SMALL CLEANING ROBOT FOR OFFICE WINDOW

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SMALL CLEANING ROBOT FOR OFFICE WINDOW

ISMAYUZRI BIN ISHAK

A report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
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NOVEMBER 2008

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

Cleaning window for the office building is one of the important aspects in building maintenance activities which has been carried out regularly. The cleaning jobs are done by human might involve high risk. This project focuses on the development of a small cleaning robot for office window to substitute human force in window cleaning. The robot needs to satisfy certain criteria that are; portable, small size, lightweight, automatically operated and can clean all the corner of the windowpane. This robot is operated by suction cup with vacuum pump as the adhering mechanism and two wheels for the locomotion mechanism. The small amount of liquid is injected in between suction pad and glass surface to reduce the friction while operating. The body is made from acrylic to minimize weight of the robot. The robot is programmed using microcontroller and based on the window pane size. The application of the robot in the real world is hoped to help humans and reduce cost in office window cleaning activities.

ABSTRAK

Pembersihan tingkap bangunan pejabat adalah salah satu aspek penting di dalam aktiviti penjagaan bangunan yang sememangnya kerap dilakukan. Kerja pembersihan yang dilakukan oleh manusia melibatkan risiko tinggi. Projek ini memfokuskan di dalam penghasilan robot pembersih kecil untuk tingkap pejabat bagi menggantikan manusia di dalam kerja pembersihan tingkap. Robot ini dikehendaki memenuhi beberapa criteria iaitu mudah alih, bersaiz kecil, ringan, beroperasi secara automatik dan boleh membersihkan semua penjuru tingkap. Robot ini beroperasi menggunakan pad sedutan yang dihubungkan dengan pam vakum untuk mekanisma melekap dan dua tayar untuk mekanisma pergerakan. Sedikit cecair disuntik di antara permukaan pad pelekap dan permukaan tingkap bagi mengurangkan geseran semasa beroperasi. Badan robot diperbuat daripada acrylic bagi mengurangkan berat. Robot ini di program di dalam mikrokontroller berdasarkan saiz permukaan tingkap. Aplikasi robot ini didalam kehidupan sebenar bagi membantu manusia dan mengurangkan kos di dalam kerja pembersihan tingkap bangunan.

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μ	Coefficient of friction

LIST OF ABBREVIATIONS

CAD	Computer-Aided Design
CCD	Charge-Coupled Device
EPROM	Erasable Programmable Read-Only Memory
FBD	Free Body Diagram
HSE	Health and Safety Executive
I/O	Input/Output
ICSP	In Circuit Serial Programming
OSHA	Occupational Safety and Health
PIC	Programmable Intelligent Computer
SRAM	Static Random Access Memory
USB	Universal Serial Bus

CHAPTER 1

INTRODUCTION

1.1 PROJECT MOTIVATION

The emergence of a robotic application will be the next hot field in this current new era (Gates, 2007). It shows by the emergence of many robotics products with autonomous concept for example autonomous vacuum robot (Ulrich et. al., 1997), museum tours guide robot (Burgard et. al., 1998) and etc. When dealing with hazardous job, it is better to replace human with robot that can perform a task without continuous human guidance or autonomous robot (Bekey, 2005) to overcome human risks.

Office window cleaning is a hazardous job and it involves high cost. Cases reported to Health and Safety Executive had shown that there had been between two to seven window cleaners were killed each year in Great Britain and 20-30 suffer major injuries while doing cleaning jobs (HSE, 2003). By using conventional method, human involvements are needed to the do all the task. This shows the need for small, lightweight and portable window cleaning robot for office window to replace human involvement in high risk activities.

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1.2 PROJECT BACKGROUND

Nowadays, cleaning an office window by using conventional methods is implemented widely. It is either via human involvement or by a machine. There are three types of conventional methods to clean office window. First method is by using workers suspended in the air. It can be done by using abseiling techniques or by gondola (Presto Property Services, Inc., 2008). Second method is by ground cleaning. In the ground cleaning, there are several ways that can be used. It can be done by reaching and washing technique (MPW Window Cleaners, 2008), using mobile elevated working platform (Salter Cleaning Services, 2008), using scaffold (Clear Magic Window Cleaning, 2008) or using a ladder (I Do Windows Inc., 2008). The third method is by using a customized window cleaning machines (SkyBot Ltd, 2006).

The advantage of conventional method by human is the job can be done for many complex office or building structure. The disadvantages of conventional methods by human can be described in four major points. First point is manual labour. Manual labours for conventional method undeniably gamble with high risk and long time consumption. The second point is limited efficiency. The process could be very slow as it depends on human expertise to finish the job. The third disadvantage is budget constraint. Using conventional method by human or by customized machine involves high cost for its equipment and suppliers, labours cost, insurance (Giamberardino, 2001), and by the machine itself. The last point is limiting factors. There are certain limiting factors with job done by human. If the job is done by human, it depends on weather and daylight factor. This project is hoped to overcome the limitation of conventional methods. The project is focusing in developing a small cleaning robot for office window.

1.3 PROJECT PROBLEM STATEMENT

Cleaning is routine in our life. It involves many activities in our daily life. It is a hard work job and a lot of time is consumed. Window cleaning is also one aspect of office maintenance activity. The clean windows will irrefutably provide a comfortable environment to the office inhabitants. The two main points that are stressed in this project are to overcome the hazard (HSE, 2008) of human involvement in cleaning office window activity and reduce high cost by the conventional method of cleaning window. It becomes necessary to overcome the limitation. The project intends to replace or minimize human involvement in cleaning the window by replacing it with a small cleaning robot for office window with several capabilities. The abilities are; portable, small size, lightweight, automatic operation and can clean all the corner of the office window.

1.4 PROJECT OBJECTIVES

The project is conducted to achieve the following objectives:-

a) To design a small cleaning robot for office window which is portable, small size, lightweight, automatic operation and can clean all the corners of the office window.
b) To write the software program of the cleaning robot.
c) To build the electrical part of the cleaning robot.
d) To build the mechanical part of the cleaning robot.
e) To assembly and testing the cleaning robot that can be operated on the office glass window.

1.5 PROJECT SCOPES

The scope of this project covers several issues listed as below:-

i. The developed small cleaning robot is only a prototype and not readily functioning as commercial product.
ii. The developed small cleaning robot can only operate without any other disturbance such as natural disaster like rain, storm and earth quake or by other disturbance while operating.
iii. The developed small cleaning robot is operated using battery.
iv. The developed small cleaning robot is operated on the window with no obstacles.
v. The developed small cleaning robot is limited under each rectangular windowpane.
vi. The developed small cleaning robot is independent with operating time constraint.
vii. The operating time of the small cleaning robot is limited which depends on the battery lifetime.

1.6 PROJECT REPORT ORGANIZATION

This project report consists of 5 major chapters. The descriptions of each chapter are stated below:-

a) Chapter 2 presents small cleaning robot from background knowledge as well as literature review perspectives. First the current or conventional way of cleaning window is presented. Previous researches on window cleaning robot also are then discussed. Finally, the mechanisms for window cleaning robot are presented.
b) Chapter 3 is focused on design and methodology. Development of the proposed method of small cleaning robot is presented. The system design is shown with explanation on why the design is made. Finally, all elements of the proposed design are built and assembled.

c) Chapter 4 is focused on results and discussions. The developed small cleaning robot is tested and discuss. Results of the discussion are presented.

d) Chapter 5 covers the project conclusion and the recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will explain about the conventional method of cleaning office window. This chapter also contains about previous research on window cleaning robot. In the end of this chapter, it discusses about mechanism for window cleaning robot.

2.2 Conventional Methods of Cleaning Office Window

Conventional methods of cleaning for office window can be described in three techniques or methods. The methods are by using workers suspended in the air, from ground cleaning and by customized window cleaning robot. All these methods need to qualify with the regulation that had been made by Occupational Safety and Health Regulation, OSHA and Health and Safety Executive Regulation, HSE.

Table 2.1: Conventional window cleaning method

Method	Techniques	Limitations
Workers suspended in the air	• Abseiling	• Low area coverage • High time consumption • Need skilled workers
	• Gondola	• Need skilled workers to operated the gondola
From the ground	• Reach and wash techniques	• Limited to certain height
	• Work platforms	• High time consumption • Limited to certain height • Need extra equipment
	• Scaffold	• Need extra time for preparation
	• Ladder	• Limited to high of the ladder
Customized window cleaning machine	• Skybot • SIRIUSc • etc.	• Need to satisfy building requirement • High cost

2.2.1 Using Workers Suspended in the Air

These methods are used for tall building. There are two cleaning techniques. It is by abseiling or using gondola. Abseiling can be described as technique of descending through the use of a fixed rope (ABC of Rock Climbing, 2008). Gondola or using platform can be described as the stage or platforms that use to carry humans with their equipment by rope supporting.

Figure 2.1: Cleaning method using abseiling technique

Source: Presto Property Services, Inc. (2008)

Figure 2.2: Cleaning method using gondola

Source: Presto Property Services, Inc. (2008)

2.2.2 Cleaning from the Ground

Cleaning from the ground is another method to do the cleaning. But this method is limited to certain height only. There are several techniques that can be used to do the cleaning job. First is by reach and wash technique. This technique is using a window washer with long extension. This method significantly reduces the risk of an accident to the window cleaner.

Figure 2.3: Cleaning method from the ground

Source: MPW Window Cleaners (2008)

Second method is by using work platforms. The work platform can be divided into two methods. One is by movable working platform. Using movable working platforms, several equipments or machines can be used to take the workers up to the air for example by truck mounted platforms, spiders or scissor lifts. Movable working platforms are ideal method of access for window and facade cleaning at height for many large buildings. Each group depends on the task of the job.

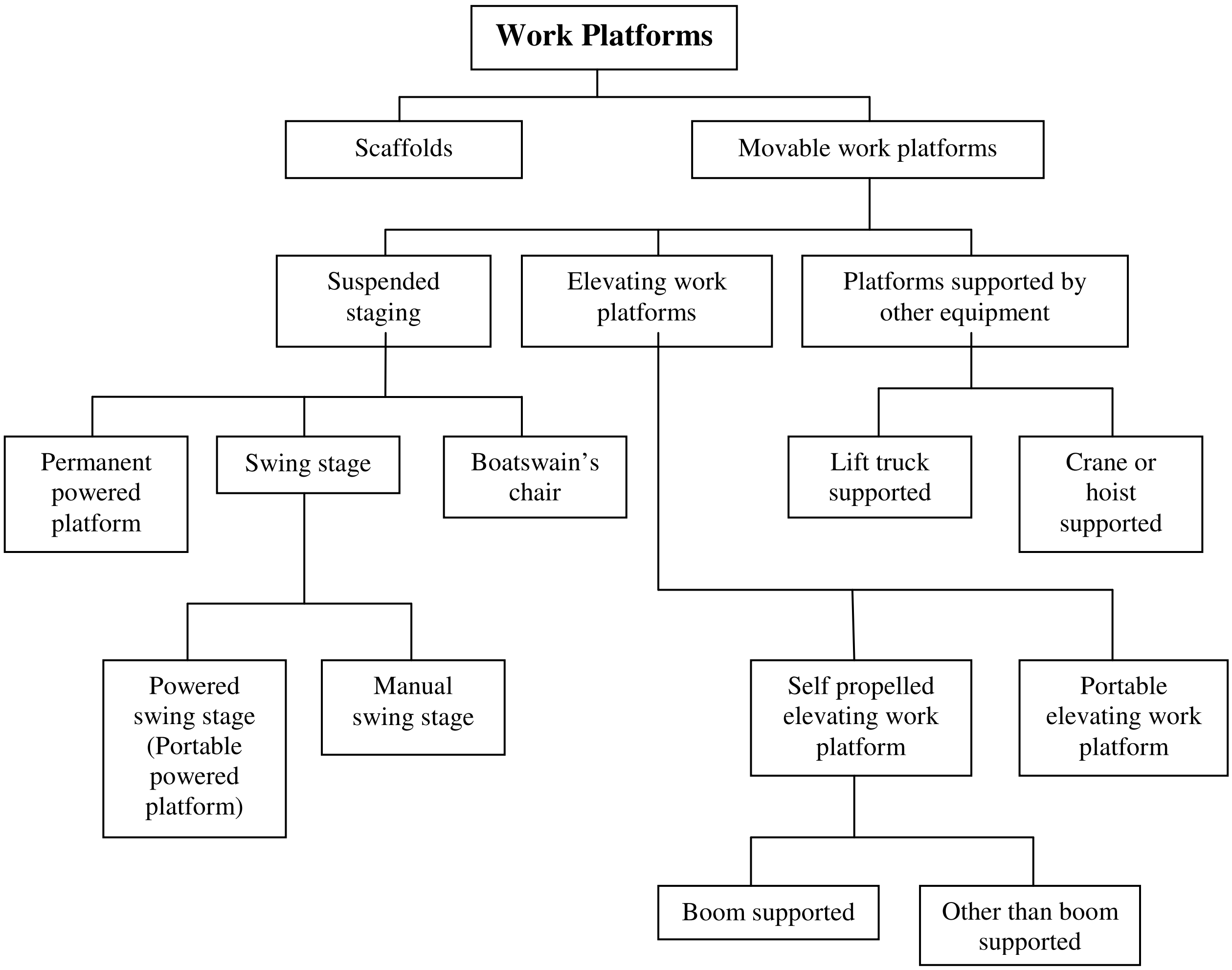

Figure 2.4: Work platform categories

Source: WorkSafeBC (2008)

Figure 2.5: Cleaning method using working platform

Source: Salter Cleaning Services (2008)

Another method in work platforms is by using scaffold. Scaffold is a platform made for workers to stand to reach higher parts of the building (Hornby, 2005).

Figure 2.6: Cleaning method using scaffold

Source: Clear Magic Window Cleaning (2008)

The fourth method is using ladder. The ladder that is used also must follow the guideline from Health and Safety Executive to prevent the misuse of the ladder or error while handling with it. There is also a standard for a ladder that is British or European standard (HSE, 2003). The British standard is a 'duty rating' type compared with European standard that is 'maximum static vertical load' type.

Figure 2.7: Cleaning method using ladder

Source: I Do Windows Inc. (2008)

2.2.3 Customized Window Cleaning Machine

Customized window cleaning machine is a machine used without human involvement in cleaning task. The machine is operated autonomously. It depends on the setting of the owner. It is fully automatic and consistent in cleaning process.

Figure 2.8: Cleaning method using customized window cleaning machine

Source: SkyBot Ltd. (2006)

2.3 PREVIOUS RESEARCH ON WINDOW CLEANING ROBOT

Various researches had been done in implementing window cleaning robot. All the research was done to achieve more efficient window cleaning robot.

Table 2.2: Comparison previous window cleaning robot

Researcher	Year	Size	Climbing Mechanism	Cleaning Mechanism	Limitation
Scharft et. al.	2000	950 mm x 1430 mm x 450 mm	Holding the window frame	Rotating brush with injected water	Need to fit the façade interface
Sun et. al.	2004	1220 mm x 1340 mm x 370 mm	Suction cups with translational mechanism	Two brush with squeegee and sucking system	Cover only spotted dirty area
Drexler	2005	100 mm x 150 mm x 50 mm	Gliding suction pad	Injected liquid with sliding motion of suction pad	Cannot cover corner path of the windowpane
Miyake et. al.	2006	300 mm x 300 mm x 100 mm	Suction cup with wheel locomotion	Wiping motion	More force to overcome the friction
Qian et. al. (Model II)	2006	1500 mm x 800 mm x 400 mm	Wheeled locomotion and tether supported mechanism	Rotating brush	Cannot cover corner path of the windowpane

Research by Schraft et. al. (2000) is based on implementing automated cleaning of windows on standard facades. This research aims to develop a cleaning robot which automatically cleans the outside of windows on a façade by holding to the window frames. The robot needs to posses certain requirement and construction features that are the two sides of the interface between the façade and the robot have to fit together in order to make the robot to operate. The robot can move in three linear axis. The robot runs up and down the row of windows with the y-axis. The x-axis is for the cleaning head on the pane from left to right. The z-axis is to deliver to the pane, over and across the horizontal bars. The robot is limited to the size of façade interface that the robot can be fit in. It needs to rearrange in order to switch to another façade interface.

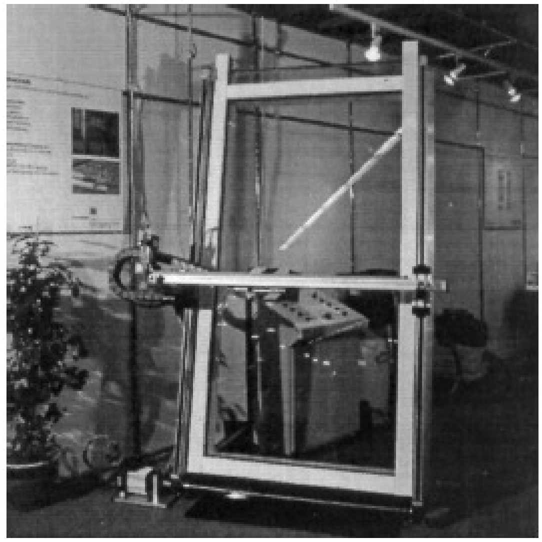

Figure 2.9: Façade window cleaning robot

Source: Schraft et. al. (2000)

Research by Sun et. al. (2004) is based on a visual sensing application to a climbing cleaning robot on the glass surface. The climbing mechanism of this robot is using suction cups with translational mechanism. It can adjust the orientation by adjusting the flexible waist. The robot is using a sensor to spot the dirty area that need to be cleaned. It used a CCD camera and two lasers diode as the visual sensor. The robot does not cover the entire window pane. It is a complex robot.

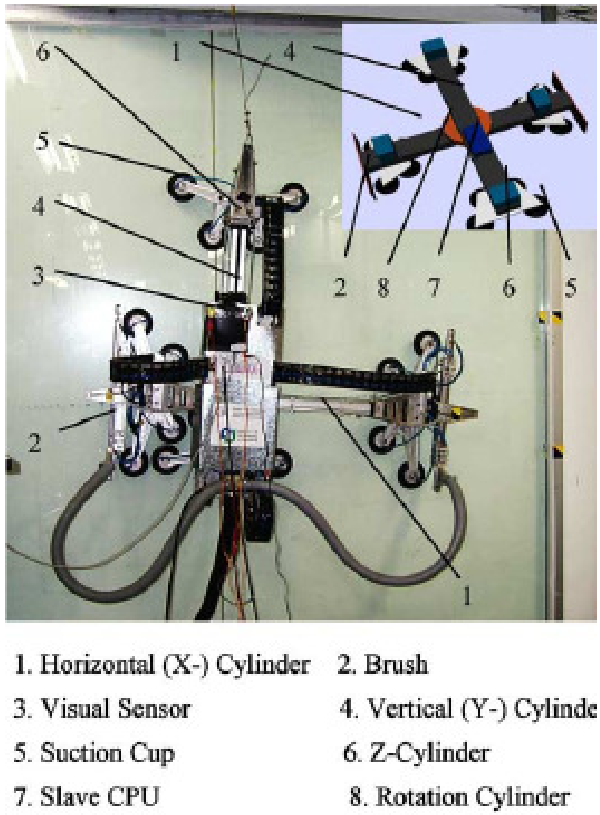

Figure 2.10: Visual sensing climbing cleaning robot

Source: Sun et. al. (2004)

Research by Drexler (2005) is on the development of a small sized window cleaner. The mechanism for moving is by the rotation of the suction pads independently for the propelling of the travelling path. The small amount of liquid is injected between the windowpane and the suction pad to reduce friction effect and give a cleaning effect. The limitation of the robot is the robot cannot cover corner path of the windowpane. It is the smallest sized robot compared to another cleaning robot.

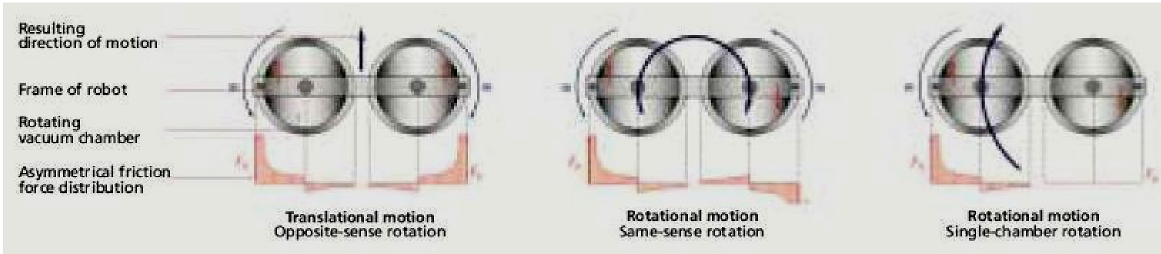

Figure 2.11: Quirl

Source: Drexler (2005)

Research by Miyake et. al. (2006) is based on the development of small-size window cleaning robot by wall climbing mechanism. This robot is in a small sized and portable. It also can clean the corner of the window which is the advantage of its design. It is an automatic operation. This robot uses suction pump as the climbing mechanism. It is also equipped with acceleration sensor for controlling the travelling path. The limitation is that more energy is needed in movement to overcome the friction between the suction pad and the window.

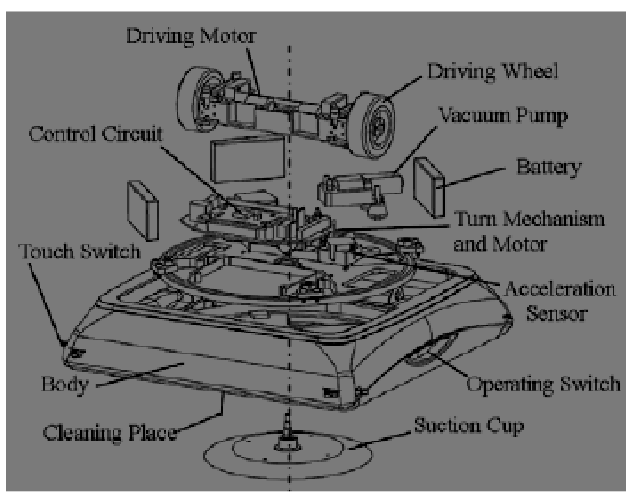

Figure 2.12: Small-size window cleaning robot

Source: Miyake et. al. (2006)

Research by Qian et. al. (2006).focuses on the development of wall-climbing robots with sliding suction cups. This robot is using combination of wheeled locomotion and tether supported mechanism. The limit of the design is the robot cannot cover the top and bottom corner right and left of the windowpane.

Figure 2.13: Wall-climbing robots with sliding suction cups

Source: Qian et. al. (2006)

2.4 MECHANISM FOR WINDOW CLIMBING ROBOT

Mechanism for window cleaning robot can be categorized into three main mechanisms. The mechanisms are cleaning mechanism, climbing mechanism and travelling path. This three main mechanism are important to differentiate between all the window cleaning robots.

The cleaning mechanism for cleaning task in office window involves washing the window usually with water and detergents. After that, it is wiped to remove the liquid. Manually, the application can be achieved by a wet sponge with cleaning liquid to clean the glass and using wiper or squeegee to remove excessive water. In the cleaning robot, there are certain models that put a rotary brush to remove dirty stain as its cleaning mechanism (Qian et. al., 2006).

There are many methods in the climbing mechanism for the climbing robot. Climbing robots use several different techniques to do the climbing job (Hawks, 2007). The techniques are by magnetic attraction, vacuum suction (Miyake et. al., 2006), adhesive-based (Daltorio et. al., 2005), tethered supported (Qian et. al., 2006), gripper force (Wu, 2006) and many more had been developed in climbing robot mechanism. All techniques are limited to certain conditions only. For example, magnetic attraction is useful for the climbing magnetic wall surfaces, adhesive-based climbing robot used dry adhesive on the foot to do the climbing job that will affect the cleanliness of the travelling path and climbing robot with gripper force are not suitable for a smooth surface. All the climbing techniques were developed generally for specific task only.

The last important criterion in window cleaning robot is the travelling path of the robot. Travelling path is as important as cleaning mechanism itself (Zhang et. al., 2006). It will determine the ability of the robot to do the cleaning task, the coverage of the robot can do and the security of the robot from falling down. The traveling generally can be simplified into two ways for the planning path. It is by right to left or down to up.

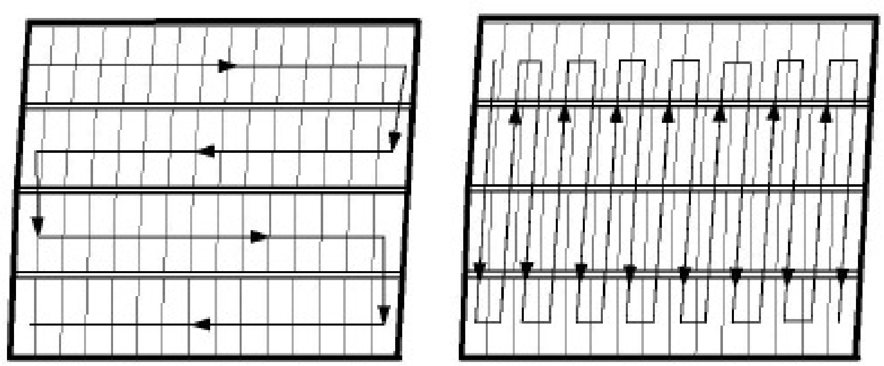

Figure 2.14: Travelling path

Source: Zhang et. al. (2006)

2.5 SUMMARY

The overall literature review in this chapter is about the concept for conventional window cleaning method, previous research that had been done on the window cleaning robot and the mechanism of window cleaning robot. There are three conventional methods in window cleaning that are using workers suspended in the air, cleaning from the ground and using customized window cleaning machine. There are also several research that had been implemented in window cleaning robot. The mechanism of window cleaning robot can be divided into three major part that are cleaning mechanism, climbing mechanism and travelling path.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter is focused on the project methodology which is the sets of methods to fabricate and the design that has been used. The implemented design has to fulfill certain criteria in order to achieve project objectives. The information in the literature review is interpreted to select the suitable design for the small cleaning robot for office window. The design needs to be transformed into a CAD software model. The steps that involve fabrication and programming the model are also stated.

3.2 DESIGN CONCEPT

The design concept for the project is important in order to determine the operation of the small cleaning robot. The design concept for the project is based on the three mechanisms; cleaning, climbing mechanism and travelling path.

The cleaning mechanism in this project is using a wiper to wipe the window by the effect of robotic motion. Cleaning liquid is injected for the cleaning purpose and improves the motion of the robot.

The suitable climbing mechanism is important to the robot. The most popular wall climbing robot is using suction cups as element in climbing mechanism (Liu, 2006).

For this small cleaning robot, the climbing mechanism is uses a suction cup with vacuum pump as adhering element for climbing mechanism.

Travelling path for the robot is using a one way direction that is by moving in vertical direction up and down or vice versa.

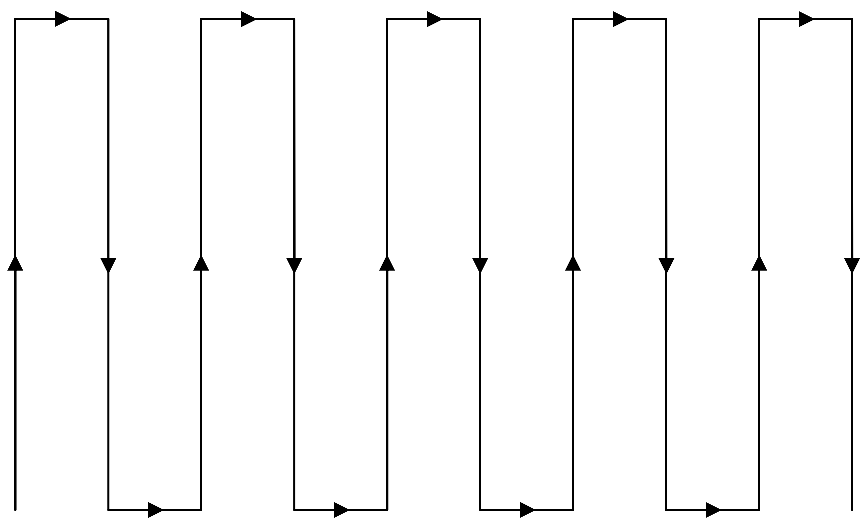

Figure 3.1: Travel path

3.2 SKETCHING IDEA

In order to produce a detailed design, sketching the ideas is an important task before moving to another step. There are three designs sketching shown as shown in Figure 3.2, Figure 3.3 and Figure 3.4. The design is upgraded from the previous design, for instance, design sketching 1 (Figure 3.2) is improved to create design sketching 2 (Figure 3.3). The comparison of all designs is important to select the best design amongst the three designs.

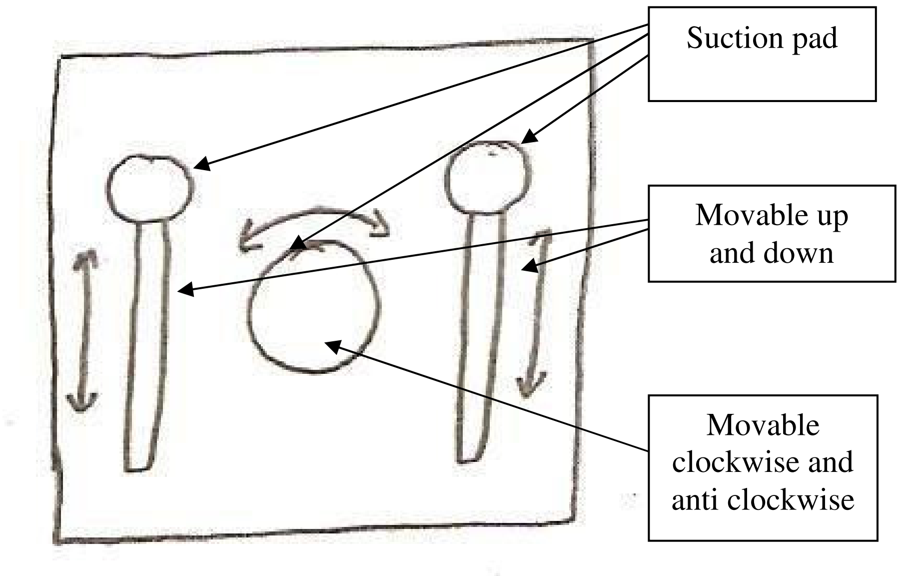

Figure 3.2: Design sketching 1

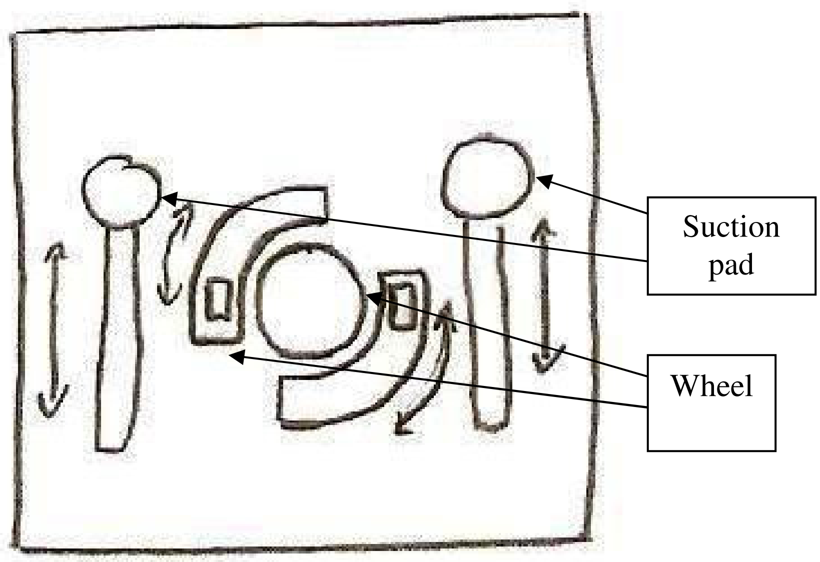

Figure 3.3: Design sketching 2

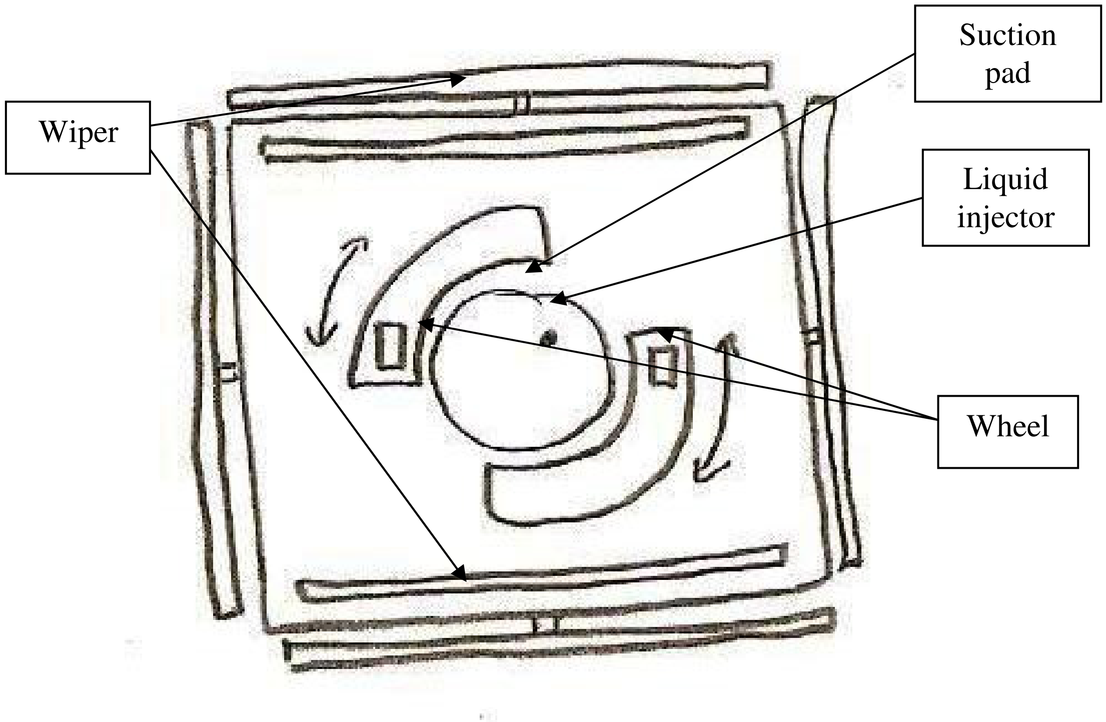

Figure 3.4: Design sketching 3

The comparison between the designs is established to find the best design. Design sketching 1 (Figure 3.2) is using three suction pads with two suction pad as locomotion mechanism for upward and downward direction and middle suction pad for rotating the robot. Design sketching 2 (Figure 3.3) is using three suction pads with two suction pad for upward and downward direction and the middle as to stick while in turning process. The two wheels are used in turning position. Design sketching 3 (Figure 3.4) is selected design because of the simplicity in the design as compared to other designs. Design 3 is using a single large suction pad with a liquid injector to reduce friction factor while moving and as a one way of cleaning mechanism. The two wheels are used in moving upward, downward direction and for the rotating mechanism for the locomotion mechanism.

3.4 FABRICATION PROCESS

The fabrication process is based on the proposed design concept. The processes start with modelling with CAD software until the assembly of all the inner and body parts are completed.

The modelling with CAD processes for the project is using Solidworks software. All designs are modelled in the Solidworks software to get the detailed specifications on the dimensions before fabricating process can be carried out.

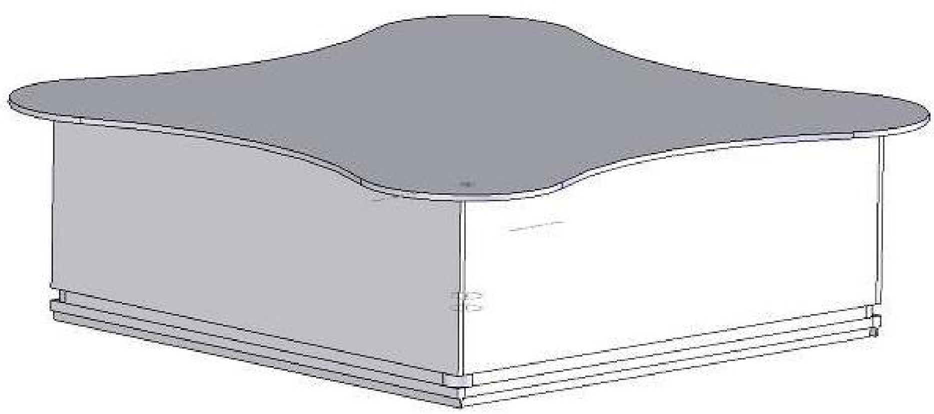

Figure 3.5: Isometric view of the robot

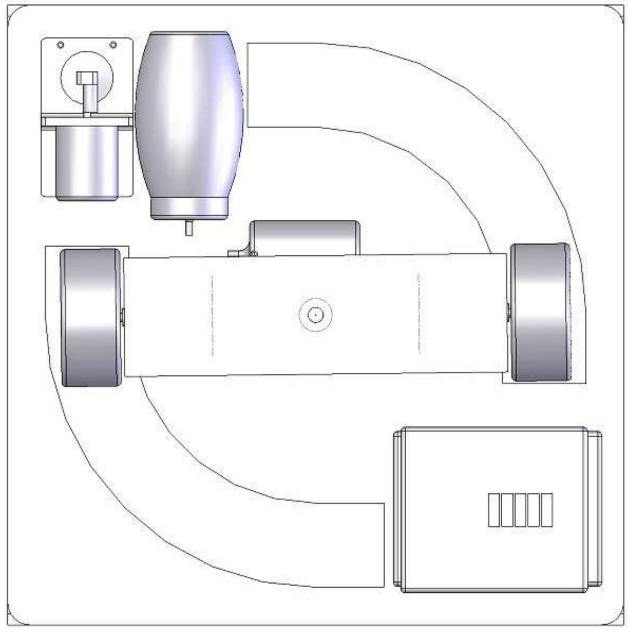

Figure 3.6: Top view without the upper body

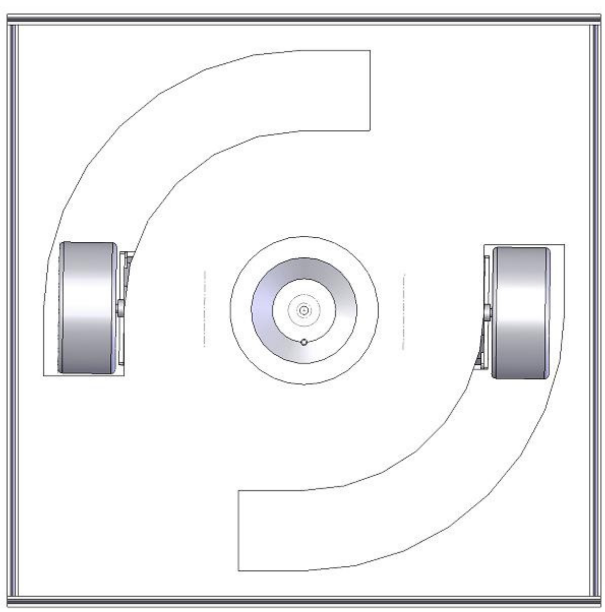

Figure 3.7: Bottom view

The assembly of the electronics parts is done on the strip board. All electronics components and motor are soldered to ease the handling and operation. The main component to control the robot is microcontroller PIC16F877A as the controller of the system.

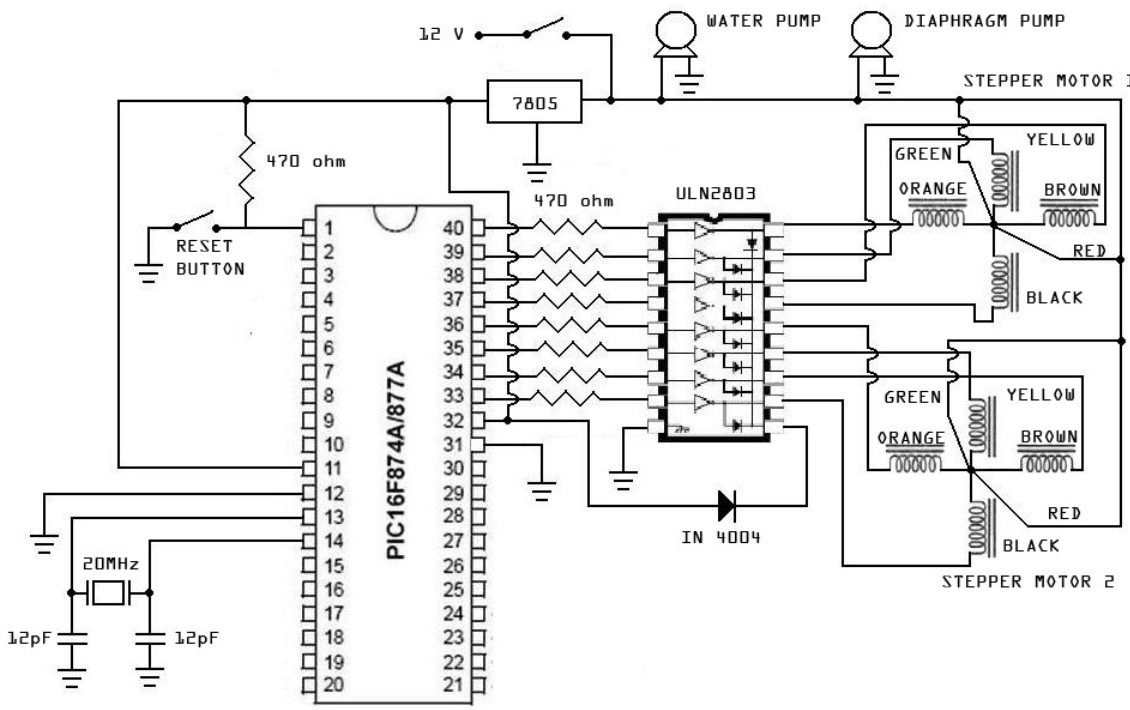

Figure 3.8: Circuit schematic diagram

Basically, every motion of the robot depends on the programming of the microcontroller. The robot uses microcontroller PIC16F877A. The microcontroller needs to be connected to the computer before it can be downloaded. One of the downloader available in the market is Cytron USB ICSP PIC Programmer UIC00A. In order to download the program, it needs to be compiled and transfered to the microcontroller. One example of the program is using PICkit v2.40 software.

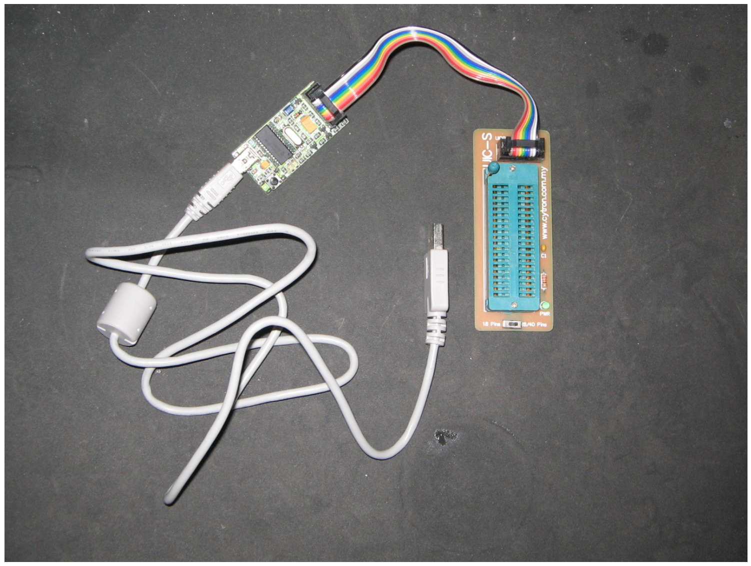

Figure 3.9: Cytron USB ICSP PIC programmer UIC00A

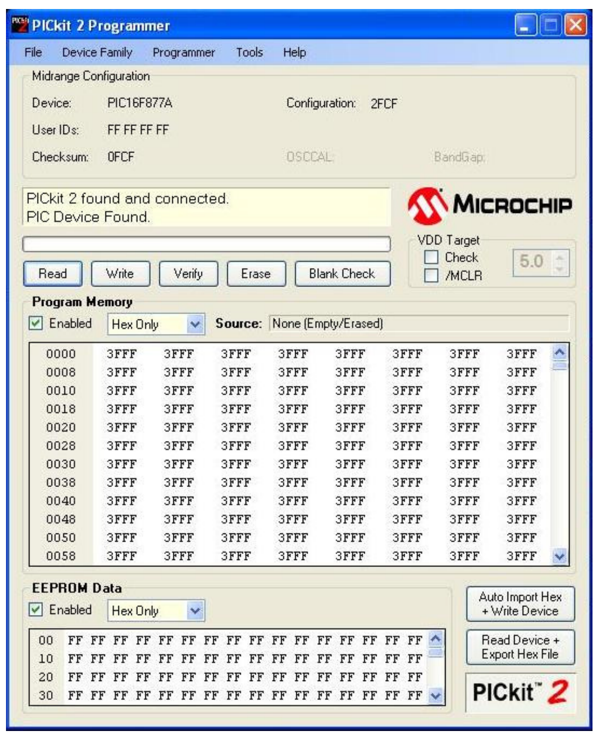

Figure 3.10: PICkit v2.40 software

All inner parts or components of the robot are assembled on the lower body. The stepper motor is hold by the aluminium bracket with pivoting point with bearing at the middle to obtain turning mechanism, the diaphragm pump is hold by screw, water pump is hold by cable tight and the strap is used for the water tank. The control board and battery are attached at the lower body.

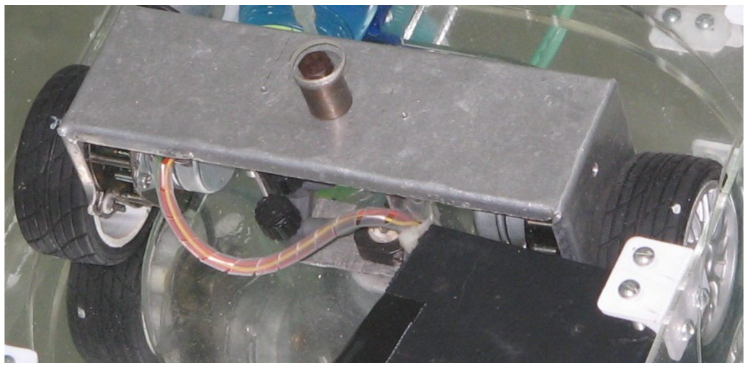

Figure 3.11: Aluminium bracket for holding stepper motor

The upper body parts are fasten with each other by using L elbow joint. The upper body parts and lower body parts are combined by a plastic hinge because make it is easier to uncover the body.

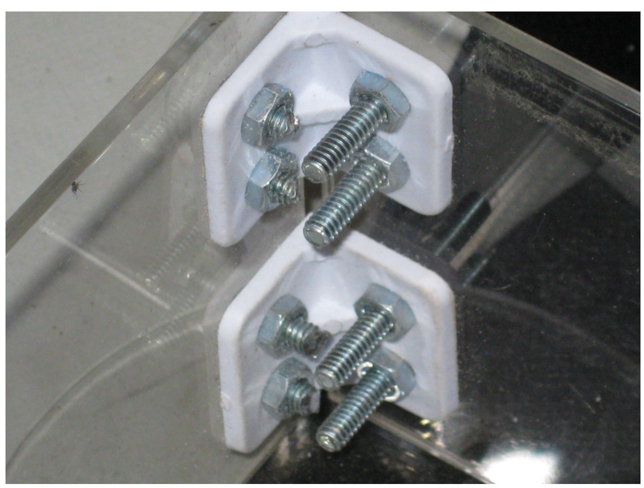

Figure 3.12: L elbow joint

3.5 SUMMARY

The whole procedures in this chapter are important to build a complete set of the small cleaning robot, starting with the design concept, ideas sketching and fabrication process. The design concept is to determine the robot mechanism which includes the cleaning mechanism, climbing mechanism and travelling path. After the design concept, the project move to the next level that is sketching ideas based on the design concept. All sketched were compared to find the best design. After obtaining the best design, fabrication process can be carried out. Fabrication processes start with modelling with CAD software. After finishing the modelling with CAD software, all the electronics, inner and body part are assembled.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter is mainly about the result, analysis and discussion from the finished product. The result means the robot's ability to perform the task by given input. Analysis was done on the performance of the robot. In the discussion section, the problems occur from the performance of the robot are being analysed to get the real factor affecting the robot performance.

4.2 SPECIFICATION

All detail specification of the dimension is based on the CAD design. The specification of the parts or components is based on the product that publishes by the company that produces it. The specification of the robot is obtained by the component that been used in the fabricating the robot. Overall specification (Table 4.1) is considering all the components involving in the operating of the robot.

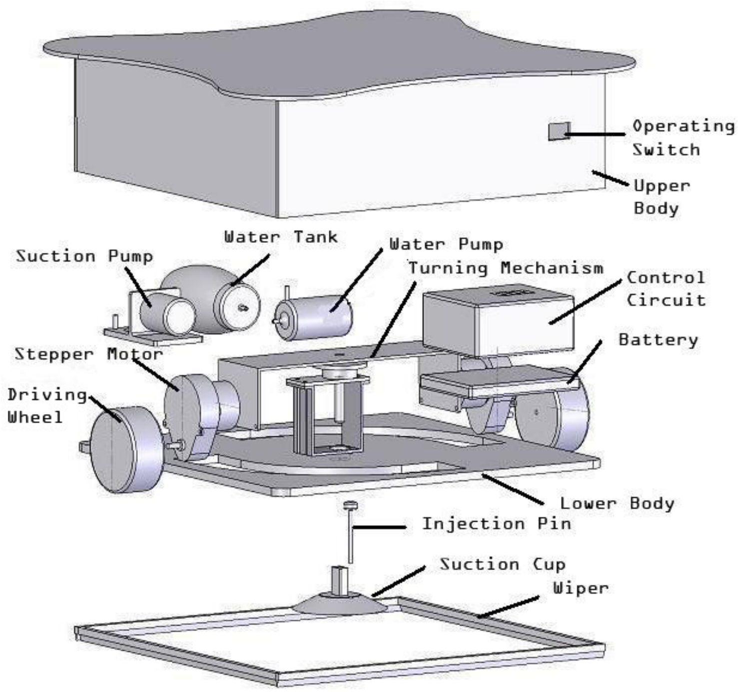

Figure 4.1: Exploded view

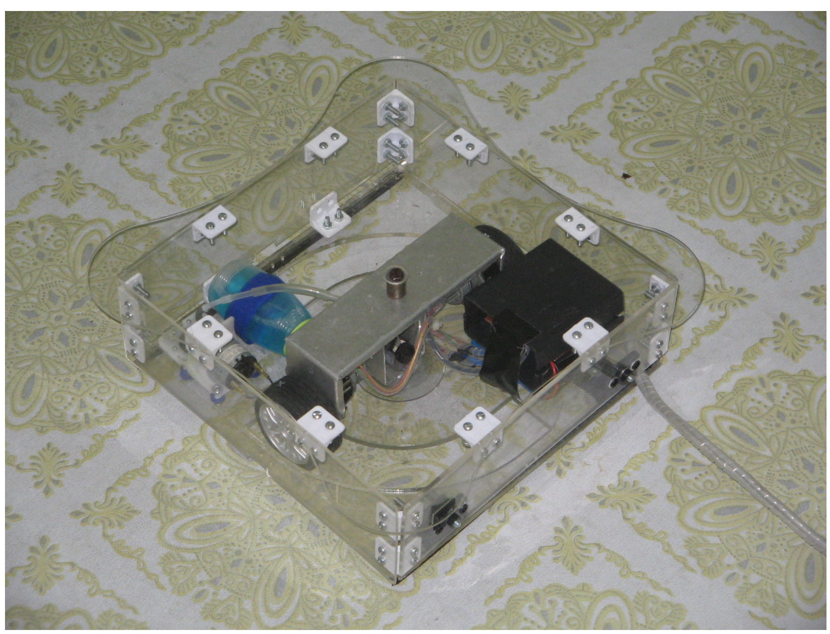

Figure 4.2: Finished product

Table 4.1: Overall specification

Item	**Specifications**
Body Material	Acrylic
Components	• 1 x Diaphragm Pump • 1 x Window Washer Pump • 2 x Geared Stepper Motor • 1 x PIC Microcontroller 16F877A • 3 mm Acrylic for Upper Body • 6 mm Acrylic for Lower Body • 2mm Aluminum Sheet for Stepper Motor Holder • 1 x Bearing for Turning Mechanism • Electronic Components • 2 x 60 mm Diameter Tires
Robot Dimension	280mm x 280mm x 100mm
Robot Mass	1.8 kg
Speed	0.02 m/s
Water Flow rate	0.09 ml/s
Power Supply	Ni-Cd Battery 12 V

During suction process to the window, diaphragm pump is used to give the negative pressure at the suction pad to stick to the window. The detail description of the diaphragm pump is in the Table 4.2 below.

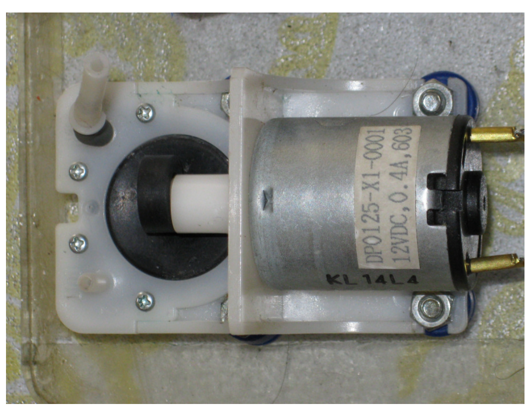

Figure 4.3: Diaphragm pump

Table 4.2: Diaphragm pump specification

Description	**Specifications**
Manufacturer	Nitto Kohki Co. Ltd.
Model	DP0125
Attainable Vacuum	-33.33 kPa
Free Air Displacement	2.5 l / min
Rated Voltage	12 V
Maximum Pressure	0.03 MPa
Gross Mass	0.08 kg
Dimensions	42(W) x 77(L) x 36(H) mm

For the movement of the robot, two stepper motors connected with tires are used to control the motion and direction of the robot. The stepper motors are held by aluminium holder with pivoting point and bearing in the middle. It is a geared stepper motor.

Figure 4.4: Stepper motor

Table 4.3: Stepper motor specification

Description	**Specifications**
Manufacturer	Mclennan Servo Supplies Ltd.
Model	415-8519
Ratio	25 : 1
Steps per revolution at output	1200
Holding Torque (Ncm)	43.9
Maximum Working Torque (Ncm)	27.6
Typical Working Torque (Ncm)	16.3
Number of Phases (L / R Drive)	4
Rated Voltage (V)	12
Current per Phase (mA)	180
Resistance per Phase (ohms)	64

Water pump is used to reduce friction effect to the surface of suction to the window and also gives cleaning effect.

Figure 4.5: Water pump

The power supply of the robot is using a 12 V Ni-Cd battery. It produces 1000 mA. The battery can easily be found on the remote control (r/c) vehicle.

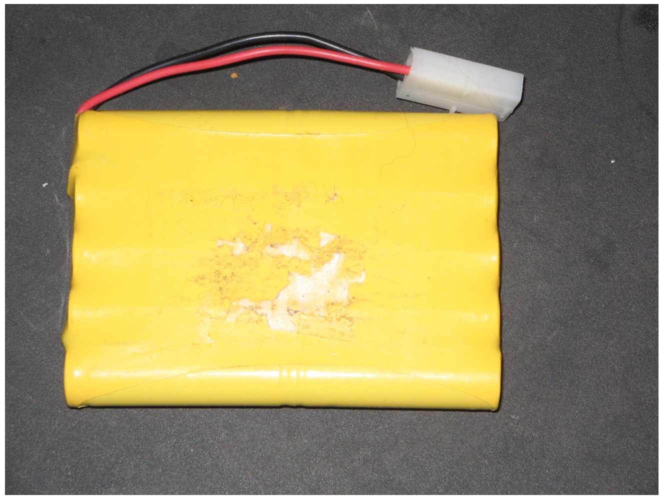

Figure 4.6: Battery

Circuit diagram for this project is consisting of several components. The entire component is fabricated based on the circuit diagram. The main component of the circuit is PIC microcontroller which is used to control the movement of the stepper motor.

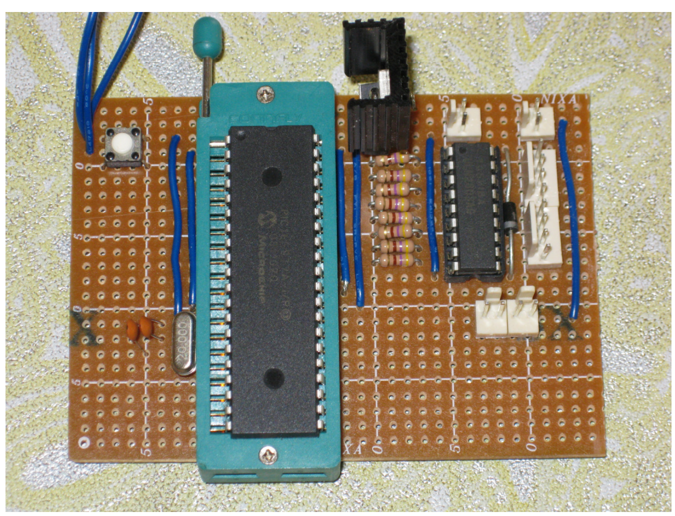

Figure 4.7: Actual circuit

Table 4.4: Components and parts list

Description	**Specifications**
Components	• PIC16F877A x 1 • ULN 2803 x 1 • Resistor 470 ohm x 9 • Capacitor 12 pF x 2 • Power Regulator 7805 x 1 • Oscillator 20 MHz x 1 • Diode IN 4004 x 1 • ZIF Socket 40 pin x 1 • IC Socket 18 pin x 1 • Strip Board 6 cm x 8 cm x 1 • PCB Connector 4 pins x 2 • PCB Connector 2 pins x 4 • Push Button Switch x 1
Parts	• Geared Stepper Motor x 2 • Water Pump x 1 • Diaphragm Pump x 1 • Battery 12 V x 1

4.3 RIGID-BODY ANALYSIS

The rigid-body analysis is to determine the equilibrium force that reacts on the robot body to overcome the gravity and body weight before the robot can be moved. All equilibrium force that exert on the body will be calculated in two positions. The first position is in the inclined plane. Using collected data during test run in the inclined plane, calculation is made to get the coefficient of the friction before being applied to the vertical plane analysis to get the suitable torque to overcome the weight and gravity. The second one is in the vertical plane mimic the real application in cleaning the window process.

4.3.1 Free Body Diagram

Free body diagram will consider all forces directly applied to the body. The force is based on the weight, reaction force, suction pad friction and thrust force to make it moves. The analysis is done on the incline plane with $\alpha = 20°$ (Figure 4.8) before using the data used in the vertical plane (Figure 4.10). The maximum degree that the robot is able to operate under is 20°.

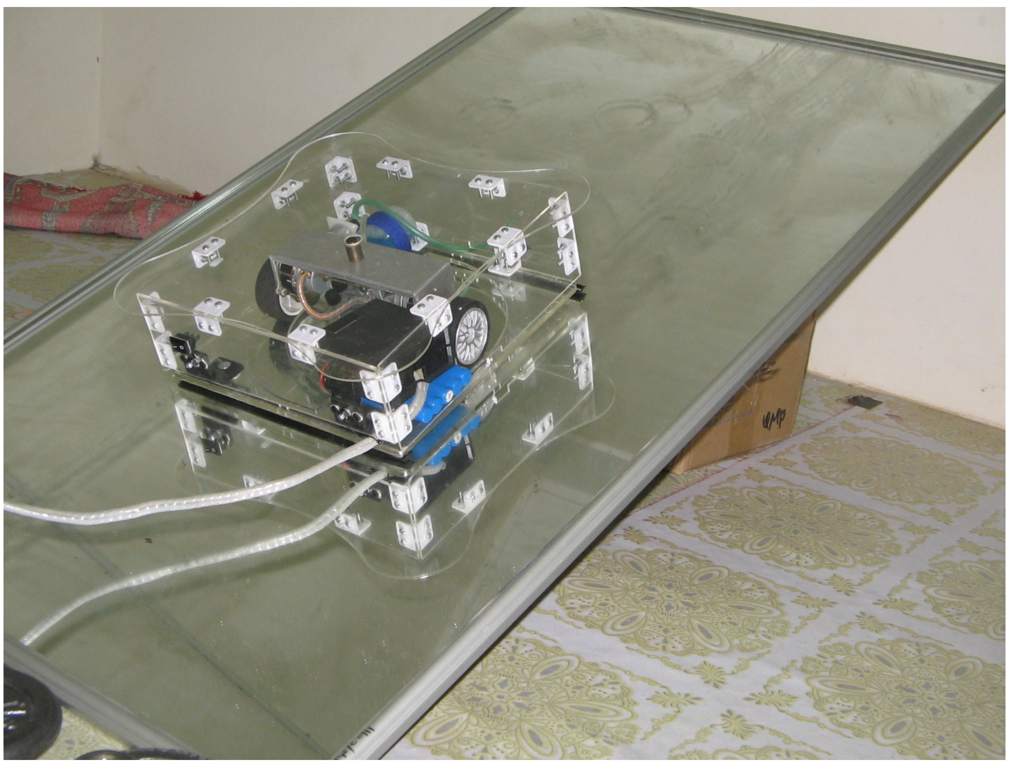

Figure 4.8: Small cleaning robot test run on inclined plane

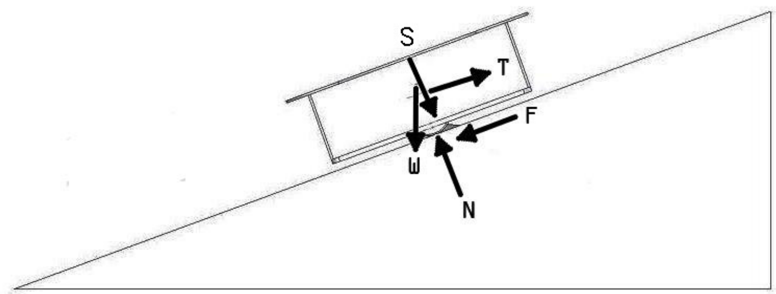

Figure 4.9: Free body diagram with plane angle, α = 20°

Based on the FBD, the applied force is:

In the horizontal direction,

$$+\rightarrow \sum F_x = ma$$

$$T - F_{suction} - W\sin\alpha = ma$$

In the vertical direction

$$+\uparrow \sum F_y = 0$$

$$N - S - W\cos\alpha = 0$$

The robot required 25 seconds to move 500 mm.

Using constant acceleration equation,

$$s = s_0 + v_0 t + \frac{1}{2} a_c t$$

$$500mm = 0 + 0(25s) + \frac{1}{2} a_c (25s)$$

$$a_c = 1.6x10^{-3} ms^{-2}$$

With,

Mass, m = 1.8 kg

Suction pad diameter, d = 70mm

Suction pad area, A = $\frac{\pi d^2}{4} = \frac{\pi(70mm)^2}{4} = 3.85x10^{-3}m^2$

The weight is W = mg = (1.8 kg)(9.81kgm/s²) = 17.658 N

Suction pad pressure, P = 33.33 kPa

Suction force, S = PA = $(33.33kPa)(3.85x10^{-3}m^2) = 128.32N$

Using Torque = Force x Radius

Torque stepper = 27.6 Ncm

$$T = Force = \frac{Torque}{Radius} = \frac{27.6Ncm}{3cm} = 9.2N$$

Using all the given data with $F_{suction} = \mu N$,

$$N = S + W\cos\alpha = 128.32N + 17.658N\cos 20° = 144.91N$$

$$\mu = \frac{T - ma - W\sin\alpha}{N} = \frac{9.2N - (1.8kg)(1.6x10^{-3}kgms^{-2}) - 17.658N\sin 20°}{144.91N} = 0.022$$

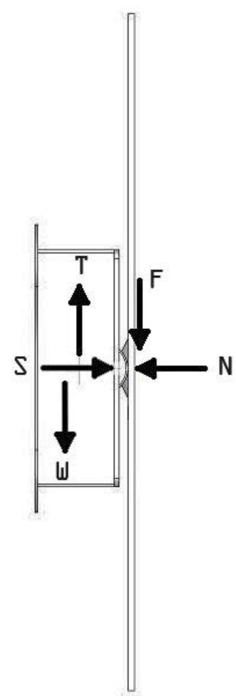

Figure 4.10: Free body diagram for vertical plane

Based on the FBD, the applied force is:

In the horizontal direction,

$$+\rightarrow \sum F_x = ma$$

$$S - N = 0$$

In the vertical direction

$$+\uparrow \sum F_y = 0$$

$$T - F_{suction} - W = 0$$

Using the same specification in the first analysis,

$$S = N = 128.32N$$

$$F_{suction} = \mu N$$

$$T = F_{suction} + W = \mu N + W = 0.022(128.32N) + 17.658N = 20.481N$$

4.4 PROGRAMMING ANALYSIS

The robot is controlled using microcontroller. The microcontroller needs to be programmed to do the specific tasks based on the working condition. For the project, the robot is program based on the test window of dimension 660 mm x 1150 mm.

Figure 4.11: Test window with size 660 mm x 1150 mm

PIC 16F877A is used in this project. PIC 16F877A has a 14.3k bytes program memory, with 368 bytes data SRAM, 256 bytes EPROM, 33 I/O port and has 40 pin. There are five ports on PIC 16F877A: port A (6 pins), port B (8 pins), port C (8 pins), port D (8 pins), port E (3 pins). The function of each pin can be software selectable. It can be for the input or the output function. The port B is used in this project.

Stepper motor is a motor that operates by the sequence of the input. It has 4 input sequences in which two coils on per sequence (Table 4.5). The different sequence will give rotation effect to the stepper motor. For the reverse rotation of the stepper motor, the sequence will be backward from sequence 4 to sequence 1. The sequence for each step can be described in Figure 4.13.

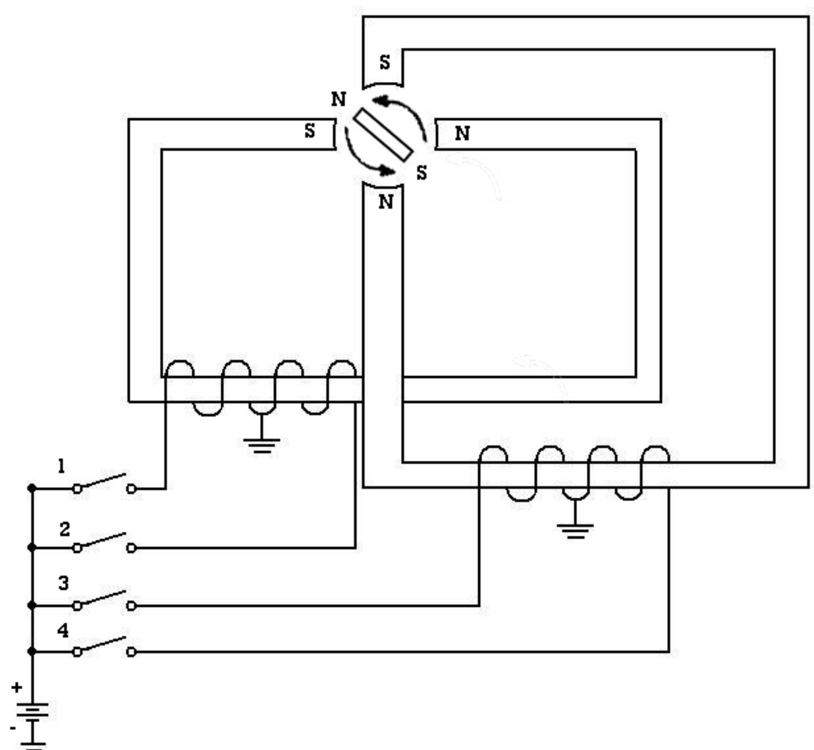

Figure 4.12: Stepper motor drive model

Source: Cetinkunt, S. (2007)

Table 4.5: Stepper motor switching sequence

	Switch 1	Switch 2	Switch 3	Switch 4
Step 1	ON	OFF	OFF	ON
Step 2	ON	OFF	ON	OFF
Step 3	OFF	ON	ON	OFF
Step 4	OFF	ON	OFF	ON

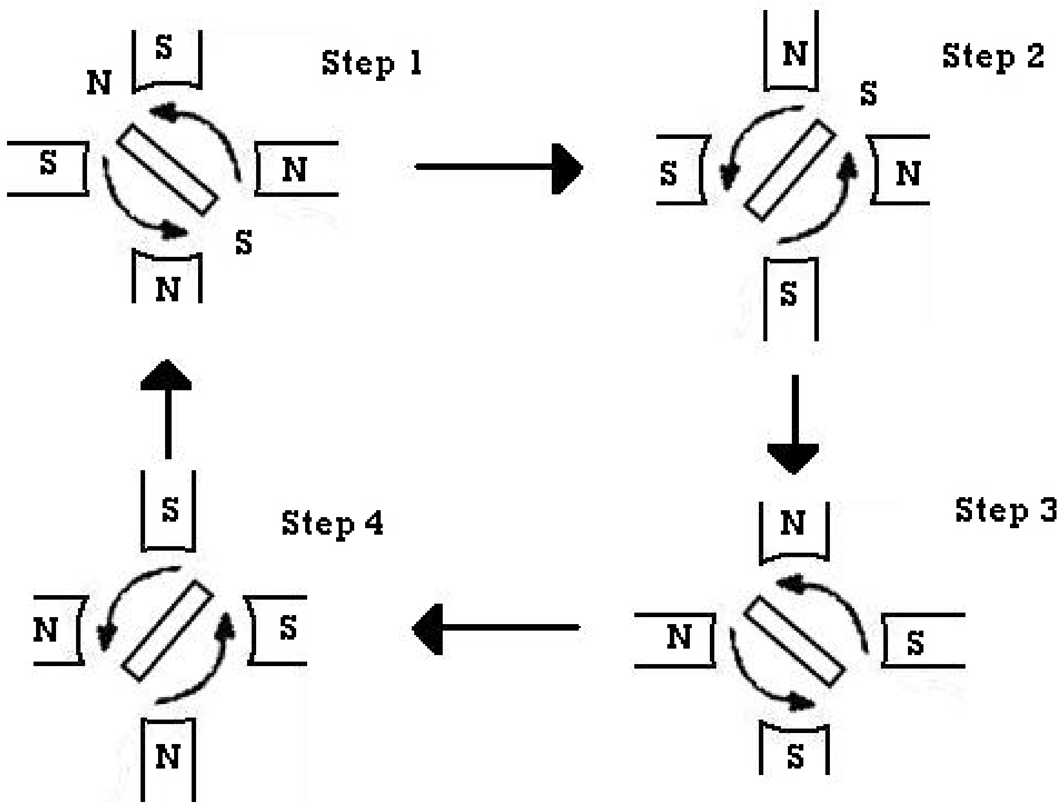

Figure 4.13: Stepper motor principal operation

Source: Cetinkunt, S. (2007)

4.5 DISCUSSION

From the given analysis, the robot can operate on the inclined plane with velocity 0.02 m/s. To operate on the vertical plane, calculation of the value of the suitable torque for stepper motor was done based on the value of the thrust force needed to overcome the friction and the the gravity in the vertical plane.

Using Torque = Force x Radius

Required torque = 20.481 N x 3 cm = 61.443 Ncm

The value in selecting the stepper motor torque must be higher than the required torque.

4.6 SUMMARY

The initial of the chapter is discusses about the specifications of all components in fabricating the robot. Then the rigid-body analysis is done to calculate the coefficient of friction in inclined plane. The data is used in vertical plane analysis to get the suitable torque for the robot to operate. After the rigid-body analysis, the programming analysis is done. The programming analysis discusses the usage of the PIC microcontroller and stepper motor operation. All information regarding this chapter can be made as references to make improvement of the project. The main problem of the robot is it does not have enough torque to move in vertical plane.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The development stage of the product is started with the background knowledge of the product. All methods in cleaning window, previous researches and working mechanisms are discussed in details. The second step is executed which include the concept designing, detailed drawing and fabrication process. The third step is analysing the finish product. After all the processes are carried out, the objective of the are verified to ensure all of the objectives are succesfully achieved.

The present study successfully indicated that the main objective of the project are achieved. The research and development on the small cleaning robot for office window can give several advantages. The cost of the product can be reduced and the operation can be executed in easier technique. Besides that, the risk of cleaning office window can be eliminated by replacing the human task to the robotic method. For the efficient usage of the robot, the improvement is still required to gain the better outcome. This small window cleaning robot prototype can be the first platform to continue the research in improving the product. All additional features, for example the solar panel and sensors can be added for more effective usage of the product. The product also can be used to another application where the climbing window pane is involved.

5.2 RECOMMENDATIONS FOR THE FUTURE RESEARCH

The first prototype is used to prove that the design concept of the robot can be effectively operated. Several improvements are needed to provide a better outcome. Therefore, based on the first prototype, there are some suggested improvements that can be done which are listed as below:

i.) Using a geared stepper motor with higher torque [torque > 61.443 Ncm]

ii.) Using a sensor to make it easier to operate to all size window panes without need to re-program again.

iii.) Using a solar power system for automatic recharging during low battery.

iv.) Improve cleaning mechanism for increasing cleaning efficiency.

v.) Reducing the body weight.

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APPENDIX A

PROGRAM CODE LISTING

```
#include <16F877A.h>
#fuses HS,NOWDT,NOPROTECT,NOLVP
#use delay(clock=20000000)

void jalan_depan(int32 step);
void jalan_belakang(int32 step);
void corner_kanan(int32 step);
void corner_kiri(int32 step);
void berhenti(int32 step);

main()
{

  int i;
  int32 step;

  set_tris_B(0);  //output
  OUTPUT_B(0x00);

  for(i=0;i<1;i++)
  {
   berhenti(500);
   jalan_depan(1385);
   corner_kiri(287);
   jalan_belakang(300);
   corner_kanan(287);
   jalan_belakang(1385);
   berhenti(500);
   corner_kiri(287);
   jalan_belakang(300);
   corner_kanan(287);
   jalan_depan(1385);
```

```
  berhenti(500);
 }

}

/**********************************************************************/
void jalan_depan(int32 step)
{
  int i;
  int speed=10;
  for(i=0;i<step;i++)
  {
  OUTPUT_B(0b10011010);
  DELAY_MS(speed);
  OUTPUT_B(0b01010110);
  DELAY_MS(speed);
  OUTPUT_B(0b01100101);
  DELAY_MS(speed);
  OUTPUT_B(0b10101001);
  DELAY_MS(speed);
  }
  return;
}
/**********************************************************************/
void jalan_belakang(int32 step)
{
  int i;
  int speed=10;
  for(i=0;i<step;i++)
  {
  OUTPUT_B(0b10101001);
  DELAY_MS(speed);
  OUTPUT_B(0b01100101);
  DELAY_MS(speed);
  OUTPUT_B(0b01010110);
  DELAY_MS(speed);
  OUTPUT_B(0b10011010);
  DELAY_MS(speed);
  }
  return;
}
/**********************************************************************/
void corner_kiri(int32 step)
{
  int i;
  int speed=10;
```

```
  for(i=0;i<step;i++)
  {
  OUTPUT_B(0b10011001);
  DELAY_MS(speed);
  OUTPUT_B(0b01010101);
  DELAY_MS(speed);
  OUTPUT_B(0b01100110);
  DELAY_MS(speed);
  OUTPUT_B(0b10101010);
  DELAY_MS(speed);
  }
  return;
}
/***********************************************************************/
void corner_kanan(int32 step)
{
  int i;
  int speed=10;
  for(i=0;i<step;i++)
  {
  OUTPUT_B(0b10101010);
  DELAY_MS(speed);
  OUTPUT_B(0b01100110);
  DELAY_MS(speed);
  OUTPUT_B(0b01010101);
  DELAY_MS(speed);
  OUTPUT_B(0b10011001);
  DELAY_MS(speed);
  }
  return;
}
/***********************************************************************/
void berhenti(int32 step)
{
  int i;
  int speed=10;
  for(i=0;i<step;i++)
  {
  OUTPUT_B(0b00000000);
  DELAY_MS(speed);
  }
  return;
}
```