SMARTPHONE BASED ROBOT CONTROLLER FOR TELEOPERATED SYSTEM

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ABSTRACT

Smartphone has been developed and installed with various technologies making it a suitable device that can be used for tele-operation via mobile networks as a controller. This project is developed to utilize smartphone as a robot controller with tele-operation capability. The project use Android application as well as Arduino microcontroller for mobile robot movement via DTMF tone. Android application was developed to read sensor data and publish a local server. This server was able to generate DTMF tones to feed to the Arduino microcontroller. Simulations and experiments were done to verify the performance of the smartphone Android application. The mobile robot was able to be controlled via webpage as the smartphone becomes a server. The server was able to be accessed through LAN or internet. Based on the result of simulation and experiment, this project verified the smartphone ability to control the mobile robot via tele-operation.

ABSTRAK

Telefon pintar telah dibangunkan dan dilengkapi dengan pelbagai teknologi yang menjadikan ia alat yang sesuai yang boleh digunakan untuk tele-operasi melalui rangkaian mudah alih sebagai pengawal. Projek ini dijalankan menggunakan telefon pintar sebagai pengawal robot dengan keupayaan tele-operasi. Projek menggunakan aplikasi Android serta mikropengawal Arduino untuk robot mudah alih bergerak melalui nada DTMF. Perisian Android telah dibangunkan untuk membaca sensor data dan menjadi "server". "Server" ini akan menghasilkan nada DTMF untuk dihantar kepada mikropengawal Arduino. Simulasi dan ujikaji telah dilakukan untuk mengesahkan prestasi perisian telefon pintar Android. Robot mudah alih ini mampu dikawal melalui laman web sebagai telefon pintar yang menjadi "server". "Server" ini telah boleh dicapai melalui LAN atau internet. Berdasarkan keputusan simulasi dan ujikaji, projek ini mengesahkan keupayaan telefon pintar untuk kawalan robot mudah alih melalui tele-operasi.

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LIST OF SYMBOLS AND ABBREVIATIONS

3D	-	3 Dimension
3G	-	3rd Generation
CDMA	-	Code Division Multiple Access
CSV	-	Comma Separated Value
DC	-	Direct Current
DTMF	-	Dual Tone Multi Frequency
EDGE	-	Enhanced Data Rates for GSM Evolution
GPRS	-	General Packet Radio Service
GPS	-	Global Positioning System
GSM	-	Global System for Mobile Communications
HD	-	High Definition
HSPA	-	High Speed Packet Access
HSDPA	-	High Speed Downlink Packet Access
HSUPA	-	High Speed Uplink Packet Access
HTML	-	HyperText Markup Language
HTTP	-	The Hypertext Transfer Protocol
IMU	-	Inertial Measurement Unit
IP	-	Internet Protocol
LAN	-	Local Area Network
LTE	-	Long Term Evolution
NFC	-	Near Field Communication
NMOS	-	N-channel MOSFET (Metal–Oxide–Semiconductor Field-Effect Transistor)
PC	-	Personal Computer
SAR	-	Search And Rescue
UMTS	-	Universal Mobile Telecommunications System
VLC	-	Video LAN Codec

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CHAPTER 1

INTRODUCTION

1.1 Research background

Research of tele-operation has been done since the beginning of radio age. Early principles and system that perform tele-operation were developed by Nikola Tesla in 1800s [1]. Tele-operation is crucial to navigate robot for various applications especially in environments where human involvement is limited, dangerous, or hazardous[2]. Nowadays, tele-operation has been widely used in various fields such as space robot exploration, SAR, and medical surgery. However, the methods for these types of tele-operation are specific to its usage and usually are costly. Hence, tele-operation is not easily available to common users.

However, since the introduction of mobile network, it is possible to provide a convenient and affordable tele-operation for common users. Furthermore, the rapid evolution of mobile devices has greatly improved tele-operation applications. One of the most fast evolving mobile devices is the smartphone. Smartphone has been developed and installed with various technologies. Hence, it is a suitable device that can be used for tele-operation using mobile networks as a controller. This is due to the fact that a multitude of wireless communication protocols is supported by latest smartphones. This includes cellular communications such as UMTS and LTE for long distance, and also Bluetooth and Wi-Fi for short range and high data rate connections[3].

1.2 Problem statement

In previous researches, various methods have been used for tele-operation. These methods include Infra-Red, Bluetooth, Wi-Fi, CDMA and GSM. However, some of these methods have small coverage area which limits tele-operation capability. The best methods in term of coverage are CDMA and GSM. However, CDMA is not a universal standard and unavailable in most country. Hence, GSM is the most suitable method for tele-operation. Furthermore, the advancement of GSM protocol which evolves from 2G to 4G has made it possible to transfer data in an acceptable and affordable rate. Mobile companies also have established a vast and wide range of communication network which make it easier for tele-operation coverage.

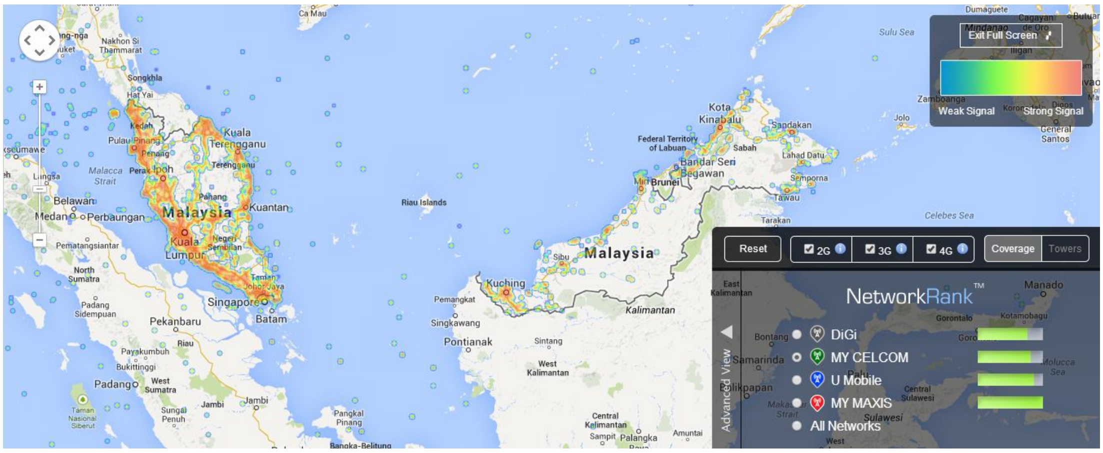


Figure 1.1: GSM coverage in Malaysia [7]

A suitable device is needed to fully utilize the advantage of GSM network for tele-operation. The device then can be used as means for data acquisition and control. A conventional controller consist of processor, memory module and I/O ports. This type of controller seldom has built in sensor modules and may need to be added according to requirement. However, a mobile device that has the capability of a controller and tele-operation can be an alternative replacement for the conventional controller. Thus, smartphone is the most suitable device that fit these requirements.

Smartphone is a small and compact device that has a functionality of a phone and a computer. It is an evolution of a simple phone that became a multifunctional device which offers various applications from web browsing to GPS navigation. Due to the rapid technology breakthrough, modern smartphone comes with various modules such as Wi-Fi, Bluetooth, accelerometer, gyro meter, proximity and GPS built in. Competitive technology development between smartphone companies such as Samsung and Nokia have made it possible for users to get a medium and high end smartphone at an affordable price. This is another factor that made smartphone a practical choice compare to conventional controller.

This project is done to utilize smartphone as a mean to control navigations with tele-operation capability. A simple robot is used to perform the controlled navigations. Smartphone will send command to the robot using DTMF module. DTMF is used as signal for telecommunication over analogue telephone lines. The frequency used is in the voice-frequency band between mobile phones and other communications devices. Since mobile network coverage is larger than LANs, we can take advantage of smartphone to control robot.[4]

1.3 Aim and objectives

The aim of this project is to utilize smartphone as a robot controller with tele-operation capability. The specific objectives of this project are as follow:

i. Design and develop a mobile robot
ii. Develop Android application software for controlling mobile robot movements via DTMF signal.
iii. Research and develop applications for tele-operation between smartphone and computer.

1.4 Scope

The scope of this project is to control the mobile robot movement by PC using tele-operation method via GSM and measuring the travel time within area of two square meters ($2m^2$).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss and analyse earlier projects that are related to this project. Discussion will be done in regards of tele-operation techniques and types of protocol being used.

2.2 Tele-operation past research

Modern smartphones incorporate various types of wireless communication protocols such as UMTS, GPRS or LTE for long distance, and also Bluetooth or Wi-Fi for short range and high data rate connections[3]. Several researches have been done by using these protocols for tele-operation.

A remote robot control system based on DTMF of mobile phone has been developed by Cho and Jeon in 2008 [4]. This is an open loop system where mobile phone is used to control the robot via CDMA modem link to DTMF receiver. The command translated by DTMF receiver is used by AVR controller to move the robot.

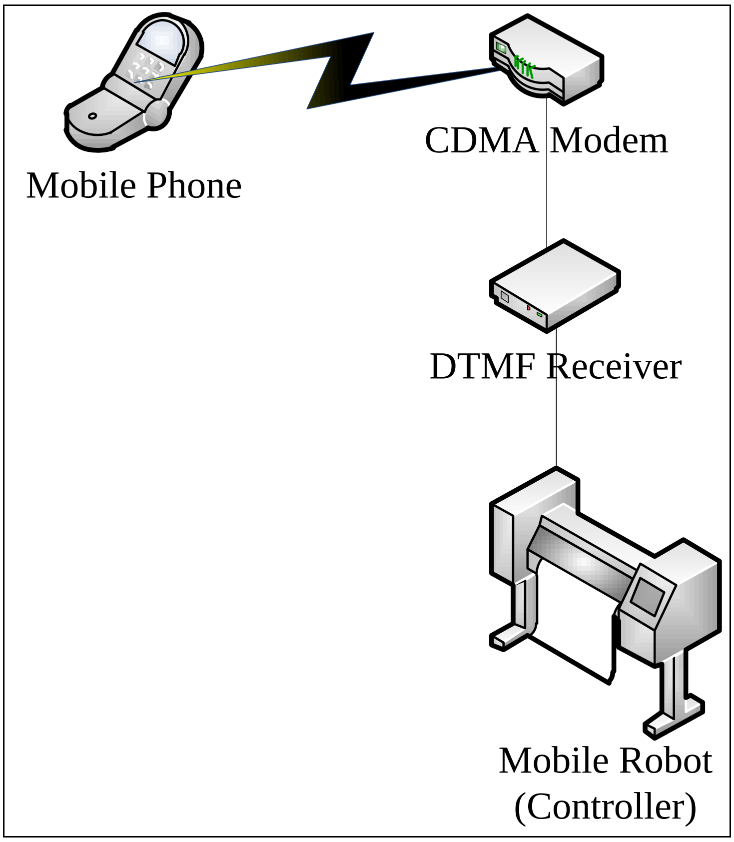


Figure 2.1: General Layout of Remote Robot Controller (redrawn from [4])

Mobile phone needed to connect direct link to the CDMA modem by call. Once connected, each button pressed on the mobile phone will generate DTMF signals and be decoded by DTMF receiver. The command is sent to the controller for robot navigation. This project used CDMA for tele-operation instead of GSM. CDMA digitize data for transfer making it unavailable in certain country including Malaysia. This project also uses open loop control system where the robot is controlled in the operator's line of sight. The lack of sensors at the robot side also limits tele-operation.

A mobile sensor data collector using Android smartphone project has been developed by Yi, Jia, and Saniie in 2012 [5]. Smartphone is used as tele-operation method to internet via Wi-Fi or Cellular communication. The focus of this project is to collect data to be stored in the server.

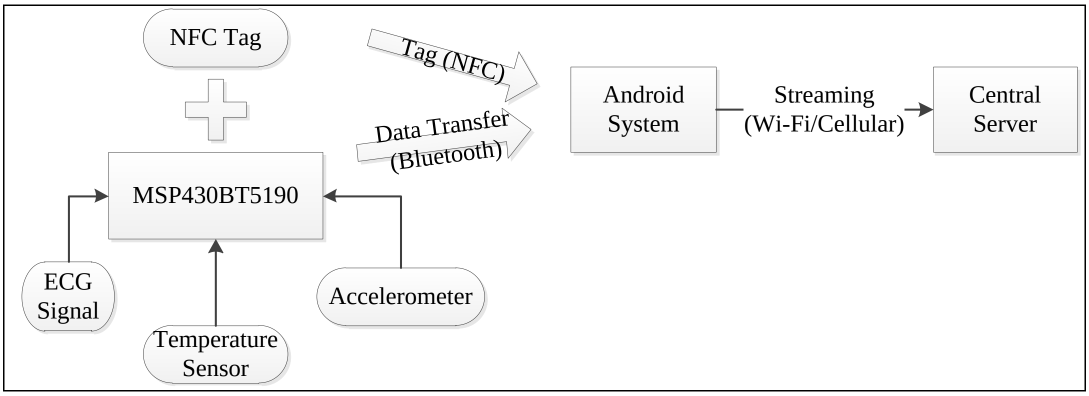


Figure 2.2: General Layout of mobile sensor data collector (redrawn from[5])

The smartphone collects data from NFC Tag and MSP430BT5190 controller. The tag can be read directly by smartphone but the controller was connected via CC2560 Bluetooth transmitter. This project is a one way communication where data is being transferred to the server. The server used UDP protocol to receive data from the internet.

A remote sensing and monitoring system running on mobile robot has been developed by Al-Aubidy, Ali, Derbas, and Al-Mutairi in 2013 [2]. Mobile phones were used as means of tele-operation using GPRS protocols. The robot sends data (images) in real time to a PC at base station.

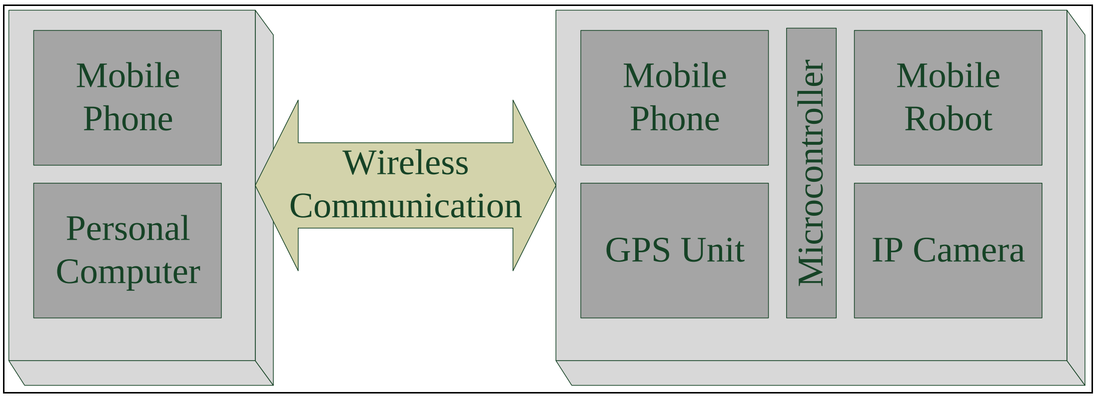


Figure 2.3: General Layout of Remote Sensing and Monitoring System (redrawn from[2])

At the base station, mobile phone is connected to the PC via Arduino UNO. A DTMF decoder and encoder are connected between Arduino and mobile phone to translate DTMF signals. On the robot side, mobile phone and GPS unit is connected to microcontroller which acted as the 'brain' of the robot. The robot uses GPS and ultrasonic sensor for local navigation while IP Camera is used in tele-operation by sending images over the internet. The base station has capability to send command to the robot for additional images from IP camera with robot repositioning option. This project used GPRS for tele-operation instead of HSDPA which has a faster data rates. It also used mobile phone only for data transfer due to lack of sensor modules availability. Hence, GPS module needs to be added making programming microcontroller more complex.

A smartphone-based 3D real-time vision system for tele-operation has been developed by Servetti and Masala in 2013 [6]. This project focuses on 3D vision and uses video data to be streamed via Wi-Fi router to a 3D workstation PC.

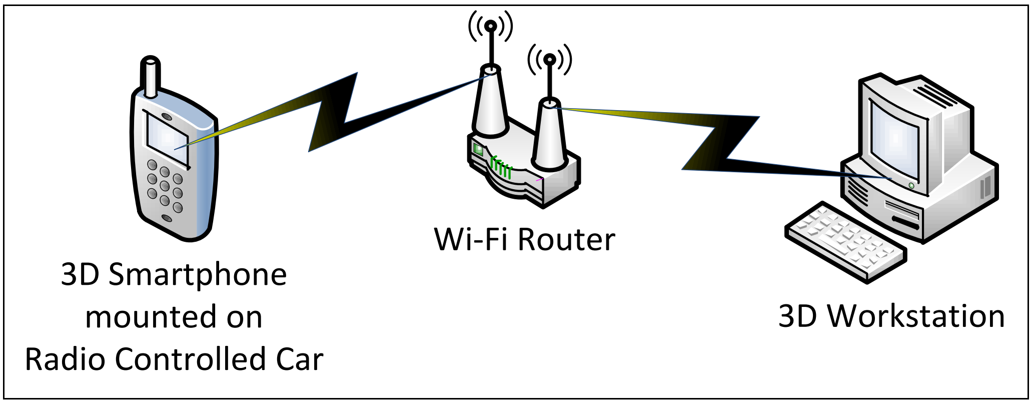


Figure 2.4: General Layout of 3D Real-Time Vision System (redrawn from[6])

3D smartphone is used to capture video and stream it directly to 3D Workstation. The smartphone is mounted on a radio controlled car which has a different set of system. This system operates using Wi-Fi as tele-operation method while the navigation is controlled by another set of system. This one way communication only focuses on streaming stereoscopic video through Wi-Fi to a workstation. The radio controlled car is not controlled by the workstation.

2.3 Conclusion

The projects discussed in this chapter show different types of tele-operation protocols. The operation of each project has also been analysed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss methods that will be used during project development. The discussion will be based on general design method which has been shown in a simple flowchart.

3.2 General design method

Development of this project is divided into 3 phase namely mobile robot construction and programming, Android programming as well as integration between smartphone and mobile robot. Mobile robot construction and programming in phase 1 can be done separately with Android programming in phase 2. The integration will take place when in phase 3 where all DTMF and tele-operation functionality will be included.

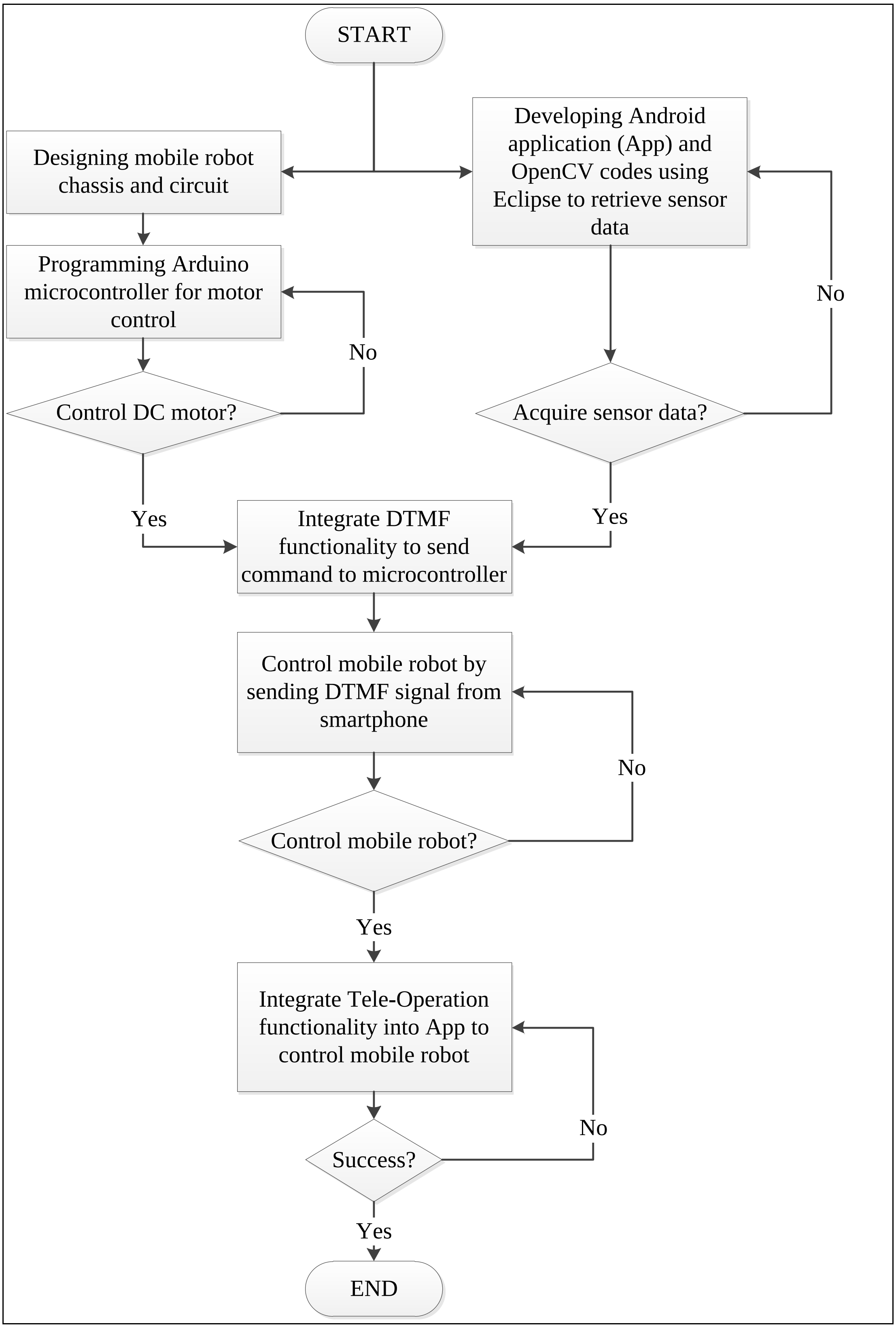


Figure 3.1: General Design Flow

3.3 Mobile robot construction and programming

Mobile robot is constructed to show navigation process that based on sensors data of the smartphone. The robot will be built using two DC geared motors (SPG30E-30K) with encoder, 10A NMOS H-Bridge motor driver (MDD10A), Arduino Uno microcontroller, and DTMF module (MT8870).

(a) (b) (c)

Figure 3.2: (a) DC Motor (b) Motor Driver (c) Controller

DC type motor is selected due to its convenience control, clean, quiet and the most popular type in mobile robot design. . The model is formed by quadrature Hall Effect encoder board which is designed to fit on the rear shaft of the DC motor as shown in the previous figure. Two Hall Effect sensors are placed 90° apart to sense and produce two outputs signal named A and B which is; 90° out of phase and allowing the direction of rotation to be determined. For further understanding, the tables show the state diagram while the figure shows the waveform signal that will be produced by the encoder; based on the rotational movement of the DC motor.

Table 3.1: State diagram for SPG30E-30K model.

a) Clockwise Rotation

PHASE	Signal A	Signal B
1	0	0
2	0	1
3	1	1
4	1	0

b) Counter Clockwise Rotation

PHASE	Signal A	Signal B
1	1	0
2	1	1
3	0	1
4	0	0

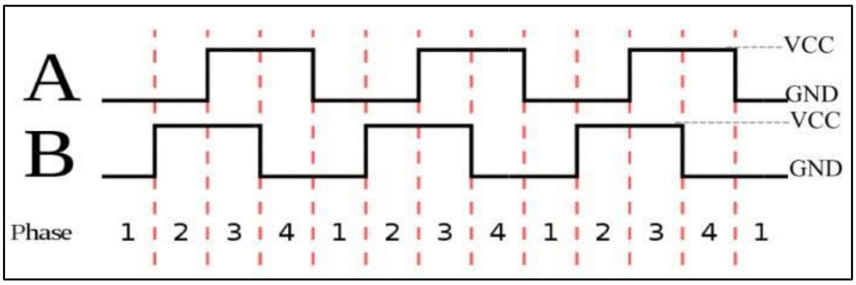


Figure 3.3: The waveform signals.

This encoder provides three counts per revolution of the rear shaft. To make it simple, the following table specifies the quadrature Hall Effect encoder for SPG30E-30K:

Table 3.2: The quadrature Hall Effect encoder attributes.

No.	Attribute
1	Operate at the range of 4.5V to 5.5V.
2	Two digital outputs.
3	Resolution: 3 pulses per rear shaft revolution; single channel output
4	90 counts per main shaft revolution for 1:30 geared motor.

For interfacing, the fully NMOS H-bridge dual channel 10A motor driver is needed to drive both DC motors for forward and backward movements. The motor driver MDD10A module is designed to drive two DC motor with high current up to 10A continuously without the heat sink since it has been integrated with fully NMOS H-bridge. The characteristics of MDD10A is shown in the following table.

Table 3.3: The MDD10A motor driver characteristics

No.	Characteristic
1	Bi-directional control for two brushed DC motor.
2	Voltage ranges from 5V to 25V.
3	Maximum current up to 10A continuous and 30A peak (10s) for each channel.
4	Speed control PWM frequency up to 25 KHz.

Smartphone will be mounted on the robot body to utilize the built in sensors (GPS, IMU and camera) and connected to the controller via MT8870 DTFM decoder module. Arduino UNO is will translate 4-bit data from DTMF decoder module to control the DC motors. Programming codes will be done to the controller to navigate robot to move forward, reverse, turn and stop.

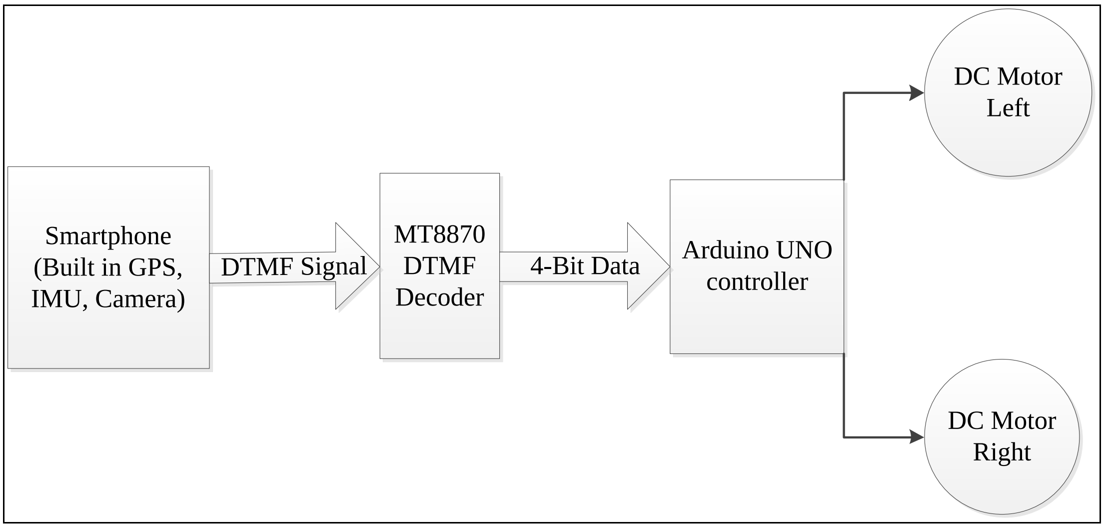


Figure 3.4: General Layout Design of Mobile Robot

3.4 Smartphone sensors data retrieve

Using Android Developer Tools by Java Eclipse, an application will be developed to retrieve data from smartphone sensors. Sensors that will be used are GPS, IMU and camera. IMU sensors needed by this project are accelerometer, compass and gyroscope. These sensors will be used to retrieve data of rotational movements.

A gyroscope allows a smartphone to measure and maintain orientation. Gyroscope sensors can monitor and control device orientation, positions, direction, angular motion and rotation. Gyroscope in smartphones helps to determine the position and orientation of the phone. On the other hand, an accelerometer measures acceleration as well as tilt, tilt angle, incline, rotation, vibration and collision. An accelerometer can automatically change the device's screen orientation vertically or horizontally. In an environment free of magnetic interference, the compass or magnetic sensor measures Earth’s magnetic field. It can be used to determine the 3-dimensional orientation in which the phone is being held. Hence, it is clear that these sensors can be used to determine orientation of the smartphone. However, each of them has their own weakness alone. The use of all these sensors together will complement each other’s’ functions.

The smartphone camera will be used to detect translational or linear movements by integrating OpenCV functions into Eclipse coding. GPS will be used during tele-operation to retrieve latitude and longitude data of the smartphone.

A suitable smartphone is needed to be used in this project. Several smartphone have been surveyed to check that these smartphone met the requirements of their network capability, audio jack (for DTMF module connection), sensors and camera.

Based on the market, there are many smartphone that met the requirements mentioned before. The development of this project will be using Samsung Galaxy Note 2 because of availability. The finished application will also be tested on one of the other affordable cost listed in the table. As mentioned earlier, listed devices were chosen because they met the requirements needed for this project. Network capability of each listed device has met GSM 900 or GSM 1800 or UMTS (HSDPA) 2100. This requirement will be discussed further afterwards in Tele-operation section. All of the devices also have audio jack for connecting to DTMF module to send the command signal for the motor. Camera and sensors for each of the listed device matched with the requirements.

Table 3.4: Smartphone comparison

			
Phone Model	Samsung Galaxy Note II	Huawei Honor 3C	Samsung Galaxy Grand Quattro
Price (RM)	1409 - 1489	499 - 514	868-898
Network Technology	GSM 850 / 900 / 1800 / 1900	GSM 900 / 1800 / 1900	GSM 850 / 900 / 1800 / 1900
	HSDPA 850 / 900 / 1900 / 2100	HSDPA	HSDPA 850 / 1900 / 2100
	LTE 700 MHz Class 17 / 2100		
CPU	Quad-core 1.6 GHz Cortex-A9	Quad-core 1.3 GHz	Quad-core 1.2 GHz Cortex-A5
RAM	2 GB	2 GB	1 GB
GPU	Mali-400MP	Mali-400MP	Adreno 203
Platform / OS	Android OS v4.1.1,upgradeable 4.1.2 (Jelly Bean)	Android OS, v4.2.2 (Jelly Bean)	Android OS v4.1.2 (Jelly Bean)
3.5mm Audio Jack	Yes	Yes	Yes
HSDPA	HSDPA, 42 Mbps; HSUPA, 5.76 Mbps; LTE, Cat3, 50 Mbps UL, 100 Mbps DL	HSDPA, HSUPA	HSDPA, 21 Mbps; HSUPA, 5.76 Mbps
WLAN	Wi-Fi 802.11 a/b/g/n, dual-band, DLNA, Wi-Fi Direct, Wi-Fi hotspot	Yes	Yes
EDGE	Yes	Yes	Yes

Table 3.1 (continued)

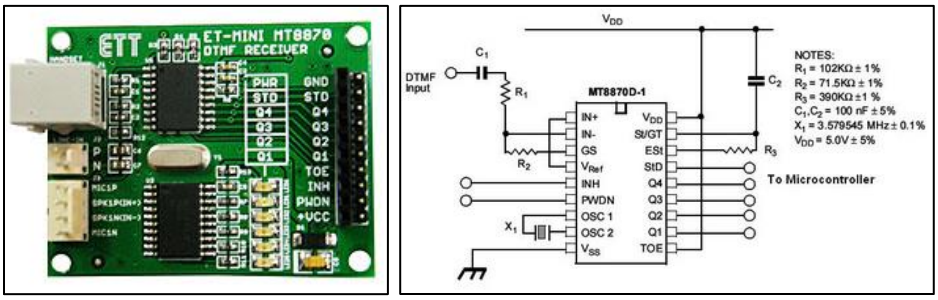
GPRS	Yes	Yes	Yes
WiFi Hotspot	Yes	Yes	Yes
GPS	Yes	Yes	Yes
Bluetooth	Yes, v4.0 with A2DP, LE, EDR	Yes, v4.0 with A2DP	Yes, v4.0 with A2DP, LE, EDR
Sensor	Accelerometer, Barometer, Compass, Gyro, Proximity	Accelerometer, Compass, Gyro, Proximity	Accelerometer, Compass, Gyro, Proximity
Type / Capacity	8 Megapixel	8 Megapixel	5 Megapixel
Max. Resolution	3264x2448	3264x2448	2592x1944
Flash	Yes	Yes	Yes

The application will be coded and compiled using Android Developer Tools (ADT) by Java Eclipse. This software is chosen because it is open-source, has multiplatform capability and can be integrated with OpenCV. This software also has a vast library for hardware manipulation such as sensors, camera and touchscreen. ADT that will be used in this project is version v22.3.0-887826. The software can be downloaded free at http://developer.android.com/sdk/index.html. The site also provides steps of installing and setting up the developer environment. Since this software uses Java programming language, it needs Java Development Kit (JDK) to be installed and configured beforehand. This JDK is also free to be downloaded at http://www.oracle.com/technetwork/java/javase/downloads/index.html.

Figure 3.5: Android Developer Tools by Java Eclipse

3.5 DTMF control using smartphone

Smartphone will send command using DTMF signal to Arduino UNO controller. The signal is translated to digital signal by MT8870 DTMF decoder module. The module is connected to smartphone via audio jack. The module is used to decode the mobile DTMF tone signal received from the smartphone into 4-bit digital signal. The decoder is operated with a 3.58 MHz crystal along with capacitor to filter the noise.



(a) (b)

Figure 3.6: (a) DTMF decoder module; (b) Schematic diagram for MT8870

DTMF signals that will be used are of dial buttons 0 to 9 including button # and *. Based on the datasheet of the module, the command from smartphone has been planned and laid out. These commands will be sent to Arduino UNO to control motors.

Table 3.5: MT8870 DTMF signal decode

Dial	Command	Q4	Q3	Q2	Q1
1	Turn slightly left forward	0	0	0	1
2	Forward	0	0	1	0
3	Turn slightly right forward	0	0	1	1
4	Turn Left	0	1	0	0
5	Stop	0	1	0	1
6	Turn Right	0	1	1	0
7	Turn slightly left reverse	0	1	1	1
8	Reverse	1	0	0	0
9	Turn slightly right reverse	1	0	0	1

3.6 Tele-operation

Tele-operation is used to send smartphone sensors data to internet. This is another advantage of using smartphone since it has also internet connection capability. Tele-operation method that will be used is GSM/UMTS (3G or 4G). GSM/UMTS is chosen due to its availability, acceptable data transfer speed and coverage. However, transfer rates will differ based on area of coverage. Mobile network companies in Malaysia provide different sets of network services. This also affects the data transfer rates of either upload or download.

Table 3.6: Comparison of mobile network service in Malaysia

Mobile Network	MAXIS	CELCOM	DiGi	U MOBILE
Frequency Band	GSM 900 / GSM 1800 / UMTS 2100	GSM 900 / GSM 1800 / UMTS 2100	GSM 1800 / UMTS 2100	UMTS 2100
2G Download Speed	1.7 Mb/s	1 Mb/s	0.8 Mb/s	0.9 Mb/s
3G Download Speed	3.1 Mb/s	2 Mb/s	1.9 Mb/s	3.2 Mb/s
4G Download Speed	12.8 Mb/s	14.6 Mb/s	18.2 Mb/s	19.4 Mb/s
2G Upload Speed	1.5 Mb/s	0.9 Mb/s	0.7 Mb/s	0.7 Mb/s
3G Upload Speed	1.4 Mb/s	1.2 Mb/s	1.7 Mb/s	1.5 Mb/s
4G Upload Speed	7.1 Mb/s	15 Mb/s	7.4 Mb/s	7.5 Mb/s

Basically, mobile technology is divided into two major protocols: GSM and CDMA. A simple explanation on the difference between these two is GSM divides the frequency bands into multiple channels so that more than one user can place a call through a tower at the same time while CDMA networks layer digitized calls over one another, and unpack them on the back end with sequence codes. Since Malaysia doesn't apply CDMA, discussion will only be made on GSM. This project will apply the use of GSM/UMTS. UMTS is the evolution of GSM with 3G capability.

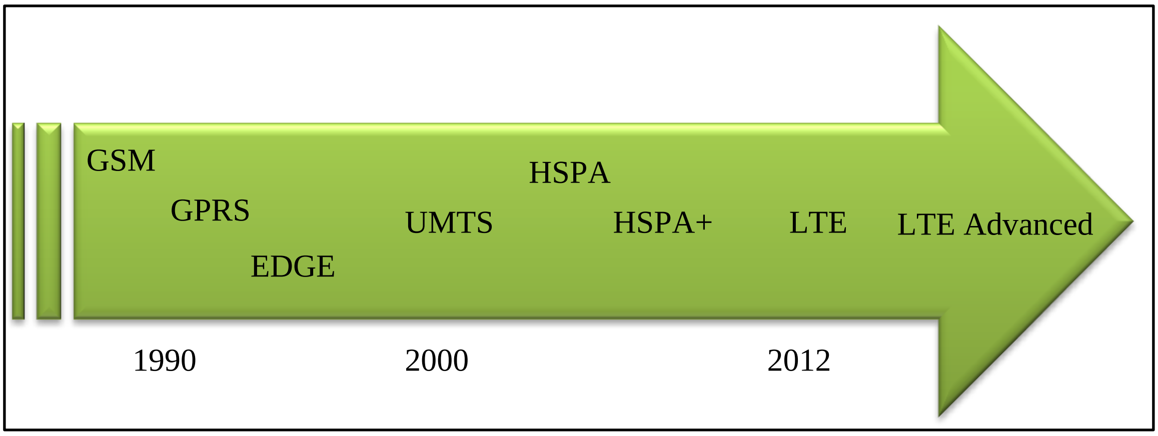


Figure 3.7: GSM family technology evolution

The data from the smartphone mounted on the robot will then be sent to a PC via GSM protocols using internet connection. The smartphone becomes a HTTP server capable of generating DTMF signals.

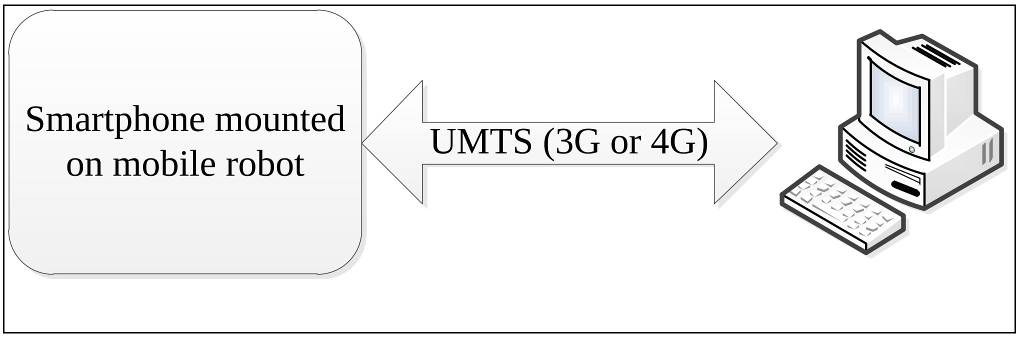


Figure 3.8: Tele-operation method

The PC also will have the capability to send command to relocate the robot's position. When the smartphone get the command from PC, it will send command to Arduino UNO to move the motor to achieve the desired point.

3.7 Conclusion

Planning of procedure and method has been discussed in this chapter. The project will be developed in a sequential manner to make test and troubleshooting procedure easier.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

This chapter will discuss the results of the project. Analysis and discussion will be made on results based on movement control, sensor data logging and network performance with or without the robot.

4.2 Mobile robot

All mechanical parts have been assembled and the programming of Arduino UNO controller has been finalized. The code consist of controlling left and right motor based on signals from the DTMF module.

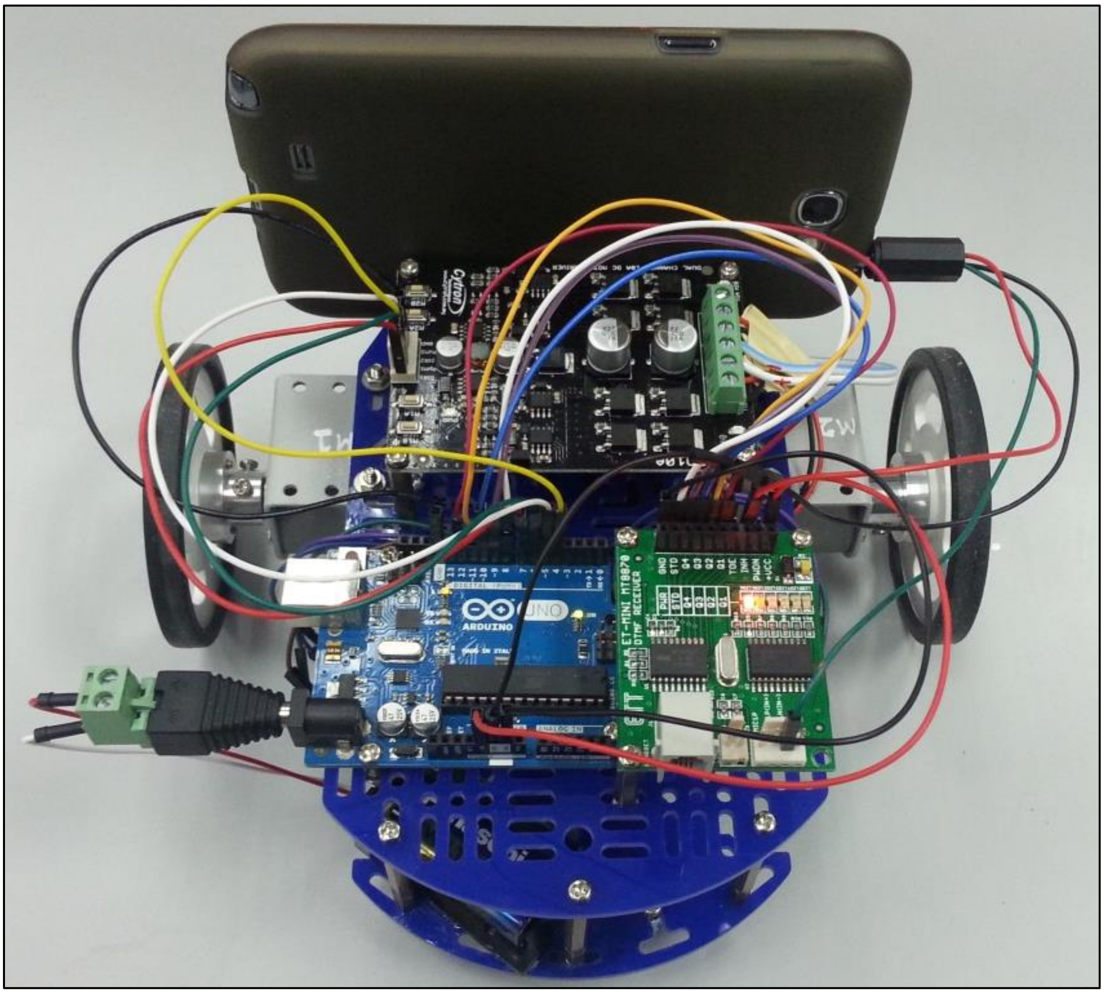
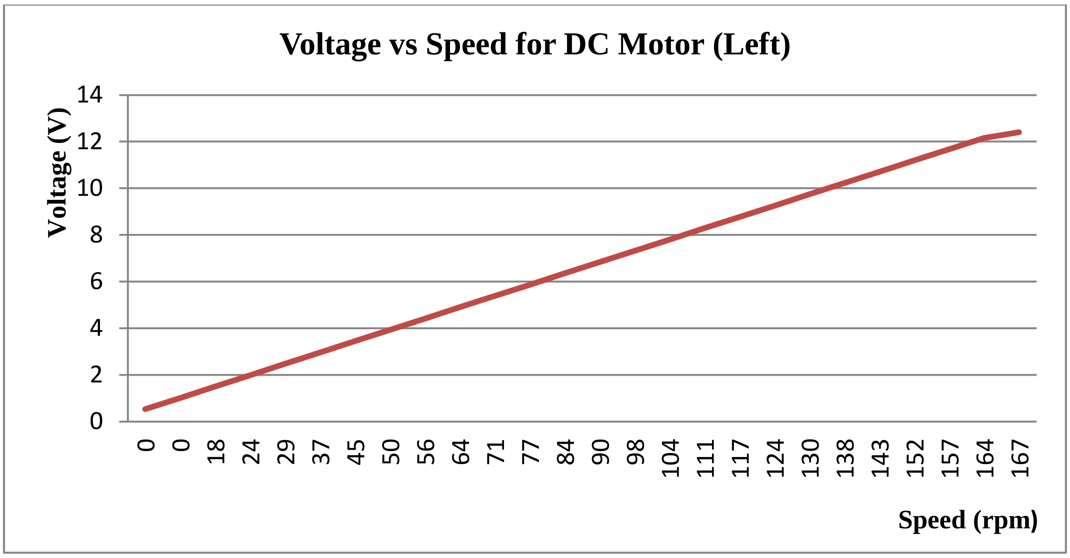
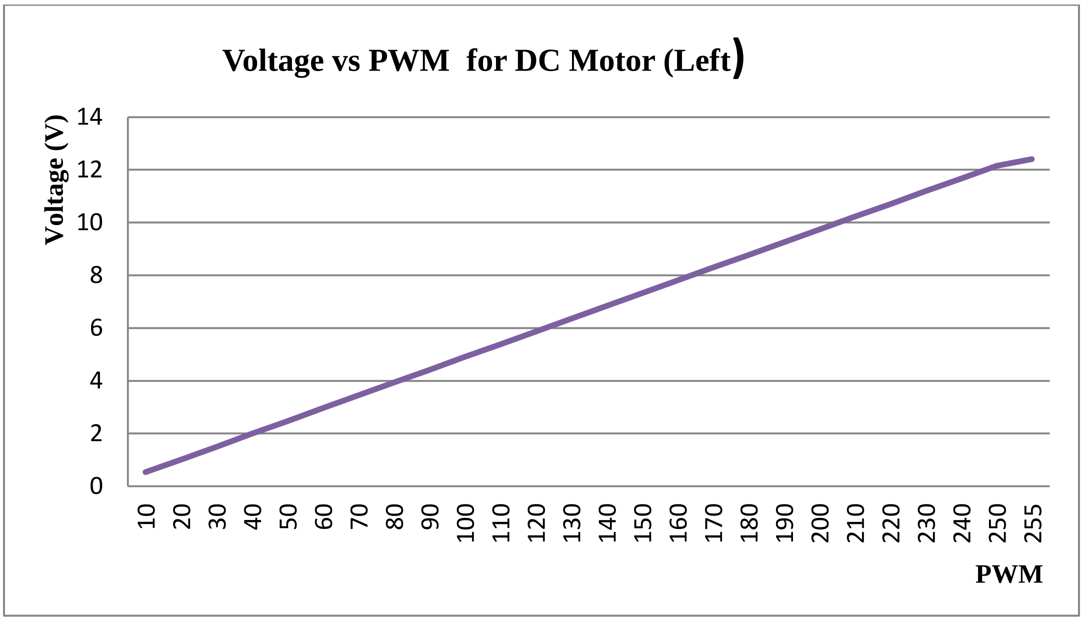


Figure 4.1: Assembled mobile robot

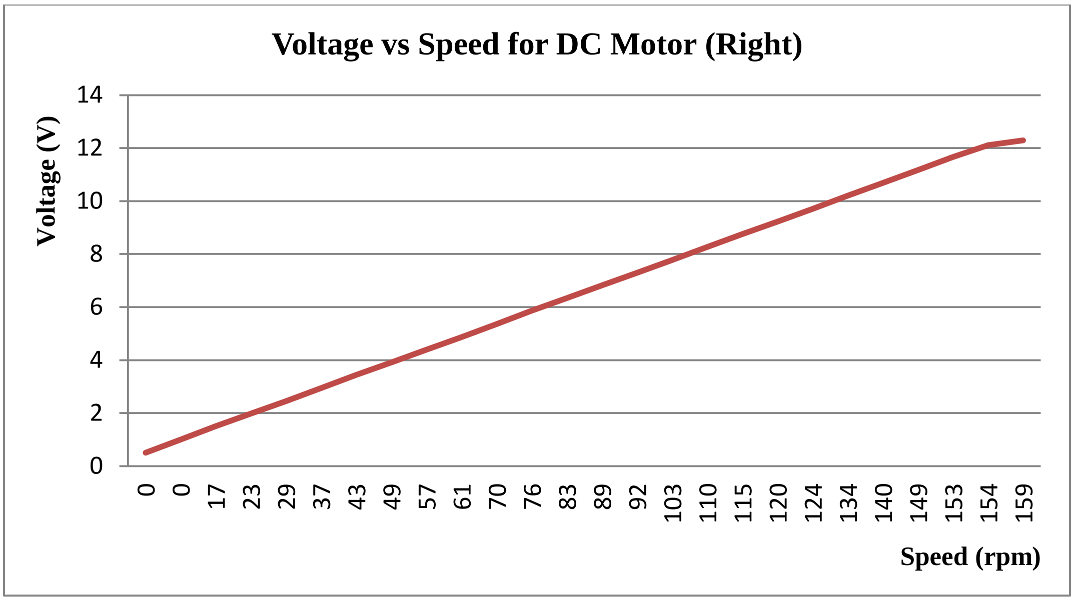
The mobile robot has been tested its movement before the smartphone is connected. This is to verify the movement based on Arduino UNO control. An experiment to test the motor rotation of mobile robot has been done. Using a tachometer, the rotational speed of the motor is measured. The measurement is then compared to the desired speed set in the Arduino UNO codes. Voltage supplied at each set point is also measured.


Voltage vs Speed for DC Motor (Left)
Voltage (V)
14
12
10
8
6
4
2
0
0 0 18 24 29 37 45 50 56 64 71 77 84 90 98 104 111 117 124 130 138 143 152 157 164 167
Speed (rpm)

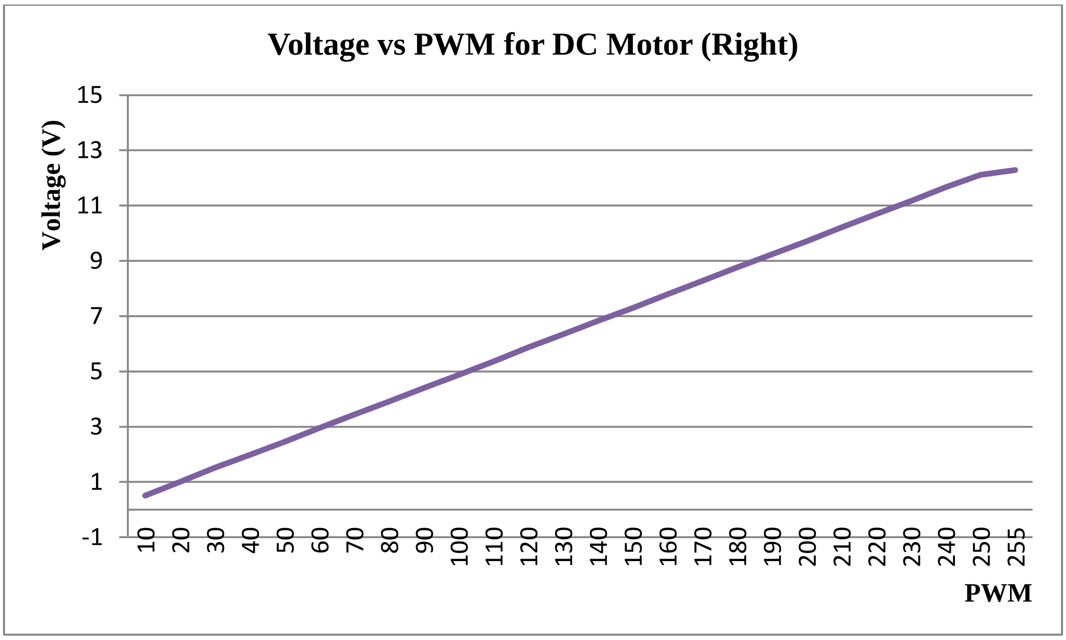
(a)


Voltage vs PWM for DC Motor (Left)
Voltage (V)
14
12
10
8
6
4
2
0
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 255
PWM

(b)



(c)



(d)

Figure 4.2: (a)(b)(c)(d) PWM Result for Left and Right Motor

The experiment shows that PWM and speed for each motor are proportional with voltage supplied to the motors. Hence it can be said that the motor is calibrated and will turn according to PWM signal. However, upon testing a straight line movement, the robot seems to stray away to the left side. This is due to several factor including the robot build, uneven surface and the robot weight balancing. It is planned that the smartphone sensor will counter this effect by continuously send command to steer the robot through a straight path. However, that project will be done by others and will not discussed here.

4.3 Smartphone sensor application

An application has been done using Android Developer Tool by Java Eclipse to read smartphone sensors. The smartphone used for this has the following details:

i. Make: Samsung Galaxy Note 2

ii. Model Number: GT-N7100

iii. Android Version: 4.4.2 (upgraded to Kit-Kat)

The application acquires data from chosen sensors and shows them in text form. The sensor chosen are accelerometer, gyrometer and magnetometer. The data is logged and changed according to movement of the smartphone.

```
/**
 * Begin logging data to an external .csv file.
 */
private void startDataLog()
{
    if (logData == false)
    {
        CharSequence text = "Logging Data";
        int duration = Toast.LENGTH_SHORT;

        Toast toast = Toast.makeText(this, text, duration);
        toast.show();

        String headers = "Generation" + ",";

        headers += "Timestamp" + ",";

        headers += this.plotAccelXAxisTitle + ",";

        headers += this.plotAccelYAxisTitle + ",";

        headers += this.plotAccelZAxisTitle + ",";
```

(a)

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