SMARTPHONE-BASED ROBOT CONTROL FOR LOCALISATION

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ABSTRACT

This project developed to use smartphone as a robot controller since it’s more powerful and equipped with several sensors that are useful for robots. The project uses Android application as well as Arduino microcontroller to locate and control the robot via DTMF tone from distance. Magnetometer and accelerometer sensor is used as input to trigger mobile robot movement for localisation purpose. The input sensor is designed to generate DTMF tone based on North Pole direction and force the robot to move only one direction referenced by North Pole. Several analyses have been done such as network provider analysis, robot operator analysis, sensor analysis as well as robot localisation analysis. The mobile robot was able to be controlled via developed Android application and all analyses regarding to robot performance is taken for future development purpose.

ABSTRAK

Projek ini dibangunkan dengan menjadikan telefon pintar sebagai pengawal robot kerana prestasinya yang berkuasa serta dilengkapi dengan pelbagai sensor yang berguna untuk pembangunan robot. Projek ini juga menggunakan aplikasi Android bersama-sama mikropengawal untuk mengesan dan mengawal robot melalui isyarat dwi-nada pelbagai frekuensi (DTMF) dari jarak jauh. Sensor magnetik dan sensor pecutan digunakan sebagai masukan untuk mencetuskan pergerakan robot mudah alih bagi tujuan penyetempatan. Sensor ini direka supaya dapat menjana nada DTMF berdasarkan arah Kutub Utara dan memaksa robot untuk bergerak hanya pada satu arah pada paksi Kutub Utara. Beberapa analisis telah dilakukan seperti analisis pembekal rangkaian, analisis pengendali robot, analisis sensor serta analisis robot untuk penyetempatan. Robot mudah alih ini akhirnya dapat dikawal melalui aplikasi Android yang dibangunkan dan semua analisis mengenai prestasi robot diambil dan dikaji bagi tujuan penambahbaikan pada masa depan.

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LIST OF ABBREVIATIONS

3D	-	3 Dimension
ARIA	-	Advanced Robot Interface for Applications
DC	-	Direct Current
DTMF	-	Dual Tone Multi Frequency
EDGE	-	Enhanced Data Rates for GSM Evolution
EKF	-	Extended Kalman Filtering
FLC	-	Fuzzy Logic Controller
GPRS	-	General Packet Radio Service
GPS	-	Global Positioning System
GUI	-	Graphical User Interface
HSPA	-	High Speed Packet Access
HSDPA	-	High Speed Downlink Packet Access
IMU	-	Inertial Measurement Unit
IO	-	Input and Output
NMOS	-	N-channel MOSFET (Metal–Oxide–Semiconductor Field-Effect Transistor)
PC	-	Personal Computer
PWM	-	Pulse Width Modulator
RTMU	-	Robot Tele-operation Maemo User Interface
SLAM	-	Simultaneous Localization and Mapping
WLAN	-	Wireless Local Area Network

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CHAPTER 1

INTRODUCTION

1.1 Background

Smartphone has become one of the most popular electronic devices in recent years. Due to its popularity, many engineers, academicians, or researchers interested to utilize all the advantages of smartphones in their researches. Furthermore, current smartphones have a variety of sophisticated built-in sensors that can be explored to build robot[1]; in specific as controller for the robot. Controller is the main part especially for mobile robots. It is act like a “brain” for the robot [1]. There are several approaches to develop controller interface and it is depends on the cost or requirements.

Basically, the common approach to design a robot is by using microcontroller. This approach suit for educational purpose since it is low cost and easy to construct. Sensors and actuators (SAs) will be connected directly to the microcontroller such as the Microchip PIC or Atmel (Arduinos) and the program’s architectures then wrote by using programming language and after that it is stalled in the microcontroller’s ROM. However, microcontroller usually has limitation in term of processing which is specify has less than 100MHz processing unit and its memory is frequently of several Kilobytes or less [1]. To make this approach become more powerful in processing system, a computer will be used as the controller. At this point, microcontroller is used to read sensors as inputs and control actuators at the outputs while the main control (program’s architecture) run in the computer through specific operating system depends on the types of microcontroller.

In the industries or commercials approach, SAs are directly connected to the input/output (I/O) board. The IO board then will be interfaced with a computer that has been installed with related IO board software to control the IO boards. All the control algorithms and programs are executed in that computer.

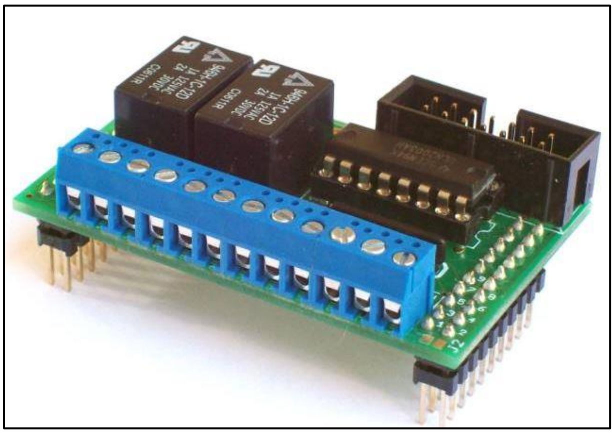


Figure 1.1: An IO board model MXD2R for Single Board Computer (SBC) industrial application [2].

Another approach is by using network as part of interface connection. The SAs were connected to microcontrollers and computers. The network such as Ethernet then used to exchange data between sensors, actuators and the main computer [1]. All these types of controller interface depend on digital electronics component.

In order to apply the robot's controller, most robot designers use microcontrollers or computers and various accordance sensors that purchased to build the robot's sensing systems. Buying all the sensors usually embedded in a smartphone would surely more expensive than buying a new smartphone. Furthermore, most of the smartphones nowadays powered with processors faster than 1GHz, regularly multi-core and 1 GB of RAM memory or more [1].

Moreover, many projects currently were created aiming to use smartphones as the robot's main controller because of its capability to execute complex robotics algorithms although with a 300MHz build in processors [1], plus most of today's smartphones have a variety of built-in sensors that can be discovered. Many of them have accelerometer, camera, Wi-Fi, Bluetooth, speakers, microphone, Global Positioning System (GPS) receiver, compass, and some even have stereo camera for 3D imaging as well as gyroscopes [3]. This various sensors within a smartphone has lead designers to provide a simple robot's hardware architecture but with a great computational platform. Besides, with a simple architecture, it also beneficial for educational robotics because students can build their own robots with low cost and uses them as platform for experiments like developing the localisation strategies for a mobile robot.

1.2 Problem statement

For the past few years, conventional implementations usually involve expensive sensors and hardware with powerful computing ability to develop a robot. For example, a robot that controlled by a joystick affect higher cost due to the external sensors used or any other interfacing circuit between the joystick and the robot like a device named NXT programming kit [3].

Recently, to design a robot along with navigation computing platform is not a problem anymore. In robotics, navigation refers to the way a robot finds its way in the environment and is a common requirement for almost any mobile robots [4]. Today smartphone already equipped with multiple built-in sensors for navigation purposed like accelerometer, gyroscope, camera, GPS, and Wi-Fi transceiver plus most of them embedded with fast processors [5]. The designers have wide options to choose any built-in sensors to create their navigation platform of their robots. It is like using the smartphone as “brain” for the robots [1].

In this project, by using the Dual Tone Multi Frequency (DTMF) connection, the robots could be controlled in the wide range area more than other connections such as Infrared, Wi-Fi, WLAN or Bluetooth [6] since DTMF technology is one of the wireless communication practise used to control the robots [7]. Normal practice for past few years ago, robots are controlled by using RF circuits, which have several limitations like working range, frequency range and control range. These limitations could be vanished by using smartphones for robotic control; plus they have more advantages like robust control, large working range coverage and the biggest advantage is long lasting controlled. For comparison, from [8] definition; “Wi-Fi is a cheap solution aimed to cover short distances such as airport, hotels, and conference areas”. From this, it is clear that Wi-Fi as some limitations in providing wide coverage solution, while the Infrared, WLAN, and Bluetooth technology only able to remote some equipment in the coverage less than Wi-Fi.

1.3 Aim and objectives

The aim of this project is to use smartphone as mobile robot controller for localisation strategies.

The specific objectives are:

i. To develop a two wheel mobile robot.

ii. To develop an Android application for controlling mobile robot movements according to the DTMF signal.

iii. To analyse localisation performance of mobile robot.

1.4 Scope and limitation

The scope of this project is to control the robot movement and measuring the time of travel via simple or complicated route in an indoor environment within area of two square meters ($2m^2$).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussed the analysis about earlier existing projects and has been divided into two segments. From types of controller interface, the discussion also covered into several localisation strategies that has been developed in recent years.

2.2 Types of controller interface

Nowadays, smartphones have the capability to be interfaced with robots; where all built-in sensors can be used to control robots. There are several ways to control mobile robot wirelessly through a smartphone. As mentioned earlier in the problem statement, several ways are through Bluetooth, Wi-Fi, or WLAN connection.

A mobile robot (G.N. Coelho, 2008) [4] with Bluetooth connection as the interface medium has noticed several navigation problems which are including mapping, localization and path planning. This project evaluates performance of the navigation algorithms, by comparing executions time and memory usage between Nokia N80, Nokia N95, and a computer desktop.

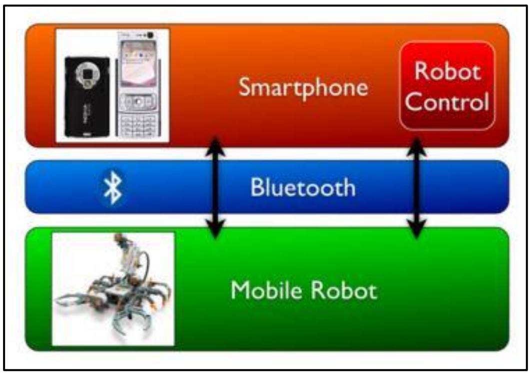


Figure 2.1: System organization [4].

From the result analysis, it is clear that computer has the ability to execute navigation program algorithms faster than two smartphones, but in memory usage performance analysis, both smartphones have better result compare to the computer desktop.

Then a mobile robot called P3DX (Ehab, 2010)[9] with WLAN connection as the interface medium and the Nokia N770 model is chosen as its "brain". The GUI application named Robot Tele-operation Maemo User Interface (RTMU) essentially an ARIA (Advanced Robot Interface for Applications) client is an open-source software development kit based on C++ programming language. This GUI application will be programmed into the N770 and the robot movement is controlled via WLAN connection. According to project analysis, a main problem has been indicated in which it is hard to maintain the WLAN signal strength [10].

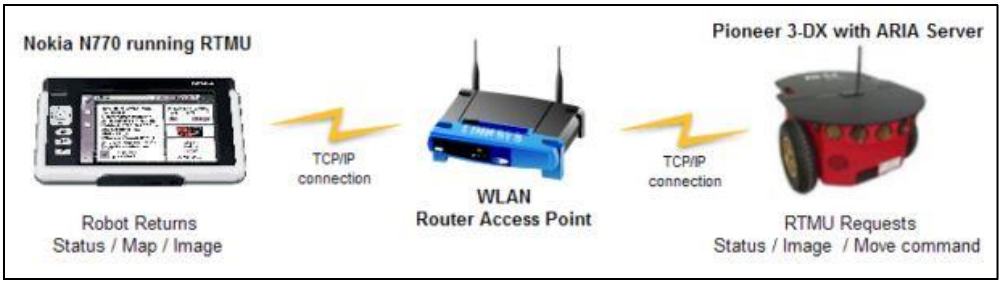

Nokia N770 running RTMU
Pioneer 3-DX with ARIA Server
TCP/IP connection
WLAN Router Access Point
TCP/IP connection
Robot Returns Status / Map / Image
RTMU Requests Status / Image / Move command

Figure 2.2: The P3DX robot overall system [10].

The next interface medium is using general packet radio service (GPRS) that applied for real-time remote monitoring and controlling for a mobile robot (K.M. Al-Aubidy, M.M. Ali, A.M. Derbas, A.W. Al-Mutairi, 2013)[11]. The GPRS technology makes it possible for mobile phone users to make telephone calls and transmit data at the same time. The architecture consists of two main stations; a base station and a remote station as shown in Figure 2.3. Based on the system layout, data exchange from both mobile phones at the base and remote station are through the DTMF generator IC (TP 5088) and the DTMF decoder IC (MT8870).

The GPS unit at the remote station is used to give the mobile robot the ability to define its position. For outdoor positioning, by using GPS is not a big problem since GPS technology is the best solution for positioning and navigation tasks [12]. All the positions data is determined from the sensors that attached to the robot frame and not depends on the built-in sensors from the mobile phone.

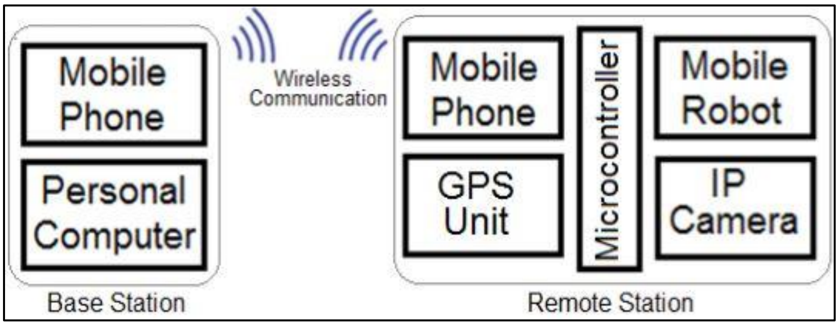


Figure 2.3: General layout of the system [11].

Another mobile robot controlled by DTMF technology is developed for stair climbing (T. S. Vamsi, K. Radha, 2013) [7]. The robot is controlled by a mobile phone that makes a signal to the mobile phone attached to the robot. Based on Figure 2.4; the received tone is decoded into 4 bit binary number by using MT8870 DTMF decoder and processed through the LPC2148 controller. The controller then give the instruction based on the pre-programmed codes to the motor and robot will moves for a specified direction.

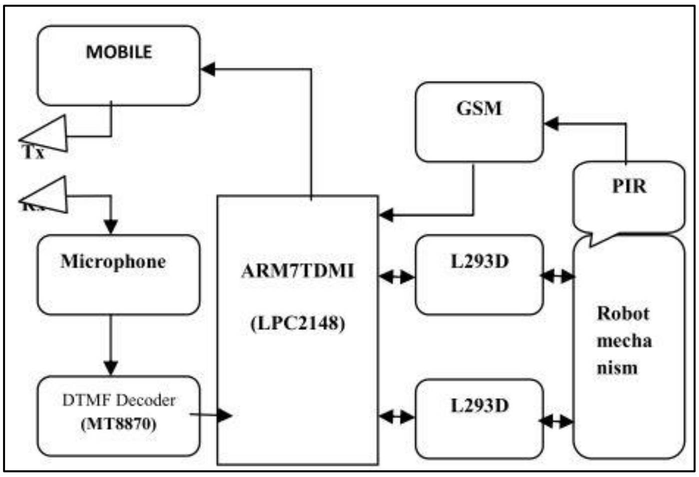


Figure 2.4: General block diagram [7].

2.3 The localisation strategies

For simple understanding about the localization term, it can be summarized with three questions; “where am I?”, “where am I going?” and “how should I get there?” [13]. Localization is the process of assessing the location of robot, relatively to some model of the environment by using any sensor measurements that available [14]. As the robot keeps moving, the estimation of its position drifts and changes, and has to be kept updated through active computation [14],[15].

In the early 90s, a tracking geometric beacons localization strategy is developed for a mobile robot (J.J Leonard, 1991) [13]. The goal of this system is to use the artificial beacon systems and compare with the structure of typical indoor environments without modifying the environment. This system is using the extended Kalman filter (EKF) to solve mobile robot navigation problem in a known environment. From a man-made indoor environment, each feature from the environment is modelled to be a geometric target. This geometric beacon is a special type of target that can be reliably observed in successive sensor measurements (ultrasonic sensor) and that can be accurately described in terms of a concise geometric parameterization [13]. Based on Figure 2.5, the localization algorithm will be developed from this plant model.

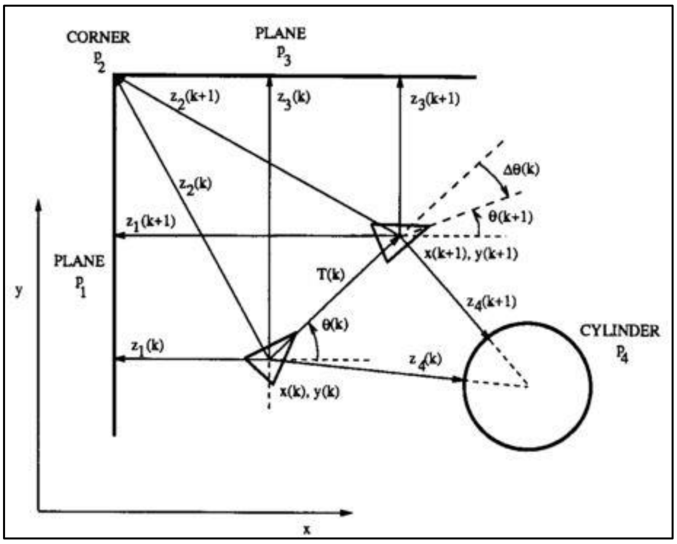


Figure 2.5:Localization by concurrent observation of several geometric beacons [13].

Then a vision-based localization (M. Carreras, 2003) [16] for underwater robot is developed in a structured environment. The localization system is based on a coded pattern placed on the bottom of the water tank as shown in Figure 2.6. This system will estimate the position, orientation as well as velocity of the underwater robot through components like on-board down-looking camera and a coded pattern as mentioned above.

The algorithm calculates the 3D position and orientation, referred to the water tank coordinate system [16], with computation of the vehicle’s velocities, including surge, sway, heave, roll, pitch and yaw by using the velocity-based low level controller of the robot.

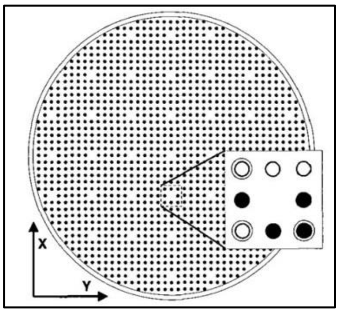


Figure 2.6**:** The coded pattern that inspired the localization algorithm [16].

The localization algorithm which designed to work at 12.5Hz comprises several phases; a) *pattern detection*, b) *dots neighbourhood*, c) *dots global position*, and d) *position & orientation estimation*. From the result, the localization system has drift-free estimations due to the condition of water and bottom pool is clean, plus there is no direct light from the Sun that will influence the environment's illumination.

Next, visual landmark recognition by using solid colour artificial landmarks is proposed for a mobile robot (G.N. Coelho, 2008)[4] as one of the localization strategy. This method applied by using cylindrical shaped objects with solid colour as artificial landmarks as shown in Figure 2.7 because a simple visible landmark in rectangular form can be provided from any side viewpoint where the mobile robot observation could take place [4].

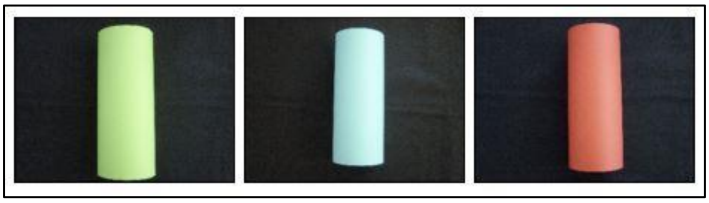
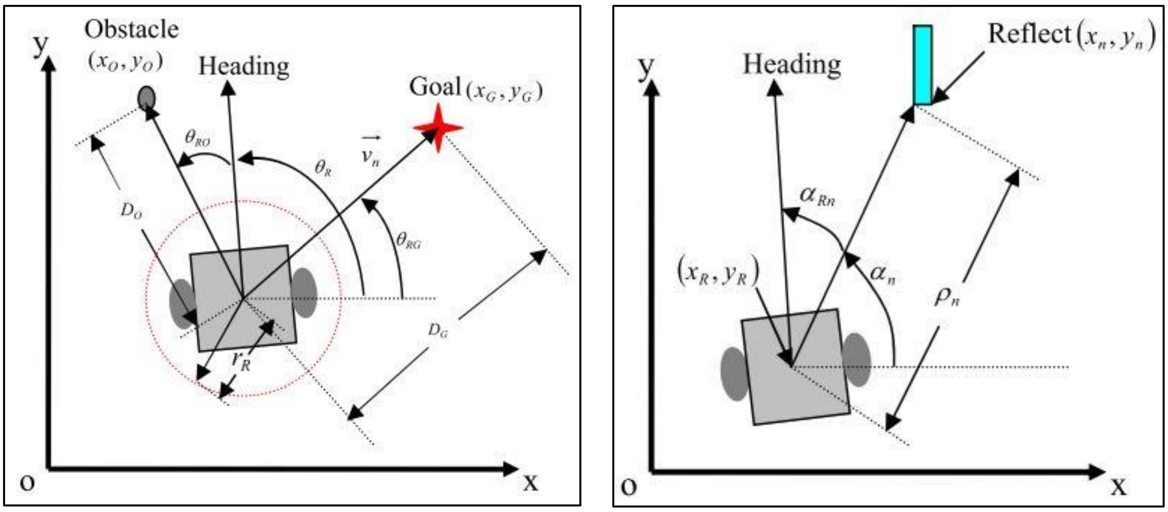


Figure 2.7**:** Landmark colours made out of A4 cardboard coloured paper; have 40 mm in radius and 210 mm in height [4].

With the same method proposed by [17]; the system detects one landmark, classifies the landmark and calculates its distance and orientation to the visual sensor (built-in camera) and only one landmark will be identified for an image captured. The image processing will go through in colour segmentation and image noise reduction process. For distance and orientation calculation, they used an equations that proposed by [18]. From this strategy, if more complex environments used, the colour image segmentation calculations will become more challenging and need a smartphone with higher processing unit to execute the localization algorithms.

Another project is using the Tangent method, the Kalman filtering algorithm, as well as the fuzzy logic controller (FLC) for localization of a mobile robot (G. Huang and H. Lin, 2009) [19]. All these methods have several specific purposes in which to determine the robot's shortest path, the Tangent method is used, to estimate the robot's location; the Kalman filtering algorithm is applied while to modify navigating error, FLC will be used. The approach is based on the developed model for mobile robot motion and location measurement as shown in Figure 2.8 (a) and (b).



(a) (b)

Figure 2.8: (a) Model of robot motion; (b) Model of location measurement [19].

In the robot motion model, a number of ultrasonic sensors were installed to measure the object (robot, target and obstacle) locations within the 180-degree range area in the front of moving robot [19]; while the laser navigation system is used to solve the reflect reference location based on Figure 2.8 (b). By combining three methods as mentioned above, both simulation and practical results prove that the mobile robot can get the optimal route with fast and accurate response. From this, a complex analysis has to perform within high processing microprocessor in order to solve the Tangent and Kalman filtering algorithm.

An indoor navigation with smartphone-based visual SLAM (Simultaneous Localization and Mapping) for a mobile robot has been done by (W. W. Kao and B. Q. Huy, 2013) [5]. Two smartphone model has been used which are the LG Optimus P970 (a low-end dual-core processor) and the HTC One X+ (a high-end quad-core processor) for comparison purposed. Built-in camera from the smartphones along with the state equation and OpenCV has been applied to provide the visual SLAM formula and the overall layout of the project is shown in the Figure 2.9. The OpenCV is chosen because it provides the library processing that compatible with Android for the smartphones.

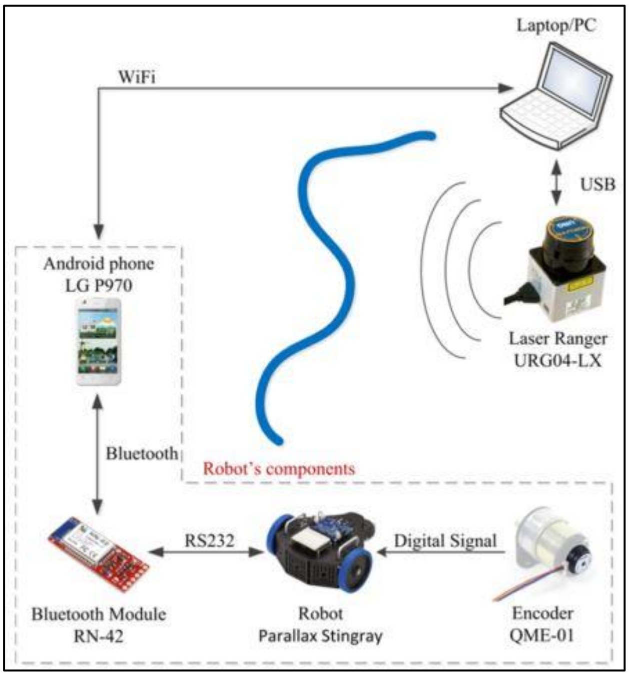


Figure 2.9: System layout diagram for the experiment [5].

Based on Figure 2.9, a laser ranger that connected to a laptop PC is used to obtain the real path of the robot [5] and as the references for positioning results. From the results, several drawbacks have been indicated which are; the lack of speed for camera autofocus, the lighting condition that will contribute noise for captured image, and the computational speed on the smartphones: to execute a complex image processing algorithms.

2.4 Summary

Several comparisons and brief introduction of previous works from the types of controller interface and the localization strategies have been enumerated in this chapter. For better understanding, some motivational examples is provided through the given citations and references.

CHAPTER 3

METHODOLOGY

3.1 Introduction

All the details about this project development will be delivered in this chapter. The discussion will be covered through the overall flow chart of the project, the hardware and software development.

3.2 Flow Chart of the Project

The flow chart is given in Figure 3.1 shows the overall process to develop a smartphone-based robot controller for localization. From the start, the process divided into three main processes; a) mobile robot design and construction; b) the Android program development; and c) the integration between smartphone and mobile robot via DTMF decoder module where the localization strategies will took place in this part.

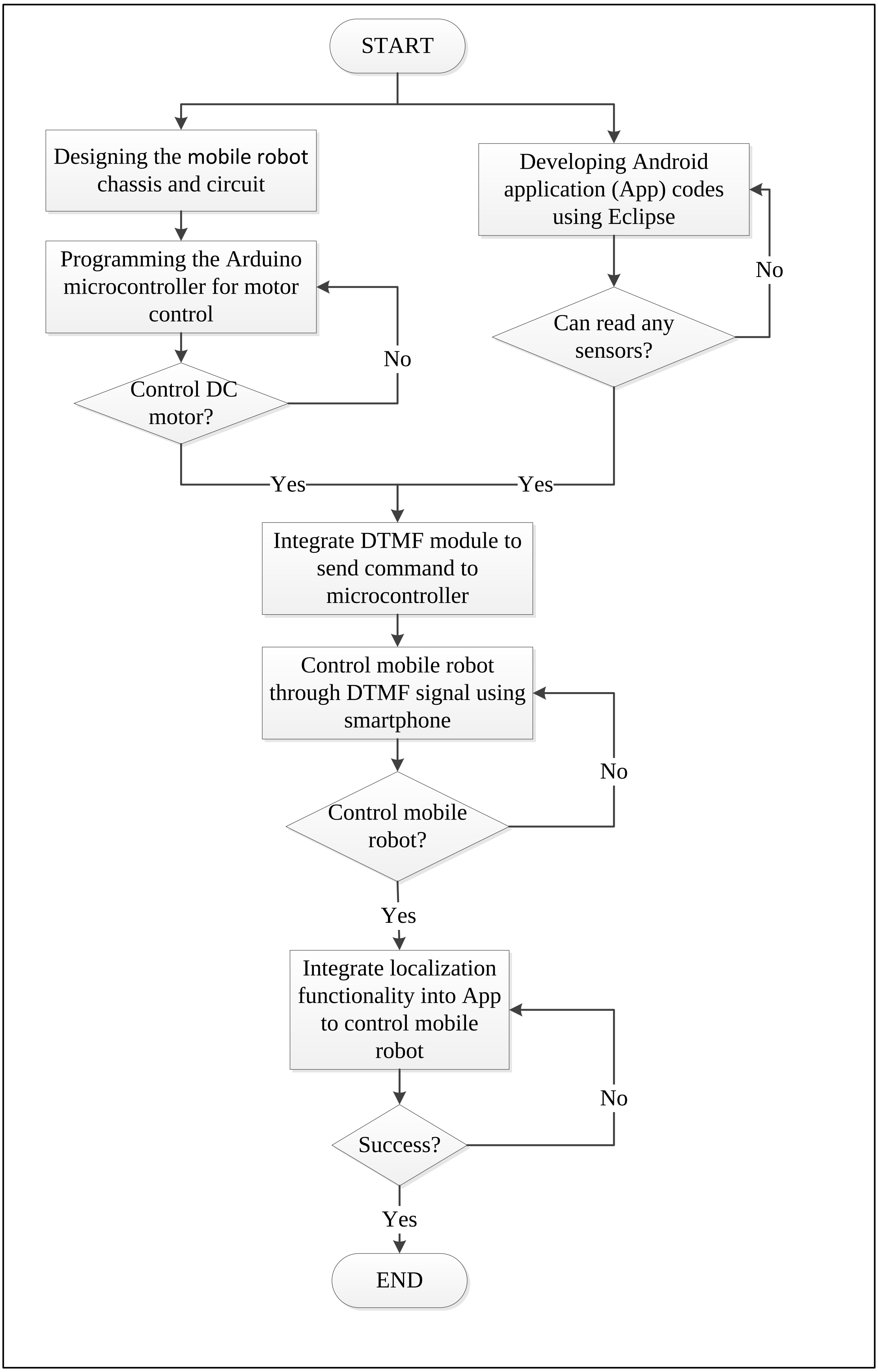

START
Designing the mobile robot chassis and circuit
Developing Android application (App) codes using Eclipse
Programming the Arduino microcontroller for motor control
No
Can read any sensors?
No
Control DC motor?
Yes
Yes
Integrate DTMF module to send command to microcontroller
Control mobile robot through DTMF signal using smartphone
No
Control mobile robot?
Yes
Integrate localization functionality into App to control mobile robot
No
Success?
Yes
END

Figure 3.1: The overall flow chart of the project.

3.2.1 Mobile Robot Design and Construction

Normally a mobile robot consists of one or more driven wheels and have optional passive or caster wheel and possibly steered wheels while most designs require two motors for driving and steering a mobile robot [20].

The components and hardware can be summarized according to a block diagram that is shown in Figure 3.2 while Figure 3.3 shows circuit diagram for a single motor developed by Fritzing software. Major components are two DC geared motors (SPG30E-30K) with encoder, the 10A NMOS H-Bridge motor driver, the Arduino Uno microcontroller, the DTMF module (MT8870), and a smartphone.

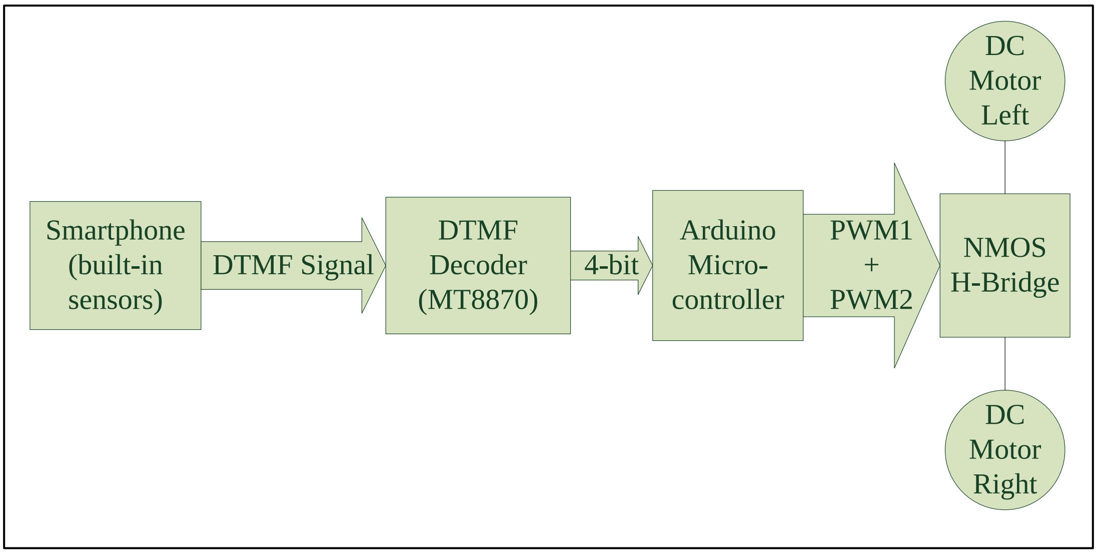


Figure 3.2: The block diagram of hardware development.

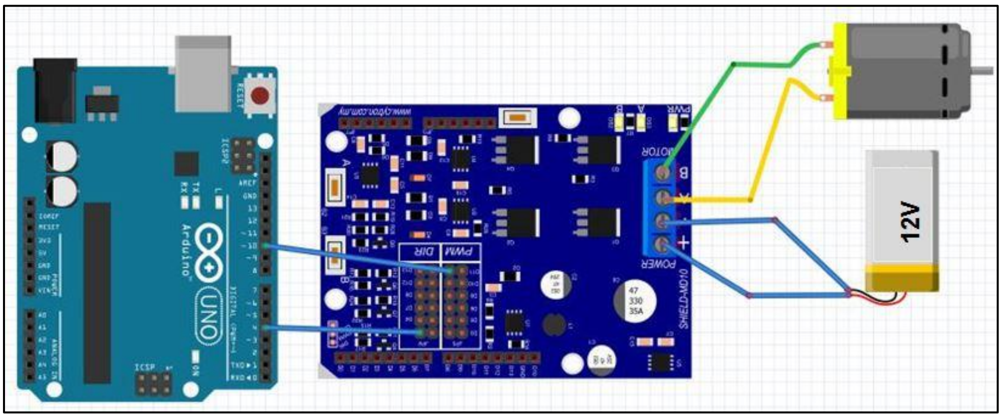


Figure 3.3: Circuit diagram for a single DC motor.

The DC geared motors were chosen as the driven mechanism in this project because of it is easy to control, clean, quiet and the most popular used in mobile robot design. The characteristics are shown in Figure 3.4. From the figure, the maximum torque (stall torque) equal to 23.5m Nm at 1.8A (stall current), while for efficiency (50% of duty rate), the rated torque equal to 5.88m Nm at 0.41A (rated current).

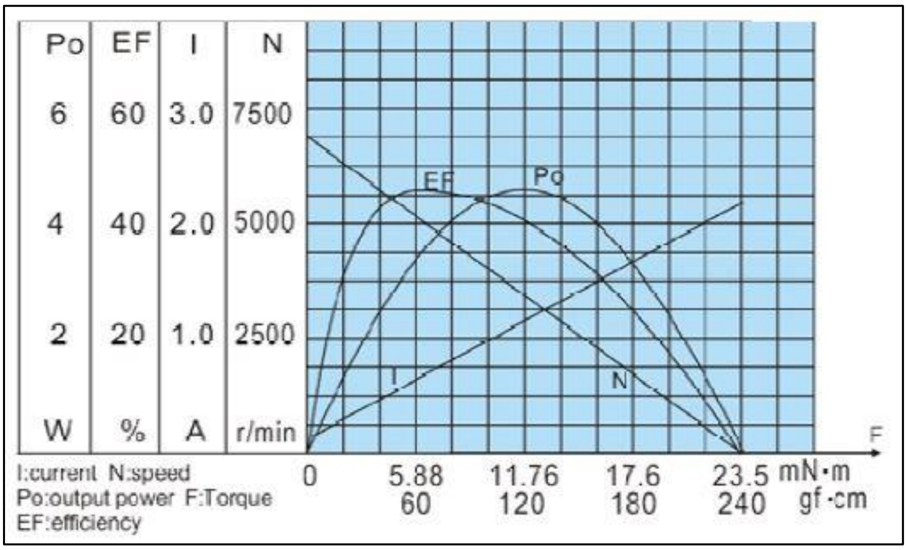


Figure 3.4: SPG30E-30K Dc motor characteristics.

The reason using encoder in both DC motor is to put reference for distance analysis of translation movement. Besides, this encoder also can be used to balance the speed for two DC motor so that the movement of mobile robot always is stable in its route. Figure 3.5 depicts the SPG30E-30K that used to drive mobile robot in this project.

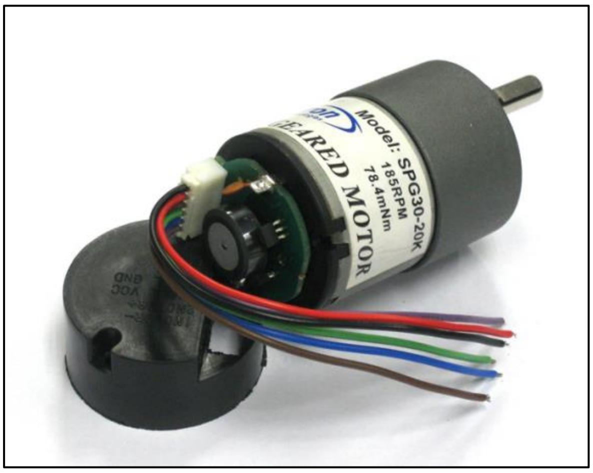


Figure 3.5: The SPG30E-30K DC motor.

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 above 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, Table 3.1 (a) and (b) is showing the state diagram while in Figure 3.6, it is showing the waveform signal that will be produced by the encoder; consequence from the rotational movement of the DC motor.

Table 3.1: State diagram for SPG30E-30K model; (a) Clockwise Rotation, (b) Counter Clockwise Rotation

a)

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

b)

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

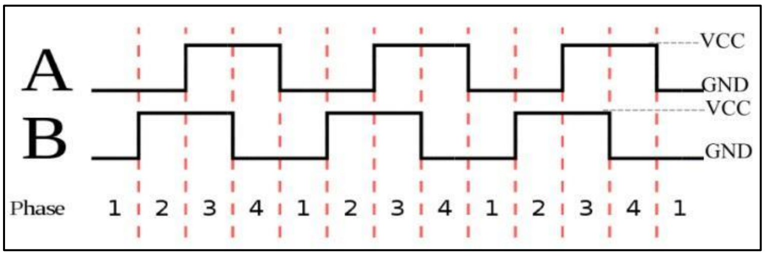


Figure 3.6: The waveform signals.

This encoder provides three counts per revolution of the rear shaft. To be simplified, Table 3.2 below specifies the quadrature Hall Effect encoder for SPG30E-30K:

Table 3.2: The quadrature Hall Effect encoder attributes.

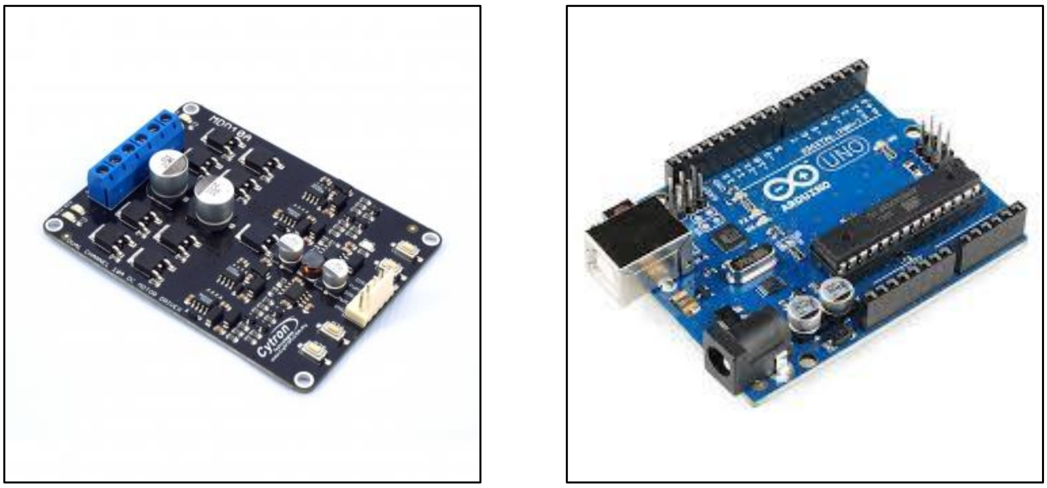
No.	Attribute
1	Operate at the range of 4.5V to 5.5V.
2	Two digital outputs.
3	Resolution: 3 pulses per rear shaft revolution; single channel output
4	90 counts per main shaft revolution for 1:30 geared motor.

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 model is depicted in Figure 3.7 (a). It 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. For instance, Table 3.3 shows the characteristics of MDD10A:

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.

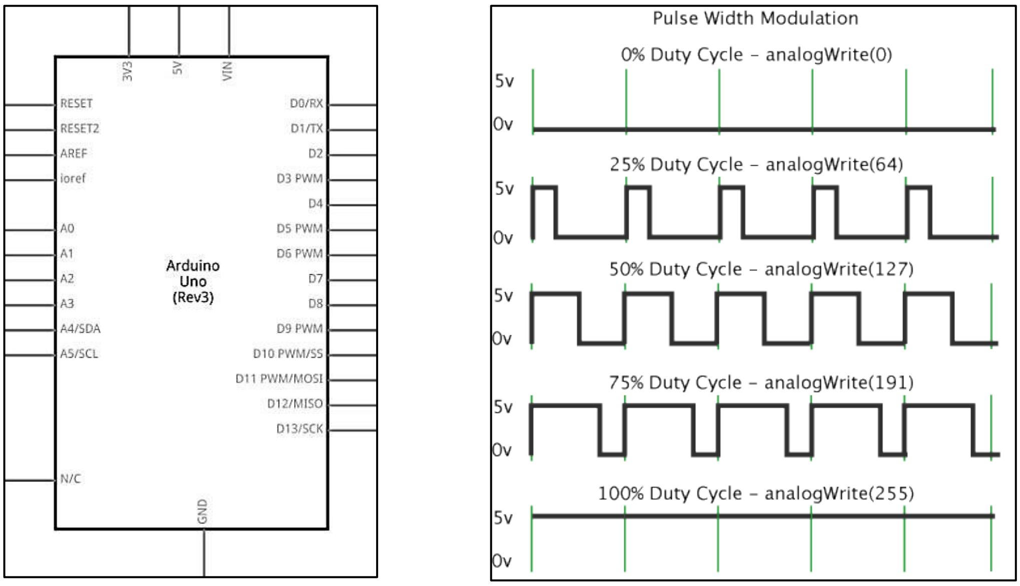
Smartphone will be attached on the robot chassis to utilize the built-in sensors and connected to the DTMF decoder module, MT8870. The Arduino microcontroller will be ruled to translate 4-bit data from DTMF module to control the PWM for DC motors via H-Bridge motor driver.



(a) (b)

Figure 3.7: (a) MDD10A dual channel motor driver; (b) Arduino Uno.

Arduino Uno as shown in Figure 3.7 (b) is chosen as the DC motor controller because low cost, the most reliable microcontroller and open source coding in the robotic field. Since this project purpose is more focus on the programming architecture development, so it is necessary to use low cost microcontroller rather than using microcontroller with high specifications. It is operates in between 3.3V till 5V from external supplied voltages like battery. For novice in the programming world, Arduino provides a Java based platform called Integrated Development Environment (IDE) and the codes written in C or C++. All programs to control DC motor written in this platform.



(a) (b)

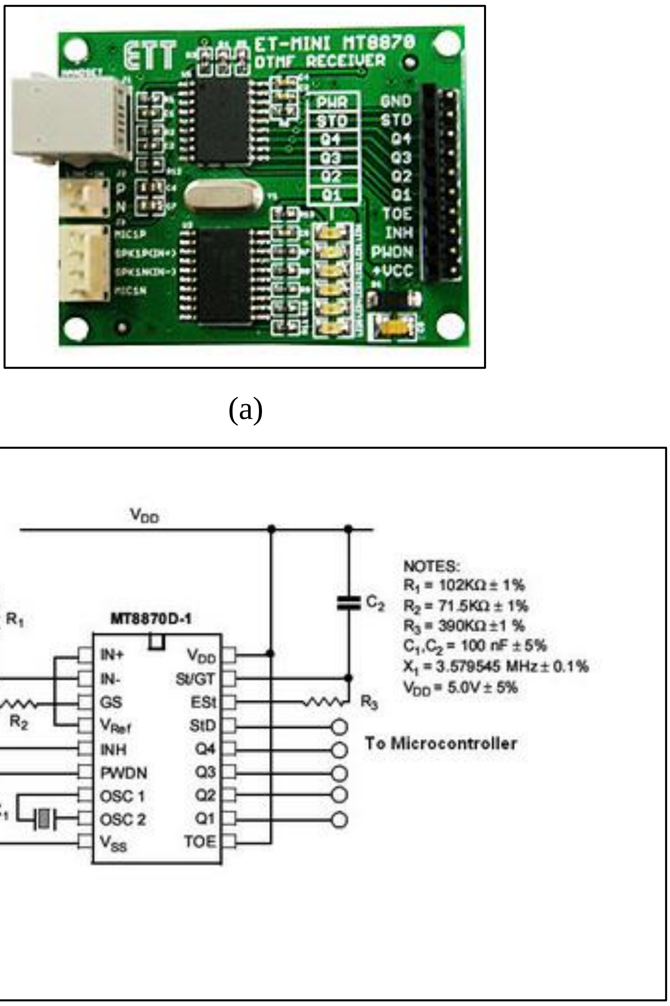
Figure 3.8: (a) Arduino board schematic diagram; (b) PWM concept.

Figure 3.8 (a) depicts the schematic for input and output (IO) pins for Arduino Uno Rev3. It has six analogue input pins (A0-A5) that can be used to assign voltage value needed for the electronic devices output such as DC motor. While for digital pins (D0-D13), it can be used as IO depends on assigned function from user.

In this project, both DC motors will be controlled by using pulse width modulation (PWM) technique that programmed by Arduino. The concept of PWM is based on Figure 3.8 (b). PWM is a technique for getting analogue results with digital means [21]. Digital control will be used to form a square wave (a signal switched between on and off). This on-off pattern can simulate voltages in between full on (5V) and off (0V) by changing the portion of the time the signal spends on versus the time that the signal spends off. The pulse width term came from the duration of "on time signal" in the square wave. A code "*analogWrite ( )"* is on a scale of 0-255 bits since Arduino Uno has 8-bits binary output. For example, to get the maximum speed for DC motor, the code will be written as "*analogWrite (255)"*.

DTMF decoder module, type MT8870 is used for decoding the mobile DTMF tone signal received from the smartphone into 4-bit digital signal is shown in Figure 3.9 (a) and (b) below. Based on Figure 3.9 (b), the decoder is operated with a 3.58 MHz crystal along with capacitor (C_1) used to filter the noise and two unit resistors (R_1 and R_2) is used to amplify the input signal.

In this project, the module is connected to smartphone through audio jack. Table 3.4 shown DTMF signals in 4-bit data that will be used according to buttons 0 to 9 including button # (hash) and * (star). Each dial signal is decoded into 4-bit data and will be sent to Arduino microcontroller to control DC motors (movements of mobile robot).



(a)

(b)

Figure 3.9: (a) DTMF decoder module; (b) the schematic diagram for MT8870

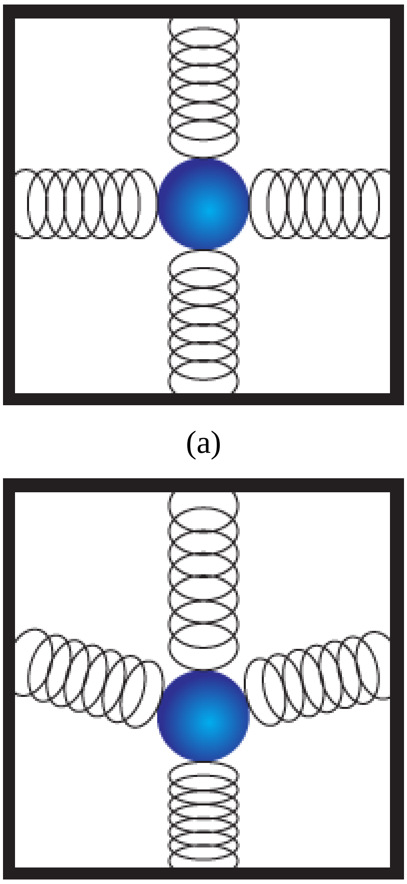
Table 3.4: DTMF signal decode.

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

The last major component to design and construct mobile robot in this project is smartphone. A smartphone that used is Samsung Galaxy Note II model because of availability. This model is chosen based on its processing performance which it was integrated with Quad-Core processor with 1.6 GHz CPU speed. This powerful processor can provide more efficiency for complex algorithm calculation especially to create localisation strategies. Table 3.5 is showing specs comparison between Note II and other smartphones that has been mentioned in literature review. From the table, Note II has more type of sensors, biggest internal memory, and longest battery lifetime compared to other smartphones.

Nowadays smartphones have features that very useful in robotic field. Some topics will be discussed about several major features that have been used to develop a smartphone-based robot controller for localisation.

i. Accelerometer:



(a)

(b)

Figure 3.10: (a) Mass on spring concept; (b) mass under gravity

This feature usually used to measure acceleration as well as tilt, tilt angle, incline, rotation, vibration and collision. It is easiest to visualize as a mass on a spring as show in Figure 3.10 (a). In Figure 3.10 (b) the mass will droop under gravity because the force of gravity on the mass acts and pulls it down. The accelerometer measures 1g because that is the amount of earth’s gravity. For explanation, there is additional force holding the structure up and the mass will droop under gravity. The accelerometer actually measures the force that holding the structure up when its axis is pointing up. Figure 3.11 depicted a visual of an accelerometer when it is in sideways movement.

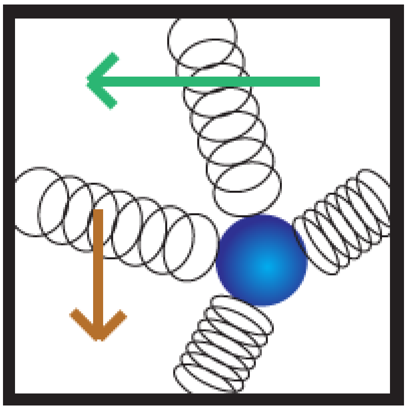


Figure 3.11: Linear movement of accelerometer.

In mobile phone application, an accelerometer can automatically modify the device's screen orientation vertically or horizontally. Advantage of the accelerometer sensor includes a high accuracy even in applications with noises. Example, with Kalman filtering algorithm, accelerometer can do more accurate in positioning when it is combined with encoders.

ii. Gyroscope:

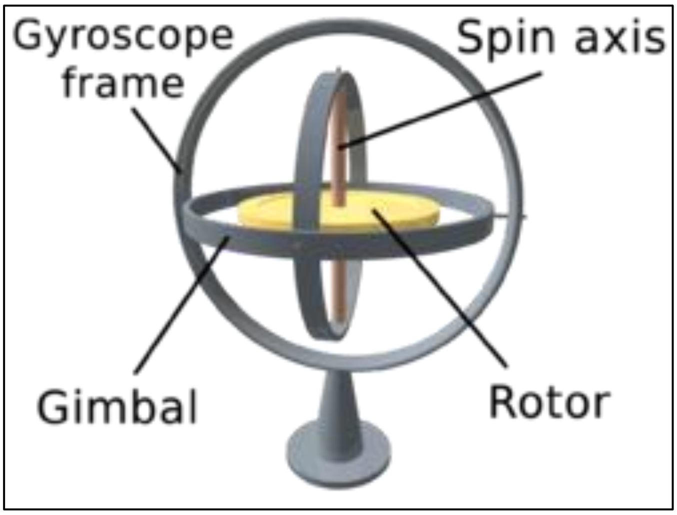
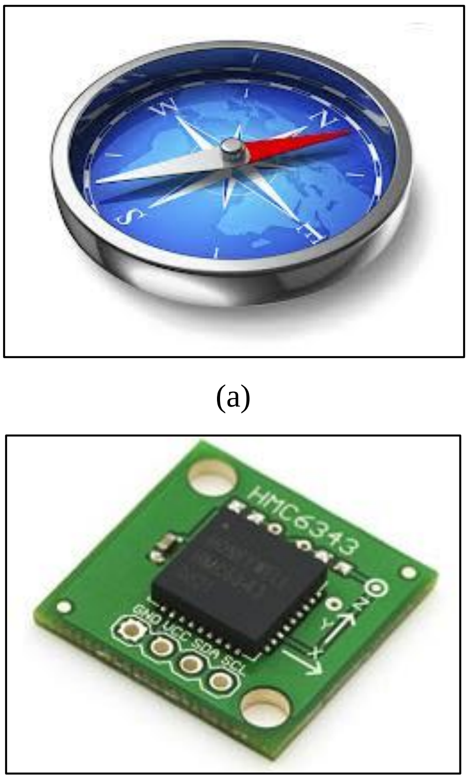


Figure 3.12: A visual of gyroscope.

A gyroscope is a device that senses an angular velocity. This applied by the Coriolis Effect theorem [22]. Based on Figure 3.12, the Coriolis Effect happens when there is a mass that’s moving and the frame of reference is rotating. So when that happens, it will produce a fictitious force on the mass and it can be known how the frame of reference is rotating. For the analogy, the Earth is rotating, so the Earth's rotation has some impact on things for example, weather systems effect.

Generally gyroscope is used in robotic applications for balancing, sending corrections to motors, as well as for drones to stabilize the flight. In smartphones, this sensor also 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.

iii. Magnetometer (Compass):



(a)

(b)

Figure 3.13: (a) A conventional compass; (b) Compass sensor.

Compass or magnetometer is a magnetic field sensor. It picks every possible magnetic field that includes the vibrating motor right next to it if this is not a phone. In mobile phone, a compass will measure any possible magnetic field that includes the Bluetooth chip, speakers, microphones, or anything on the circuit board that is been magnetized. The compass

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