INSPECTION ROBOT FOR POWER LINE

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Inspection Robot for Power Line

by

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CERTIFICATION OF APPROVAL

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Approved by,

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Main Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

UGASCINY ARUMUGAM

ABSTRACT

Power line cable and insulator inspection and verification procedures require experienced and highly-skilled technicians. These inspections are done with the aid of binoculars and helicopters, where the inspector will be able to visualize points where damaged spots are seen. These traditional methods have several drawbacks; high operational cost, poor blind-area-free inspections and also fails to provide a safe working environment. Besides complementing the service of inspection in transmission lines and making it less dependent on technical skill, this study/research is necessary especially in damped weather countries like Malaysia where several factors could contribute especially to insulator failures; i.e. rust or corrosion. Hence, to serve the objective best, an inspection robot will travel on the transmission tower close enough to capture high definition pictures on the insulators and also a zoomed picture of the overhang live line from the tower. This would mean that the robot does not need to move along the transmission cable. In this project, a remotely controlled robot is presented as a tool to automate the operations of inspection and has great application prospects for engineering application here in Malaysia.

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ABBREVIATIONS AND NOMENCLATURES

TNB	Tenaga Nasional Berhad, Malaysia
CNC	Computer Numerically Controlled
ISO	International Organization for Standardization
IC	Integrated circuit or a black chip with pins coming out from it
LED	Light Emitting Diode
CPU	Central Processing Unit
PC	Personal Computer
DC	Direct Current
ICSP	In-Circuit Serial Programming
FYP	Final Year Project
VB	Visual Basics
IDE	Integrated Development Environment
GUI	Graphical User Interface
WCL	Wireless Communication Library
COM	Component Object Model
SPP	Serial Port Profile
RISC	Reduced Instruction Set Computer

CHAPTER 1
INTRODUCTION

1.1 Background of Study

1.1.1 Transmission System/Power Line in Malaysia

Transmission system is a system of High Voltage network which interconnects main generating stations with major load centre. The system also enables bulk transfer of power between these transmission points. In Peninsular Malaysia, this transmission system is known as the National Grid. The voltages at which bulk transfer takes place in the National Grid are 132 kV, 275 kV and 500 kV. TNB transmission Network Sdn. Bhd. maintains the towers and transmission lines, and high voltage equipment at substations.

The Hydro Power Generating Stations in Malaysia produces 11 - 20 kV of electric power at frequency of 50Hz. The power is then transformed to higher voltages (132 - 275 kV) using power transformers and transformed through the Transmission System to substations where voltage is lowered to 33 or 11 kV. Distribution system only begins after this point and power is further distributed to load centre where voltages are further reduced before reaching factories, homes and other end consumers [1].

1.1.2 Power Line Inspection

High-voltage power line inspection plays an important role in the power maintenance, which aims electrical and mechanical malfunction diagnosis and the first hand field information collection for condition based maintenance. Currently, the traditional method of inspection practiced by TNB is either done manually or with the use of helicopters at difficult areas, like forest or hills. Manual method is where highly trained technicians would climb up the pylon for routine inspection on conductors, insulators and live-line. Conductors and insulator inspections are done using bare-eyes and hot-sticks. Live-line inspection, on the other hand, is mostly done with the use of binoculars. These methods have its drawback as well. Industrial accidents can easily occur when inspection tools are being dropped accidently due to human errors. It also very risky for any human to work on high voltage transmission towers for any reason.

1.2 Problem Statement

1.2.1 Problem Identification

A problem often faced by TNB is that a relatively high-expense placed on inspection and maintenance. At present, the general method of power transmission line insulator inspection adopted either manual or helicopter power line inspection or both are very costly to practice. These methods of inspection are not only costly but also fail a successful blind-area-free inspection. High-voltage power line maintenance becomes tougher when involving difficult places of access such as primitive forest, large rivers and so on. Talking about high-voltages and high-altitudes, safety is a matter of concern. Risks of dropping materials while inspection or technicians slipping off exist even when safety precautions are taken with this manual inspection method.

1.2.2 Significance of the Project

The technology of robot is relatively new especially in the area where high voltage is at risk. Such ambiguities of the application of robot in this area reduce their chances to be used as competitive products compared to the well-known manual and helicopter inspection methods. With the completion of this project, it is hoped that it would offer another opportunity window to review the development of robotics technology and for new discoveries towards the exploitation of this technology in Malaysia in particular.

Since robot inspection method is practically unknown in the National Grid inspection practice, this research and development paper would be able to determine the feasibility of using robot as the ultimate alternate solution to the current methods. This study would also be able to be used as the platform of a better understanding on the potential of inspection robot as the alternative solution for the problems faced by TNB in this area. Ongoing research and development efforts are essential for improving and optimizing the effectiveness of inspection robot for power/transmission lines.

1.3 Objective and Scope of Study

1.3.1 Objectives

The objectives of this project are as follow:

i. To search for an alternative solution to the insulator inspection problems faced by TNB currently.

ii. To build an inspection robot featuring advantages such as higher inspection precision and higher consistency than the manual inspection, lower cost, effective blind-area-free inspection, and work safety which makes the inspection robot more competitive in the field of high-voltage power line maintenance.

1.3.2 Scope of Study

This project is ranged from the robot's mechanical design and considerations to electrical and microwaves deliberations. This project would also determine the unique robot operation suited best for a standard transmission steel lattice. This information would especially be important in the industrial scale as the adaptability to such narrow steel lattice would be an attraction and increases its competitiveness.

1.4 Feasibility

The project is considered feasible based on the time given and also the abundance of information on robots from the Internet and journals available in Universiti Teknologi PETRONAS (UTP) Resource Centre. The work and assignment of this project shall be distributed evenly to ensure that every task can meet deadline and fair concentration on all parts can be achieved.

CHAPTER 2
LITERATURE REVIEW

2.1 Transmission Line Tower/Pylon

Transmission tower designs are very much dependent on the load and its destination path. In this project however, the mechanism of the robot would be adjusted or scaled down to a single tower structure due to constraints of time and financial investment. Modifications on the mechanical design or on the programming of the robot intelligence are possible for a mass scale in future.

Figure 1 illustrates the National Grid distribution according to TNB records [2];

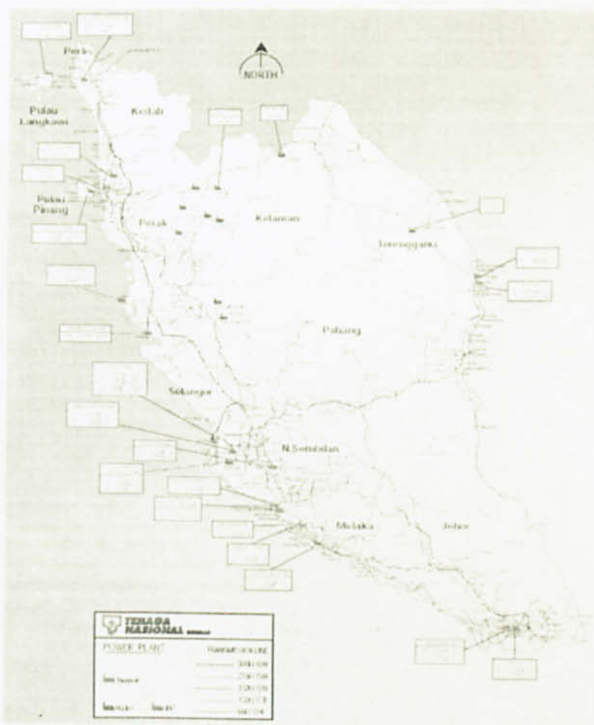

Figure 1: National Grid distribution

Data in Figure 1 is tabulated as shown in Table 1;

Table 1: Transmission line distribution

OVERHEAD LINE		**(17,258)**
Length (circuit-km)	500kV	890
	275kV	6,199
	132kV	9,998
	66kV	171
CABLE		**(723)**
Length (circuit-km)	275kV	49
	132kV	674
	66kV	-
TRANSFORMERS		**(69,381)**
Transformation Capacity (MVA)	500kV	4,500
	275kV	26,213
	132kV	38,258
	66kV	410
SUBSTATIONS		**(375)**
Number of Substations (TNB)	500kV	4
	275kV	67
	132kV	299
	66kV	5

By simply analysing the figures in *Table 1*, the most common transmission tower used in Malaysia is the 132kV transmission tower having 38,258 number of transformers distributed. Thus, the robot operation for this project would be based on the 132kV lattice tower.

Generally, different types of transmission towers are used in terms of its design. These towers are suited best based on its voltage load transmission and also on its direction control in certain cases. There are three types of specific power lines for 132kV lines; L6 - the largest design in normal use, L2 – a smaller design ad L12 – a more modern design used for most new construction. For a précised discussion, the L2 tower, a smaller design is chosen in this project. *Figure 2* illustrates the L2 tower measurement;

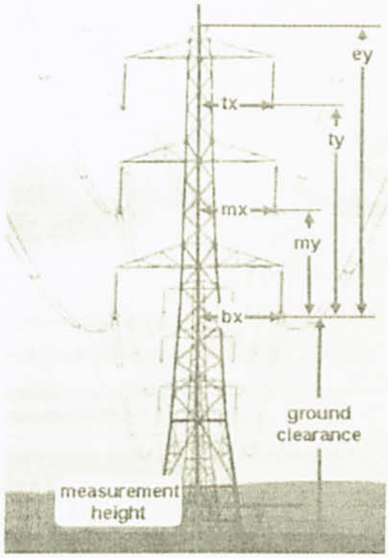

Figure 2: L2 tower and its dimensions

The dimensions for these towers, including the L2 tower specifications, are tabulated in *Table 2*;

Table 2: Power line tower specifications

Dimension		code on diagram	tower type			units
Conductor	direction		L6	L2	L12	
earth wire	horizontal from tower centre	-	0	0	0	m
	vertical above bottom phase	Ey	29.51	21.26	27.22	m
top phase	horizontal from tower centre	Tx	6.98	5.49	6.30	m
	vertical above bottom phase	Ty	19.54	15.62	18.00	m
middle phase	horizontal from tower centre	Mx	10.45	5.72	9.12	m
	vertical above bottom phase	My	9.00	7.85	8.70	m
bottom phase	horizontal from tower centre	Bx	8.44	6.10	7.12	m
	vertical above bottom phase	-	0	0	0	m
conductor bundle	number of conductors		4	2	2	
	Spacing		305	305	500	mm
	Diameter		28.6	28.6	37.3	mm

Regardless of the transmission tower used for high-voltage transmission, the inspection target in this project is on its insulators precisely.

2.2 Insulators

Overhead line insulators are used to electrically insulate pylons from live electrical cables. There are seven different types of insulators however; disk type, longrod type, pin type, shackle type, post type, Hewlett type and pot type. Here, in this project, the disc type insulators, which are widely used for high-power transmission lines is given focus. *Figure 3* shows the disc-type insulator being applied as a strain string.

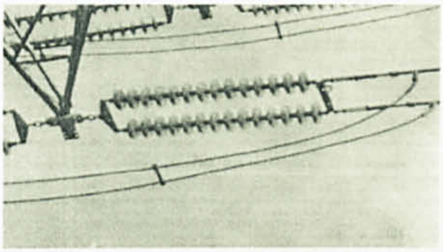

Figure 3: Disc-type insulator applied as a strain (tension) string

Besides mechanical strain (tension) requirements, the higher the line voltage insulated, the more insulator units used in the string. Hence, looking at 132kV lines, 20-25 11kV insulator discs are placed with typically a minimum of 20-25 mm/kV of distance between the porcelain and the insulators (4).

i) 11kV disc insulators (IS-731/1971) has minimum(5) ;

   a) Creepage distance (shortest path between two conductive parts) : 320mm

   b) Shank diameter (thread diameter) : 16mm

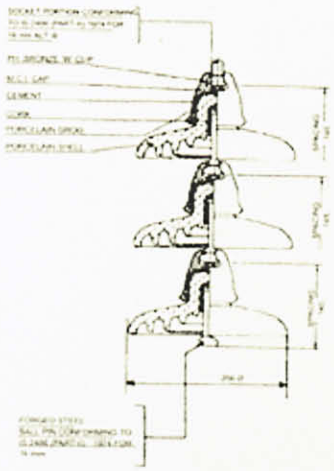

Figure 4: 11kV Disc-type insulators (IS-731/1971)

ii) T and C type disc insulators

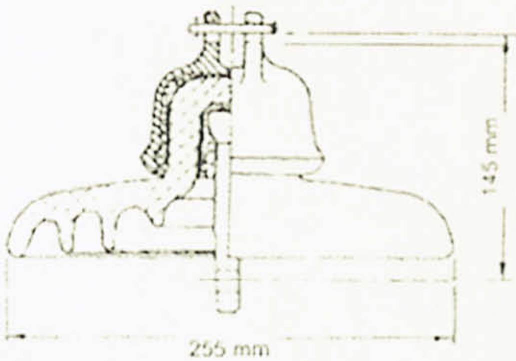

Figure 5: T and C type disc insulator

Figure 5 graphically illustrates the most common type of insulators on market today, T and C type disc insulators. The specifications are seen in detail on *Table 3*;

Table 3: T and C type disc insulator specification

STANDARD PARTICULARS		
Drawing No.		
Porcelain Dia	mm	255
Spacing	mm	145
Total Creepage Distance	mm	320
Combined Electro-Mechanical Strength	KN	70
Flashover Voltage		
Power Frequency	Dry KV	65
	Wet KV	45
Impulse	+ve kVp	110
	-ve kVp	120
Withstand Voltage		
1 Min. Power Frequency	Dry KV	50
	Wet KV	35
Impulse Withstand Voltage	Kvp	170
Impulse	Postive kVp	75
	Negative kVp	80
Puncture Voltage	KV	105

For line insulators in general, changes in surface resistance due to chemical variations and changes on surface or pollutive films covering the surface have an effect on surface resistance, leakage currents and withstand voltage of the insulator. Thus, voltage discharge external to the insulator may occur when the insulation material is too polluted, wet, and has a reasonably low resistance path allowing for the discharge during lightning, switching or transient overvoltages. Each time a discharge (external flashover) occurs, the insulator is at risk of "tracking", a phenomenon where a physical indentation or scar appears as a semiconductor "track" caused by an electrical arc over the insulator surface. However, arching horns are installed on line insulators to reduce the risk of surface tracking by providing discharge path further away from the insulator material. Hence, it is safe for a robot to reach a safe distance from the insulators.

With an estimation of the size and length of insulator and the risk of tracking, now the robot can be set for a draft design. Before that, one should know that the inspection must be done thoroughly as insulator failures may also be due to corrosion at disc insulator pin, which is placed in between discs (4). *Figure 6* in text shows the corroded pin on a disc-type insulator due to airborne saltwater.

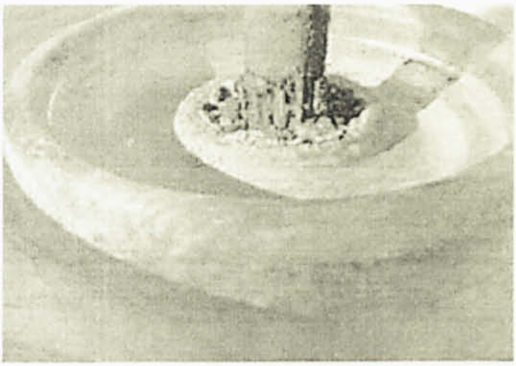

Figure 6: Disc insulator pin corroded by airborne saltwater

2.3 Robot Usage in Industries

Mankind has always strived to give life-like qualities to its artifacts in attempt to find substitutes for himself to carry out his orders and also to work in a hostile environment. Industrial automation, which started in the eighteenth century as fixed automation has transformed into flexible and programmable automation in the last 15 to 20 years. CNC machine tools, transfer, and assembly lines are some examples in this category [6]. The industrial robot is officially defined by ISO as an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes [7].

Generally, the inspection robot being presented in this paper is a remotely controlled inspection robot. The robot navigation is managed from ground level by a technician. Unlike robot systems proposed in the patent works that has been done worldwide, robots moving along the live-lines, this paper introduces a new scope of inspection with a relatively new method. This is necessary as robots moving along live-line cannot provide a worthy inspection on the insulators as this inspection requires a closed up picture or video on the string of insulators. To serve the main objective of this project, the robot will be designed such to achieve an effective inspection with a reasonable cost.

2.4 Patent study

Currently, theories and concept had been put into practice to construct several types of inspection robot although none is yet being applied successfully here in Malaysia and also in many other parts of the world. Present inventions relate to robot mechanism that only captures surveillance pictures of power transmission live-line. This does not promise the best inspection on the insulators as close-up pictures are required to assure the insulator are free from corrosion or any kind of damages for the matter.

By research, five patents are discussed in this session hereafter to give a wider idea on the existing projects that are being carried out around the world. Below are the five patents by comparison;

2.4.1 *"An Inspection Robot for High Voltage Power Transmission Line and Its Dynamics Study"* © Wuhan University, P.R. China

This patent illustrates a robot that is capable of inspecting transmission system without suspending power supply in usage of the equipped sensors, detection instruments and data communication apparatus. It is applied for inspecting mechanical/ electrical failures in high-voltage (110kV, 220kV) and extra high voltage (500kV or above) power transmission system.

This robot operation can simply be visualized as in *Figure 7* below;

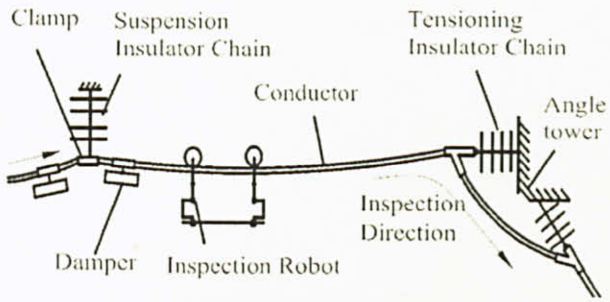

Figure 7: An inspection robot and its flexible obstructive working path

As illustrated on above figure, the performance of the robot is weighed on its precision of obstacles' location and failure signal' detection, which are affected by the coupling vibration of the robot and overhead transmission line.

Among the pros of this design is that the robot could move autonomously along 220kV phase line without being driven remotely. This self-governing on robot's obstacle-overcoming is realized by means of autonomous navigation of multiple electromagnetic sensors and machine visual hybrid servo. This robot feeds on the magnetic energy of transmission conductor, which is converted into electrical energy as the power supply. Summing up, this robot is efficient and safe to assure high detection quality, especially in severe conditions, comparing with such current inspection approaches as inspectors and unmanned aerial vehicles (UAV) [8].

2.4.2 "*A Novel Self-navigated Inspection Robot along High-Voltage Power Transmission Line and Its Application*" © Wuhan University & Ningbo Bull Electric Company Limited

This patent proposes a novel self-navigating inspection robot along 220kV overhang power transmission live line. The robot illustrates three main features, each featuring its mechanical schematic, key technologies and power supplying techniques respectively. Precisely, this robot has only six freedom degrees designed into double anti-symmetrical arms for sliding and suspending structures. This enables rolling or crawling along the overhead transmission line and striding the obstacles autonomously. Several key technologies are adopted to satisfy global environment detection, rough recognition and the extra location and attitude recognition using GPS-GIS, machine vision and multi-electromagnetic sensors technology respectively. The electrical energy supply in line is utilized by non-contact supply technology. Similar to the above patent, the inspection environment of the robot can be illustrated in *Figure 8*.

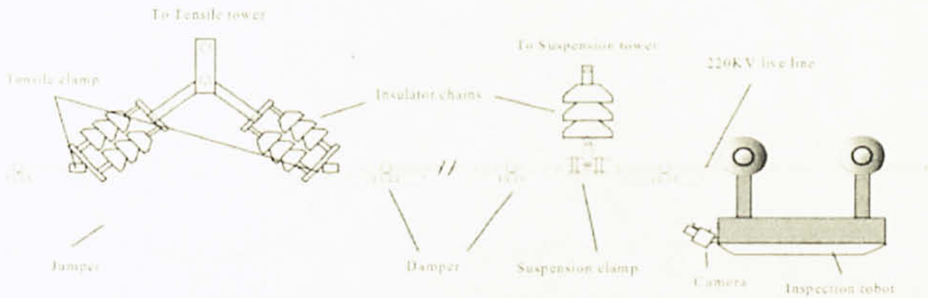

Figure 8: Inspection environment along moving path

Weighing the pros and cons, although the robot strides obstacles autonomously and fulfils the key technology functions, the maximum control distance and image transmission distance are only about 5km with rate of 22f/s. The pictures taken by the robot also fails to give a good opportunity for insulator inspections [9].

2.4.3 *"Visual Navigation for a Power Transmission Line Inspection Robot"* © Chinese Academy of Science & Shandong University of Architecture and Engineering, Jinan, China

In this project paper, a structure-constrained obstacle recognition algorithm was proposed based on improved circle detection methods to recognize obstacles from complex background robustly. Once obstacles recognized, a region based stereo matching algorithm is used to search the correspondence points in the stereo images, and the position of the obstacle relative to the robot is calculated by 3D reconstruction. The operation and obstacles on power transmission line considered in this patent is very much similar to the earlier patents.

Among the drawbacks are on the 3D reconstruction while calculation as to improve the matching speed, the epipolar constraint and a dynamic search window needs to be applied. This complicates further the operation system and makes the system maintenance complicated as well. Besides, the robot has to plan its motion sequence according to the type of obstacles it encounters. However, obstacle recognition is the key problem of the navigation system as it is not easy to recognize the clamps. Hence, simple geometric patterns of the isolator strings, which consist of disks that can be identified by their projections on the camera's image plane, are taken as the clues of the obstacle existence [10].

2.4.4 *"Inspection Robot for High-Voltage Transmission Lines"* © 2004 by ABCM Symposium Series in Mechatronics – Vol. 1

In this work, a mobile robot is presented as a tool to automate the operations of inspection by taking advantage of the global positioning system (GPS) technology, sophisticated cameras and related data-recording equipment, aerial access to remote areas and robotics. To analyze this work, mechanical system, mechanism for transposition of towers, base – robot operations communication architecture, development of the control system and development of the visual inspection system need to be reviewed thoroughly as in the patent attached in appendix D.

Briefly, an evolutive methodology was adopted to design the robot's mechanical design. Physically, as shown in below figure, the hook touches the cramp that supports the cable, transposes the obstacle and the vehicle stops, the first hook grabbing the cable beyond the obstacle; then a control procedure triggers a mechanism actuation which raises the wheels, fixes the hooks in the cable and bends the box; the box is mived along its track until it approaches the forward hook; then, it hangs again from the cable and the track moves back to its original position. *Figure 9* illustrates the robot configuration.

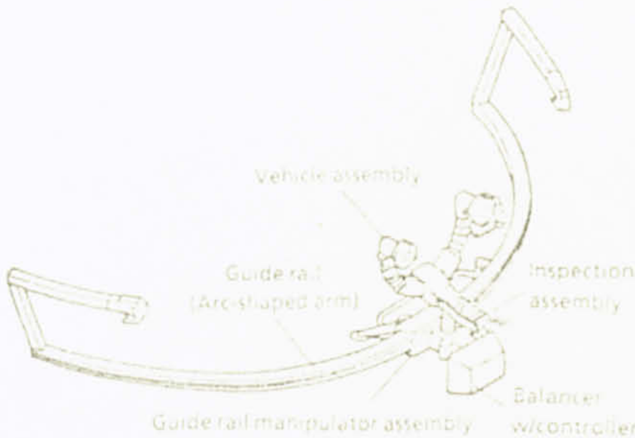

Figure 9: Robot configuration

Figure 10 in the text shows the logical system of the system discussed in this patent.

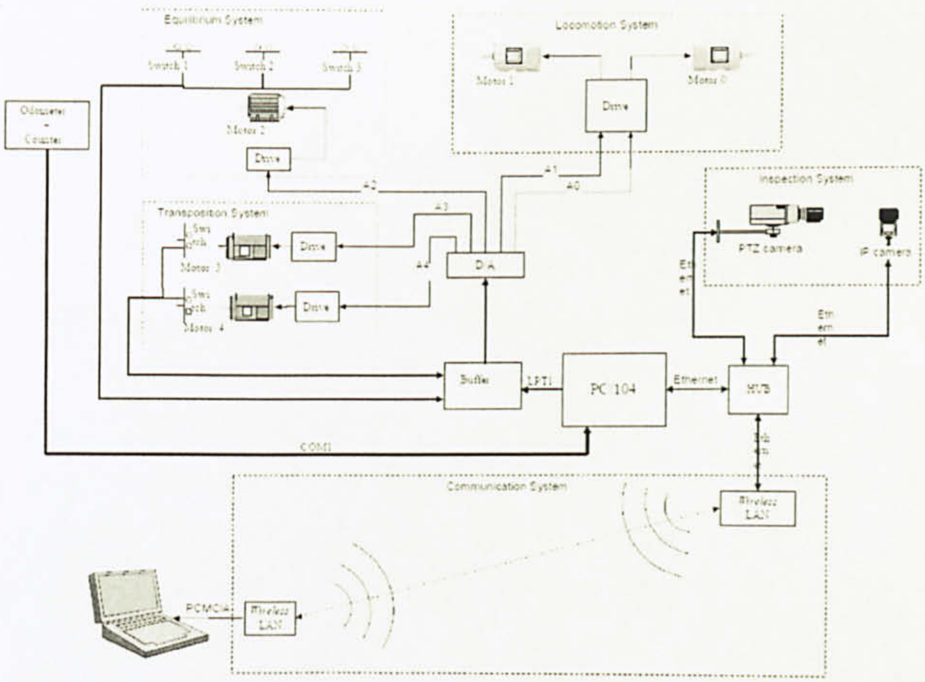

Figure 10: Logical system of the system

Analyzing the pros of this design, the tool was observed to automate the inspection of transmission line, decreasing the time interval of line disconnection and increasing the safety of the maintenance procedure as many of the robots developed for this purpose.

However, all the four patents discussed above have a similar drawback, where none were designed to concentrate on the insulator inspections. Inspection along the transmission live-line is not necessary in this case as the robot can remain at its position on the transmission tower and uses a high-definition camera to capture surveillance pictures of the live-line. This can save technicians' workload that requires them to use hot-stick for the best inspection result on insulators. The last patent discussed here illustrates a robot mechanism for not only inspecting live-line insulators but also to clean them [11].

2.4.5 *"Robot Mechanism for Cleaning and Inspection of Live-line Insulators"* © KENYON & KENYON LLP

This patent demonstrates an autonomous robot mechanism that adopts a dry cleaning method to clean the surface of live-line insulators without using water while moving along an insulator string. The robot mechanism includes a main unit having upper and lower wing frames connected with each other by a connecting bracket to surround the insulator string, a cleaning unit disposed between the upper and lower wing frames and including a base frame to perform dry cleaning with a rotational brush and a CM guide, a lift unit including a clamp and a ball-bearing screw to move the main unit up or down, and an inspection unit to electrically inspect the insulators; and a coupling unit to couple a pair of the main units to allow the pair of main units to move along a tension insulator string or a suspension insulator string.

However, this robot mechanism is not feasible to be adopted for this project as removing dry-cleaning function involves changing its mechanical design and also the programming for its motion itself [12].

2.5 Theory

2.5.1 Bluetooth

Bluetooth is a wireless communication protocol, like any other communication protocol that we may use everyday which possess client-server architecture but intended to connect to smaller device like PDA's and mobile phones within the range of 30 feet at 1Mb/s which allows a low-power wireless technology [13]. Bluetooth provides communication between the cell phone and the robot with complete isolation.

Layers of Protocol Stacks are important if we use Bluetooth communication, a device without a stack can be compared to a computer without an operating system [13]. The Bluetooth has several protocol stacks that the author will focus which are

2.5.1.1 OBEX

OBEX known as Object Exchange is a binary protocol designed to allow a variety of devices to exchange data spontaneously. Spontaneity is important in this application. OBEX has client/server architecture, and allows data to be pushed to server or pull data from a server. In our application, OBEX exchanges data with the microcontroller to perform specific tasks desired [13].

2.5.1.2 RFCOMM

RFCOMM is commonly known as the wireless serial port or the cable replacement protocol. RFCOMM simulates the functionality of a standard serial port. In this case the Bluetooth module on the robot and the cell phone would use the RFCOMM layer to synchronize its data with each other as if they were physically connected by a cable [13].

2.5.1.3 Profiles

Profiles are designed to provide a set of functionality for Bluetooth devices. In the author's case, he has determined to use the **Serial Port Profile (SSP)** that interacts directly with the RFCOMM layer in a Bluetooth protocol stack. This profile is used to create a virtual serial port on the Bluetooth-enabled device [13].

2.5.1.4 Bluetooth Adapter

A Bluetooth adapter is a device that simplifies the connection of a Bluetooth device without any tedious and messy electronic connection as shown as below.

(a) KC-21 Wire free

The KC-21 is the perfect candidate that has full-featured of Bluetooth modules available designed for maximum performance and easy assembly to customize needs. The KC-21 module includes 14 programmable input/output lines and offers high speed serial communication up to 921kbaud [14]. Most importantly it provides fully embedded and ready to use Bluetooth technology with flash memory contains embedded firmware for serial cable replacement deploying the Bluetooth serial port profile (SPP) [14].

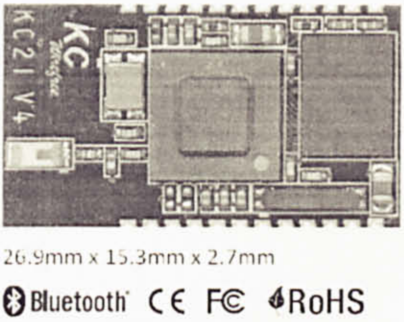

Figure 11: KC-21 v4 Wire free OEM Module

(b) SKKCA –KC Wire free Bluetooth Starter Kit

The SKKCA is a starter kit developed by an electronic company, Cytron Technologies, which distributes the KC-21 or other Bluetooth modules with necessary presoldered components that is designed for 5v TTL logic interface that is ready to be connected to a microcontroller or USB interface depending on user application.

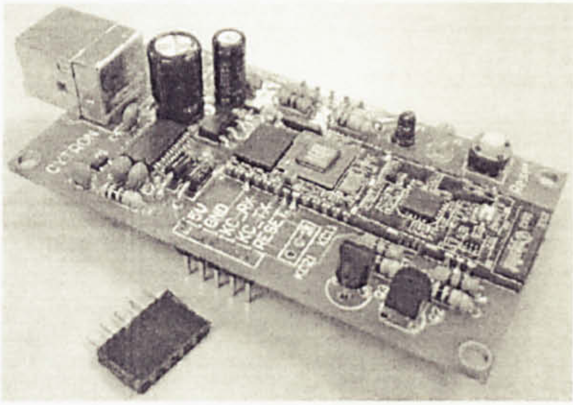

Figure 12: SKKCA-21

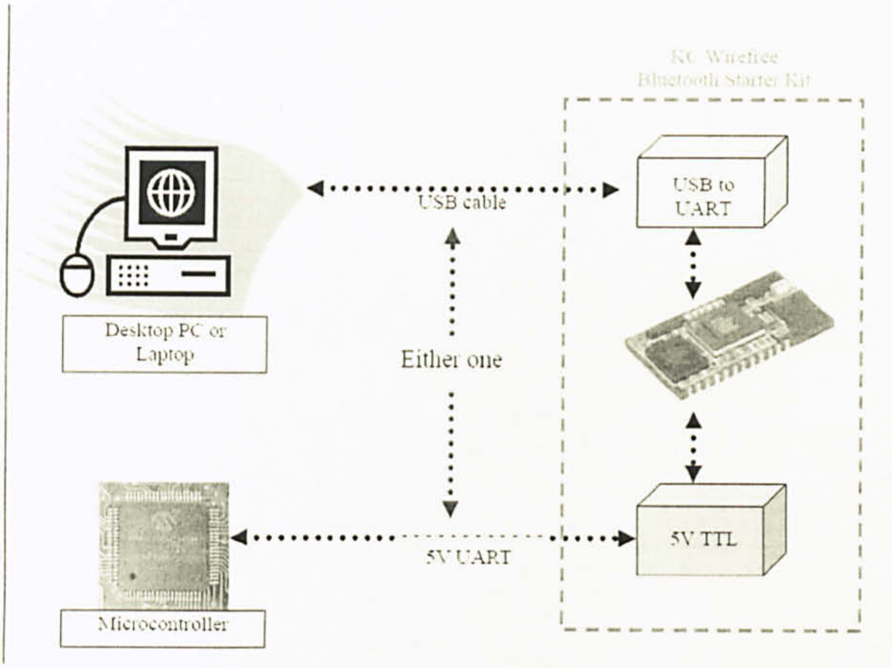

Figure 13: SKKCA System Overview

Based on *Figure 13*, we can observe how we can implement the SKKCA Bluetooth adapter in this project. We can use the starter kit by either using the USB connectivity to connect to a computer or to connect to a microcontroller which supports UART communication. The computer is needed to check the Bluetooth adapter's address before it could be paired with other Bluetooth devices as in our case will be the cell phone. Once the address is obtained, the UART connection will be used to connect the Bluetooth adapter with the microcontroller.

2.5.2 Microcontroller

A microcontroller is a powerful low-power device that potentially can be used to control robot. In general, a microcontroller is a small scaled computer where it has all the attributes of a computer like ALU, Register, RAM, ROM and I/O ports. There are many type of microcontroller available in the market varying from manufacturers, performance, features. In this project, the author will be more focused on PIC microcontroller from Microchip®. Microchip produces a series of family when it comes to microcontrollers. So far the appropriate microcontrollers that has been chosen is **PIC 16F877A.** This two microcontrollers offer features as below [15];

- **High-performance RISC CPU, only 35 single-word instructions**
- **32K FLASH Memory, 1.5K SRAM (1K = 1024)**
- **Register-to-register & accumulator-based operations**
- **Rich set of peripherals**
  - **5 Digital I/O ports with 25mA sink/source capacity**
  - **Three 8/16-bit Timer/counters**
  - **Capture/Compare/PWM (CCP) modules**
  - **8 10-bit A/D channels**
  - **Synchronous Serial Bus: SPI (Master mode) or I2C (Master/Slave)**
  - **Parallel Slave Port (PSP) – 8 bits wide with external RD, WR and CS controls (40/44 pin only)**
  - **USART, supports RS-232**

Figure 14: PIC 16F877A

2.5.3 Programming Language

A programming language is an artificial language designed to express computations that can be performed by a machine, particularly a computer. It can be used to create programs that control the behavior of a machine, to express algorithms precisely, or as a mode of human communication [16]. There are three fundamental types of programming language;

- Machine language

  This is a system of instructions and data executed directly by a computer's CPU. It is the only language the machine can understand directly. This may also be referred as a primitive programming language or the lowest-level representation of a compiler.

- Assembly language

  These languages are a type of low-level languages for programming computers, microprocessors, microcontrollers and other ICs. It is a symbolic representation of the machine language, where it uses easily recognizable codes. However, an assembler is needed in order to translate the assembly language into machine language before the device could carry out the task given.

- High level language.

A high level programming language is a programming language with strong abstraction from the details of the computer. It uses natural language elements that is easy to be understood by new users. Among the most common example of high level language application is Visual Basics.

CHAPTER 3
METHODOLOGY

Generally, the inspection robot being presented in this paper is a remotely controlled inspection robot. The robot navigation is managed from ground level by a technician. Unlike robot systems proposed in the patent works that has been done worldwide, robots moving along the live-lines, this paper introduces a new scope of inspection with a relatively new method. This is necessary as robots moving along live-line cannot provide a worthy inspection on the insulators as this inspection requires a closed up picture or video on the string of insulators. To serve the main objective of this project, the robot will be designed such to achieve an effective inspection with a reasonable cost. The robot is equipped with limit switches, and data communication capability for control, navigation and feedback or output.

3.1 Operational system

The typical hollow structure of the transmission tower allows a pulley system to assist robot placement on the transmission tower. Hence, taking advantage of this option, a motorized pulley can be implemented as for the vertical movement of the robot. As an added feature to the transmission pylon, a platform can be attached to provide the robot path at every level of insulators. The concept above is illustrated in *Figure 15* while the red arrows on *Figure 15* show the travelling path of the robot for the first level of insulators. This leaves us to only the horizontal movement and inspection navigation to be considered in the robot designing.

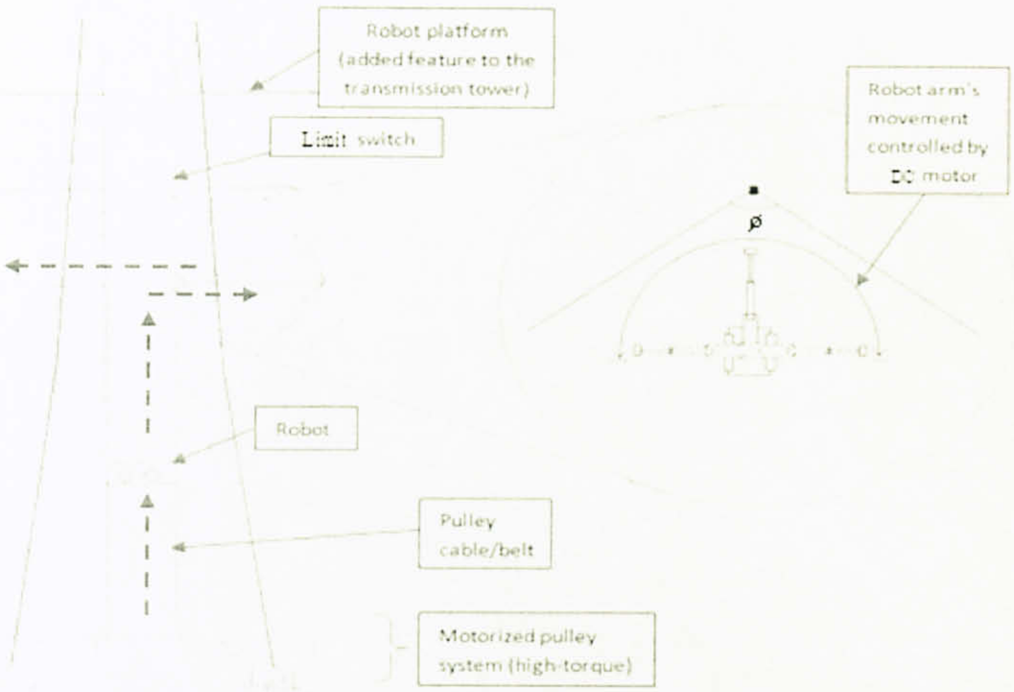

Figure 15: Conceptual design of robot operation

3.2 System configuration

Considering the obstructive working platform, as seen in *Figure 16*, the performance of the inspection robot is fully controllable by user. However, with the use a microcontroller with memory, the robot can be programmed to 'remember' its path and actions accordingly based on its initial operation.

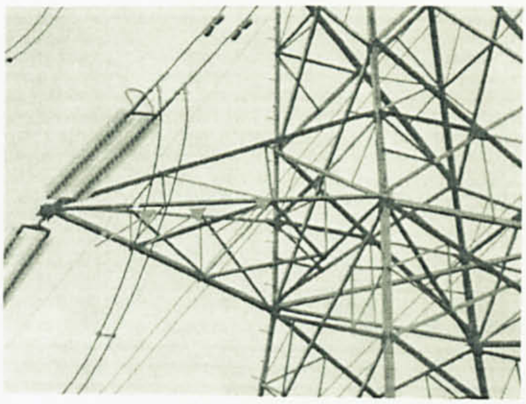

Figure 16: Pylon design obstructs arm movement

Figure 17 shows the system configuration, which consists of a robot embedded with SKKCA-21 (Bluetooth module) and a wireless camera, and a main control station integrated with Bluetooth communication for controls and output respectively. Hence, user can wirelessly navigate the robot from a reasonable distance on ground level via a personal computer.

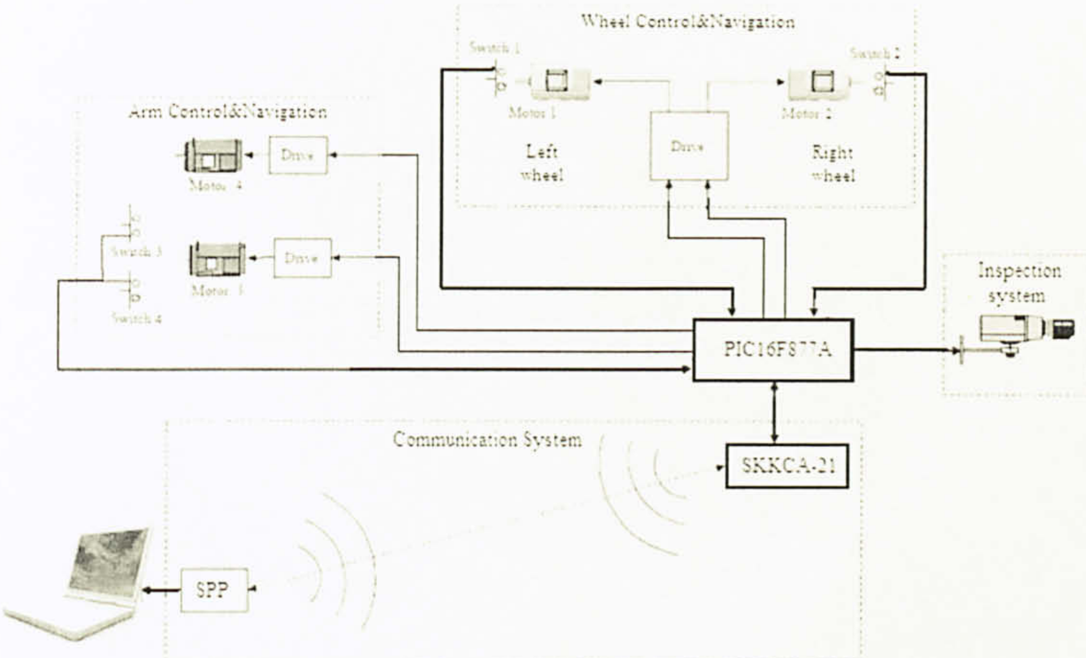

Figure 17: System configuration

This project is developed based on the development flow shown in *Figure 13* which illustrates the Hardware Development Life Cycle and *Figure 17* illustrates the Software Development Life Cycle respectively.

3.2.1 Hardware Development

Based on the illustration on *Figure 17*, the development of hardware begins with the first step which is collecting data which are related with the hardware of the robot which ranges from dimension, material type, circuitry, electronic components with respect to each sub-parts of the robot. Then, the data collected will be analyzed to ensure that it fits characteristic of the robot.

Any data that doesn't support the main purpose of the robot will be discarded or will be just archived for later use. Designing of the circuit schematic and frame sketches stage will take place soon after the analytical stage has concluded the final attributes of the robot. After the design stage, the best design chosen will be fabricated using the appropriate tools available and by referring to datasheet with respect to the component that being used to develop the circuit and dimension for each parts of the robot that has to be fabricated and assembled. The last stage is the testing stage where everything that has been put together will be tested until the goal is met. Otherwise, the process of development will initialized again to ensure a suitable and working prototype is achieved.

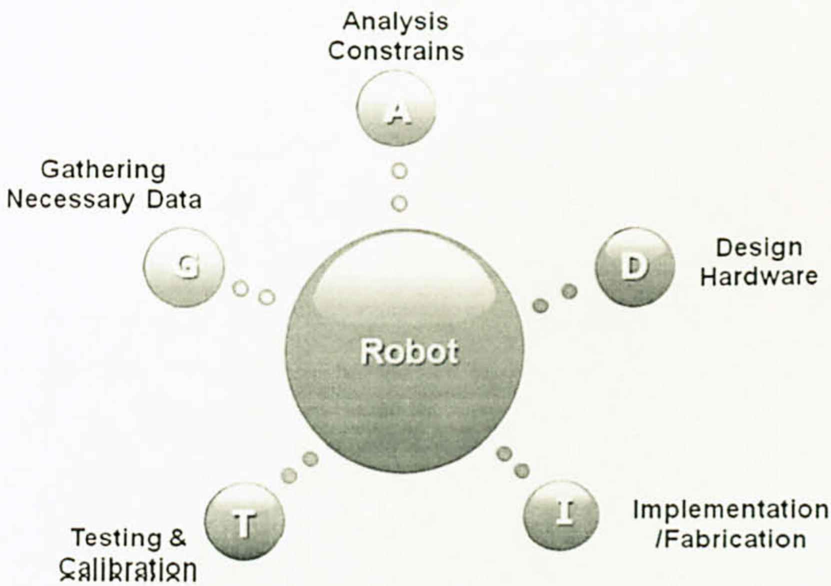

Figure 18: Hardware Development Life Cycle

3.2.2 Software Development

The software development of this project is vital to ensure that the system works well with the hardware of the robot. To meet this goal, a software development life cycle is used to sequentially guide the author to develop the software for the robot and the controller. *Figure 19* shows how the software development for the robot is initiated by gathering the requirements of the software for the robot and the controller respectively. The data is then analyzed and the important parts of the software are then noted before the designing stage takes place. Coding is a stage which takes place right after the analysis has concluded the main parts and the sub parts of the software. Testing takes place to ensure a working code. The cycle is repeated whenever there are changes in the software starting from analysis sequence, which is to analyze the fault of the error before further changes are made in the design and software code.

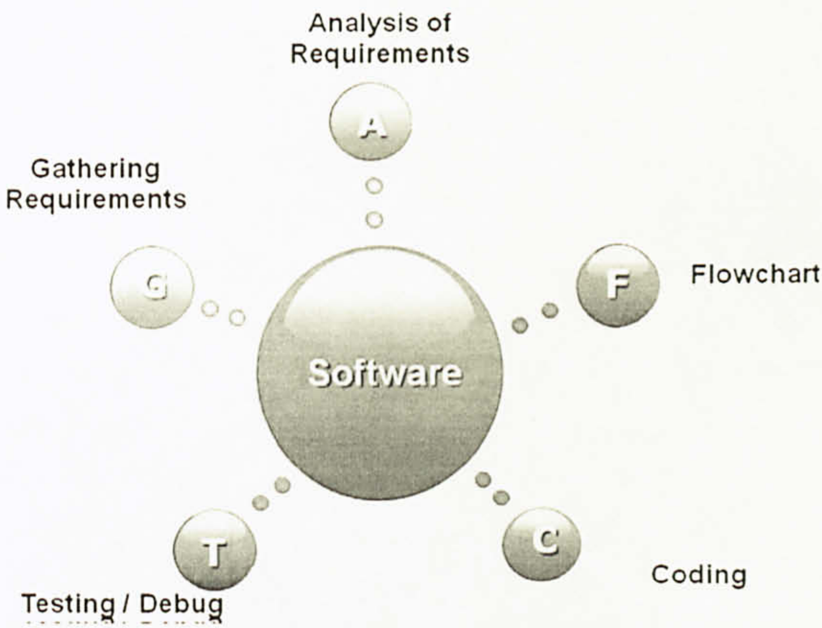

Figure 19: Software Development Life Cycle

3.2.3 Hardware and Software Integration

Hardware and software integration is the most vital part of this project. This is the part where the software coded for the robot must match the physical requirements of the robot. Failure to meet this requirement will result in a malfunctioning prototype and the analytical stage of both hardware and software must be further studied in crder to achieve a hand in hand agreement between the software and hardware of the robot.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Hardware design

The basic mechanical design requirement is a balanced structure with wheels to move forward and backward by controls. This design also has to have a retractable arm fixed to a motor that enables arm rotation at the same time. This arm rotation needs to be in full control of the user while the d retraction can be automated using two limit switches to avoid damages to the motor. Hence, looking into these requirements, the robot is designed such as shown in *Figure 20* below.

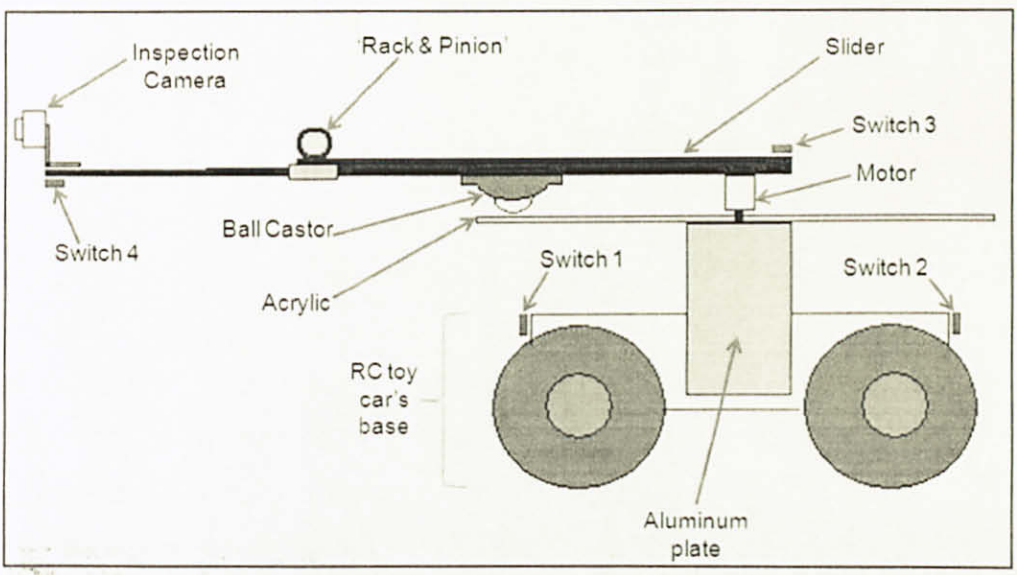

Figure 20: Hardware design of the robot

The design above incorporates two DC motors for wheels using a L298 driver and two mini DC geared motors (150:1) for arm driven by L293D driver. This robot is build using a RC toy car's base (4WD) where four wheels are in use. The left wheels controlled by one DC motor with the help of gears and similar on the right side of the body. As for the arm, a drawer slider has been utilized to suit the purpose. For extension and retraction of the slider, 'rack & pinion' approach was used where the rack is made of scrap material (belt) and the pinion is made of acrylic in the centre with the belt along its edge. The wireless camera is attached at the slider's edge and would we carried along while extension and retraction processes. The arm can be extended up to 30cm. A ball castor is placed to support the weight of the slider efficiently even with full extension. The aluminum plate, acrylic, and ball castor as shown in the design are mainly added to the design to support the arm structure on the base. The developed hardware design is as shown in *Figure 21* below.

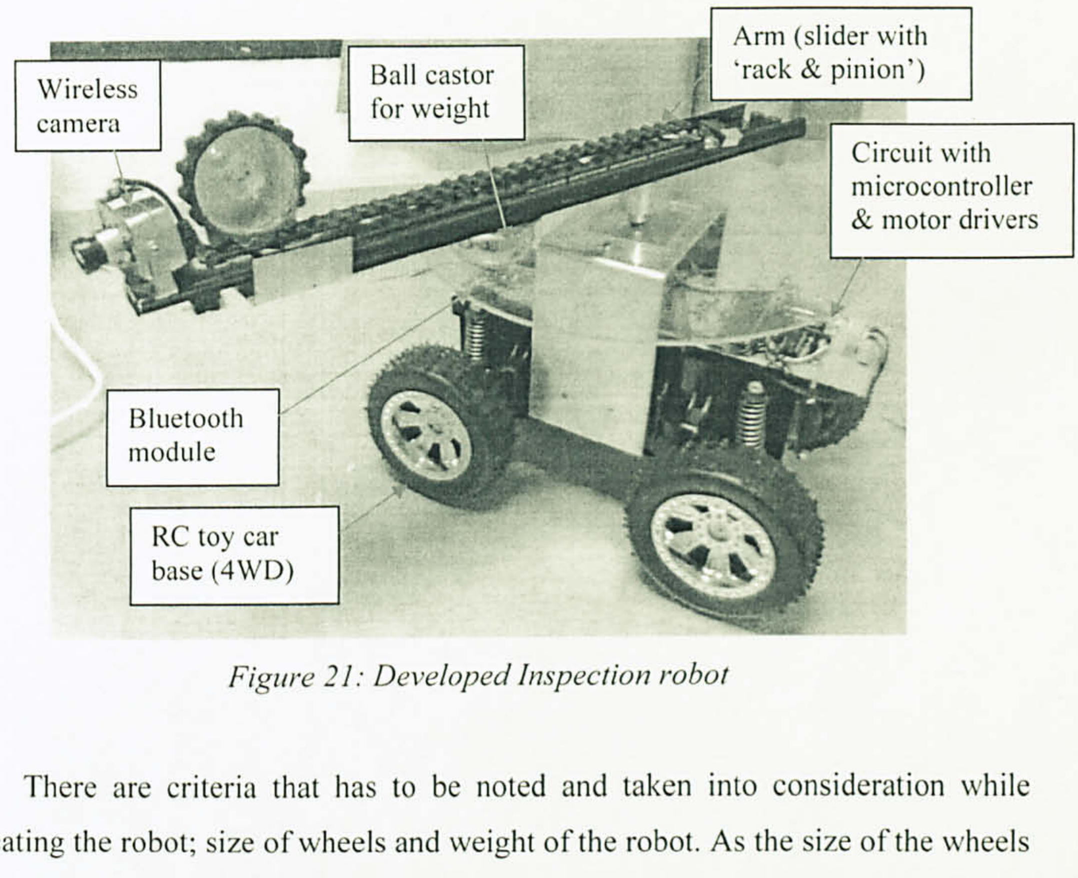

Figure 21: Developed Inspection robot

There are criteria that has to be noted and taken into consideration while fabricating the robot; size of wheels and weight of the robot. As the size of the wheels increases, the speed of the robot will be reduced. The speed is also influenced by the weight of components used to construct the robot. However, since the robot is embedded with a 16-bit microcontroller, the speed of the wheels can also be controlled accordingly using PWM inputs.

4.2 Technical Design

For the technical design of the inspection robot, PIC16F877A microcontroller is embedded to the operating circuit as shown in *Figure 21* below. PIC16F877A is a RISC processor that includes a sequencer, a register ALU (RALU), data RAM, and a coprocessor interface. It is driven by a 20 MHz crystal oscillator in this case, which gives 0.02 cycles per nanosecond.

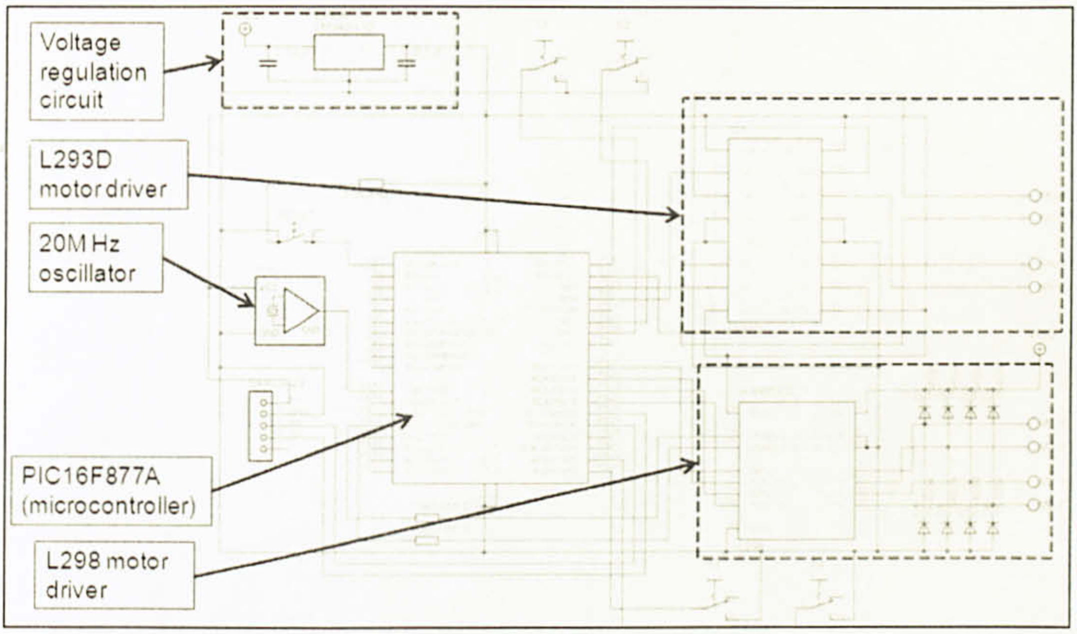

Figure 22: Electronic schematic design

The writer is supplying 12V supply to the robot. However, for circuit operation, only 5V is needed and any voltage higher than that would damage the electronic components on board. Therefore, L7805 chip is used to regulate the 12V to a 5V supply into the electronic circuit. *Figure 23* shows the circuit diagram for the voltage regulator.

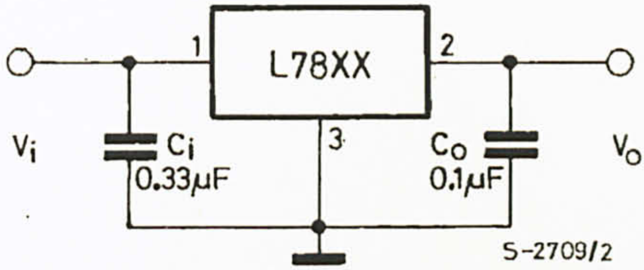

Figure 23: L7805 circuit diagram

L298 motor driver uses IN4001 diodes to sink current spikes produced during motor braking. To protect L298, 10kΩ resistors are placed at enable inputs. By grounding pin 1 and pin 15 of L298, a clean grounding at motor terminals was obtained; 0V when logic 0 at the terminal output. The finale motor controller circuit using L298 is shown in *Figure 24* below.

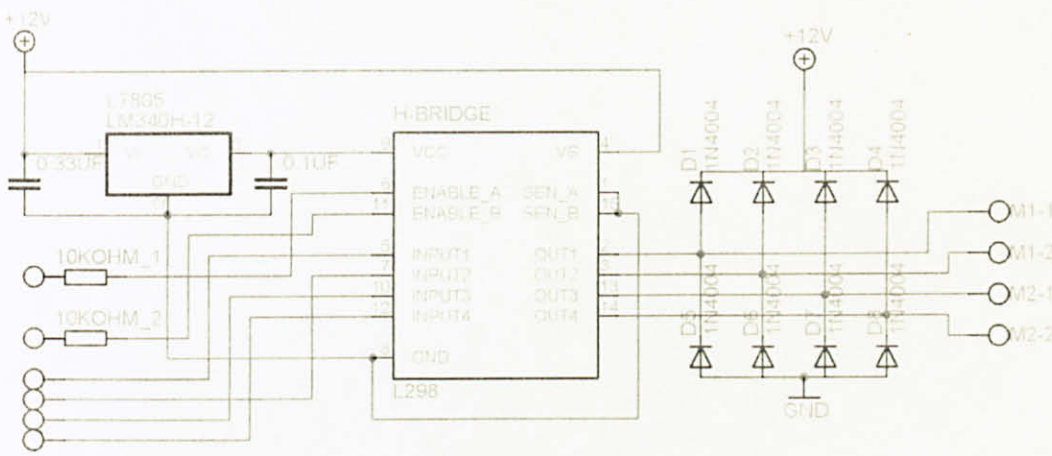

Figure 24: Electronic Schematic Diagram (L298 motor driver)

However, since the arm uses smaller motors and requires less current, L293D driver was chosen. L293D is an integrated chip that has internal diodes. Thus, external circuit for current spike sink is not necessary. However, this two-channeled IC only produces peak output current of 1.2Amp per channel. Unlike L298 which was installed with a heat sink to avoid overheat, L293D is over-temperature protected. *Figure 25 shows* the block diagram of L293D's internal circuit;

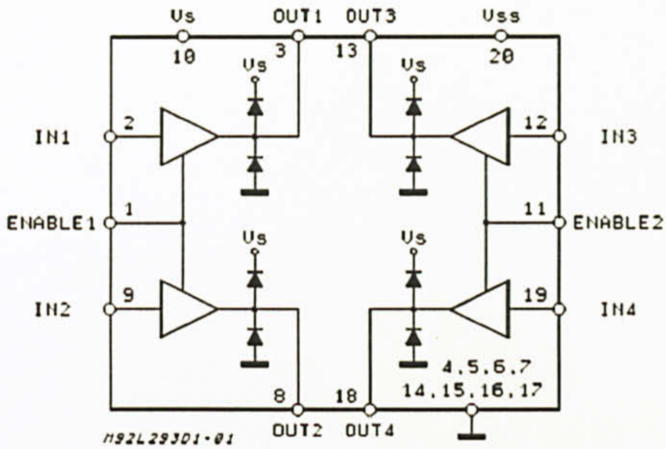

Figure 25: L293D Block Diagram

This IC works efficiently on its own without requiring any extra components; resistors, diodes, etc. For a wireless transmission, SKKCA-21 is integrated to the microcontroller. Further controls are controlled or created via PIC programming. Therefore, the final electronic circuit developed based on the design as described is shown as in *Figure 26*.

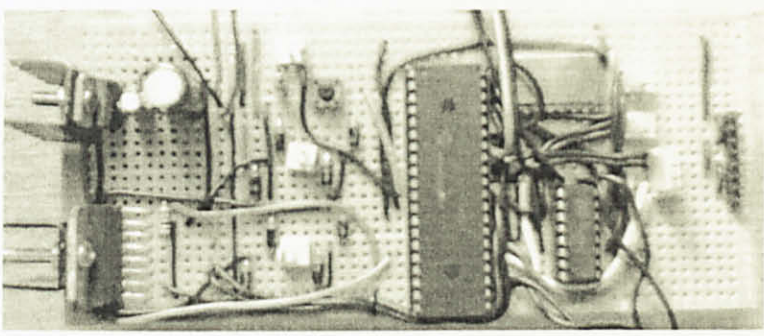

Figure 26: Developed electronic circuit

4.3 Software Design

Software has to be written for the PC and Robot in order to enable the wireless communications. The software design for the system is divided into two main parts;

- Communication between Robot with Bluetooth transceiver
- Communication between PC with Bluetooth transceiver

The user operates the robot from the main control station that is located on ground level within the wireless medium range from the robot. To ease navigation, Visual Studio 2005 (VS 2005) application is being used as it is a user-friendly application with easy-to-use buttons that are programmed using C codes. VS 2005 is the third-generation event-driven programming language or simply a high-level language. It is an IDE from Microsoft for its COM programming model. To establish a wireless connection via laptop, SPP connection is used. Shortly, the software design concept is illustrated in the flowchart below.

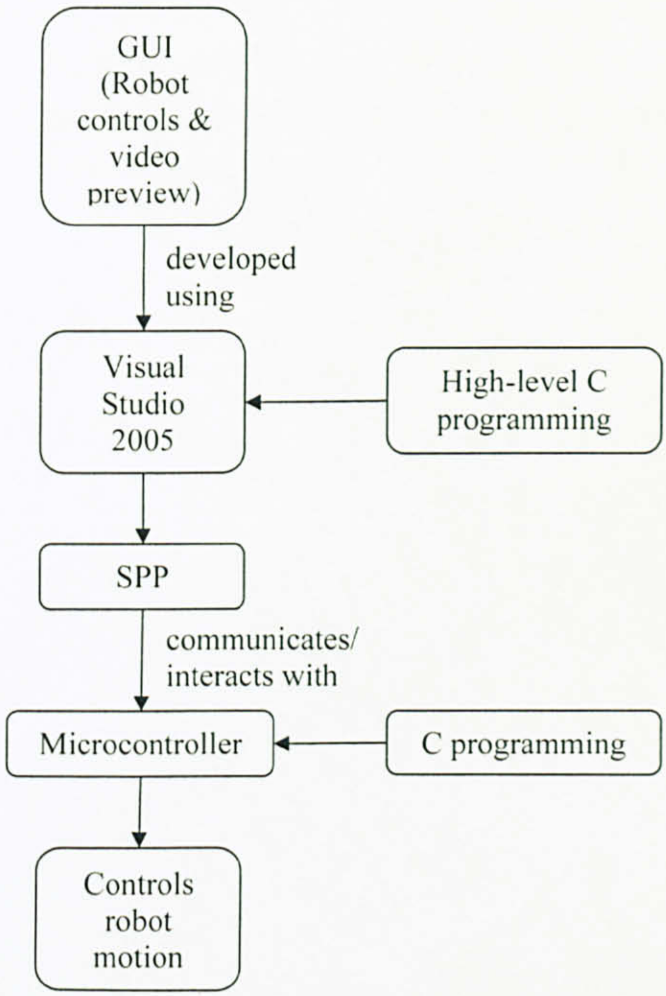

Figure 27: Software design flowchart

To send and receive control data, Bluetooth technology is utilized as this technology is the most affordable and efficient wireless technology that best demonstrates the concept of this inspection robot. A Bluetooth dongle, which utilizes COM26 of the laptop ports, is paired to the SKKCA-21 (KCWireFree Device) which is placed on the robot and connected to the PIC16F877A chip. The PIC chip, receiving instructions from user, would then navigate the robot accordingly. The Graphical User Interface (GUI) developed using VS 2005 is shown in *Figure 28* below. A live video coverage can also be viewed in the control box where 'Start Recording' and 'Stop Recording' functions are also available.

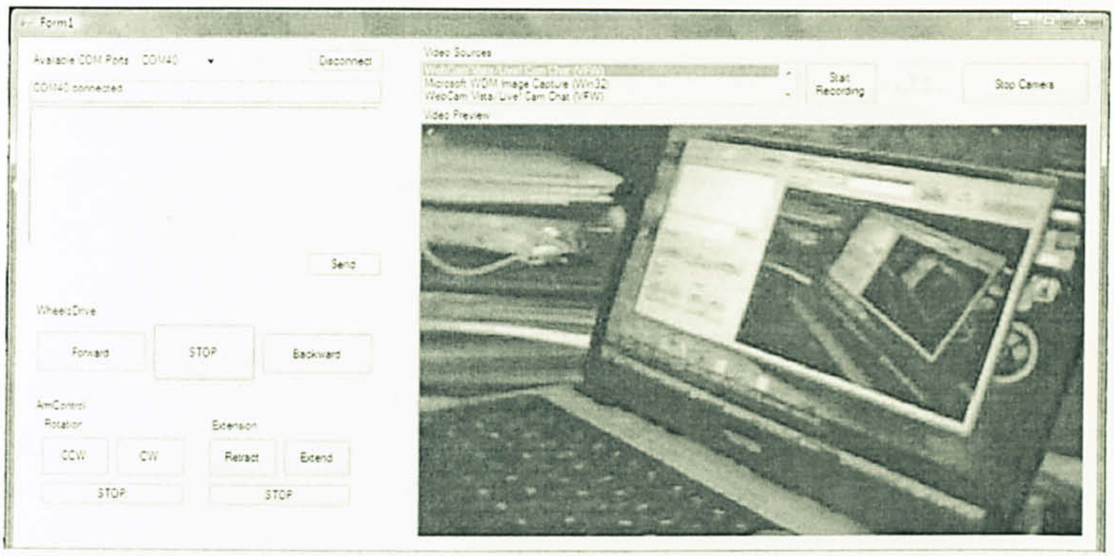

Figure 28: GUI

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

Reliability of the power transmission system has a very major impact on the state's economic activity and ultimately customer satisfaction. In this paper, an inspection robot is introduced to replace the traditional and expensive method of inspection involving binoculars and helicopters. In short, the inspection robot is composed of mechanism, power supply, sensor, navigation, image capturing, data wireless transceiver and its control system. Though, with the budget constrain, an industrial-scale inspection robot may not be developed. However, this robot is practical and can be adjusted to a laboratory scale to demonstrate the concept and effectiveness of the idea.

The proposed extendable arm inspection robot prototype can fulfill full-path kinematic target, including moving along the no-obstacle customized platform and varying moving paths (bi-direction). The flexible working path decreases the performance of the robot, but the robot is capable of carrying out the present kinematic target along its path although technical difficulties were faced in its software designing causing inability of the prototype to function as programmed. The model proposed in this paper is not far from demonstrating the actuality in inspection work environment. Further research can be conducted to improve the robot's dynamic performance, simulation for obstacle-overcoming in flexible working environment and the effects of electromagnetic wave in wireless transmissions.

To further upgrade the project, a PCB board can be used to replace the Veroboard circuit design as applied here. PCB board promises less failure occurrences compared to a volatile veroboard design. Besides that, the wireless transmission medium used in this paper need to be tested on real working environment as wave interference is expected to occur as Bluetooth bandwidth ranges in 2.45 G Hz while the emf wave induced by transmission live line can range higher. In case of interference, the current wireless technology can be replaced with a more efficient and interference-free transmission medium for optimum performance.

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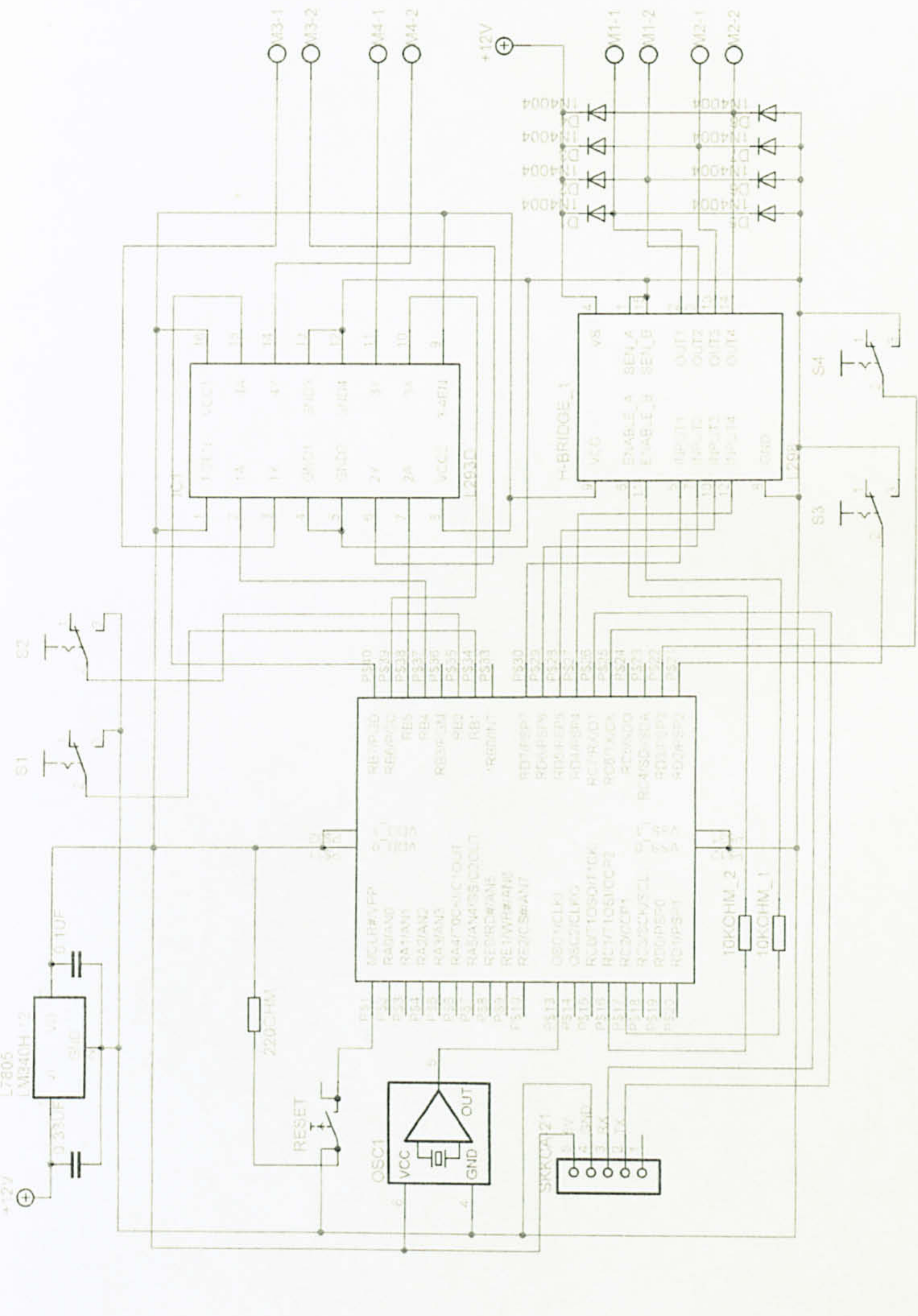
APPENDIX A

Electronic Schematics Diagram



APPENDIX B

Main Source Code for PIC16F877A microcontroller

```
#include <16F877A.h>
//#device adc=8
#use delay(clock=20000000)
#fuses NOWDT,HS, PUT, NOPROTECT,
NODEBUG, NOBROWNOUT, LVP,
NOCPD, NOWRT
#use
rs232(baud=115200,parity=N,xmit=PIN_
C6,rcv=PIN_C7,bits=8)


#define switch1 input(PIN_B1) //this is
switch input for front
#define switch2 input(PIN_B2) //this is
switch input for back
#define switch3 input(PIN_D2) //this is
switch input for full arm extension
#define switch4 input(PIN_D3) //this is
switch input for full arm retraction

//int y;
//int x;
char inst;


//>>>>>WheelzDrive<<<<<<

void motor_stop()      //stop function
{
output_low(PIN_D7);
output_low(PIN_D6);
output_low(PIN_D5);
output_low(PIN_D4);
set_pwm2_duty(0);
set_pwm1_duty(0);
//delay_ms(500);
}

void motor_forward(int x) //forward
function
{
//motor_init();
if(switch1 !=1){
output_high(PIN_D7);
output_low(PIN_D6);
output_high(PIN_D5);
output_low(PIN_D4);
set_pwm2_duty(x);
set_pwm1_duty(x);
}
else
motor_stop();
}

void motor_reverse(int y)
{ //reverse function
if(switch2 !=1){
output_low(PIN_D7);
output_high(PIN_D6);
output_low(PIN_D5);
output_high(PIN_D4);
set_pwm2_duty(y);
set_pwm1_duty(y);
}
else
motor_stop();
}

//>>>>>Arm Control [Rotation]<<<<<<

void arm_rotate_stop()      //stop arm
rotation
{
output_low(PIN_B4);
output_low(PIN_B5);
}

void arm_rotate_CW()   //arm rotating
clockwise function
{
output_high(PIN_B4);
output_low(PIN_B5);
}
```

```
void arm_rotate_CCW()  //arm rotating counter-clockwise function
{
output_low(PIN_B4);
output_high(PIN_B5);
}

//>>>>>Arm Control [Extension]<<<<<<

void arm_extension_stop()            //stop function for arm
{
output_low(PIN_B6);
output_low(PIN_B7);
}

void arm_extend()     //arm extending function
{
if (switch3 !=1){
output_high(PIN_B6);
output_low(PIN_B7);
}
else
arm_extension_stop();
}

void arm_retract()    //arm retracting function
{
if (switch4 !=1){
output_low(PIN_B6);
output_high(PIN_B7);
}
else
arm_extension_stop();
}

//>>>>>>>Main Function<<<<<<<<

void instruction()
{
inst = getchar();
switch(inst)
{
case 'D': motor_forward(100);
break;
case 'A': motor_reverse(100);
break;
case 'W': motor_stop();
break;
case 'L': arm_rotate_CW();
break;
case 'O': arm_rotate_CCW();
break;
case 'P': arm_rotate_stop();
break;
case 'J': arm_extend();
break;
case 'G': arm_retract();
break;
case 'Y': arm_extension_stop();
break;
default : motor_stop();
break;
}
}

int main(){
  setup_timer_2(T2_DIV_BY_1, 200, 1);//have to get proper values to achieve 25khz [mode,period,postscale]
  setup_ccp1(CCP_PWM);
  setup_ccp2(CCP_PWM);

  while(1){
  instruction();
  //detect_obs()  }
}
```

APPENDIX C

Source Code for Visual Studio 2005 controller (High-level language)

```
Imports
System.Runtime.InteropServices

Public Class Form1

    Const WM_CAP_START = &H400S
    Const WS_CHILD = &H40000000
    Const WS_VISIBLE =
&H10000000

    Const WM_CAP_DRIVER_CONNECT
= WM_CAP_START + 10
    Const
WM_CAP_DRIVER_DISCONNECT =
WM_CAP_START + 11
    Const WM_CAP_EDIT_COPY =
WM_CAP_START + 30
    Const WM_CAP_SEQUENCE =
WM_CAP_START + 62
    Const WM_CAP_FILE_SAVEAS =
WM_CAP_START + 23

    Const WM_CAP_SET_SCALE =
WM_CAP_START + 53
    Const
WM_CAP_SET_PREVIEWRATE =
WM_CAP_START + 52
    Const WM_CAP_SET_PREVIEW =
WM_CAP_START + 50

    Const SWP_NOMOVE = &H2S
    Const SWP_NOSIZE = 1
    Const SWP_NOZORDER = &H4S
    Const HWND_BOTTOM = 1

    '--The
capGetDriverDescription
function retrieves the version
description of the capture
driver--
    Declare Function
capGetDriverDescriptionA Lib
"avicap32.dll" _
        (ByVal wDriverIndex As
Short, _
        ByVal lpszName As
String, ByVal cbName As
Integer, ByVal lpszVer As
String, _
        ByVal cbVer As Integer)
As Boolean

    '--The
capCreateCaptureWindow function
creates a capture window--
    Declare Function
capCreateCaptureWindowA Lib
"avicap32.dll" _
        (ByVal lpszWindowName As
String, ByVal dwStyle As
Integer, _
        ByVal x As Integer,
ByVal y As Integer, ByVal
nWidth As Integer, _
        ByVal nHeight As Short,
ByVal hWnd As Integer, _
        ByVal nID As Integer)
As Integer

    '--This function sends the
specified message to a window
or windows--
    Declare Function
SendMessage Lib "user32" Alias
"SendMessageA" _
        (ByVal hwnd As Integer,
ByVal Msg As Integer, ByVal
wParam As Integer, _

<MarshalAs(UnmanagedType.AsAny)
> ByVal lParam As Object) As
Integer

    '--Sets the position of the
window relative to the screen
buffer--
    Declare Function
SetWindowPos Lib "user32" Alias
"SetWindowPos" _
```

```
        (ByVal hwnd As Integer,
_
        ByVal hWndInsertAfter
As Integer, ByVal x As Integer,
ByVal y As Integer, _
        ByVal cx As Integer,
ByVal cy As Integer, ByVal
wFlags As Integer) As Integer

    '--This function destroys
the specified window--
    Declare Function
DestroyWindow Lib "user32"
(ByVal hndw As Integer) As
Boolean

    Dim VideoSource As Integer
    Dim hWnd As Integer
    Dim WithEvents serialPort
As New IO.Ports.SerialPort


    Private Sub
Form1_Load(ByVal sender As
System.Object, ByVal e As
System.EventArgs) Handles
MyBase.Load

        For i As Integer = 0 To
My.Computer.Ports.SerialPortNam
es.Count - 1

cbbCOMPorts.Items.Add(My.Comput
er.Ports.SerialPortNames(i))
        Next
        btnDisconnect.Enabled =
False

btnStartRecording.Enabled =
True

btnStopRecording.Enabled =
False
        '---list all the video
sources---
        ListVideoSources()
    End Sub

    '--disconnect from video
source---
    Private Sub
StopPreviewWindow()
        SendMessage(hWnd,
WM_CAP_DRIVER_DISCONNECT,
VideoSource, 0)
        DestroyWindow(hWnd)
    End Sub

    '---list all the various
video sources---
    Private Sub
ListVideoSources()
        Dim DriverName As
String = Space(80)
        Dim DriverVersion As
String = Space(80)
        For i As Integer = 0 To
9
            If
capGetDriverDescriptionA(i,
DriverName, 80, DriverVersion,
80) Then

lstVideoSources.Items.Add(Drive
rName.Trim)
            End If
        Next
    End Sub

    '---save the image---
    Private Sub CaptureImage()
        Dim data As IDataObject
        Dim bmap As Image

        '---copy the image to
the clipboard---
        SendMessage(hWnd,
WM_CAP_EDIT_COPY, 0, 0)

        '---retrieve the image
from clipboard and convert it
        ' to the bitmap format
        data =
Clipboard.GetDataObject()
        If
data.GetDataPresent(GetType(Sys
tem.Drawing.Bitmap)) Then
            bmap =
CType(data.GetData(GetType(Syst
em.Drawing.Bitmap)), Image)
            PictureBox1.Image =
bmap
            StopPreviewWindow()
        End If
    End Sub
```

```
    '---preview the selected
video source---
    Private Sub
PreviewVideo(ByVal pbCtrl As
PictureBox)
        hWnd =
capCreateCaptureWindowA(VideoSo
urce, WS_VISIBLE Or WS_CHILD,
0, 0, 0, 0,
pbCtrl.Handle.ToInt32, 0)
        If SendMessage(hWnd,
WM_CAP_DRIVER_CONNECT,
VideoSource, 0) Then
            '---set the preview
scale---
            SendMessage(hWnd,
WM_CAP_SET_SCALE, True, 0)
            '---set the preview
rate (ms)---
            SendMessage(hWnd,
WM_CAP_SET_PREVIEWRATE, 30, 0)
            '---start
previewing the image---
            SendMessage(hWnd,
WM_CAP_SET_PREVIEW, True, 0)
            '---resize window
to fit in PictureBox control---
            SetWindowPos(hWnd,
HWND_BOTTOM, 0, 0,
pbCtrl.Width, pbCtrl.Height,
SWP_NOMOVE Or SWP_NOZORDER)
        Else
            '--error connecting
to video source---
            DestroyWindow(hWnd)
        End If
    End Sub


    Private Sub
lstVideoSources_SelectedIndexCh
anged(ByVal sender As
System.Object, ByVal e As
System.EventArgs) _
       Handles
lstVideoSources.SelectedIndexCh
anged

        '---stop video in case
it is on---
        StopPreviewWindow()
        '---check which video
source is selected---
        VideoSource =
lstVideoSources.SelectedIndex
        '---preview the
selected video source

PreviewVideo(PictureBox1)
    End Sub

    Private Sub
btnStopCamera_Click(ByVal
sender As System.Object, ByVal
e As System.EventArgs) Handles
btnStopCamera.Click
        StopPreviewWindow()
    End Sub

    Private Sub
btnStartRecording_Click(ByVal
sender As System.Object, ByVal
e As System.EventArgs) Handles
btnStartRecording.Click

btnStartRecording.Enabled =
False

btnStopRecording.Enabled = True
        '---start recording---
        SendMessage(hWnd,
WM_CAP_SEQUENCE, 0, 0)
    End Sub

    Private Sub
btnStopRecording_Click(ByVal
sender As System.Object, ByVal
e As System.EventArgs) Handles
btnStopRecording.Click

btnStartRecording.Enabled =
True

btnStopRecording.Enabled =
False
        '---save the recording
to file---
        SendMessage(hWnd,
WM_CAP_FILE_SAVEAS, 0,
"C:\RecordedVideo.avi")
    End Sub

    Private Sub
btnCapturePhoto_Click(ByVal
sender As System.Object, ByVal
e As System.EventArgs)
        CaptureImage()
```

```
    End Sub
    Private Sub
DataReceived(ByVal sender As
Object, ByVal e As
System.IO.Ports.SerialDataRecei
vedEventArgs) Handles
serialPort.DataReceived


txtDataReceived.Invoke(New
myDelegate(AddressOf
updateTextBox), New Object()
{})
    End Sub

    Private Sub
btnSend_Click(ByVal sender As
System.Object, ByVal e As
System.EventArgs) Handles
btnSend.Click
        Try

serialPort.Write(txtDataToSend.
Text & vbCrLf)
            With
txtDataReceived
                .SelectionColor
= Color.Black

.AppendText(txtDataToSend.Text
& vbCrLf)

.ScrollToCaret()
            End With
            txtDataToSend.Text
= String.Empty
        Catch ex As Exception
            MsgBox(ex.ToString)
        End Try
    End Sub

    Public Delegate Sub
myDelegate()
    Public Sub updateTextBox()
        With txtDataReceived
            .Font = New
Font("Garamond", 12.0!,
FontStyle.Bold)
            .SelectionColor =
Color.Red

.AppendText(serialPort.ReadExis
ting)
            .ScrollToCaret()
        End With
    End Sub

    Private Sub
btnConnect_Click(ByVal sender
As System.Object, ByVal e As
System.EventArgs) Handles
btnConnect.Click
        If serialPort.IsOpen
Then
            serialPort.Close()
        End If
        Try
            With serialPort
                .PortName =
cbbCOMPorts.Text
                .BaudRate =
96000
                .Parity =
IO.Ports.Parity.None
                .DataBits = 8
                .StopBits =
IO.Ports.StopBits.One
                ' .Encoding =
System.Text.Encoding.Unicode
            End With
            serialPort.Open()

Me.Form1_Load(sender, e)

            lblMessage.Text =
cbbCOMPorts.Text & "
connected."
            btnConnect.Enabled
= False

btnDisconnect.Enabled = True
        Catch ex As Exception
            MsgBox(ex.ToString)
        End Try
    End Sub

    Private Sub
btnDisconnect_Click(ByVal
sender As System.Object, ByVal
e As System.EventArgs) Handles
btnDisconnect.Click
        Try
            serialPort.Close()
            lblMessage.Text =
serialPort.PortName & "
disconnected."
            btnConnect.Enabled
= True
```

```
btnDisconnect.Enabled = False
        Catch ex As Exception
            MsgBox(ex.ToString)
        End Try
    End Sub

    Private Sub
motor_forward_Click(ByVal
sender As System.Object, ByVal
e As System.EventArgs) Handles
motor_forward.Click
        serialPort.Write("D" &
vbCrLf)
    End Sub

    Private Sub
motor_stop_Click(ByVal sender
As System.Object, ByVal e As
System.EventArgs) Handles
motor_stop.Click
        serialPort.Write("W" &
vbCrLf)
    End Sub

    Private Sub
motor_reverse_Click(ByVal
sender As System.Object, ByVal
e As System.EventArgs) Handles
motor_reverse.Click
        serialPort.Write("A" &
vbCrLf)
    End Sub

    Private Sub
arm_rotate_CCW_Click(ByVal
sender As System.Object, ByVal
e As System.EventArgs) Handles
arm_rotate_CCW.Click
        serialPort.Write("O" &
vbCrLf)
    End Sub

    Private Sub
arm_rotate_CW_Click(ByVal
sender As System.Object, ByVal
e As System.EventArgs) Handles
arm_rotate_CW.Click
        serialPort.Write("L" &
vbCrLf)
    End Sub

    Private Sub
arm_rotate_stop_Click(ByVal
sender As System.Object, ByVal
e As System.EventArgs) Handles
arm_rotate_stop.Click
        serialPort.Write("P" &
vbCrLf)
    End Sub

    Private Sub
arm_retract_Click(ByVal sender
As System.Object, ByVal e As
System.EventArgs) Handles
arm_retract.Click
        serialPort.Write("G" &
vbCrLf)
    End Sub

    Private Sub
arm_extend_Click(ByVal sender
As System.Object, ByVal e As
System.EventArgs) Handles
arm_extend.Click
        serialPort.Write("J" &
vbCrLf)
    End Sub

    Private Sub
arm_extension_stop_Click(ByVal
sender As System.Object, ByVal
e As System.EventArgs) Handles
arm_extension_stop.Click
        serialPort.Write("Y" &
vbCrLf)
    End Sub
End Class
```

APPENDIX D

Gantt Chart

No	Detail/Week	1	2	3	4	5	6	7	8		10	11	12	13	14	15	20	22
1	Project work continues from FYP1									Mid-semester break								
2	Submission of Progress Report 1																	
3	Submission of Progress Report 2																	
4	Pre-EDX																	
5	Submission of Draft Report																	
6	Submission of Final Report (soft cover)																	
7	Submission of Technical report																	
8	Oral Presentation																	
9	Submission of Final Dissertation (hard cover)																	