DESIGN, CONSTRUCTION AND ANALYSIS
OF
CEILING FAN CLEANING ROBOT

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“ I hereby declare that I have read through this report entitle “Design, Construction and Analysis of Ceiling Fan Cleaning Robot” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronics Engineering.

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Supervisor‟s Name : Dr. Fariz Bin Ali @ Ibrahim

Date :

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Mechatronics Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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I declare that this report entitle “Design, Construction and Analysis of Ceiling Fan Cleaning Robot” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Lee Mun Hoe

Date :

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ABSTRACT

The traditional ways of cleaning the ceiling fan required users use a dry dust cloth and get up to the height of ceiling fan using a step ladder, or use an extension rod with a brush. However, these methods are dangerous because users may fall down from the ladder and cause environment hygiene problem. Hence, alternative solution has proposed by design a ceiling fan cleaning robot. Meanwhile, the problems that should take into consideration are the weight of robot, different size of the fan blade, and physical structure of the robot. Consequently, the objective of this project is to design and develop a ceiling fan cleaning robot and analyse the performance of it by considering robot locomotion. Furthermore, there are some important criteria in the methodology of this project. The body structure of fan cleaning robot is designed using SolidWorks software, and several technologies are combined to accomplish the basic features of the robot. This is included the material selection of mechanical parts, such as body structure and cleaning equipment; power supply for robot in electrical parts; and electronic components, like an Arduino Leonardo microcontroller, infrared sensors and limit switch, DC motors with gears as actuators, and also indicators like LEDs and buzzer. A series of experiments are conducted to analyse the performance of the robot, such as rotational speed of DC motor; sensitivity of infrared sensor; accuracy of digital compass. And also, experiment to determine the difference between rechargeable battery and power adapter on weight of robot, velocity, and swinging angle on fan blade. The experimental results confirm the proposed methodology; and showed that the power adapter is preferable as power supply for fan cleaning robot. In summary, the fan cleaning robot can be developed with future expansion in mind.

ABSTRAK

Kaedah tradisional untuk membersihkan kipas siling memerlukan pengguna menggunakan kain kering dan memenjat tangga sehingga ketinggian kipas siling atau menggunakan batang sambungan dengan berus. Walau bagaimanapun, kaedah tersebut adalah bahaya kerana pengguna berkemungkinan akan terjatuh dari tangga dan menyebabkan masalah kebersihan alam sekitar. Oleh itu, penyelesaian alternatif telah dicadangkan dengan mereka bentuk robot pembersihan kipas siling. Sementara itu, masalah yang perlu diambil kira adalah berat robot, perbezaan saiz bilah kipas, dan struktur fizikal robot. Oleh yang demikian, objektif projek ini adalah untuk mereka bentuk dan membina sebuah robot pembersihan kipas siling dan menganalisis prestasi sistem robot dari segi pergerakan robot. Tambahan pula, terdapat beberapa kriteria penting dalam metodologi projek ini. Struktur badan robot direka bentuk dengan menggunakan perisian SolidWorks, dan gabungan beberapa teknologi untuk mencapai ciri-ciri asas robot. Ini termasuklah pemilihan bahan bahagian mekanikal, seperti bahan untuk membina struktur badan robot dan peralatan pembersihan; bekalan kuasa dan komponen elektronik dari segi elektrik dan elektronik, seperti pengawal mikro, pengesan dan penunjuk. Beberapa eksperimen telah dilakukan untuk menganalisis prestasi robot, ini termasuklah kelajuan DC motor; kepekaan pengesan inframerah; ketepatan kompas digital. Selain itu, eksperimen untuk mengkaji perbezaan di antara bateri boleh dicas semula dan plag penyesuai pada berat robot, halaju dan sudut berayun pada bilah kipas. Hasilnya, eksperimen dapat mengesahkan kaedah metodologi yang dicadangkan; dan menunjukkan plag penyesuai adalah lebih baik sebagai bekalan kuasa untuk robot pembersihan kipas siling. Kesimpulannya, robot pembersihan kipas siling boleh dikaji dan dikembangkan pada masa depan.

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LIST OF ABBREVIATIONS

DSP	-	Digital Signal Processor
MIPS	-	Million Instructions Per Second
CPR	-	Count per Revolution
EEPROM	-	Electrically Erasable Programmable Read-Only Memory
CPU	-	Central Processing Unit
A/D converter	-	Analog-to-digital converter
DIO channel	-	Digital input / output channel
LAN	-	Local Area Network
RC	-	Radio Control
V	-	Travelling velocity
$\dot{\theta}$	-	Angular velocity of robot attitude
ω_L , ω_R	-	Rotational velocity of left and right wheels
W	-	Tread
R	-	Radius of wheel
ζ_L , ζ_R	-	Output duty rate of PWM motor control
ζ_{L0} , ζ_{R0}	-	Initial velocity of robot travelling expressed as duty rate
K_P	-	Feedback gain
IR LED	-	Infrared Light Emitting Diode
α	-	Angle of inclination of the plane to the horizontal
W	-	Weight of the robot
h-r	-	Height of the centre of gravity above the axle plane
H	-	Height of incline plane
r	-	Distance between the centres of the wheels to incline plane
b	-	Perpendicular distance of centre of gravity from the rear axle
a	-	Perpendicular distance of centre of gravity from the front axle
L	-	Distance between the centres of the rear and front wheels
R_{A}	-	Total normal reaction between the ground and the front wheels
R_{B}	-	Total normal reaction between the ground and the rear wheels

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Industrial robotics researches have been around since a long time ago. They are widely used in industrial to increase the efficiency of the manufacturing process. However, these researches and technologies have been emerged with the development of service robots to perform service useful to the community regardless in semi- or fully autonomous, such as medical robots, underwater robots and other type of robot that can carry out a multitude of jobs [1]. Therefore, service robots have become more active than ever due to demand of people"s need and market grows.

One of the service robots of everyday tools for people is the home appliance cleaning robot, particularly a floor cleaning robot. Normally, these cleaning robots are integrated with vacuum pump and rotating brushes to sweep floors. Hence, these robots can help people perform cleaning task which is usually tedious and repetitive. One of the advantages of these residential cleaning robots is that it does not require any complex moving parts.

According to Science News, there are about 610,000 autonomous vacuum cleaners and lawn-mowers were in operation by the end of 2003 and this number is deemed to increase throughout the years [2]. Based on Figure 1.1, a tendency increasing of US patents in cleaning robot from 2000 to 2013. This is shown a reasonable prediction by Science News about the market grows of cleaning robot, although the numbers shown in 2013 is not the total number of patents published [1].

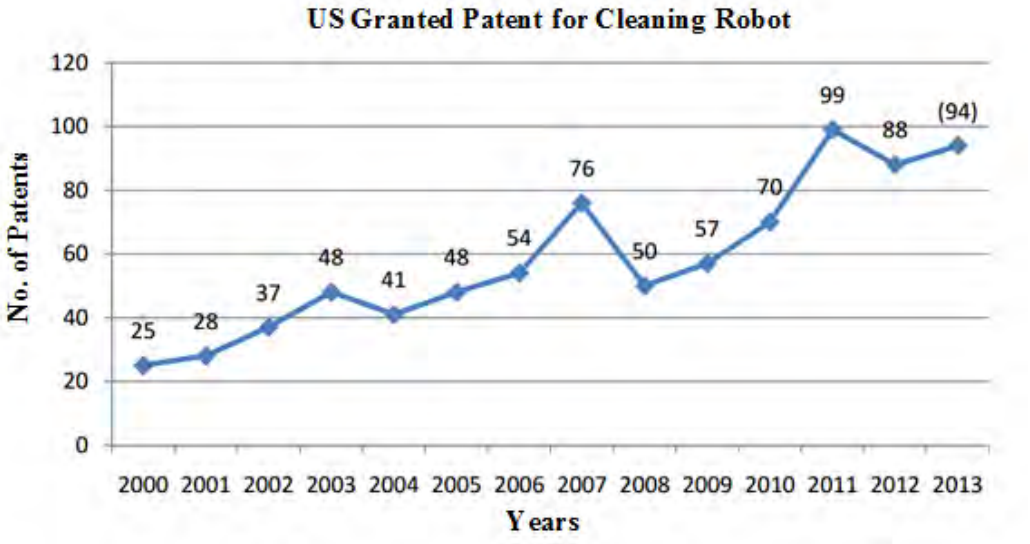

Figure 1.1: US granted patents from 2000 to 2013 [1].

Meanwhile, the developments of cleaning robot still a big gap to commercialize in the market, although some of the advanced robots have powerful functions, such as the navigation system and high efficiency of cleaning performance. Some of the possible reasons are the residential robot designed needed to consider the use for non-professional users, and the unreachable cleaning function of the robot in some area [1] like outside area of the building. These dangerous areas are needed to take further attention before developed to be marketed, especially think about the elder users.

On the other hand, according to French researchers, cleaners are suffering from exposure to many high risk factors for musculoskeletal disorders (MSDs). There are about 74% reported cleaners are experiencing muscular aches, and 52% of them sought for medical advice. About 46% experienced low back pain, 33% suffer neck and upper limb disorders, 22% to 24% is right wrist or hand, right shoulder and knee pain [3]. However, the occurrence of MSDs is mainly due to prolonged work with overhead cleaning. They have to do their jobs with a flexed or twisted body under long duration of cleaning tasks. Besides that, a study report claimed that 54% to 74% of all cleaners expose to continuous repetitive movement [3].

In consequence, ceiling fan is one of the unreachable places to be cleaned and overhead cleanest. It is common that dirt deposited on the surfaces of fan blades after the ceiling fan is used for a certain period. The traditional way to clean the ceiling fan is to

wipe the dust from the blades. Users need to use a step ladder to get up to the height of fan blades and clean with a dry dust cloth, or a dust cloth coated with some cleaning solution. However, this can be dangerous for the person who does the cleaning task is at risk of falling down from the ladder [4].

On the other hand, an extension rod with brush is an alternative way can use for cleaning the ceiling fan, and reduce the risk of falling down from the ladder. But, the cleaning method is not effective as the surfaces of the blades are not fully cleaned and the dust from the blades will spread to surrounding, causing the environment hygiene problem. Hence, users need to sweep the dust on the floor after using the long stick with brush for cleaning the ceiling fan, however, this is spending and wasting of their time [5].

Thus, these factors have emerged to the interest in designing residential cleaning robot for different cleaning station and ceiling fan cleaning robot implementation would be the start of it.

1.2 Problem Statement

For the ceiling fan cleaning robot, the theoretical knowledge of static and dynamic mechanisms of a moving object is needed in designing and develops the robot. The fan cleaning robot needs to achieve stable moving motion on ceiling fan blades with appropriate speed. Therefore, actuator with higher torque is needed to actuate the robot and move on fan blade; and also it can stop instantly with minimum inertia and momentum to prevent it from falling down. This element is important in developing the robot structure.

Furthermore, the weight of the robot is needed to take into account. After the robot is placed on fan blade, the blade will be pushed downwards. Hence, the material chosen to build the robot is important, so that the robot won‟t damage to the ceiling fan, and can operate normally. Another aspect needed to be considered is the hardware component selection can influence the overall performance of the system. There are different designs of ceiling fan available in the market, particularly the fan blade designed by manufacturer to increase the airflow efficiency. Therefore, the development of fan cleaning robot is needed to consider the size of fan blade since it needs to move on it. A design of the

flexible pulley in fan cleaning robot can be used to guide the robot move on the fan blade by pressing from both sides of the fan blade.

In addition, basic knowledge of the Arduino microcontroller using C language to design the control algorithms is needed. The algorithm loaded in the microcontroller is used to control the operation of the robot integrated with input and output electronic components. And also, the most important criteria for fan cleaning robot are the analysis of the robot locomotion mechanism to achieve the optimum performance of the robot.

1.3 Objectives

To complete this project, the following objectives are to be achieved at the end of this research:

1. To design and develop a semi-autonomous ceiling fan cleaning robot.
2. To analyse the system performance of the ceiling fan cleaning robot by considering robot locomotion.

1.4 Scopes

1. The fan cleaning robot is controlled by Arduino Leonardo as the main microcontroller to operate the robot system.
2. The robot is designed to move in forward and reverse direction only to remove the dust on the fan blades.
3. The body of the robot is constructed using plywood that is lightweight and cheap.
4. Infrared sensor and limit switch are integrated with the robot to detect the edge of fan blade to prevent from falling down.
5. Small pulleys are added to guide the robot moving in a straight line forward and reverse direction.
6. An extension rod is used to place the robot on the ceiling fan blade.
7. The dust cleaning analysis is not included in this report.

1.5 Report Outlines

This project focuses on the design and construction of the fan cleaning robot. The organization of this report is as follows:

1. Chapter 1 is to identify the development of cleaning robot and introduces the idea of ceiling fan cleaning robot. This chapter also covered the goals to be achieved and scope of this project.
2. Chapter 2 is the literature review of the previous work of researches about the cleaning robot.
3. Chapter 3 describes the methodology to design and construct the ceiling fan cleaning robot. This chapter also describes the method used to examine the performance of robot in terms of robot locomotion.
4. Chapter 4 discusses the findings obtained using statistical techniques and also the evaluation of the results.
5. Chapter 5 concludes the project findings and recommendation for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Design and Basic Construction

In order to develop a fully autonomous floor cleaning robot with the navigation system to avoid obstacles and perform the cleaning task efficiently, the LG‟s Roboking has been introduced by Core Technology Group, as shown in Figure 2.1 [6]. Roboking has a total number of 24 sensors to gather the environmental information for navigation purpose, included 14 ultrasonic sensors: 5 sensors to detect tall obstacles and 9 sensors to find flat obstacles. And also, 8 infrared sensors for cliff detection and to seek the charging station respectively, while another 2 tactile sensors for detecting small and slender objects [6].

Figure 2.1: Roboking [7].

Roboking has built in Texas instruments 320LF2406A digital signal processor (DSP) to control the robot operation, such as motor on board. This processor can run at 40 MHz with 40 MIPS (Million Instructions Per Second) performance [6].

In addition, a 12V / 3Ah nickel-metal hydride rechargeable battery is implemented on the robot as a power source. Once the battery power is low, Roboking can navigate itself back to the charging station automatically. Two types of DC motor have been used: a 12V, 70W suction power for suction nozzle work with rotating brushes as cleaning equipment, and 12V, 15W for navigation motor. The encoder is used for motor control which has 180 Count per Revolution (CPR) resolution [6]. Figure 2.2 is shown the Roboking system circuit block diagram.

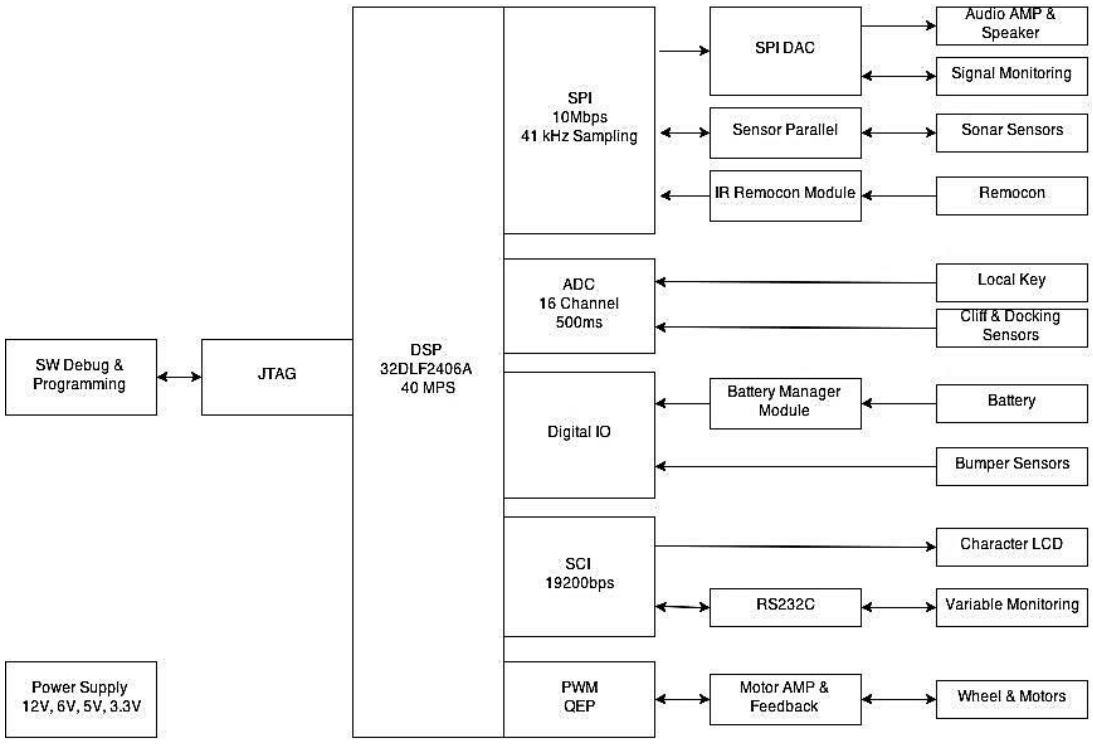

Figure 2.2: Roboking system circuit block diagram [6].

On the other hand, a floor cleaning mobile robot for domestic use has been proposed by Jordi. There are a few types of sensor built in this robot, including infrared sensors to prevent the robot from falling down stairs, mechanical contact sensors detect the obstacles, and Polaroid 6500 series ultrasonic sensors allowed the robot planning and building the path for mobility as well as wall alignment [8]. The cleaning device for this floor cleaning robot is an electric broom manufactured by Karcher. The roller brush is battery-powered, which can clean the floor using a friction mechanism and prevent dust generation by generating a suction airflow [8]. Figure 2.3 is shown the proposed cleaning robot by Jordi.

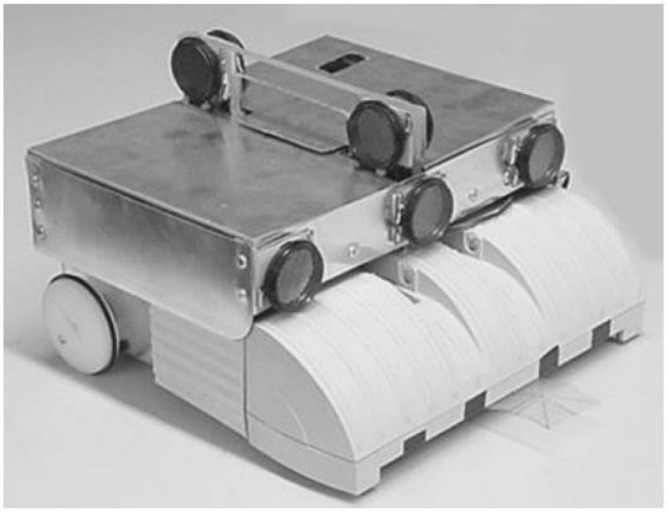

Figure 2.3: Cleaning robot proposed by Jordi [8].

Next, three microcontrollers have been used for robot control in Jordi‟s floor cleaning robot. The main microcontroller has a memory bank of 256 KB built using I2C EEPROM devices, which enable the robot to store the environment map. [8] Then, a 6V lead-acid battery is used as power supply for the robot and rechargeable by using recharge equipment. Two DC geared Maxon motors are used for robot travelling and one brush motor for fixes cleaning intensity. A Hewlett Packard digital encoder with 1000 pulses per turn has built in the Maxon motor for speed measurement [8]. Figure 2.4 is shown the robot control diagram for the floor cleaning robot.

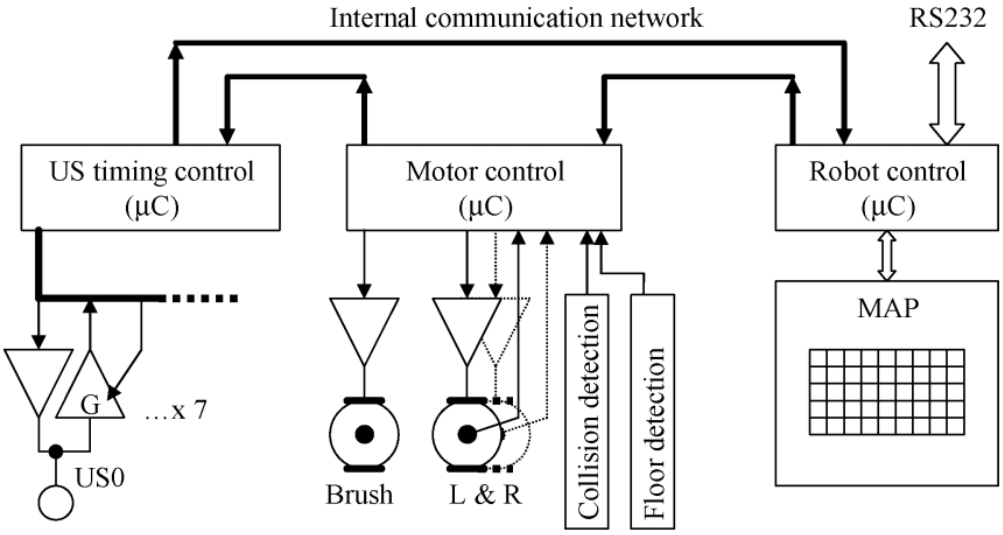

Figure 2.4: Floor cleaning robot control diagram [8].

In contrast, researchers had also fabricated a cleaning robot to perform cleaning tasks at the outside surface of the building, such as window glass of the modern architecture. A prototype of window cleaning robot shown in Figure 2.5 had been developed by Miraikikai Inc. The robot is small, lightweight and portable to perform the cleaning on a single large windowpane [9].

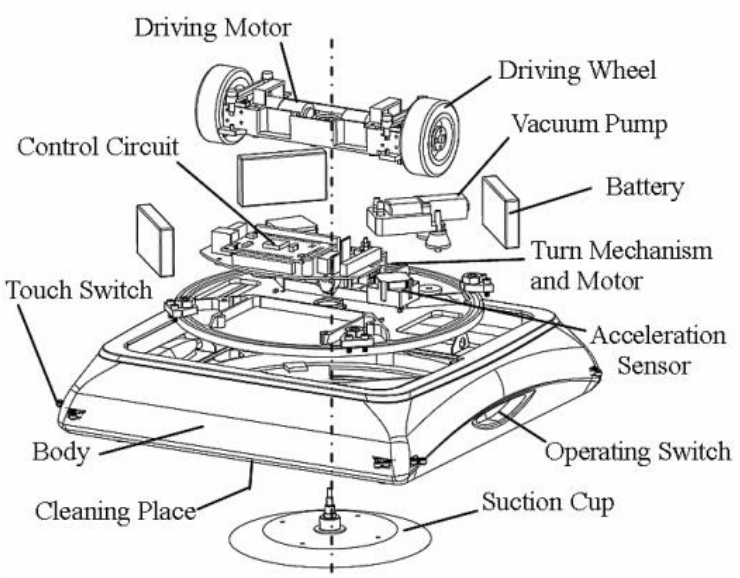

Figure 2.5: Mechanism of small-size window cleaning robot [9].

There are two types of sensors used on this window cleaning robot, which is touch switch and acceleration sensor The function of the touch switch is to detect the corner of windowpane while the robot travel from place to place, and the acceleration sensor is used for altitude control to detect the convoluted value between the acceleration of gravity and acceleration by the motion of the robot. A vacuum pump with maximum pressure 33.3 kPa and flow volume of 2.5 l/min is used as cleaning equipment to get rid of all the dust from the window surface [9].

Besides that, this window cleaning robot is implemented a PC 104 embedded controller to control the robot operation. This controller is a type of CPU Pentium 166 MHz, had built in with A/D converter, DIO channels, motion control and wireless LAN card. Next, the power supply for this robot is lithium-polymer battery with maximum current of 30 A. The power dissipation from the battery for controller and actuators are 7.2V and 14.4V respectively. The actuators of the cleaning robot are DC servo motors for