RESEARCH AND DEVELOPMENT ON MOTION CONTOL FOR ONE LEGGED TYPE HOPPING ROBOT

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RESEACH VOTE NO:
PJP/2010/FKE (25C) S00726

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2011

ABSTRACT

(Keywords: jumping type, hopping robot, central pattern generator)

In half of century, there are a lot of types of autonomous locomotion robot which have been explored. Most of mobile robots are wheeled type locomotion because of the simplicity in robot construction. The wheeled type locomotion excels on prepared surface such as rails and roads, but most of them have not yet been explored. As a result, the study on animal-like robot locomotion i.e. in multi legged, snake-like, bipedal walking and hopping robot has been received much attention from many researchers because of the adaptive locomotion on unknown surface which are frequently faced by mobile robots in real-life environment. The construction of useful legged type locomotion need the systems that able to control joint motion, cycle use of legs, monitor and manipulate balance, generate motions to use known footholds, sense the terrain to find good footholds and calculate negotiable footholds sequences. However, from almost of legged type robots which have been developed are having low energy efficiency and low transferring efficiency while moving performances because of their difficulties on mechanism and control systems. Consequently, study on jumping type robot was carried out although it has complex control system. The jumping type locomotion can be divided into two types which are hopping and jumping type robot. The big difference of hopping and jumping type robot is jumping robot can make only one big jump moving performance. In contrast, the hopping robot can generate the continuous and rhythmical jumping performance while making movement. Generally, the hopping robot can be used for searching the lost victims who need help instantly. Therefore, it can be applied in rescue activities. Recent years, the ultimate disasters are becoming worse such as earthquake, landslide and etc. On the other hand, it also can be used for surveillance activities such as in the estate, forest and outer space such as moon surface.

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ACKNOWLEDGEMENT

First and foremost I wish the greatest grateful to Allah S.W.T for giving me this great opportunity to proceed this short term project report. For being very helpful through his continuing guidance, advice and suggestion throughout of my performance in completing this project, a big thanks to the co-researchers. I also would like to thank you to all my friends, who has supporting me by giving me helps and ideas in each they can. Special thanks to Master Research student, Miss Nurul Hafizah binti Abdul Rahim and Final Year Project student Mr. Arman Hadi bin Azahar for giving their effort in order to completing this project. Thanks for my family which has been supporting me from behind, giving me enough support morally and physically. Thanks to all that has been supporting me in completing this projects whereas from the starting until this report has been submitted. Last but not least thanks to all that has been supporting my project either intentionally or unintentionally

Table of Contents

List of Tables

List of Figures

CHAPTER 1

Introduction

Legged robots which are capable of dynamic operation and active balance have the potential for similar mobility, efficiency, and dexterity as their biological counterparts. There are only such robots would be able to operate in a much larger range of environments and surface conditions than current wheeled and tracked vehicles. Moreover, similar system design and control advances would benefit applications beyond those requiring traditional locomotion, for example dexterous mechanisms for the inspection of power lines, steel trusses, or pipe systems. Once stable and autonomous legged systems are feasible and affordable, there will be no lack of applications. Unfortunately, it is not yet power-autonomous because of its low power and unprecedented efficiency represents important milestones toward that goal [1].

The construction of the useful legged type locomotion need the systems that are able to control joint motion, cycle use of legs, monitor and manipulate balance, generate motions to use known footholds, sense the terrain to find good footholds and calculate negotiable footholds sequences. The jumping type locomotion can be divided into two types which are hopping and jumping type robot. The big difference of the hopping and jumping type is hopping robot can generate the continuous and rhythmical jumping performance while making movement compared to jumping robot which is can make only one big jump moving performance. Generally, the hopping robot can be used for searching the lost victims who need help instantly. Therefore, it can be applied in rescue activities [2].

Problem Statement

There are a lot of types of autonomous and manual control locomotion robot had been explored. Most robots that have been explored consist of the locomotion toward prepared surface such as rails, roads and flat surface which has a simple degree of freedom (DOF) motion but most of them have not yet explored. There is a problem faced for most mobile robots to adapt on unknown surface in real-life environment. Only about half of earth's surface is accessible for wheeled type locomotion and much larger surface can be reached by animal-like locomotion and time can be reduce to achieve or cover such a large surface compared to time taken for a wheeled locomotion cover the same path of surface.

However, most of developed legged robots have difficult mechanism and control system design. The mechanisms of the legged robot especially for hopping robots are difficult to design synchronously with control system. Consequently, low efficiency and low transferring efficiency problem occurs when they are moving. These problems contribute to the unstable rhythmical jumping performance. Thus, the jumping is not synchronous and the percentage of problems will increase. Consequently, a study on jumping type robot was carried out and the hopping locomotion robot is covered in this study in order to generate the continuous and stability of rhythmical jumping performance while making movement. In directly, the hopping robot can be applied for rescue activities cause of its specialty on locomotion that can move on unknown surface in high speed movement.

Project Objectives

Locomotion is of fundamental importance in understanding adaptive behavior. The aims of this project entitle "Study and develop the motion control system of hopping robot for real time application" are:

i. to design and develop the system on one leg hopping robot for real time performance;
ii. to investigate the validity of model to generate rhythmical hopping performance;
iii. to measure and evaluate the maximum hopping height which can be achieved by the one legged hopping robot proposed;
iv. to evaluate the stability of the rhythmical hopping performance of the one legged hopping robot.

Scope

Normally, when dealing with locomotion, the focus is on the control aspects, as illustrated by most of the research in the field of robotics. In this project, the study will focus primarily on a development of one-legged hopping robot and its experimental motion control system. Other aspect that will cover in this project is to design the control system to generate the hopping motion in real time application which is the sampling time, T_s is 0.01 sec. The analysis on the measurement hopping height for hopping robot are obtained from analog distance measurement sensor used which is called Infra Red Sensor (IR Sensor). Matlab Simulink software is used to control the motion system and the gain involved in the motion control system block diagram is fixed. For the hardware design, the structure of the robot is designed with the spring coefficient; *k* is shown in Chapter 4.

Project Overview

Basically, this project is mainly about to study and develop the motion control system of hopping robot for real time application which is to find the stability of the hopping robot in real time. This project is implementing based on human brain and neural network.

Generally, the proposed configuration control system is generated by a host computer using Matlab & Simulink. Analog command signal from the host computer will transmit through Digital to Analog Converter (DAC) and amplifying by DC amplifier to the DC geared motor on the robot. Then the height is measured by an infrared sensor and the signal is transmitted to host computer through the Analog to Digital Converter (ADC). The signal from ADC can be plotted in the xPC Target computer.

This project will be done according to a few phase starting from literature review until functionality testing. It begins with searching for information which is related to the project and the resources would come from books and/or internet resources. It is necessary to search as much as information used possible for references to find out the best alternative to complete the project.

Lastly, comparison for methodology is the next step to figure out the most suitable method used to complete the project. The method chosen is applied with designing the hardware one legged hopping robot and testing the control system the hopping robot. The control system is generated by using Matlab & Simulink software. This process repeated done for several time until the system is fully tested before proceed to construct any experiment. These process only stops after the system really work and achieve the objectives of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Legged Robot

Legged robots which are capable of dynamic operation and active balance have the potential for similar mobility, efficiency, and dexterity as their biological counterparts. There are only such robots which would be able to operate in a much larger range of environments and surface conditions than current wheeled and tracked vehicles. Moreover, similar system design and control advances would benefit applications beyond those requiring traditional locomotion, for example dextrous mechanisms for the inspection of power lines, steel trusses, or pipe systems. Once stable and autonomous legged systems are feasible and affordable, there will be no lack of applications. Unfortunately, it is not yet power-autonomous because of its low power and unprecedented efficiency represents important milestones toward that goal[1].

The construction of the useful legged type locomotion need the systems that able to control joint motion, cycle use of legs, monitor and manipulate balance, generate motions to use known footholds, sense the terrain to find good footholds and calculate negotiable footholds sequences. The jumping type locomotion can be divided into two types which are hopping and jumping type robot. The big difference between the hopping and jumping type is that the hopping robot can generate the continuous and rhythmical jumping performance while making movement compared to jumping robot which can make only one big jump moving performance. Generally, the hopping robot can be used for searching the lost victims who need help instantly. Therefore, it can be applied in rescue activities[2].Aside from the sheer thrill of creating machines that actually run, there are two serious reasons for exploring the use of legs for locomotion. One is mobility: There is a need for vehicles that can travel in difficult terrain, where existing vehicles cannot go. Wheels excel on prepared surfaces such as rails and roads, but perform poorly where the terrain is soft or uneven. Because of these limitations, only about half the earth's landmass is accessible to existing\ wheeled and tracked vehicles, whereas a much greater area can be reached by animals on foot. It should be possible to build legged vehicles that can go to the places that animals can now reach. One reason legs provide better mobility in rough terrain is that they can use isolated footholds that optimize support and traction, whereas a wheel requires a continuous path of support. As a consequence, a legged system can choose among the best footholds in the reachable terrain; a wheel must negotiate the worst terrain. A ladder illustrates this point: Rungs provide footholds that enable the ascent of legged systems, but the spaces between the rungs prohibit the ascent of wheeled systems[3].

Table 1 Types of locomotion

Type	**Advantages**	**Disadvantages**
Wheel	• High transferring efficiency on the level floor • Easy mechanism and control	• Narrow action range
Leg	• High capability to overcome obstacle	• Low energy efficiency • Low transferring efficiency • Difficult mechanism and control
Crawler	• The action range is wider than a wheel.	• Larger frictional resistance and lower efficiency than a wheel.
Hopping	• An obstacle can be overcome by a jump.	• Difficult mechanism and control

Another advantage of legs is that they provide an active suspension that decouples the path of the body from the paths of the feet. The payload is free to travel smoothly despite pronounced variations in the terrain. A legged system can also step over obstacles. In principle, the performance of legged vehicles can, to a great extent, be independent of the detailed roughness of the ground[3].

2.1.1 Hopping Robot

The jumping type locomotion is divided into two types which are hopping and jumping type robot as shown in Figure 1. The big difference that differentiates the hopping and jumping type robot is the jumping type robot can be make only one big jump moving performance. On the other hand, the hopping type robot can generate the continuous and rhythmical jumping performance. M.H Raibert is the main contributor on the hopping robot research which is research on one-legged hopping robot[4]. The one-legged robot consists of two main parts which are body and leg whereby it equipped with a pair of pneumatic actuators to exert a torque between the leg and the body about to hip. Afterward, Koditscheck and Buhler have created the discrete dynamic system theory to analyze the dynamics of a simplified hopping robot that studied only the vertical movement[5].

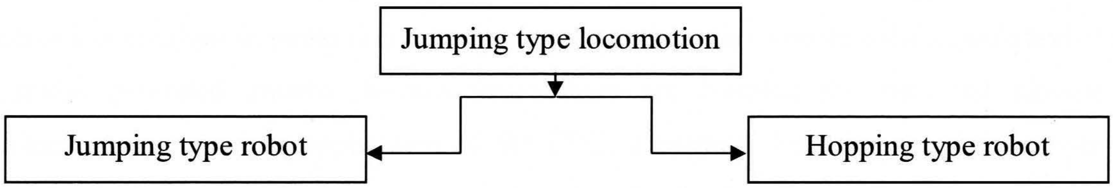


Figure 1 Jumping type locomotion

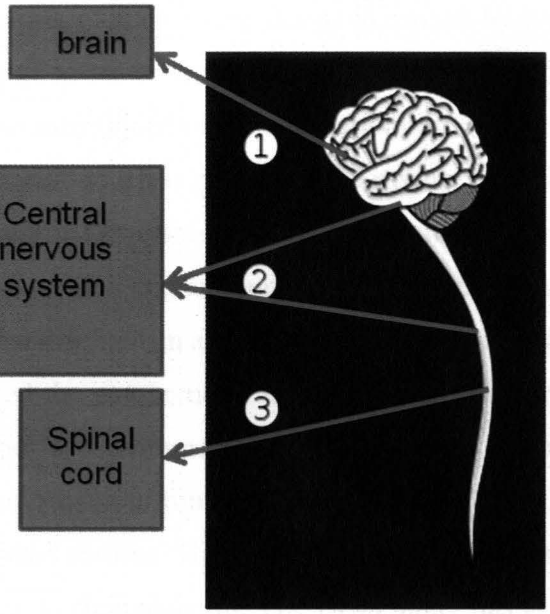
Besides that, I. Murakami et. al. has done his research on hopping robot by linear DC motor which is hopping and moving motion control by using the attitude control with gyroscope. The linear DC motor was designed into the body part and the leg part of the hopping robot and constructed the design of the jumping machine using self-energizing spring. This research has produced a machine or robot to jump high by using small output actuators. Moreover, Tukagoshi et. al. has studied in numerical analysis and design for higher jumping rescue robot by using a pneumatic cylinder. They developed and overcome the irregular surface (jumping locomotion). Meanwhile, Kondo et. al. has developed the quadruped hopping robot which is using Central Pattern Generator (CPG)s to generate the continuous jumping performance while control the stability of body balance[1].

2.2 Central Pattern Generator (CPG)

Physiological experiments suggest that basic locomotors patterns of most living bodies such as walking, flapping, flying and swimming are generated by Central Pattern Generator (CPG) which generates rhythmic activities. CPG is neural networks that can endogenously (i.e. without rhythmic sensory or central input) produce rhythmic patterned outputs; these networks underlie the production of most rhythmic motor patterns. The periodic activities of the CPG which are initiated by a burst from the higher motor center induce the muscle activities. After the initiation of the locomotion, the activities of the CPG are affected by sensory signals which show the bending of the body and so on. The procreative sensory feedback plays an important role in the shaping and coordination of the neural activity with the mechanical activity.

Furthermore, neurophysiologic studies of insect locomotion suggest that sensory feedback is involved in patterning motor activity and that it is more than the modulation of the centrally generated pattern. Several researchers are coupled the neuronal circuits to mechanical body and as application of the CPG, a method designing control systems for legged robot motion has been carried out. On the basic of the definition, walking is locomotion emerging from that interaction between the environment and the body[2].The behavior of the human and animals are act based on the data processing which is determined by united of neuron cells. For the advanced animal, the nerve forms are ensemble as the brain, ganglions, and the spinal cords as shown in Figure 2. Neuron cell passes the information through the neural network and transmits to a specific group of muscles. The reflex action is taken according to the shrink of muscle regularly as shown in Figure 2.

Figure 2 In a lot of living bodies, the behavioral pattern is caused by the program which is existed in the central nerve. The locomotors program is based on the fixed neuron circuit when the movement program is activated by movement pattern cooperation which has been taken spatially and timely and generates the locomotors pattern.



(a)

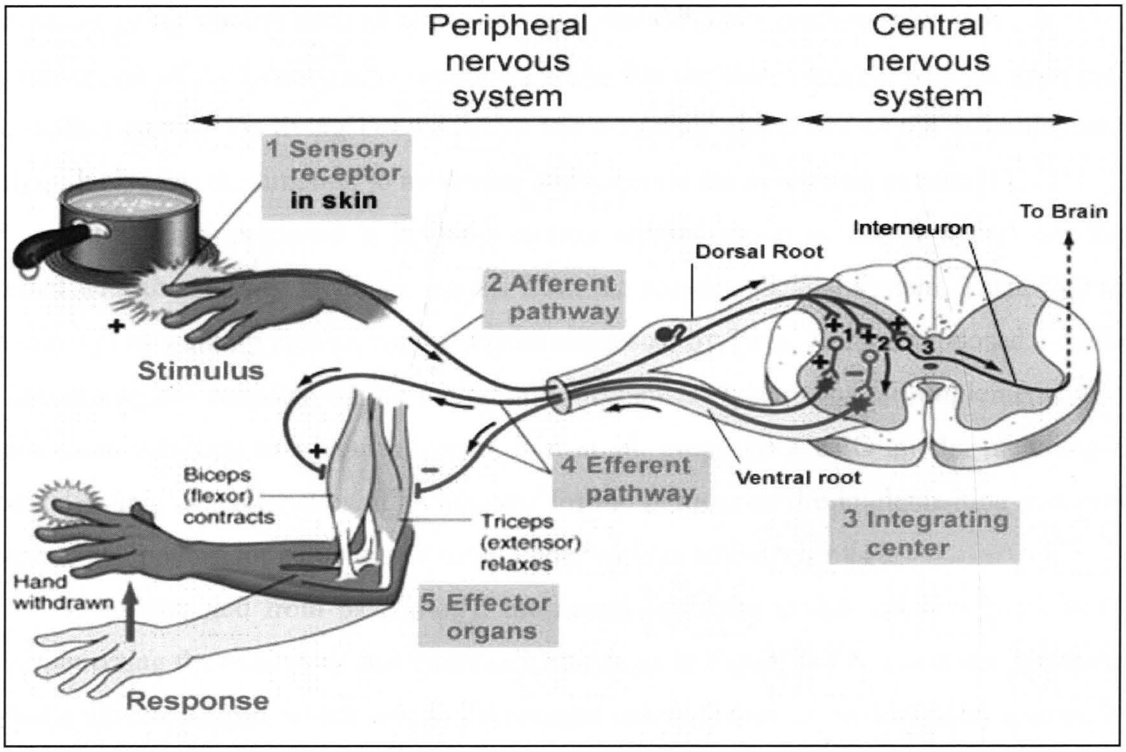


Figure 2(a) The nerve forms (b) Neuron information transferring

The periodic locomotion of such living things is caused by a periodic excitement of the nerve system in the ganglion nerve and the spinal cord that could generates the rhythm pattern autonomously. It also memorized in the structure of the neural network and generates when it is necessary. The circuit which is generated the rhythm is thought to be in the spinal cord that called Central Pattern Generator (CPG). The instruction input from a high-rank center is assumed to be a switch signal and reproduced the autonomous and muscle contraction. It can be said that mechanism as the central of the locomotors nervous system.

The CPG is generated the autonomous and intermittent rhythmical pattern which the commands are received from a cerebrum. The CPG gives the stimulation to each muscle which is considered as the information from the sensory organ. Then, the movement occurred when the muscle is strained and shrinks. The sensory organ perceived the movement which is generated and sends the state to the cerebrum. The living body has achieved the control and the power addition and subtraction of the skilled locomotion by the favor of the mechanism that corresponds to such feedback. It can be said that the training is often can make the movement going smooth such as sports, although the CPG is a mechanism which can control the movement of the living body. Therefore, it also has the ability to deal with the problem of the motion control for living body such as the nonlinear characters of the musculoskeletal system. It also has the function to memorize and generate the movement pattern [1].

Here, Taga proposed a walking motion control mode in which neural oscillator interact with the sensory feedback signals from the musculoskeletal system. Then, by using the concept of walking motion control model suggested by Taga, Kimura proposed a method of structuring the coupling of the neural and mechanical system for the implementation of autonomous adaption to irregular terrain. Son et. al. proposed a CPG ,model including the motor dynamic characteristics of an actuator for the purpose of the implementing generation adaptive gait pattern for a quadruped robot under various environment[1].

It is identified from psychology; the neural oscillator model can be represented by interconnecting the excitatory and inhibitory neuron as in Figure 3. The oscillator generates a periodic motion pattern, which acts as a command centre for the musculoskeletal system. The CPG neuron model which is shown in Figure 3 is regarded as on unit of the nerve oscillator although the rhythmical movement can been achieved by the network of the complex nerve oscillators. The black circle shown in the figure shows a negative unit and white circle shows as positive unit.

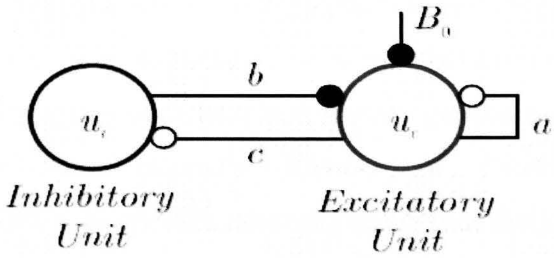


Figure 3 CPG neuron model

a	:	Intrinsic excitatory coupling parameter
b	:	Inhibitory coupling parameter
c	:	Excitatory coupling factor
B_0	:	Constant bias input
u_e	:	Excitatory unit (internal state)
u_i	:	Inhibitory unit (internal state)

2.2.1 Anatomy

Although anatomical details of CPGs are specifically known in only a few cases, they have been shown to originate from the spinal cords of various vertebrates and to depend on relatively small and autonomous neural networks (rather than the entire nervous system) to generate rhythmic patterns. Neural rhythmicity can arise in two ways: "through interactions among neurons (network-based rhythmicity) or through interactions among currents in individual neurons (endogenous oscillator neurons). A key to understanding rhythm generation is the concept of a half-center oscillator (HCO). "A half-centre oscillator consists of two neurons that individually have no rhythmogenic ability, but which produce rhythmic outputs when reciprocally coupled." Half-center oscillators can function in a variety of ways. First, the two neurons may not necessarily fire in antiphase and can fire in any relative phasing, even synchrony, depending on the synaptic release. Second, half-centers can also function in an "escape" mode or a "release" mode. Escape and release refer to the way in which the off-neuron turns on; by escape or release from inhibition. Half-center oscillators can also be altered by intrinsic and network properties and can have dramatically different functionality based on variations in synaptic properties. For a more detailed description of the neural circuitry underlying the leech heartbeat rhythm generator and the pyloric network of decapods crustacean see "Hooper's Review of Central Pattern Generators". The classical view of CPGs, as specific networks of neurons dedicated to this function alone, has been challenged by numerous data obtained mostly on the central nervous system of invertebrates. In addition to be classical dedicated networks, most of the CPGs seem in fact to be either reorganizing or distributed circuits, and a single neural circuit can combine features typical of each of these architectures. The observation in invertebrates of pattern generators temporarily formed before the production of motor activity strengthens the assumption.

2.2.2 Rhythm Generators

Central pattern generators can also play a role in rhythm generation for other functions in vertebrate animals. For example, the rat vibrissa system uses an unconventional CPG for whisking movements. "Like other CPGs, the whisking generator can operate without cortical input or sensory feedback. However, unlike other CPGs, vibrissa motoneurons actively participate in rhythmogenesis by converting tonic serotonergic inputs into the patterned motor output responsible for movement of the vibrissae [8]. Breathing is another non-locomotive function of central pattern generators. For example, larval amphibians accomplish gas exchange largely through rhythmic ventilation of the gills. A study by Broch, et al. showed that lung ventilation in the tadpole brainstem may be driven by a pacemaker-like mechanism, whereas the respiratory CPG adapts in the adult bullfrog as it matures. Broch, Lise, et al. "Regulation of the respiratory central pattern generator by chloride-dependent inhibition during development in the bullfrog (*Rana catesbeiana*)." *The Journal of Experimental Biology* (2002): 205, 1161–1169 .Thus, CPGs hold a broad range of functions in the vertebrate animal and are widely adaptable and variable with age, environment and behavior.

2.3 Hardware Specification

Many of the mechanical and electrical components are used and applied in a experiment. These components are involved in order to create the achievement of a project by completing all goals and objectives. There are two types of important hardware components to play their own role and calibrate each others in the control system. The components are as below:

- Mechanical Hardware
- Electrical Hardware

2.3.1 Mechanical Hardware

One Legged Hopping Robot

The structure of one legged hopping robot is the inertia load of the system. It is made up by integration of stainless steel and aluminum plate. It can be mounted on the both shaft of the DC geared motor by screw each cranks. The structure of the one legged hopping robot is shown in Figure 4.

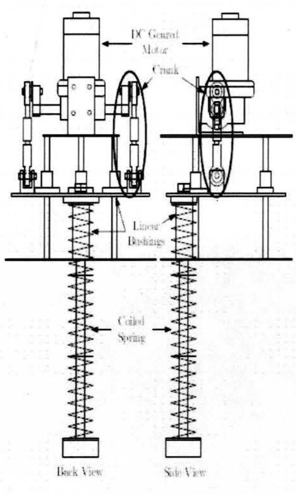


Figure 4 The structure of the one legged hopping robot

2.3.2 Electrical Hardware Description

DC Geared Motor

Figure 5 shows the DC geared motor with the warm gear which the important part that used in the hopping robot development to generate the hopping performances. The DC motor with the warm gear or also known as DC geared motor is manufactured by a company in Japan, SAWAMURA Electric Industry Co. Ltd. The bottom part of the DC motor is a gear part of DC motor accessory that used for transmitting the power from the DC motor to generate the hopping. For the information, the specification of the DC geared motor is shown in Table 2.

Table 2 DC motor specification

DC motor (SS23F)		
Rated voltage	12	V
Rated current	1.6	A
Rated torque	0.032	Nm
Rated speed	3000	Min^{-1}
DC motor (SS23F-E-EW) with geared		
Rated current	0.8	A
Rated torque	0.098	Nm
Rated speed	200	Min^{-1}
Gear ratio	15:1	

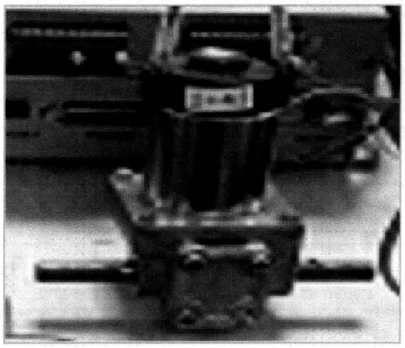


Figure 5 DC geared motor

Infrared Ranging Sensor

Figure 6 shows the external or actual physical view of the infrared ranging sensor (2Y0A21F) and the Table 3 shows the information of the specification of the infrared sensor (IRS). This IRS manufactured by Sharp Co. Ltd. The IRS is an analog distance sensor which is a device that use infrared ray to detect an object or obstacle in between 10 cm to 80 cm away. This IRS also provides a non-linear relation between the voltage output and the distance of an object from the sensor.

Figure 6 Infrared Sensor

Table 3 Specification of Infrared Sensor

Parameter	**Symbol**	**Rating**			**Unit**
Supply voltage	V_{cc}	-0.3 to +7			V
Output terminal voltage	V_o	-0.3 to V_{cc} +0.3			V
Operating temperature	T_{opr}	-10 to +60			^oC
Storage temperature	T_{stg}	-40 to +70			^oC
Parameter	**Symbol**	**MIN.**	**TYP.**	**MAX.**	**Unit**
Average supply current	I_{cc}	-	30	40	mA
Distance measuring	ΔL	10	-	80	Cm
Output voltage	V_o	0.25	0.4	0.55	V
Output voltage differential	ΔV_o	1.65	1.9	2.15	V

Micro-Box

Micro-Box 2000/2000C is a rugged, high-performance x86-based industrial PC with no moving parts inside. It supports all standard PC peripherals such as video, mouse, and keyboard. For engineers who have real-time analysis and control systems testing needs, Micro-Box 2000/2000C offers an excellent mix of performance, compact size, sturdiness, and I/O expandability. It is available with several different I/O selections, supporting both SCI and TCP/IP communication interfaces and various PC/104 based AD/DA, DIO, Encoder, CAN Bus and Counter (PWM) modules that address numerous prototyping requirements.

User uses Micro-Box 2000/2000C integrating with MATLAB/Simulink and related control modules could run real-time modeling and simulation of control systems, rapid prototyping, and hardware-in-the-loop testing. And these tasks don't need any manual code generation and complicated debug process. The result benefits users in saving much of the costs and developing time. Figure 7 shows the Micro-Box 2000/2000C equipment and the specification is listed in the Table 4.

The features of the Micro-box are listed below:

- Rugged, high-performance industrial PC
  - Fanless, low-power consumption with 22W(Typical)
  - Support all standard PC peripherals
  - Sturdiness, compact size
- I/O-expandability, equipped with AD/DA, Encoder, CAN, Counter PWM and DI/O modules.
- Onboard Celeron® M 1GHz/256 MB DDR RAM, 64MB compact flash (expandable to 1GB)
- External floppy, power supply input Min. 48 W. (9~36 VDC, e.g+24V@2A)
- Stand-alone ability, xPC self-installed software tools (xPC Target Embedded Option) are able to run on stand-alone mode. Users can burn the pre-set Simulink model to CF card without connecting through internet.

Figure 7 Micro-Box 2000/2000C

Basically, Micro-Box 2000/2000C has three pair of connectors. There are connector 1, connector 2 and connector 3 respectively for CAN, ADC/DAC and Encoder connector pair. Rear panel of Micro-Box 2000/2000C has four D-Sub 9 Pin connectors for RS232/RS485 (COM1, COM2, COM3, and COM4), two local area network communication ports LAN1, LAN2 and power socket, shown in Figure 8.

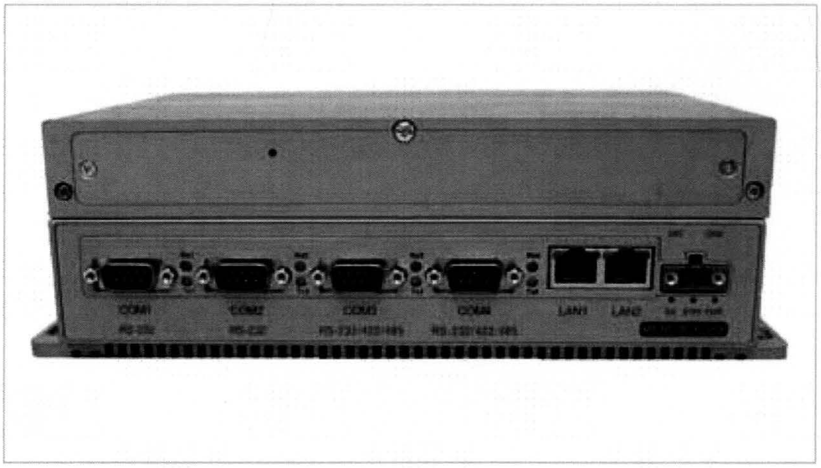


Figure 8 Rear panel of Micro-Box

Table 4 Micro-Box specification

CPU	Celeron® M 1GHz, with 256MB DDR DRAM
Flash Memory	64MB Compact Flash Card (Expandable to 1GB)
Power Input	Input Power Range 9~36Volts, Min. 50W. Input Power 19 VDC/3.42 A (100 ~ 240 VAC Adapter included)
Dimensions & Weight	255(W) x 152(D) x 82(H) mm, 2.0 kg
Communication Interface	Support both Serial Port and TCP/IP Interface (R8139 chipset)
ADC-Build-in I/O	Sensoray526, 8-ch Single-Ended 16-bit A/D Converter (±10 V)
DAC-Build-in I/O	Sensoray526, 4-ch 16-bit D/A Converter (±10 V)
Digital I/O-Build-in I/O	Sensoray526, 8-bit Digital I/O
Encoder-Build-in I/O	Sensoray526, 4-ch with 24-bit Incremental Encoder(1x,2x or 4x)
Digital I/O-Build-in I/O	8-bit from Parallel Port
CAN Bus-Option I/O	Softing CAN-AC2-104 with 2 Ports, Speed up to 1Mbps