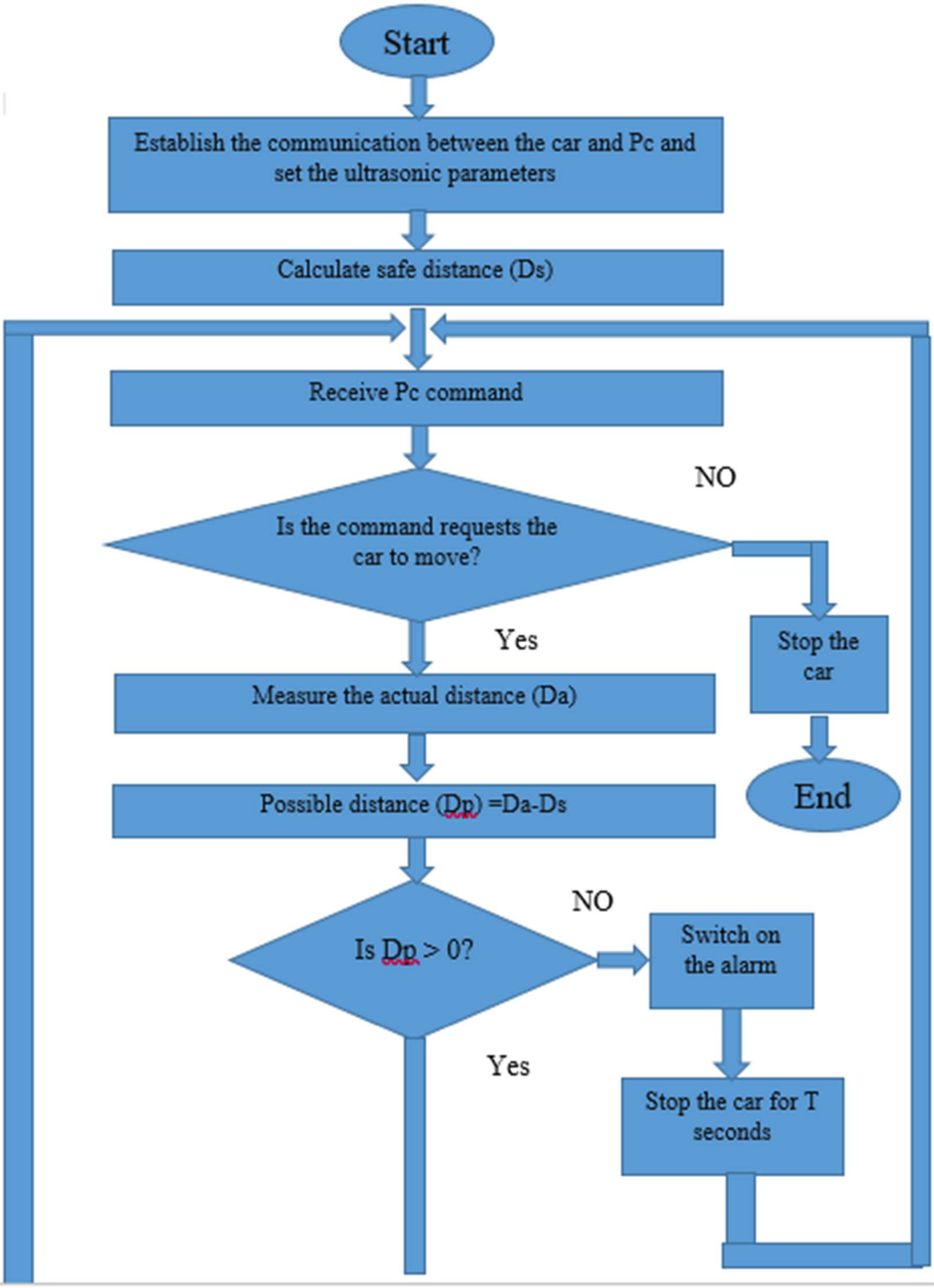


Figure 5.9: Prototype-car program flow-chart

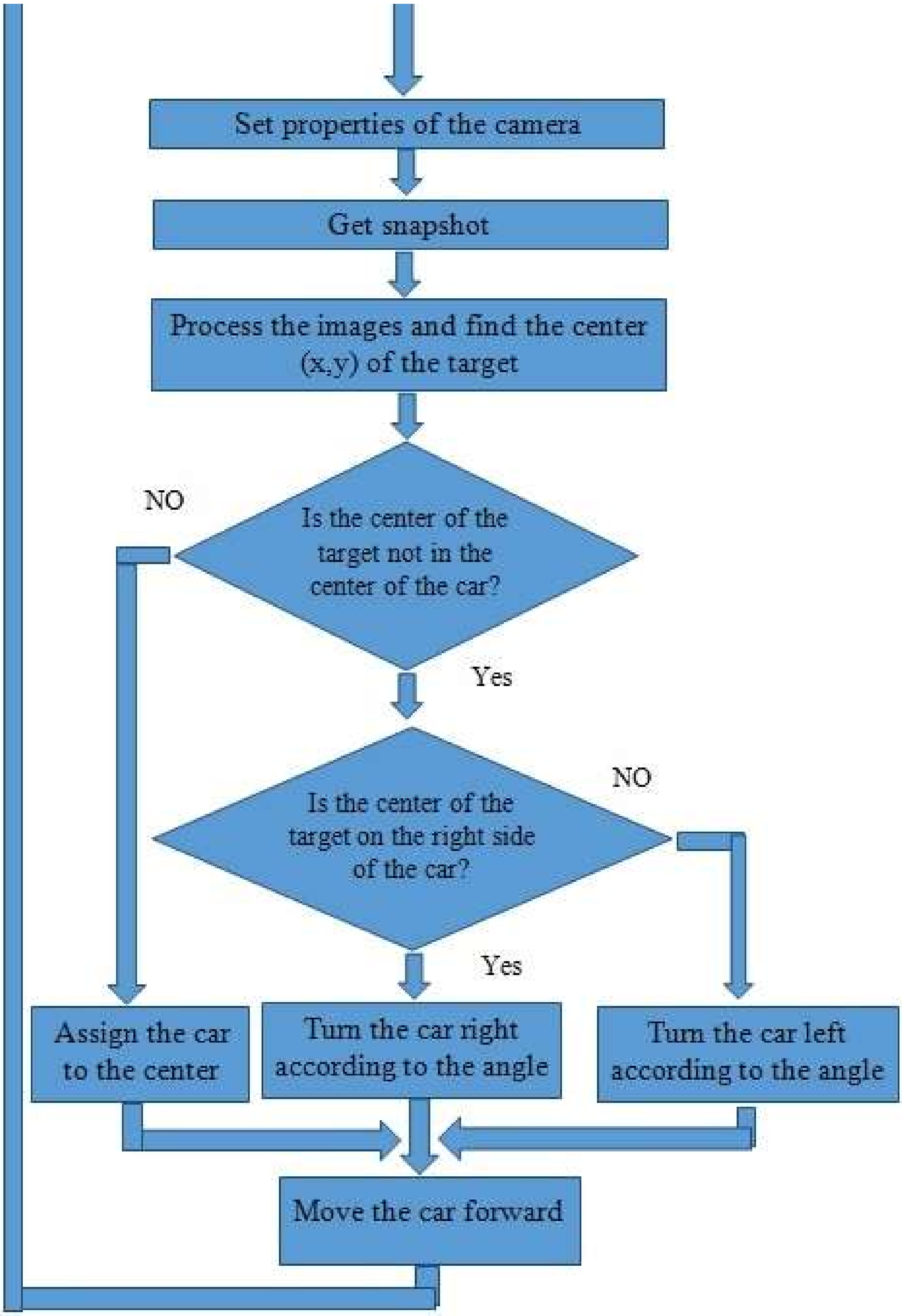


Figure 5.9 Prototype-car program flow-chart (continued)

As shown in Figure 5.9, the program starts with establishing the communication between the prototype-car and the control PC, thus the ultrasonic sensors parameters are set as inputs. Then the program calculates the Safe Distance (Ds) for the Simulation case, or input the Ds value for the prototype-car. Afterwards the program receives the PC command to Start or Stop, so there are 2 possible conditions here, first; if the command does not request the car to move, in this case the program stops the prototype-car. Second; if the PC input command requests the prototype-car to move, thus the program asks for the ultrasonic sensors distance measurements between the prototype-car and the car in front (Da). If the value of Da is less than the value of Ds this means the prototype-car approaches a danger situation therefore, the program switches the alarm ON and Stops the prototype-car for a few seconds = T and then repeat the distance measurement steps. As soon as Da is larger than Ds this is a safe situation and so the prototype-car can move forward therefore, the program sets properties of the camera, get snapshot, Process the images and find the center (x, y) of the front target. Then check if the prototype-car in the center and if necessary assign it to the center using the wheels motor and move the prototype-car forward. Then repeat the loop by checking the PC command.

It is Important to mention here that, the program cannot calculate the Safe Distance for the prototype-car due to the absence of the velocities values of both tracking cars, therefore the Safe Distance of the prototype-car should be entered as input value.

5.5 Calculation of The Safe Distance Between Two Tracking Vehicles

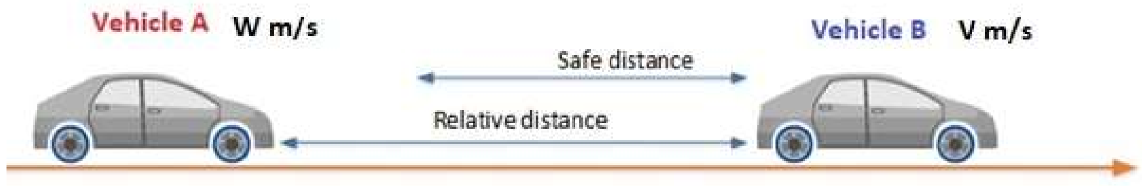


Figure 5.10: Two tracking vehicles A after B

In order to calculate the safe distance of two tracking vehicles A after B as showing in Figure 5.10, we assume that B is the leading vehicle in front and running with velocity of W, for the reason that we are concerned with the rear vehicle the relative velocity of the vehicle A may be expressed with the following equation: (5.1).

$$V_{B.A} = V - W \tag{5.1}$$

Where V is the Velocity of vehicle A, on this situation there is one possible case that a collision can take place between A & B, that if W is greater than V, this can be due to either acceleration of A or deceleration of B. In case B starts to decelerate at $t = t_2$ and stops at $t = t_5$. When A detects the front vehicle deceleration and starts to decelerate accordingly at $t = t_3$ and stops at $t = t_4$. The deceleration of B and A can be presented with the following equations (5.2) and (5.3) respectively. By considering the deceleration constant in this condition then we get:

$$a_b = \frac{V - 0}{t_5 - t_2} \tag{5.2}$$

$$a_a = \frac{W - 0}{t_4 - t_3} \tag{5.3}$$

Where a_b is the acceleration (or deceleration) of vehicle B and a_a is the acceleration/deceleration of vehicle A. Therefore, the safe distance (X) can be expressed as,

[Travel distance of vehicle A from the time incremental = t_1 until time incremental= t_5] – [Travel distance of vehicle B from time incremental = $t_1$until time incremental = t_4].
where t_1,t_2, t_3, $t_4$and t_5 are times incremental in seconds one after the other, this can be written

$$X = \left[Wt_3 + \frac{W\,(t_4 - t_3)^2}{2(t_4 - t_3)} \right] - \left[Vt_2 + \frac{V\,(t_5 - t_2)^2}{2(t_5 - t_2)} \right]$$

Or

$$X = \frac{(t_3+t_4)W}{2} - \frac{(t_2+t_5)V}{2} \qquad (5.4)$$

Replacing (5.2) and (5.3) in (5.4) can give,

$$X = 0.5\left(\frac{W^2}{aa} - \frac{V^2}{ab}\right) + Wt_3 - Vt_2 \qquad (5.5)$$

In particle life such vehicle A can only measure its own velocity and the relative velocity, therefore equation (5.5) can be written in terms of W and $V_{B.A}$ Using (5.1) and (5.5).

$$X = 0.5\left(\frac{W^2}{a} - \frac{(W+V_{B.A})^2}{b}\right) + W(t_3 - t_2) + V_{B.A}\, t_2 \qquad (5.6)$$

The Relative Velocity V_{BA} can be calculated using the time and distance measurements. The distance detection sensors of the rear vehicle A measure the distance to the vehicle in front at sequential cases. The relative distance could be the ratio of distance travelled at some point of two-time cases to the time spent. These procedures are continuously performed in order to get the relative velocity difference that may shows a possible collision, so V_{BA} can be expressed by the following equation:

$$V_{B.A} = \frac{\Delta R}{\Delta T} \qquad (5.7)$$

Where ΔR is the displacement that obtained by the sensors or the vision system at time ΔT. So, the equation can be re-written as:

$$X = 0.5\left(\frac{W^2}{a} - \frac{(W+\Delta R/\Delta T)^2}{b}\right) + W(t_3 - t_2) + \frac{\Delta R}{\Delta T} t_2 \qquad (5.8)$$

Equation (5.8) presents the method of the safe distance on a vehicle with ACC.

The time required to apply the brakes after receiving the warning is almost equal to the reaction time of the driver in the real life which was estimated to be 1.5s (National Highway Traffic Safety Administration (NHTSA), 1998). Many researchers found that the drivers decelerate their vehicles at a rate of 3.4 m/s- (Officials, 2001).

5.6 Calculation of Deceleration the Rear Tracking Vehicle

$$V_{B.A} = V_{0B.A} - a_{B.A}\, t$$

$$t = \frac{V0B.A - VB.A}{a_{B.A}} \tag{5.9}$$

$$D_{B.A} = D_{0B.A} + V_{0B.A} t + \frac{1}{2} a_{B.A}\, t^2 \tag{5.10}$$

But as our main aim is to maintain the required safe distance then

$D_{B.A} = X$

Then, Replace (5.9) in (5.10)

$$X = D_{0B.A} + V_{0B.A} \left(\frac{V_{0B.A} - V_{B.A}}{a_{B.A}}\right) + \frac{1}{2} a_{B.A} \left(\frac{V_{0B.A} - V_{B.A}}{a_{B.A}}\right)^2$$

Or,

$$X - D_{0B.A} = V_{0B.A} \left(\frac{V_{0B.A} - V_{B.A}}{a_{B.A}}\right) + \frac{1}{2} a_{B.A} \left(\frac{V_{0B.A} - V_{B.A}}{a_{B.A}}\right)^2$$

However, in order to reach the safe distance X the value of $V_{B.A}$ should be = 0

Therefore, we can rewrite the equation as:

$$X - D_{0B.A} = V_{0B.A} \left(\frac{V_{0B.A}}{a_{B.A}}\right) + \frac{1}{2} a_{B.A} \left(\frac{V_{0B.A}}{a_{B.A}}\right)^2$$

The above equation can be rearranged as,

$$a_{B.A} = \frac{3}{2}\left(\frac{{V_{0B.A}}^2}{X - D_{0B.A}}\right) \tag{5.11}$$

Equation (5.11) represents the deceleration calculation however, it is so important to highlight that if $X = D_{0B.A}$, then there will be a calculation error therefore we suggest solving this case with different method.

Note if vehicle B is out of the sensor detection range then vehicle A will accelerate smoothly to reach the maximum set velocity as in the normal Cruise Control System.

5.7 Simulation Using Delphi Program

A computer program using Delphi (Appendix E) was prepared in order to explain the behavior of two tracking cars A & B, one after the other, car A assumed as a car with ACC system and travelling in the highway in straight direction.

The program calculates the required safe distance, velocity and acceleration using the equations those mentioned in section 5.5 and 5.6 and compare them with the measured values by the distance sensors then sends the necessary commands to the ECM Engine Control Module), TCM (Transmission Control Module) and ABS (Anti-lock Brake System) those fitted in car A network. This program could maintain the safe distance between car A & B and prevents any collision with car B.
Different tests were carried using this computer program in order to ensure its correct operation.

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Simulation Tests of Delphi Program

During the simulation tests, it was assumed that there is two tracking vehicles A and B one after the other as indicated in the previous sections, these two vehicles were tested with different starting movement data, and the obtained results were recorded over the tracking time of the tests. The simulation will present the cases those could not be implemented practically using the prototype-car such as changing of the velocity and acceleration. The input information that applied are:

T = Starting Time in s

X_A= Starting Distance of the vehicle A

V_A= Starting Velocity of the vehicle A

A_A = Starting Acceleration of the vehicle A

X_B= Starting Distance of the vehicle B

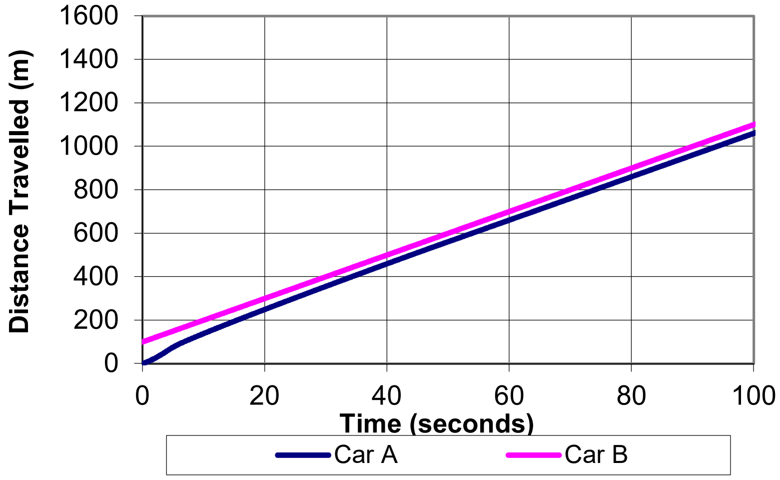
V_B = Starting Velocity of the vehicle B

A_B= Starting Acceleration of the vehicle B

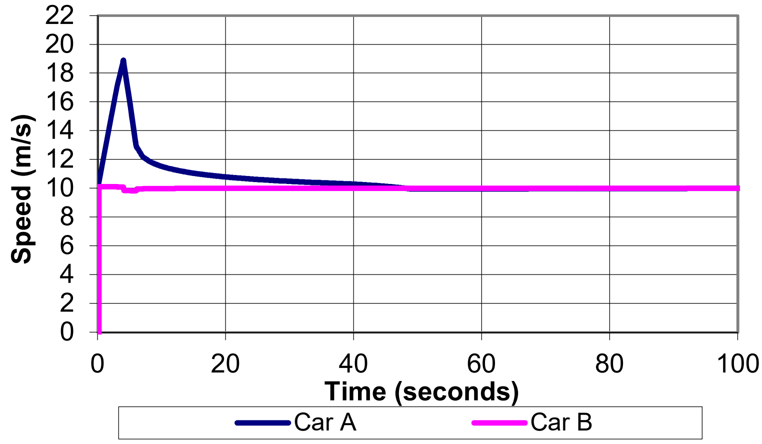
Test 1:

Time		**Car A**			**Car B**	
T	XA	VA	AA	XB	VB	AB
0	0	30	0	200	10	0

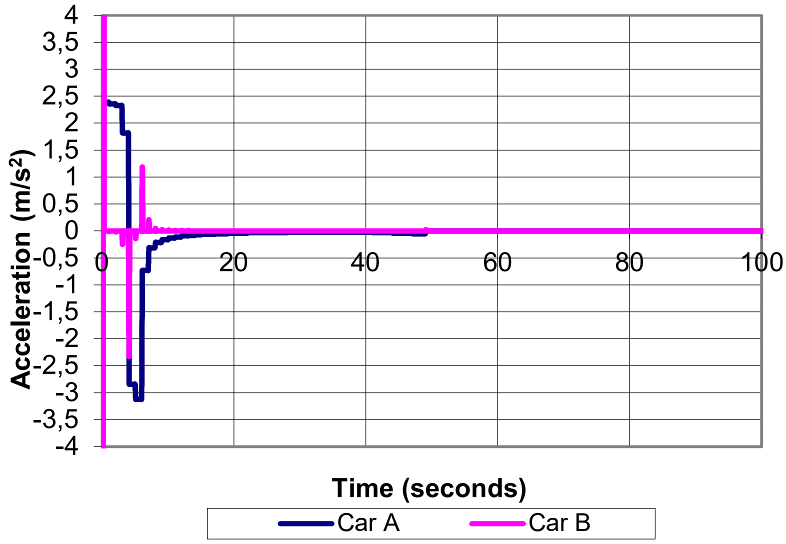
Table 6.1 Test 1



1600
1400
1200
1000
800
600
400
200
0
Distance Travelled (m)
0
20
40
60
80
100
Time (seconds)
Car A
Car B



22
20
18
16
14
12
10
8
6
4
2
0
Speed (m/s)
0
20
40
60
80
100
Time (seconds)
Car A
Car B



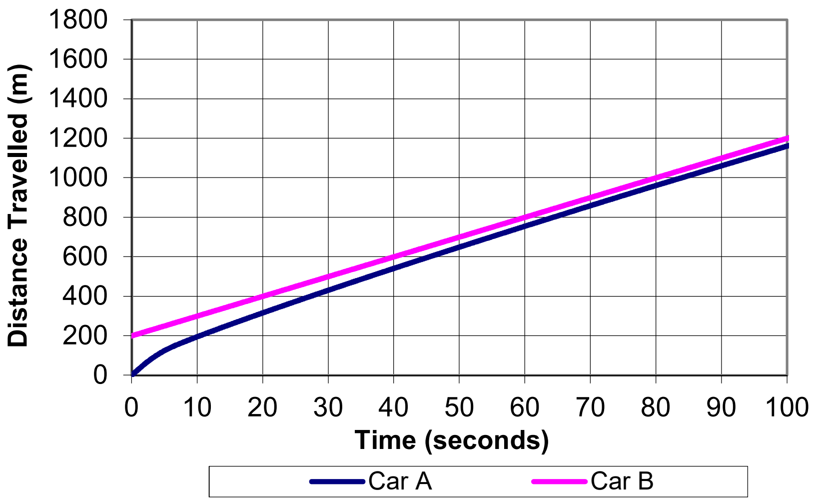
4
3,5
3
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
-2
-2,5
-3
-3,5
-4
Acceleration (m/s²)
0
20
40
60
80
100
Time (seconds)
Car A
Car B

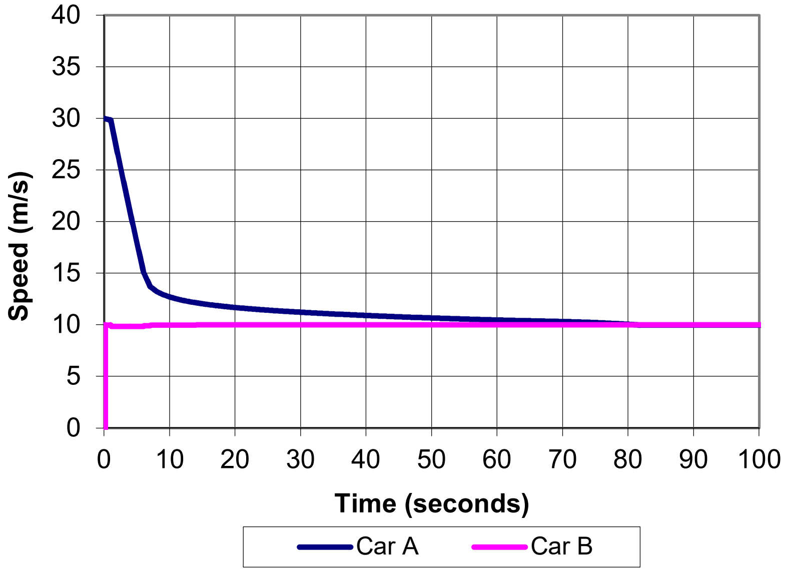
Test 1 was carried while both vehicles were moving with same velocity of 10m/s vehicle A was 100 m behind vehicle B. Vehicle B was keeping its constant velocity of 10m/s therefore, vehicle A started to accelerate in the beginning of the test as the distance 100 m was more than the required safe distance in that condition. When vehicle A realized B in front, A started to decelerate in order to maintain the required safe distance and continued accordingly.

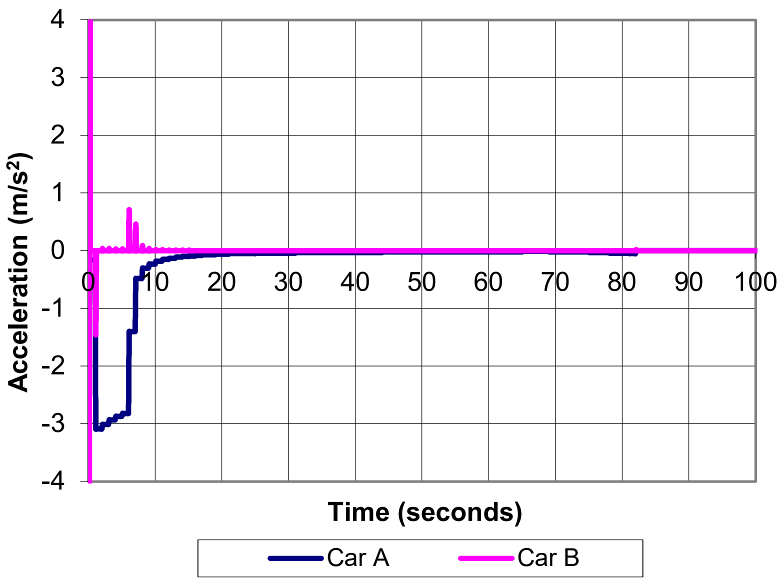
Test 2:

Time		Car A			Car B	
T	XA	VA	AA	XB	VB	AB
0	0	30	0	200	10	0

Table 6.2 Test 2





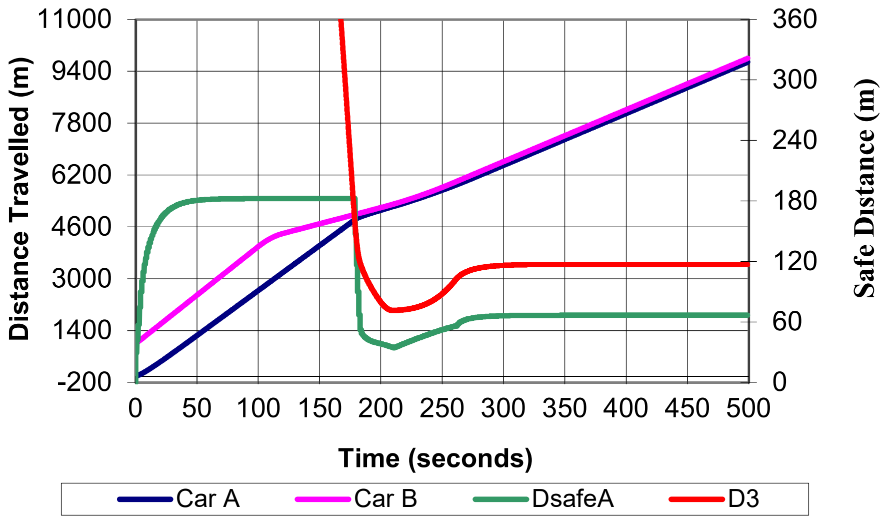


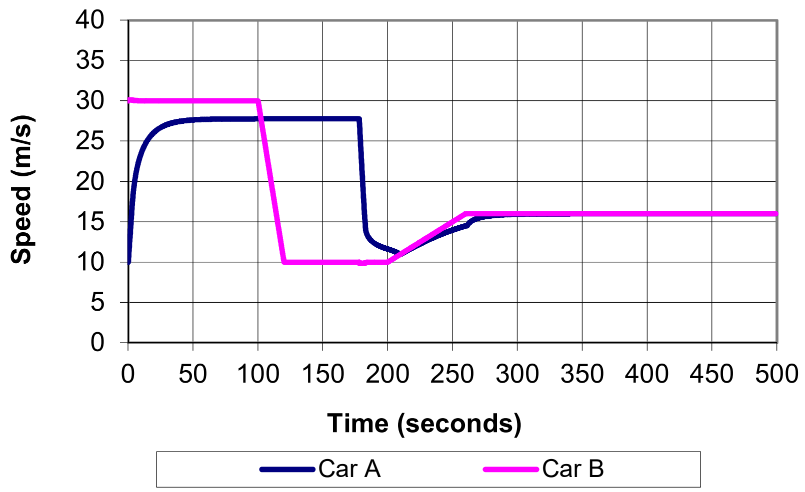
Test 2 shows that vehicle A started its velocity at 3 m/s while vehicle B started with a constant velocity of 10m/s. Vehicle A was 200 m behind vehicle B. In this case vehicle A was getting closer to B with the time therefore, vehicle A started to decelerate in order to maintain the required safe distance and continues accordingly.

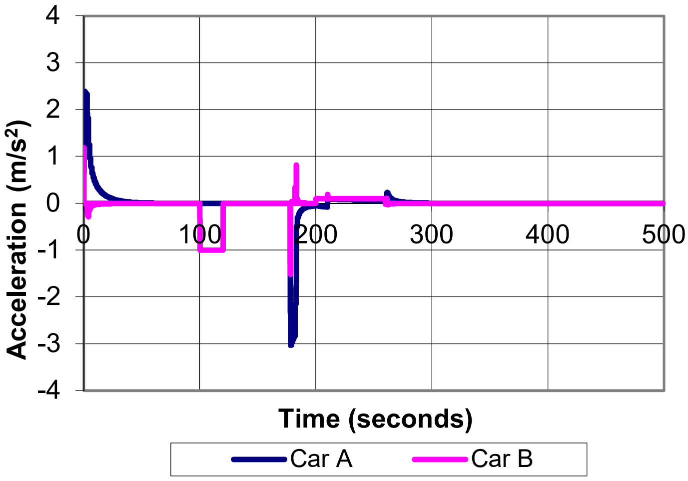
Test 3:

Time		Car A			Car B	
T	XA	VA	AA	XB	VB	AB
0s	0	10	0	1000	30	0
100s						-0,1
120s						0
200s						0,1

Table 6.3 Test 3







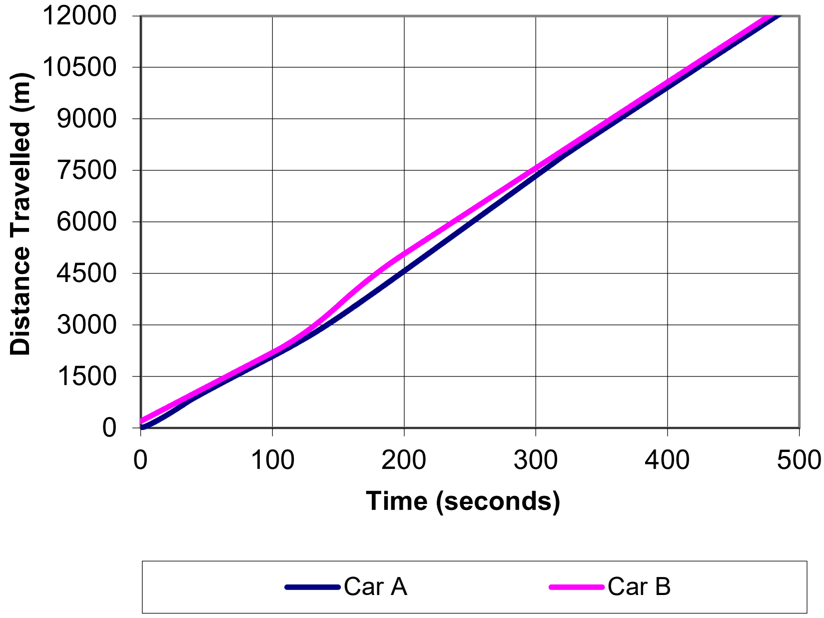
In Test 3 we have 4 different driving stages for vehicle B as it started with constant velocity of 30m/s then decelerated with -0.1m/s^2 then again kept constant velocity of 10m/s then accelerated with 0.1m/s^2, therefore vehicle A passed through 5 different stages accordingly. In the beginning vehicle A accelerated with 10m/s to reach velocity of 28m/s then kept its velocity as constant, then decelerated to 12m/s then accelerated again to 16m/s and finally kept this 12m/s as constant velocity along the rest of the test time.

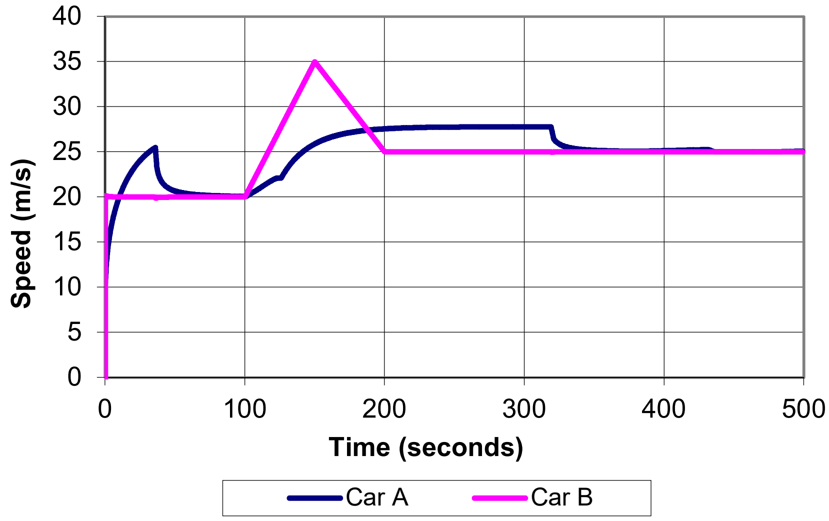
It is important to mention here that vehicle A can have its maximum allowed velocity (V_{maxA}) that the driver sets as input therefore, even if vehicle B continues accelerating with velocity more than V_{maxA}, vehicle A will not follow vehicle B anymore and will keep driving with velocity $=V_{maxA}$ as a constant velocity, test 4 will present this condition in details.

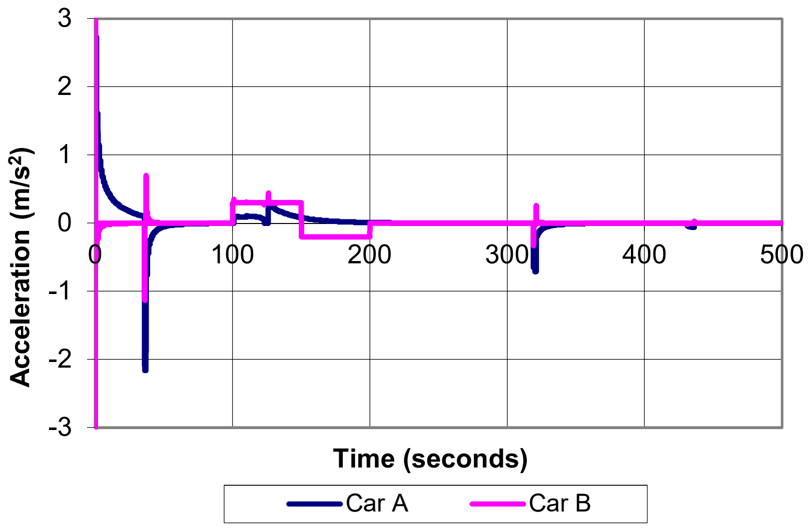
Test 4:

Time		**Car A**			**Car B**	
T	XA	VA	AA	XB	VB	AB
0s	0	10	0	200	20	0
100s						0,3
150s						-0,2
200s						0

Table 6.4 Test 4


12000
10500
9000
7500
6000
4500
3000
1500
0
Distance Travelled (m)
0
100
200
300
400
500
Time (seconds)
Car A
Car B


40
35
30
25
20
15
10
5
0
Speed (m/s)
0
100
200
300
400
500
Time (seconds)
Car A
Car B



In the Test4 we have again 4 different driving stages for vehicle Bas shown in the above diagrams. Vehicle B started with constant velocity of 20m/s then accelerated with 0.3m/s2 and suddenly decelerated with - 0.2m/s2 and finally continued with constant velocity of 25m/therefore, vehicle A also passed through 7 different driving stages accordingly. In the beginning vehicle A accelerated from V = 10m/s to V = 26m/s then realized the sudden braking of vehicle B therefore, decelerated to 20m/s then accelerated to V = 27m/s as this is the same value of V_{maxA} then decelerated to 25m/s and continued with this constant velocity along the rest of the test time.

6.2 Prototype-car Tests

The prototype-car was tested using PC commands and found performing well according to the principles of the ACC, it can move and stop on time according to the set safe distance without crashing the car in front.

Figure 6.1: Prototype-car Tests

During the tests some errors were recorded between the desired safe distances and the actual measured distances between vehicle A & B, this can due to the lower efficiency of the prototype-car braking system in the other hand the necessary response time of the other hardware parts. Below tables showing those obtained results during testing of the prototype-car with lower and higher input voltages, lower input voltage selected to be 7.50 Volt while the higher input voltage was selected to be 12 volts. Applied Input Distance refers to the estimated safe distance between Vehicle A and B, while the Real Stopping Distance refers to the measured stopping distance between vehicle A and B using the ACC system.

Test 1: Supplying input voltage of 7.50 V

Applied Input Distance	Real Stopping Distance	Error
5 cm	4 cm	1 cm
10 cm	8.7 cm	1.3 cm
15 cm	13.8 cm	1.2 cm
20 cm	18.6 cm	1.4 cm
25 cm	23.9 cm	1.1 cm

Table 6.5 Input voltage of 7.50 V

Table 6.5 shows the different between the Applied Distance and the Real (measured) Distance at lower voltage which means also lower car speed, it is clear that we always have an error as the prototype -car does not stop at the required distance.

Test 2: Supplying input voltage of 12.00 V

Applied Input Distance	Real Stopping Distance	Error
5 cm	3.8 cm	1.2 cm
10 cm	8.2 cm	1.5 cm
15 cm	12.8 cm	1.8 cm
20 cm	17.9 cm	2.1 cm
25 cm	23.1 cm	1.9 cm

Table 6.6 Input voltage of 12.00 V

Table 6.6 shows again the different between the Applied Distance and the Real (measured) Distance at higher voltage which means also higher car speed, it is clear that we also have some errors as the car does not stop at the required distance.

The above results indicated the necessity of using a safety factor while calculating the safety distance. This factor should be calculated after the car has been tested many times with different driving, atmospheric conditions and speeds. The biggest obtained value of error will be used to calculate the safety factor as following:

$$F = 1 + \frac{e_{max}}{S}$$

Where F is the safety factor, e_{max} is the maximum error and S is the travelled distance during the test with the maximum error.

Therefore, we should always multiply the calculated safe distance by F value in order set a correct safe distance.

The results can be concluded as following:

The prototype-car was tested for tracking of another front vehicle or object and found performing well.

Vehicles tracking simulations using Delphi program was recorded and presented, for real vehicles an advanced language program should be used for better performance.

Ultrasonic sensors can be used for only short-range detection however, for long rage detection, Radar or LIDAR sensors should be used.

Advantages of ACC

- Reducing the number of accidents.
- Creates more driving comforts specially for long driving conditions.
- Reducing the fuel consumption by adjusting the speeds.
- Setting of the maximum speed can help the driver to respect some streets rules.

Disadvantages of ACC

- Production cost is usually very high.
- It may reduce the driver attention and make him careless.
- A default on the system could lead to accident.
- No suitable for heavy traffic or crowded roads.
- May not work well with roads conditions

CHAPTER 7

CONCLUSION AND FUTURE WORK

Conclusion:

This thesis presented a prototype-car that can be considered as basic design of a car with ACC. ACC is an advanced version of cruise control system that includes anti-collision system in order to associate in decreasing the possibility of some road accidents by giving more driving safety and comfort.

The calculation method of the Safe Distance between two vehicles running in the same layer one after the other was explained and the final equation was driven.
Necessary equation for Acceleration and Deceleration of a vehicle tracking another in the same layer was determined.

While preparing this thesis the Author assumed that, the engine control unit and the brake control system are responsible for determining the required Forces to accelerate or decelerate the vehicle without more interfering from the ACC system.

A prototype-car with ACC was designed in order to show the system works however, in real life vehicles some higher quality components should be used for better performance, this may include radar detection sensors those capable to measure farther distances and faster Cameras that able to define the front obstacles in less time.
Delphi Program was also prepared to present some simulation tests and their results.
It is important to mention here that such system is designed to help the driver and create more driving comfort however; he should always be ready to interfere in the emergency cases.

Future Work:

This system can just control the speed of the vehicle and stop it in the emergency cases however, more studies should be carried to produce a system that has possibility to control the steering directions to overtake the other vehicles in the road and follow the navigation map in order to reach the desire place.

Moreover, the behaviors of the ACC vehicle should have more studies and improvements during the non-straight roads particularly the roundabout, up down hills as well as during the windy weather.

As explained in the simulation part, there is a possible calculation error during the deceleration if the Safe Distance is equal to the inertial distance between the two tracking vehicles therefore we advise to solve this case with different method.

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APPENDIX A

MATLAB code

```
a = imaqhwinfo;
b=Bluetooth('Robotic_car',1);
% [camera_name, camera_id, format] = get CameraInfo(a);
fopen(b);
% input the video
url='http://192.168.173.43:8080/shot.jpg?rnd=350264';
degree=0;
message=0;
direction_l1_r2=0;
direction_f1_b2=0;
flag=0;
while (1)
degree=0;
message=0;
tic
flag=0;
   c=imread(url); %%% read image from url
sprintf('%s','yes')
x=0;
y=0;
% we have to subtract the blue component
% from the grayscale image to extract the red components in the image.
   e = im subtract(c(:,:,1), rgb2gray(c));
% Convert the resulting grayscale image into a binary image.
   e = im2bw(e,0.17);
% Remove all those pixels less than 300px
   e = bw area open (e,100);
% Label all the connected components in the image.
```

```
   cc = bwlabel(e, 8);
% We get a set of properties for each labeled region.
stats = region props(cc, 'Bounding Box', 'Centroid');
Figure(1);imshow(c)
hold on
%This is a loop to bound the red objects in a rectangular box.
for object = 1:length(stats)
flag=1;
bb = stats(object).BoundingBox;
bc = stats(object).Centroid;
rectangle('Position',bb,'EdgeColor','r','LineWidth',5)
plot(bc(1),bc(2), '*')
       x= num2str(round(bc(1)));
       y= num2str(round(bc(2)));
        m=text(bc(1)+50,bc(2), strcat('X: ', x, '    Y: ', y));
      set(m, 'FontName', 'Arial', 'FontWeight', 'bold', 'FontSize', 14, 'Color', 'yellow');
   x=str2num(x);
   y=str2num(y);
   %////////////////////////////////////xxxxxxxxxxxxx
switch(x)
case num2cell(0:100)
            direction_l1_r2=1;
if(x<75)
degree=2;
else degree=1;
end
case num2cell(100:200)
            direction_l1_r2=0;
degree=0;
case num2cell(200:320)
         direction_l1_r2=2;
```

```
if(x<225)
degree=1;
else degree=2;
end
end
% ////////////////////////////////////////yyyyyyyyyyyyy
switch(y)
case num2cell(0:80)
        direction_f1_b2=1;
if(direction_l1_r2==1)
message=10;
else if(direction_l1_r2==2)
message=20;
else message=30;
end
end
message=message+degree;
fwrite(b,message);
case num2cell(80:130)
if(direction_l1_r2==1)
message=10;
else if(direction_l1_r2==2)
message=20;
else message =90;
end
end
message=message+degree;
fwrite(b,message);
case num2cell(130:240)
          direction_f1_b2=2;
if(direction_l1_r2==1)
```

```
message=60;
else if(direction_l1_r2==2)
message=50;
else message =40;
end
end
message=message+degree;
fwrite(b,message);
end
end
if(flag==0)
fwrite(b,90);
end
hold off
toc
end
```

APPENDIX B

Arduino Code

```
#include <Servo.h>
#include <SoftwareSerial.h>

Servo myservo;  // create servo object to control a servo

#define RxD 6 // This is the pin that the Bluetooth (BT_TX) will transmit to the Arduino (RxD)

#define TxD 7 // This is the pin that the Bluetooth (BT_RX) will receive from the

intpos =30;    // variable to store the servo position

constinttrigPin = 10;

constintechoPin = 12;

constint trigPin2 = 3;

constint echoPin2 = 4;

long duration;

int distance;

long duration2;

int distance2;

SoftwareSerialbluetooth(RxD,TxD);

int x;

int x1;

int x2;

intleft_max=10; // left max

intleft_min=20; // left min

intright_max=75; //right max
```

```
intright_min=50; // right min
int straight=40; // center
void setup() {
pinMode(trigPin, OUTPUT); // Sets the trigPin as an Output
pinMode(echoPin, INPUT); // Sets the echoPin as an Input
pinMode(trigPin2, OUTPUT); // Sets the trigPin as an Output
pinMode(echoPin2, INPUT); // Sets the echoPin as an Input
Serial.begin(115200);
bluetooth.begin(9600);
myservo.attach(11);  // attaches the servo on pin 11 to the servo object
pinMode(8,'Output'); // pin number 8 as digital output
pinMode(9,'Output');  // pin number 9 as digital output
pinMode(13,'Output'); // pin number 8 as digital output

myservo.write(straight); //send pulse to servo to make it at center
}
void loop()
{
  // Clears the trigPin
digitalWrite(trigPin, LOW);
delayMicroseconds(2);
// Sets the trigPin on HIGH state for 10 micro seconds
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
// Reads the echoPin, returns the sound wave travel time in microseconds
duration = pulseIn(echoPin, HIGH);
// Calculating the distance
distance= duration*0.034/2;
digitalWrite(trigPin2, LOW);
delayMicroseconds(2);
```

```
// Sets the trigPin on HIGH state for 10 micro seconds
digitalWrite(trigPin2, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin2, LOW);
// Reads the echoPin, returns the sound wave travel time in microseconds
duration2 = pulseIn(echoPin2, HIGH);
// Calculating the distance
distance2= duration2*0.034/2;
analogWrite(5,180);
Serial.flush(); // delete every thing from bluetooth
  x=-1;
if(distance<30||distance2<30)
   {
pos=straight;
myservo.write(pos);
digitalWrite(13,HIGH);
digitalWrite(9,LOW);
digitalWrite(8,LOW);
    }
if (bluetooth.available() < 1)
  {
return; // if serial empty, return to loop().
  }
  x = bluetooth.read(); //read the bluetooth signal and save it in x
x1=x/10;
x1=round(x1);
x2=x-x1*10;
if(distance<30||distance2<30)
   {
x1=9;
   }
```

```
switch(x1)
{
case 1 :
{
if(x2==2)
pos=left_max;
else if(x2==1)
pos=left_min;
myservo.write(pos); //send command to servo motor
digitalWrite(13,LOW);
digitalWrite(8,LOW);
digitalWrite(9,HIGH); //move car forward
return;
}
case 2 :
{
if(x2==2)
pos=right_max;
else if(x2==1)
pos=right_min;
myservo.write(pos);
digitalWrite(13,LOW);
digitalWrite(8,LOW);
digitalWrite(9,HIGH);
return;
}
case 3 :
{
pos=straight;
myservo.write(pos);
```

```
digitalWrite(13,LOW);
digitalWrite(8,LOW);
digitalWrite(9,HIGH);
return;
}
case 4 :
{
pos=straight;
myservo.write(pos);
digitalWrite(13,LOW);
digitalWrite(9,LOW);
digitalWrite(8,HIGH);
return;
}
case 5 :
{
if(x2==2)
pos=left_max;
else if(x2==1)
pos=left_min;
myservo.write(pos);
digitalWrite(13,LOW);
digitalWrite(9,LOW);
digitalWrite(8,HIGH);
return;
}
case 6 :
{
if(x2==2)
```

```
pos=right_max;
else if(x2==1)
pos=right_min;
myservo.write(pos);
digitalWrite(13,LOW);
digitalWrite(9,LOW);
digitalWrite(8,HIGH);
return;}
case 9 :
{
pos=straight;
myservo.write(pos);
digitalWrite(9,LOW);
digitalWrite(8,LOW);
digitalWrite(13,HIGH);
return;
}}}
```

APPENDIX C

Arduino:

Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** This pin outputs a regulated 5V from the regulator on the board. The board can be supplied with power either from the DC power jack (7 - 12V), the USB connector (5V), or the VIN pin of the board (7-12V). Supplying voltage via the 5V or 3.3V pins bypasses the regulator, and can damage your board. We don't advise it.
- **3V3.** A 3.3-volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.
- **IOREF.** This pin on the Arduino board provides the voltage reference with which the microcontroller operates. A properly configured shield can read the IOREF pin voltage and

select the appropriate power source or enable voltage translators on the outputs for working with the 5V or 3.3V.

Memory

The ATmega328 has 32 KB (with 0.5 KB used for the bootloader). It also has 2 KB of SRAM and 1 KB of EEPROM

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pin Mode(),digital Write and digital Read () functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 KOhms. In addition, some pins have specialized functions:

•**Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB to-TTL Serial chip.

•**External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attach Interrupt () function for details.

•**PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analog Write () function.

•**SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication using the SPI library.

•**MISO** (Master In Slave Out) - The Slave line for sending data to the master,

•**MOSI** (Master Out Slave In) - The Master line for sending data to the peripherals,

•**SCK** (Serial Clock) - The clock pulses which synchronize data transmission generated by the master

and one line specific for every device:

•**SS** (Slave Select) - the pin on each device that the master can use to enable and disable specific devices.

•**LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

There are a couple of other pins on the board:

•**AREF.** Reference voltage for the analog inputs. Used with analog Reference ().

•**Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

•**AREF:** This is the analog voltage reference. It can be used instead of the standard 5V reference for the top end of the analog spectrum.

•**IOREF:** This is a voltage corresponding to the i/o of that board, for example an Uno would supply 5v to this pin, but a Due would supply 3.3v

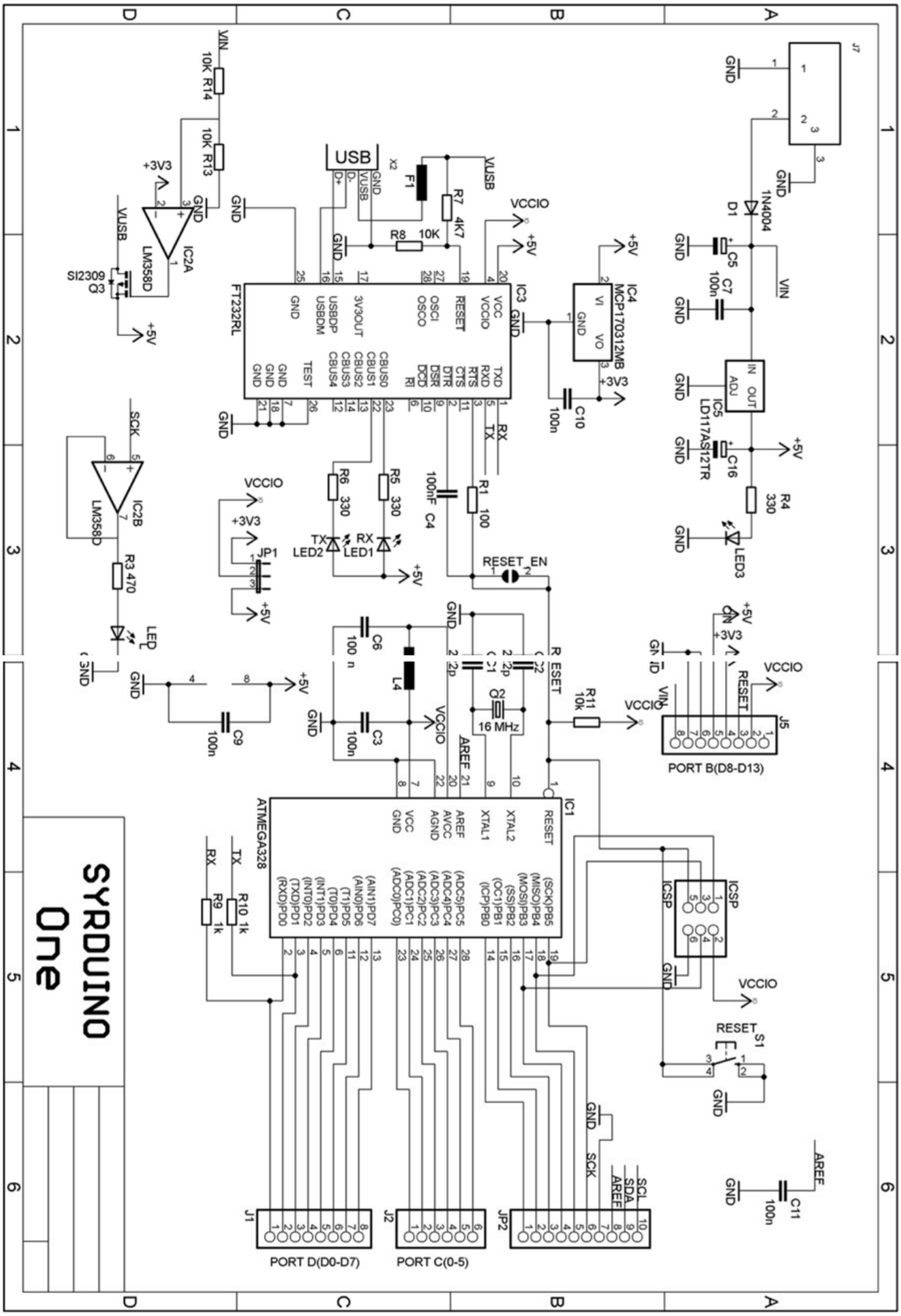
Programming

The Syrduino Uno can be programmed with the Arduino software.

The ATmega328 on the Arduino Uno comes pre-burned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol.

•**USB Over Current Protection:**

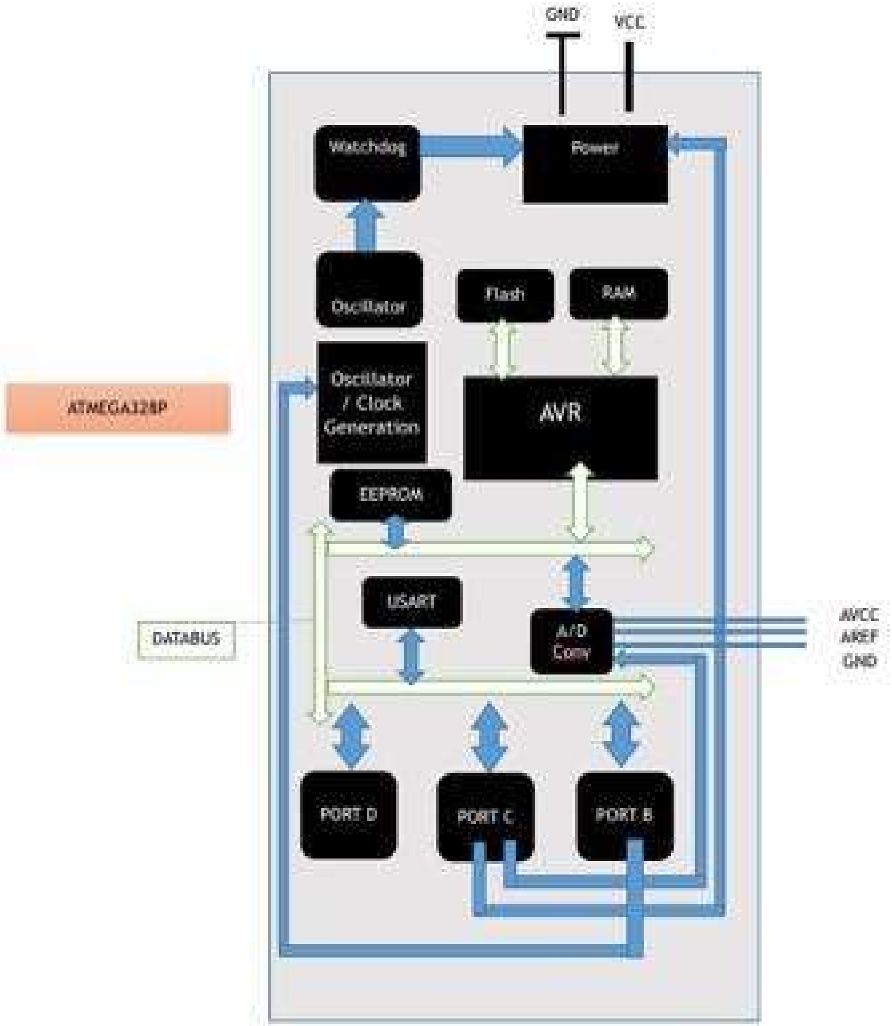
The Arduino Uno has a resettable polypus that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.


SYRDUINO
One
FT232RL
ATMEGA328
USB
LM358D
SI2309
MCP1700312MB
LD1117AS12TR
1N4004
16 MHz
RESET_EN
PORT B(D8-D13)
PORT D(D0-D7)
PORT C(0-5)
ICSP
RESET
VIN
VUSB
VCCIO
GND
+5V
+3V3

APPENDIX D

ATMEGA328P

Microcontroller ATMEGA328P block diagram



Features

• High Performance, Low Power AVR® 8-Bit Microcontroller

– Up to 20 MIPS Throughput at 20 MHz

High Endurance Non-volatile Memory Segments

–32K Bytes of In-System Self-Programmable Flash program memory (ATmega328P).

–1K Bytes EEPROM (ATmega328P).

–2K Bytes Internal SRAM (ATmega328P).

– Write/Erase Cycles: 10,000 Flash/100,000 EEPROM. Data retention: 20 years at 85°C/100 years at 25°C.

• Peripheral Features

– Two 8-bit Timer/Counters with Separate Pre- scaler and Compare Mode. – One 16-bit Timer/Counter with Separate Pre- scaler, Compare Mode, and Capture Mode.

– Real Time Counter with Separate Oscillator.

– Six PWM Channels.

– 8-channel 10-bit ADC.

– Programmable Serial USART.

– Programmable Watchdog Timer with Separate On-chip Oscillator. – On-chip Analog Comparator.

• Operating Voltage:

– 1.8 - 5.5V for ATmega328P.

• Temperature Range: – -40°C to 85°C.

• Speed Grade:

– 0 - 20 MHz @ 1.8 - 5.5V.

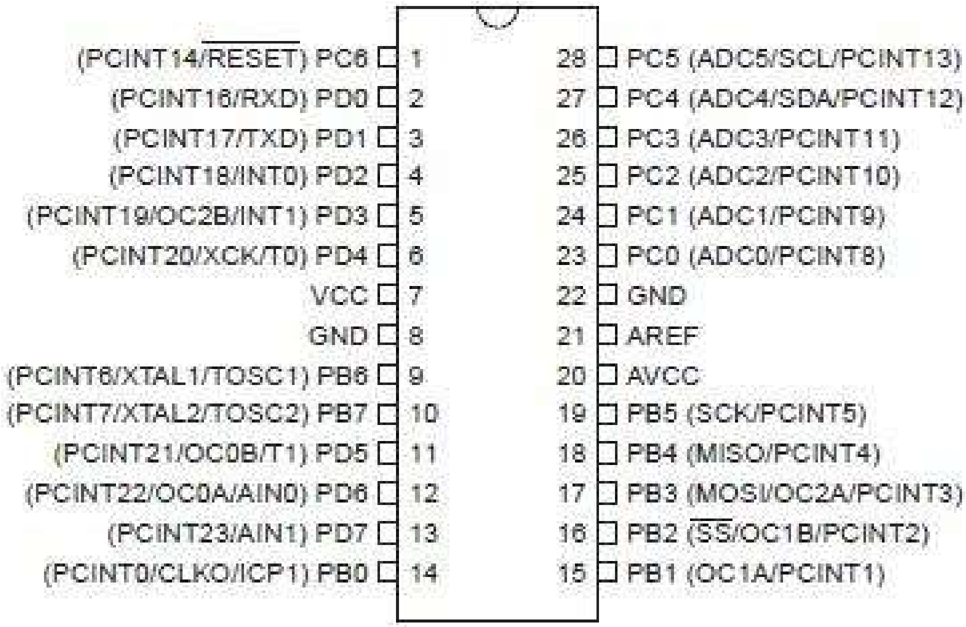
• Low Power Consumption at 1 MHz, 1.8V, 25°C for ATmega328P:

– Active Mode: 0.2 mA.

– Power-down Mode: 0.1 µA.

– Power-save Mode: 0.75 µA.

Pin Descriptions :



VCC:

Digital supply voltage.

GND: Ground.

Port B (PB7.PB0):

Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port B also serves the functions of various special features of the ATmega328P.

Port C (PC7.PC0) Port C is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit. The Port C pins are tri-stated when a reset condition becomes active, even if the clock is not running. Port C also serves the functions of various special features of the ATmega32

Port D (PD7..PD0) is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port D pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port D also serves the functions of various special features of the ATmega32

RESET:

Reset Input. A low level on this pin for longer than the minimum pulse length will generate a reset, even if the clock is not running. The minimum pulse length. Shorter pulses are not guaranteed to generate a reset.

XTAL1:

Input to the inverting Oscillator amplifier and input to the internal clock operating circuit.

XTAL2:

Output from the inverting Oscillator amplifier.

AVCC:

AVCC is the supply voltage pin for the A/D Converter. It should be externally connected to VCC, even if the ADC is not used. If the ADC is used, it should be connected to VCC through a low-pass filter.

AREF: AREF is the analog reference pin for the A/D Converter.

APPENDIX E

Delphi code

```
unit ACCunit12;
interface
uses
  Windows, Messages, SysUtils, Variants, Classes, Graphics, Controls, Forms,
  Dialogs, StdCtrls, Buttons, ExtCtrls;
type
  TForm1 = class(TForm)
    RadioGroup1: TRadioGroup;
    RadioGroup2: TRadioGroup;
    RadioButton1: TRadioButton;
    RadioButton2: TRadioButton;
    RadioButton3: TRadioButton;
    RadioButton4: TRadioButton;
    RadioButton5: TRadioButton;
    RadioButton6: TRadioButton;
    RadioButton7: TRadioButton;
    RadioButton8: TRadioButton;
    RadioButton9: TRadioButton;
    RadioButton10: TRadioButton;
    RadioButton11: TRadioButton;
    RadioButton12: TRadioButton;
    RadioButton13: TRadioButton;
    RadioButton14: TRadioButton;
    RadioButton15: TRadioButton;
    RadioButton16: TRadioButton;
    RadioButton17: TRadioButton;
    RadioButton18: TRadioButton;
    RadioButton19: TRadioButton;
```

```
RadioButton20: TRadioButton;
RadioButton21: TRadioButton;
RadioButton22: TRadioButton;
CheckBox1: TCheckBox;
GroupBox1: TGroupBox;
GroupBox2: TGroupBox;
Edit1: TEdit;
Label2: TLabel;
Label1: TLabel;
Label3: TLabel;
Label4: TLabel;
Label5: TLabel;
Label6: TLabel;
Label7: TLabel;
Label8: TLabel;
Button1: TButton;
Label9: TLabel;
Label10: TLabel;
Label11: TLabel;
Label12: TLabel;
Label13: TLabel;
Label14: TLabel;
Label15: TLabel;
procedure RadioButton1Click(Sender: TObject);
procedure RadioButton2Click(Sender: TObject);
procedure RadioButton3Click(Sender: TObject);
procedure RadioButton4Click(Sender: TObject);
procedure RadioButton5Click(Sender: TObject);
procedure RadioButton6Click(Sender: TObject);
procedure RadioButton7Click(Sender: TObject);
procedure RadioButton8Click(Sender: TObject);
```

```
    procedure RadioButton9Click(Sender: TObject);
    procedure RadioButton10Click(Sender: TObject);
    procedure RadioButton11Click(Sender: TObject);
    procedure CheckBox1Click(Sender: TObject);
    procedure Edit1Change(Sender: TObject);
    procedure Button1Click(Sender: TObject);
  private
    { Private declarations }
  public
    { Public declarations }
  end;
  var
  Form1: TForm1;
  implementation
     CONST
{*** FOR THE CAR FOLLOWING ***}
        XINITIALA=     0.0;
        VINITIALA=    20.0;
        AINITIALA=     0.0;  {ASSUME ZERO}
{*** FOR THE CAR IN FRONT ***}
        XINITIALB=   300.0;
        VINITIALB=    10.0;
        AINITIALB=     0.0;
        TIMEINCREMENT=  0.1;
        Femax=3000;
        FRICTIONCOEFF=  0.3;
        DRAGCOEFF=    0.35;     {Cd}
        AREA=         2.25;     {m2}
        AIRDENSITY=   1.20;     {kg/m3}
        ROLLINGRESISTANCE= 0.012; {Cr}
        DRIVEFRICTION= 0.15;     {Cf}
```

```
      MASS=       1000.0;     {kg}
      GRAVITY=      9.81;     {m/s2}
      VMAX=         60.0;     {m/s}
      SAFESAFE=      1.05;
    TYPE
      ATYPE=BYTE;
      BTYPE=EXTENDED;
var
  Fgas,Fbrake:extended;
  Fgastext,Vmaxtest,dummytext:string;
D1,D2,D3,DSAFE,DSAFEA,DSAFEB,DSAFEMAX,DRESPONCE,VA1,VA2,VB1,VB2,
AA,AAreal,AAZERO,AB,ABold,XA,XB,MAXLOCATION:BTYPE;
      VMAXA:BTYPE;
      XofB,VofB,AofB:BTYPE;
      TIMES:BTYPE;
      TETA,TETACALC:BTYPE;
      Fe,Fe2,THROTTLE:BTYPE;
      DUMMY1,DUMMY2:BTYPE;
      CAR:atype;
      I:INTEGER;
      keyboarddummy,bvk:atype;
      IOUT:TEXT;
      DateTime : TDateTime;
      key : char;
{**** DESCRIPTION OF THE VARIALBLES*****
    XINITAIALA    : Initial position of the driven car
    VINITAIALA    : Initial velocity of the driven car }
{$R *.dfm}
{*****************************************************************}
{*********** GAS PEDAL POSITION**************}
procedure TForm1.RadioButton1Click(Sender: TObject);
```

```
begin
Fgas:=0;
str(Fgas:5:2,Fgastext);
Label1.Caption:=Fgastext+' km/h';
end;
procedure TForm1.RadioButton2Click(Sender: TObject);
begin
Fgas:=0.1;
str(Fgas:5:2,Fgastext);
Label1.Caption:=Fgastext+' km/h';
end;
procedure TForm1.RadioButton3Click(Sender: TObject);
begin
Fgas:=0.2;
str(Fgas:5:2,Fgastext);
Label1.Caption:=Fgastext+' km/h';
end;
procedure TForm1.RadioButton4Click(Sender: TObject);
begin
Fgas:=0.3;
str(Fgas:5:2,Fgastext);
Label1.Caption:=Fgastext+' km/h';
end;
procedure TForm1.RadioButton5Click(Sender: TObject);
begin
Fgas:=0.4;
str(Fgas:5:2,Fgastext);
Label1.Caption:=Fgastext+' km/h';
end;
procedure TForm1.RadioButton6Click(Sender: TObject);
begin
```

```
Fgas:=0.5;
str(Fgas:5:2,Fgastext);
Label1.Caption:=Fgastext+' km/h';
end;
procedure TForm1.RadioButton7Click(Sender: TObject);
begin
Fgas:=0.6;
end;
procedure TForm1.RadioButton8Click(Sender: TObject);
begin
Fgas:=0.7;
str(Fgas:5:2,Fgastext);
Label1.Caption:=Fgastext+' km/h';
end;
procedure TForm1.RadioButton9Click(Sender: TObject);
begin
Fgas:=0.8;
str(Fgas:5:2,Fgastext);
Label1.Caption:=Fgastext+' km/h';
end;
procedure TForm1.RadioButton10Click(Sender: TObject);
begin
Fgas:=0.9;
str(Fgas:5:2,Fgastext);
Label1.Caption:=Fgastext+' km/h';
end;
procedure TForm1.RadioButton11Click(Sender: TObject);
begin
Fgas:=1.0;
str(Fgas:5:2,Fgastext);
Label1.Caption:=Fgastext+' km/h';
```

```
end;
{*********** GAS PEDAL POSITION***************}
{******************END**********************}
{*** ACC ON/OFF CHECKBOX}
procedure TForm1.CheckBox1Click(Sender: TObject);
begin
  if (Fgas=0) or (Fbrake=0) then   {ACC ON - SENSORS ON}
   begin
   end;
  if (Fgas<>0) or (Fbrake<>0) then {ACC OFF - SENSORS ON}
   begin
   end;
end;
{*** VMAXA SETTING}
procedure TForm1.Edit1Change(Sender: TObject);
begin

Label1.Caption:=edit1.text+' km/h';
VMAXA:=strtofloat(edit1.text)/3.6;
end;
{****************************************************************}
PROCEDURE INITIAL;
{****************************************************************}
BEGIN
          D1   :=1000;
          D2   :=1000;
          D3   :=1000;
          DSAFE:=0;
          VA1  :=VINITIALA;
          VA2  :=VINITIALA;
          VB1  :=0;
```

```
        VB2  :=VINITIALB;
        XofB :=XINITIALB;
        VofB :=VINITIALB;
        AofB :=AINITIALB;
        AAreal   :=AINITIALA;
        XA   :=XINITIALA;
        TETACALC:=0;
        CAR:=0;
        VMAXA:=100/3.6;
        keyboarddummy:=0;
        ASSIGN(IOUT,'NOCAR2.TXT');
        REWRITE(IOUT);
        WRITELN(IOUT,'       TIMES  ',
               '     XA      ',
               '     VA      ',
               '     AA      ',
               '     Fe      ',
               '     Fe2     ',
               '   TETACALC    ',
               '     XB      ',
               '     VB      ',
               '     AB      ',
               '    Dsafe     ',
               '    DsafeB     ',
               '     D3      ');
WRITELN(IOUT,TIMES:15:2,XA:15:2,VA2:15:2,AAreal:15:2,Fe:15:2,Fe2:15:2,TETAC
ALC/3.1416*180:15:4,XofB:15:2,VB2:15:2,AB:15:2,safesafe*dsafe:15:2,safesafe*dsafeb:
15:2,d3:15:2);
END;
{***************************************************************}
    PROCEDURE CARINFRONT;
```

```
{*****************************************************************}
    BEGIN
      AofB:=0.0;
      IF TIMES>=100 THEN AofB:=0.2;
      IF TIMES>=150 THEN AofB:=0;
      IF TIMES>=200 THEN AofB:=-0.2;
      IF TIMES>=250 THEN AofB:=0;
{       IF TIMES>=300 THEN AofB:=0.2;
      IF TIMES>=330 THEN AofB:=0.0;
      IF TIMES>=400 THEN AofB:=-0.62;
      IF TIMES>=430 THEN AofB:=0.0;}
XofB:=XofB+VofB*TIMEINCREMENT+AofB*TIMEINCREMENT*TIMEINCREMEN
T/2;
      VofB:=VofB+AofB*TIMEINCREMENT;
    END;
{****************CARINFRONT*************************************}
{*****************************************************************}
    PROCEDURE POWER;
{*****************************************************************}
    BEGIN
      DSAFEA:=VA2*VA2/(2*9.81*FRICTIONCOEFF)+0.75*VA2;
      DSAFEB:=VB2*VB2/(2*9.81*FRICTIONCOEFF)+0.75*VB2;
      IF DSAFEB<10 THEN DSAFEB:=10;
      DSAFEMAX:=VMAXA*VMAXA/(2*9.81*FRICTIONCOEFF)+0.75*VMAXA;
      DSAFE:=DSAFEA;
      IF DSAFE>DSAFEB THEN DSAFE:=DSAFEB;
{       IF (SAFESAFE*DSAFE/D3)>1 THEN DSAFE:=0;}
{       IF () THEN CAR:=0;}                  {CHECK}
      IF TIMES=100 THEN
      BEGIN
        DSAFE:=DSAFE;
```

```
        END;
{**************** No Car In Front ******************************}
        IF (D3>250) OR (CAR=0) THEN
        BEGIN
        CAR:=0;
 {OK}
Fe:=(MASS*(0)+MASS*GRAVITY*SIN(TETACALC)+ROLLINGRESISTANCE*MAS
S*GRAVITY
          +DRAGCOEFF*AREA*AIRDENSITY*VMAXA*VMAXA/2)/(1-
DRIVEFRICTION);
        END;
{***************************************************************}
{********* THERE IS A CAR IN FRONT*****}
        IF (D3<={SAFESAFE*DSAFEA}250) OR (CAR=1) THEN
        BEGIN
{********* VEL OF CAR IN FRONT IS LESS THEN VAMAX*****}
         IF VB2<=VMAXA THEN
         BEGIN
{************** NOT IN DANGER ZONE ********}
           IF D3>SAFESAFE*DSAFEb THEN     {chack abs}
           BEGIN
 {CHANGED}          IF (VA2<>VB2) AND (abs(AB-ABold)<0.05) THEN AA:=(AB-
(0.5*(VA2-VB2)*(VA2-VB2))/(D3-DSAFEb));
 {CHANGED}                { IF (VA2<VB2) AND (abs(AB-ABold)<0.05) THEN
AA:=(AB+(0.5*(VA2-VB2)*(VA2-VB2))/(D3-SAFESAFE*DSAFE));}
             IF (INT(10*VA2)=INT(10*VB2)){ OR (VA2<VB2)} THEN
             BEGIN
               AA:=AB;
             END;
           END;
{**************     AT LIMIT  ************}
```

```
IF (D3<SAFESAFE*DSAFEb) AND (D3>DSAFEb) THEN
BEGIN
  IF INT(10*VA2)=INT(10*VB2) THEN AA:=0;
  IF INT(10*VA2)<INT(10*VB2) THEN AA:=0;
  IF INT(10*VA2)>INT(10*VB2) THEN
    BEGIN
    IF AB>0 THEN AA:=0;
    IF AB<0 THEN AA:=AB*VA2/VB2; {?????}
    IF INT(100*AB)=0 THEN AA:=-(VA2-VB2)/1
{       AA:=(AB-(0.5*(VA2-VB2)*(VA2-VB2))/(D3-1));}
    END;
END;
{***************    IN DANGER ZONE ********}
IF  D3<DSAFEb THEN
BEGIN
  IF AB>0 THEN
  BEGIN
    IF VA2>VB2 THEN AA:=(AB-(0.5*(VA2-VB2)*(VA2-VB2))/(D3-1));
    IF INT(100*VA2)=INT(100*VB2) THEN AA:=0;
    IF VA2<VB2 THEN AA:=0;
  END;
  IF INT(100*AB)=0 THEN
  BEGIN
    IF VA2>VB2 THEN AA:=(AB-(0.5*(VA2-VB2)*(VA2-VB2))/(D3-1));
    IF INT(100*VA2)=INT(100*VB2) THEN
          AA:=(AB-(0.5*(VA2-VB2)*(VA2-VB2))/(D3-1));
    IF VA2<VB2 THEN AA:=0;
  END;
  IF AB<0 THEN
  BEGIN
    IF VA2>VB2 THEN AA:=(AB-(0.5*(VA2-VB2)*(VA2-VB2))/(D3-1));
```

```
            IF INT(100*VA2)=INT(100*VB2) THEN
                        AA:=(AB-(0.5*(VA2-VB2)*(VA2-VB2))/(D3-1));
            IF VA2<VB2 THEN AA:=(AB-(0.5*(VA2-VB2)*(VA2-VB2))/(D3-1));
          END;
        END;
          AA:=INT(AA*10000+0.5)/10000;
Fe:=(MASS*(AA)+MASS*GRAVITY*SIN(TETACALC)+ROLLINGRESISTANCE*M
ASS*GRAVITY
              +DRAGCOEFF*AREA*AIRDENSITY*VB2*VB2/2)/(1-
DRIVEFRICTION);
       END;
       IF VB2>VMAXA THEN
       BEGIN
        CAR:=0;     {MAY BE ERASED}

Fe:=(MASS*(0)+MASS*GRAVITY*SIN(TETACALC)+ROLLINGRESISTANCE*MAS
S*GRAVITY
            +DRAGCOEFF*AREA*AIRDENSITY*VMAXA*VMAXA/2)/(1-
DRIVEFRICTION);
       END;
{            IF (ABS(Fe)>Femax) AND (Fe>0) THEN Fe:=Femax;
        IF (ABS(Fe)>Femax) AND (Fe<0) THEN Fe:=-Femax;}
      END;
{****************************************************************}
    END;
{****************END OF POWER*************************************}
{****************************************************************}
    PROCEDURE ACCELERATION2;
{****************************************************************}
    BEGIN
{**************** No Car In Front ******************************}
```

```
IF {(D3>SAFESAFE*DSAFE) AND} (CAR=0) THEN
BEGIN
 IF TETACALC>=0 THEN
 BEGIN
   Fe2:=Fe*VMAXA/VA2*VMAXA/VA2*VMAXA/VA2;
{ IF VMAXA>=VA2 THEN
Fe2:=Fe*VMAXA/VA2*VMAXA/VA2*VMAXA/VA2;
   IF VMAXA<VA2 THEN
Fe2:=Fe/VMAXA*VA2/VMAXA*VA2*VMAXA/VA2;}
   IF Fe2>Femax THEN Fe2:=Femax;
   IF VA2<0.5*VMAXA THEN Fe2:=Femax;
 END;
 IF TETACALC<0 THEN
 BEGIN
   IF VMAXA>VA2 THEN
   BEGIN
   IF Fe>=0 then Fe2:=Fe*VMAXA/VA2*VMAXA/VA2*VMAXA/VA2;
   IF Fe<0 then Fe2:=Fe/VMAXA*VA2/VMAXA*VA2/VMAXA*VA2;
   END;
{Brake due to vel inc. down slope}
   IF VMAXA<=VA2 THEN
Fe2:=Fe/VMAXA*VA2/VMAXA*VA2/VMAXA*VA2;
   IF ABS(Fe2)>Femax THEN
   BEGIN
   IF Fe>=0 then Fe2:=Femax;
   IF Fe<0 then Fe2:=-Femax;
   END;
 END;
END;
{****************************************************************}
{********* THERE IS A CAR IN FRONT*****}
```

```
        IF (D3<={SAFESAFE*DSAFEA}250) OR (CAR=1) THEN
        BEGIN
{********* VEL OF CAR IN FRONT IS LESS THEN VAMAX*****}
          IF VB2<=VMAXA THEN
          BEGIN
            CAR:=1;
{************** SOLUTION FOR DIVISION BY ZERO*************}
{               IF ABS(SAFESAFE*DSAFEA-D3)<=(SAFESAFE-1)*D3 THEN
                BEGIN
                 Fe2:=Fe*(Va2/Vb2*Va2/Vb2*Va2/Vb2);
                 IF (ABS(Fe2)>Femax) AND (Fe2>0) THEN Fe2:=Femax;
                 IF (ABS(Fe2)>Femax) AND (Fe2<0) THEN Fe2:=-Femax;
                END;
{*************** NO DIVISION BY ZERO********}
{*************** NOT IN DANGER ZONE ********}
{               IF  (D3-SAFESAFE*DSAFEA)>(SAFESAFE-1)*D3 THEN
  {             IF  ABS(SAFESAFE*DSAFEA-D3)>=5 THEN     {chack abs}
 {              BEGIN
                 Fe2:=Fe2-(VB2-VA2)*(VB2-VA2)*(VB2-VA2)/VA2/VA2/VA2*Fe;
                 Fe2:=Fe*(Va2/Vb2*Va2/Vb2*Va2/Vb2);
                 IF (ABS(Fe2)>Femax) AND (Fe2>0) THEN Fe2:=Femax;
                 IF (ABS(Fe2)>Femax) AND (Fe2<0) THEN Fe2:=-Femax;
              END;
{***************     IN DANGER ZONE ********}
 {              IF  (D3-SAFESAFE*DSAFEA)<-(SAFESAFE-1)*D3 THEN
              BEGIN
                 Fe2:=Fe*(Va2/Vb2*Va2/Vb2*Va2/Vb2);
                 IF (ABS(Fe2)>Femax) AND (Fe2>0) THEN Fe2:=Femax;
                 IF (ABS(Fe2)>Femax) AND (Fe2<0) THEN Fe2:=-Femax;
              END;
{**************** Car in front a=0 or decelereting and our velocity is larger}
```

```
            IF (VA2> VB2) and (int(100*VB2)<=int(100*VB1)) THEN
            BEGIN
             if fe<0 then Fe2:=(fe+fe2)/2{Fe*(Va2/Vb2*Va2/Vb2*Va2/Vb2)};
             if fe>=0 then Fe2:=Fe*(Vb2/Va2*Vb2/Va2*Vb2/Va2);
             IF (ABS(Fe2)>Femax) AND (Fe2<0) THEN Fe2:=-Femax;
            END;
      {      IF (VA2> VB2) and (int(100*VB2)<int(100*VB1)) THEN
            BEGIN
             Fe2:=Fe*Vb2/Va2*Vb2/Va2*Vb2/Va2;
             IF (ABS(Fe2)>Femax) AND (Fe2<0) THEN Fe2:=-Femax;
            END;
{**************** Car in front accelerating and our velocity is larger}
            IF (VA2> VB2) and (int(100*VB2)> int(100*VB1)) THEN
            BEGIN
              Fe2:=Fe*Va2/Vb2*Va2/Vb2*Va2/Vb2;  {check}
            END;
{**************** Car in front a=0 or decelereting and our velocity is smaller or equal}
            IF (VA2<=VB2) and (int(100*VB2)<=int(100*VB1)) THEN
            BEGIN
              Fe2:=Fe*(VB2/VA2*VB2/VA2*VB2/VA2);
              IF (ABS(Fe2)>Femax) AND (Fe2>0) THEN Fe2:=Femax;
              IF (ABS(Fe2)>Femax) AND (Fe2<0) THEN Fe2:=-Femax;
            END;
{**************** Car in front accelerating and our velocity is smaller or equal}
            IF (VA2<=VB2) and (int(100*VB2)> int(100*VB1)) THEN
            BEGIN
              Fe2:=Fe*Va2/Vb2*Va2/Vb2*Va2/Vb2;
            END;
          END;
        END;
        Fe2:=Fe;
```

```
{******* CALCULATION OF THE SLOPE***********}
{ The real acceleration that the car will have according to Fe2}
        AAreal:=(Fe2*(1-DRIVEFRICTION)-
DRAGCOEFF*AREA*AIRDENSITY*VA2*VA2/2
          -ROLLINGRESISTANCE*MASS*GRAVITY-
MASS*GRAVITY*SIN(TETA))/MASS;
{ The acceleration that the car will have according to Fe2 with zero slope}
        AAZERO:=(Fe2*(1-DRIVEFRICTION)-
DRAGCOEFF*AREA*AIRDENSITY*VA2*VA2/2
          -ROLLINGRESISTANCE*MASS*GRAVITY-
MASS*GRAVITY*SIN(0))/MASS;
{ The slope calculation}
        DUMMY1:=(AAZERO-AAreal)/GRAVITY;
        DUMMY2:=SQRT(DUMMY1*DUMMY1+1);
        TETACALC:=ARCTAN(DUMMY1/DUMMY2);
      END;
{*****************END                                              OF
ACCELERATION2*******************************}
      PROCEDURE DISPVELACC;
{***************************************************************}
      VAR
        N:ATYPE;
{***************************************************************}
        BEGIN
         ABold:=AB;
         FOR N:=1 TO 10 DO
         BEGIN
           TIMES:=TIMES+TIMEINCREMENT;
           D1:=D2;
           D2:=D3;
{********** To simulate the input from distance sensor*********}
```

```
{********** D3: The distance between two cars}
            VA1:=VA2;
            VB1:=VB2;
            CARINFRONT;
{             XB:=XINITIALB+VINITIALB*(TIMES)+AofB*(TIMES)*(TIMES)/2;
{
XB:=XB+VB1*TIMEINCREMENT+AofB*TIMEINCREMENT*TIMEINCREMENT/2;
}

XA:=XA+VA1*TIMEINCREMENT+AAreal*TIMEINCREMENT*TIMEINCREMENT/
2;
            VA2:=VA1+AAreal*TIMEINCREMENT;
{FRom sensor}   D3:=XofB-XA;
{********** VB2: Velocity of the car in front}
            VB2:=(D3-D2)/TIMEINCREMENT+VA2;
            IF (CAR=1) AND (VB2>VMAXA) THEN CAR:=0;
{********** AA: Acceleration of the car}
{             AA:=(VA2-VA1)/TIMEINCREMENT;
{********** AB: Acceleration of the car in front}
            AB:=(VB2-VB1)/TIMEINCREMENT;
            AB:=INT(100*AB+0.5)/100;
{             MAXLOCATION:=XB-DSAFE;}
{
WRITELN(IOUT,TIMES:8:2,XA:10:2,XB:10:2,VA2:8:2,VB2:8:2,AA:8:2,AB:8:2,MAXL
OCATION:8:2);}
WRITELN(IOUT,TIMES:15:2,XA:15:2,VA2:15:2,AAreal:15:2,Fe:15:2,Fe2:15:2,TETAC
ALC/3.1416*180:15:4,XofB:15:2,VB2:15:2,AB:15:2,safesafe*dsafe:15:2,safesafe*dsafeb:
15:2,d3:15:2);
          END;
        END;
{****************END OF DISPVELACC*******************}
```

```
PROCEDURE WAITTHETIME;
VAR
  MMM:INTEGER;
BEGIN
{   FOR MMM:=1 TO 10000000 DO;
  BEGIN
  END;   }
  REPEAT
  UNTIL Time-DateTime>=0.000011574/2;
END;
{*** SIMULATION START}
procedure TForm1.Button1Click(Sender: T Object);
begin
 INITIAL;
{
str(VA2:4:1,dummytext);
Label3.Caption:=dummytext+' km/h';
str(AA:4:1,dummytext);
Label4.Caption:=dummytext+' m/s2';
str(VB2:4:1,dummytext);
Label5.Caption:=dummytext+' km/h';
str(AB:4:1,dummytext);
Label6.Caption:=dummytext+' m/s2';}
          FOR I:=1 TO 500 DO
          BEGIN
{  *******      DETERMINE THE DISTANCE BETWEEN THE TWO CARS
************}
{           DISTANCESENSOR;}
         IF ((D3>=0) AND (I>1)) THEN
         BEGIN
           DateTime := Time;
```

```
            SLOPE;
            POWER;
            ACCELERATION2;
            DISPVELACC;
{             ACCELERATION;}
            AAreal:=AAreal;
{             WAITTHETIME;  }
            str((VA2*3.6):4:1,dummytext);
            Label3.Caption:=dummytext+' km/h';
            str(AAreal:4:1,dummytext);
            Label4.Caption:=dummytext+' m/s2';
            str((VB2*3.6):4:1,dummytext);
            Label5.Caption:=dummytext+' km/h';
            str(AB:4:1,dummytext);
            Label6.Caption:=dummytext+' m/s2';
            str(D3:4:1,dummytext);
            Label7.Caption:=dummytext+' m';
            str(DSAFE:4:1,dummytext);
            Label8.Caption:=dummytext+' m';
            str(TIMES:4:1,dummytext);
            Label9.Caption:=dummytext {TimeToStr(TIMES)};
            REFRESH {Thanks to Dr. Cemal GOVSA}
          END;
           END;
end;
end.
```

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