Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2013
(ICMERE2013) 1-3 May 2014, Chittagong, Bangladesh

ICMERE2013-PI-202

PERFORMANCE OF A LOCALLY FABRICATED WIRELESS PC CONTROLLED SCARA ROBOT

S. K. Alen[1] **and M. A. R. Sarkar**[2]

[1, 2]Department of Mechanical Engineering, Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh

[1]educative.alen@gmail.com

Abstract*- The present work reports the fabrication and performance of wireless PC controlled SCARA robot. The arm is compliant in x-y direction, but rigid in the 'z' direction. The robotic arm consists of two links with a parallel-axis rotary joint layout. It was designed and fabricated with low cost locally available material. The SCARA is able to locate any polar coordinate within its work envelope. The kinematic chain of the links is solved by using inverse kinematics. Using DC-servo motor instead of stepper motor ensures the precise angular rotation of the links and using RF modules for wireless PC control gives it sufficient system automation. The inverse kinematics problem for linear interpolated moves was input into the C program. As the program executes, motors turn themselves to make the links rotate accordingly in order to move the arm end-effector to the desired polar coordinate.*

Keywords: SCARA Robot, Inverse kinematics, Servo motor, Wireless pc interfacing

1. INTRODUCTION

In this modern era of technology, robotics and automation of systems play an important role on the high growth rate of development. Bangladesh is a developing country and its development depends significantly on the growth of industrialization. Automation in industries is a vital part at this time. So in this work an arm is designed which can be used in different industrial applications. In order to reduce complexity in gripping and placing objects in particular positions this robot can be used. At this current stage of development semi-autonomous or fully automated robots are indispensable in an incredible number of applications. In this work performance of a wireless PC controlled SCARA robot is observed and the importance of its wireless control system in this robot is evaluated. The SCARA acronym stands for selective compliant articulated robot arm which was first designed and developed by Professor Hiroshi Makino in 1981.The jointed two-link arm layout of SCARA is similar to our human arms and hence it facilitates a lot of industrial tasks in which motion on only X-Y plane is required. This robot with its wireless control system can be used in different industrial applications such as pick and place, palletizing, assembly and packaging, automobile industry, etc.

2. KINEMATICS

Kinematics is the relationship between the positions, velocities, and accelerations of the links of a robot arm. Kinematics problem consists of forward and inverse kinematics and each of the above has its preference of application. Forward kinematics may subdivide into the followings:

- Graphical method
- D-H convention

And the inverse kinematics may be subdivided into

- Geometric method
- Algebraic method

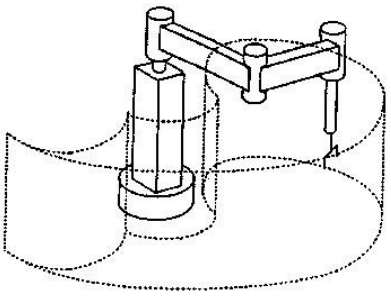

Fig.1: Kinematic Envelope of SCARA

In our case our problem is solved using inverse kinematics problem. Inverse kinematics solutions are not linear. There exist complicated solutions and there exists no solution in some cases. Applying trigonometric solution for solving inverse kinematics problem is the simplest way.

If we consider the following Fig.2 case to solve a two planar manipulator inverse kinematics then we find that (r, θ) for any polar coordinate is given and we have to find θ_1 and θ_2 for this case. Trigonometric method has been applied to solve for a joint variable and if the joint variable is solved then the manipulator can be considered as a reduced degree of freedom (DOF) mechanism- with one less joint.

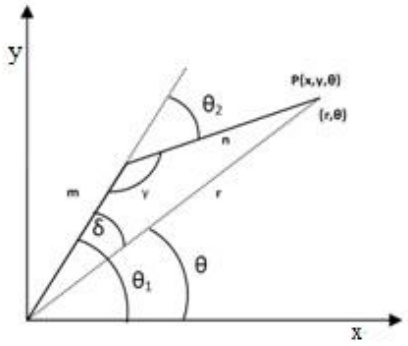

Fig.2: Geometry of two link SCARA robot

The geometric and trigonometric equations can be found as follows:

$$r^2 = x^2 + y^2 \quad (1)$$

$$\theta = \tan^{-1}(y/x) \quad (2)$$

$$\delta = \cos^{-1}[(m^2 - n^2 + r^2)/2mr] \quad (3)$$

$$\theta_1 = \theta + \delta \quad (4)$$

$$\gamma = \cos^{-1}[(m^2 + n^2 - r^2)/2mn] \quad (5)$$

$$\theta_2 = 180^o - \gamma \quad (6)$$

where, (r, θ) is the polar coordinate of the end-effector, (x, y) is the Cartesian coordinate of the end-effector, m and n are the length of the inner and outer link respectively, θ_1 is the interior angle between the x-axis and the inner link, θ_2 is the exterior angle between the two links, γ is the interior angle between the two links, and δ is the interior angle between the inner link and the imaginary straight line that extends from the robotic arm's inner joint to its outer joint.

3. MECHANICAL DESIGN

For initial designing and dimensioning SOLIDWORKS software is used. After the simulation of this design the task that comes to front is the material selection for this robot. For the joints of this SCARA robot servo motor is chosen for its high precession in the angular positioning.

3.1 Structural Frame

For making the robot a wide range of material has been studied. Initially for framing and making a model of the robot plastic wood available in local market is used and then considering its load on the end effector and the robot itself Aluminum is used for making the links of the robot. Aluminum is chosen for its light weight and comparatively high strength to weight ratio [1]. For the base of the robot, wood is chosen, and for end effector Acrylic is used.

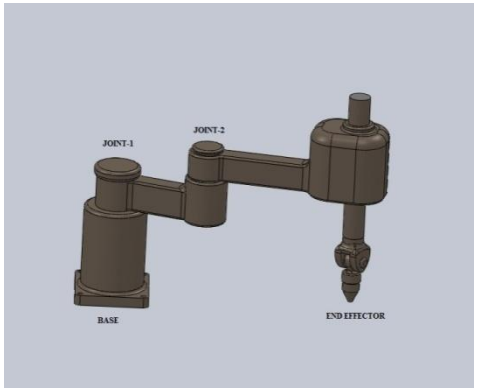

Fig.3: Schematic diagram (using SOLIDWORKS) for body structure

3.2 Servo Motor Operation

The most important part while making this robot is to choose the suitable motor for operating the joints. Though DC motor and stepper motor are widely used on various operations [2] but in this case servo motor is chosen for its high precession in rotary motion.

A Servo Motor is defined as an automatic device that uses an error-correction routine to correct its motion. A motor, control board, and a potentiometer connected to the output shafts is the major components of a servo motor.

Fig.4: Servo Motor (SG-5010)

Servos are extremely useful in robotics and automation. Servo motors are used specifically where the motor must be able to operate at a range of speeds without overheating, operate at zero speed while being able to retain its load in a set position.

In this case TowerPro SG-5010 model servo motor is chosen and the specification of this motor as follows:

Model: TowerPro SG-5010
Modulation: Analog
Torque: 4.8v (8 kg-cm), 6v (11 kg-cm)
Operating Voltage: 4.8V~6.0V
Rotational Range: 180°

The average operating speeds should be considered in selecting a servomotor that can handle the job without danger of thermal overload. Figure-5 shows the continuous motor torque for a servomotor rated at 3.8 kg-m and 4,000 rpm for example [3].

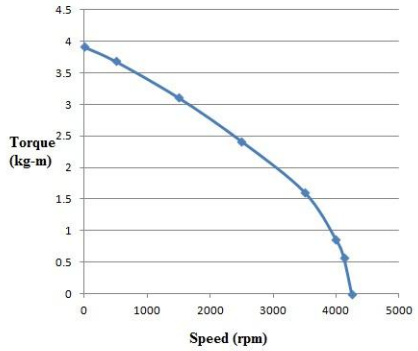

Fig.5: Typical Servo Motor Torque-Speed Curve [3]

Servo motors are high performance alternative to the stepper motor and the type of motor is not critical to a servo motor. Generally brushed permanent magnet DC motors are used considering their simplicity and low cost.

4. ELECTRONIC COMPONENTS

Electronic components of this wireless PC control SCARA system are not so complicated. For controlling the joint servo motors no motor controller is needed it can be directly controlled by the microcontroller. And for the PC interface signal level conversion IC is used and for the wireless transmission of data from the PC to the MCU (microcontroller) RF (Radio Frequency) modules are used.

4.1 PIC18F452 Microcontroller

A microcontroller (MCU) is a computer on a chip with both input output and with inbuilt timers and counters. It is a small computer on a single integrated circuit consisting of a relatively simple CPU combined with support function such as crystal oscillator, timers etc.

The PIC18F452 microcontroller is a CMOS FLASH based 8-bit microcontroller packs that features a 'C' compiler friendly development environment, 256 bytes of EEPROM, self programming, 2 capture/compare/PWM functions, 8 channels of 10-bit Analog-to-Digital (A/D), 2 USART ports [4].

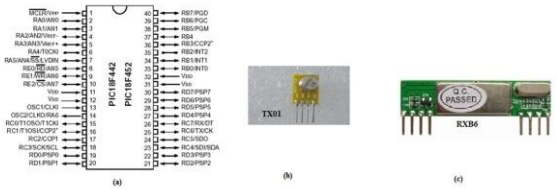

Fig.6: (a) PIC18F452 (b) TX01 (c) RXB6

Some general information of PIC18F452 MCU are given below:

- 4MHz-10MHz osc./clock input with PLL active
- Priority levels for interrupts
- Three external interrupt pins
- CCP pins and PWM output
- PWM resolution is 1- to 10-bit
- 1,000,000 erase/write cycle Data EEPROM

4.2 IC MAX232

The MAX232 IC converts signal from an RS232 serial port to signals suitable for using in TTL compatible digital logic circuits. MAX232 converts RX, TX, CTS and RTS signals. Mainly the receivers of MAX232 reduce RS-232 inputs to standard 5V TTL levels. The circuit diagram for MAX232 module is given below in Fig.7:

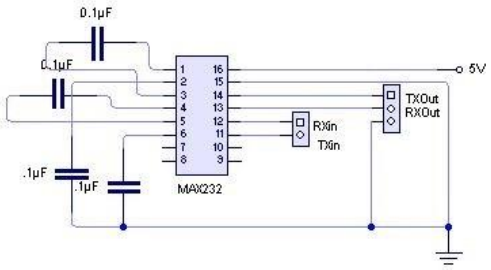

Fig.7: MAX232 Module Connection

4.3 RF MODULE

Radio frequency (also RF Module) module is an integrated electronic circuit which is used for the purpose of transmission of radio signals on one of a number of carrier frequencies. In case of medium and low volume products for consumer application RF modules may be used. RF modules are for both transmitting and receiving radio signals and individual modules are manufactured for these two cases. For transmitting data from the PC and for receiving it at the MCU end the following modules are used:

(a) RXB6
(b) TX01

Frequency for both of these modules is 433.92MHz. Generally 433.92MHz, 315MHz, 868MHz and 915MHz frequencies are used because of national and international regulations governing the use of radio for communication.

5. ELECTRONIC CIRCUITS

Mainly three individual circuits are needed for the electronic portion of this wireless PC controlled SCARA Robot system. A power supply circuit providing a constant 5V DC power supply, a servo controller circuit controlling the servo on the joints of the arm and wireless PC control module for commanding the robot through computer.

5.1 Power Supply Circuit

For a constant DC 5V power supply from the 220V-50Hz AC input the following circuit of Fig.8 is to be connected. From the AC input a bridge rectifier is used for rectifying the current. And DC output from the bridge rectifier is passed through the voltage regulator IC LM7805 and hence we get a constant 5V DC output from the output pin of 7805 IC [5]. 1n4007 diodes are used in this circuit and for reducing noise two individual capacitors of 470uf and 1uf are used at the input and output end of LM7805.

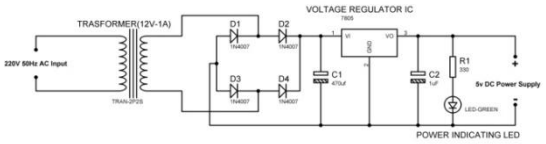

Fig.8: Power Supply Circuit for Wireless PC Controlled SCARA

5.2 Servo Controller Circuit

For controlling the servo motors of the joints of the arm no motor controller is needed, it can be directly controlled with the PIC18F452 microcontroller using Pulse Width Modulation (PWM) [6]. External crystal of value 8MHz is used for the MCU and Radio Frequency Receiver RXB6 is used in this circuit for receiving the signals which are transmitted by the TX01 of the MAX232 module.

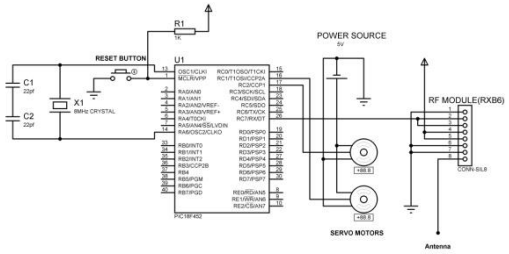

Fig.9: Schematic Circuit Diagram for SCARA Robot (using 2 servo motors and wireless PC control)

5.3 Wireless PC Control Module

Wireless PC control module is the vital part of this project. With the help of wireless transmission of data robot can be operated within the range permitted by the radio transmitter TX01 [7]. Max232 IC is used as the signal level converter (RS232 to TTL) in this circuit and TX01 is connected with the MAX232 and it also contains an antenna which is spiral for facilitating the transmission of radio frequency.

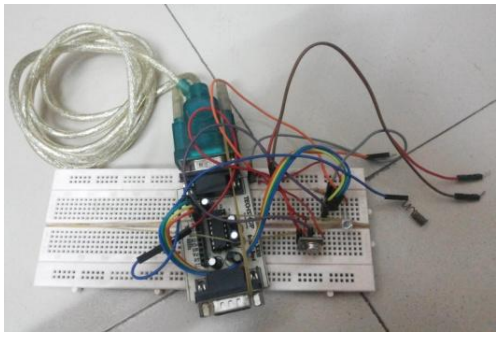

Fig.10: Wireless PC control module

6. APPLICATION FIELDS

Application field for this SCARA robot is huge. From the invention of this articulated robot arm it has been applied in different industries for the automation and it can do the task given to it at a high efficiency. Some important application where this wireless PC controlled SCARA robot can be applied are stated below:

(1) As this robot can be remotely controlled so it is possible for this robot to work in a hazardous environment.

(2) In case of material handling system such as pick and place, SCARA can be used and it can give a dependable and dynamic solution. Also inspection on the conveyor system can be provided by this robot.

(3) Palletizing that is transferring work pieces between pallets can be a application field of this robot. In this application parts are transferred to the specified place with this robot.

(4) It can provide sealing, adhesion application using 3D interpolation.

(5) Assembly and packaging is one of the major application fields of the SCARA robot. PCB cutting without stress and cracks is possible using this robot. It can be programmed to handle very precise installation work.

(6) It can be used in the automobile industry for different applications such as spray painting, fastening, gluing, parts carrying etc.

(7) SCARA robot can be applied in screw tightening; it can provide higher performance to screw tightening application using torque control.

(8) Targeting the users of home appliance maker and electric appliance maker this SCARA robot can be applied in sorting workpieces. In this application the robot will sort fed workpieces based on the product inspection data. And it will sort them according to the characteristics, barcode, lot etc and will arrange them in the predetermined positions.

Some other applications in which this SCARA robot can be applied are mentioned below:

- Vision inspection
- Arc welding
- Cutting or Drilling
- Industrial packaging
- Machine tending
- Dispensing
- Cleaning or Spraying

7. CONTROL SYSTEM AND SOFTWARE FEATURES

Control system of this robot is quite simple. It needs only microcontroller to operate servo motor. Servo motor is run with the help of pulse width modulation of a 20 ms pulse. And this modulation can be done by the built in PWM pins of the MCU and also with the timer of the MCU required pulse can be generated.

7.1 Timer

The timer is usually used to measure the signal period. Timer needs a clock pulse for timing which can be divided into two divisions:

- Timer with internal clock
- Timer with external clock

Timer0 module used in this case and it has the following features [8]:

- Software selectable as an 8bit or 16bit timer
- Readable and writable
- Clock source selectable
- Interrupt on overflow of FFh to 00h in 8-bit

7.2 Pulse Width Modulation

PWM (Pulse Width Modulation) is the term used to describe using a digital signal to generate an analogue output signal [8]. It can generate a continuously variable analogue output without using any other integrated circuits by smoothing the PWM signal with a capacitor. Pulse coded modulation is done to communicate the angle at which the servo will turn. In spite of having some deviations from the time mentioned below in Fig.11, the servo expects to see a pulse every 20 milliseconds. The length of the pulse will determine how far the motor turns. A 1.5 millisecond pulse will make the motor turn to the 90 degree position (often called the neutral position). If the pulse is shorter than 1.5 ms, then the motor will turn the shaft to closer to 0 degrees. If the pulse is longer than 1.5ms, the shaft turns closer to 180 degrees.

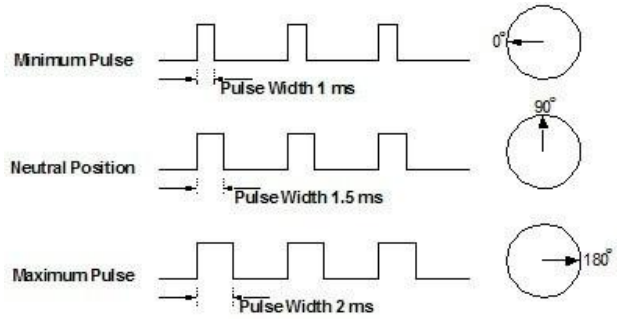

Fig.11: The Standard Time vs. Angle Chart for Operating Servo Motors

7.3 Serial Communication Interface

The universal asynchronous protocol - often simply called RS232. The universal synchronous/asynchronous interface is a serial channel which allows a serial bit stream of 7 or 8 bits to be shifted into and out of the MSP430, at a programmed rate, or at a rate defined by an external clock.

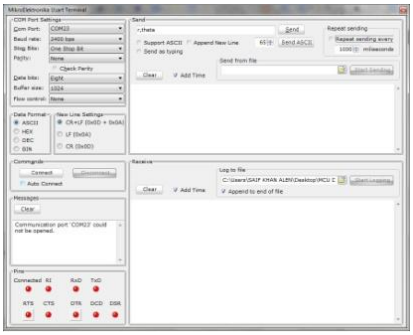

Fig.12: USART terminal for giving command From PC

To communicate from the computer 'MikroElectronika USART Terminal' is used and the communication is at a baud rate of 2400 bps. Because this TX01 module with frequency 433.92 MHz gives the best communication between the devices at a baud rate of 2400 baud per second.

7.4 Flow Diagram of the Project

The complete flow diagram at the receiving end of the SCARA robot is given below in Fig.13:

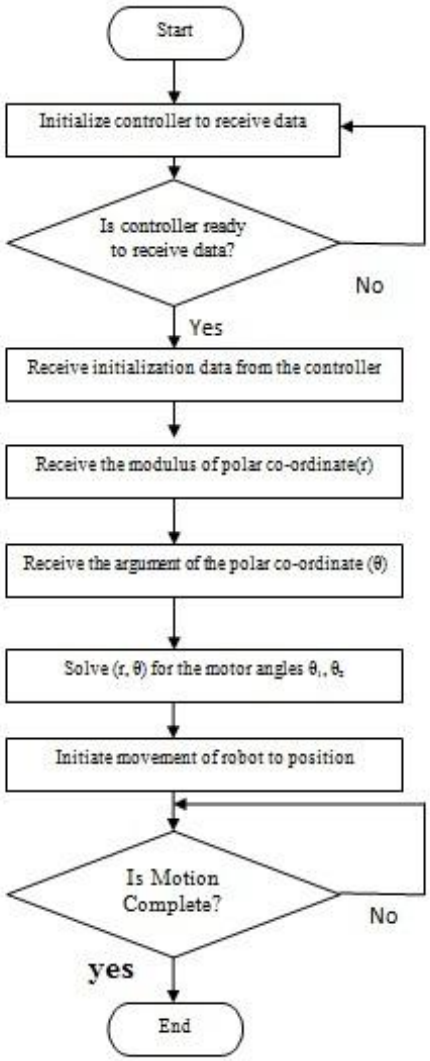

Fig.13: Flow diagram of complete wireless PC controlled SCARA Robot

Inverse kinematics mechanism is used to solve the kinematic chain of the links. The arm consists of two links with a parallel axis rotary joint layout. To drive the links DC-Servo motors are used and it is controlled with PIC18F452 microcontroller using the pulse width modulation. To communicate with PC, USART (Universal Synchronous Asynchronous Receiver Transmitter) protocol of microcontroller and for signal level conversion MAX232 IC is used. For wireless communication radio frequency (RF) receiver (RXB6) and transmitter (TX-01) modules are used. To solve the inverse kinematics problem for linear interpolated moves necessary C- programs are given input to the microcontroller. The robot is capable of finding any polar coordinate according to the given input by executing the program which makes the servo motor to turn them to the required angular position. As a result the end effector moves to its desired polar coordinate. The wireless control system helps to control a number of SCARA robot simultaneously.

With this communication logic shown in Fig.13, MCU end i.e. the robot end communicates with the PC and PC transmits data through the radio frequency.

A full project schematic diagram is shown below in Fig.14:

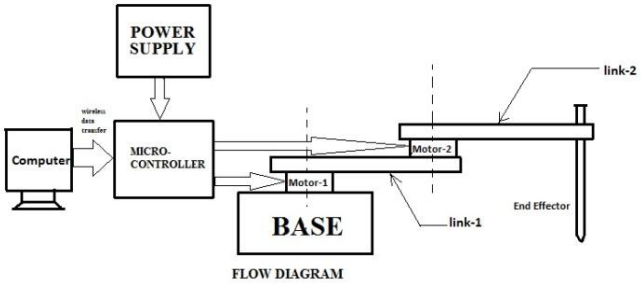

Fig.14: Schematic Diagram of the project

8. RESULT ANALYSIS AND DISCUSSION

Performance of the robot was smooth due to some definite decisions and selections made during the project. Such as selecting the servo motor instead of stepper facilitated the rotary motion and enhanced the precession to a large extent. Material selection such as wood for the base, aluminum for the link and acrylic for the gripper turned out to be effective. There exists a drawback associated with the dependency on the radio frequency for transmitting the command from the PC to MCU, some noise and garbage data may be received by the RXB6 receiver. There remain some deviations from the required position of the end effector due to the approximation during coding for the pulse coded modulation and the error proportionately increase with the increase of torque applied.

9. SUMMARY

With the satisfactory performance of the wireless PC controlled SCARA Robot we can easily summarize that SCARA robots are very useful considering its industrial applications. As a wireless control system is developed for this device, this feature enhances its field of application to a large extent. Due to this PC control a number of SCARA Robots can be simultaneously operated on the basis of individual command and individual purpose. This robot can be used in different industries in Bangladesh for achieving sufficient automation in the manufacturing process. Proper material selection, motor selection and easiness of its operation with a capability of wireless control of the device from the computer are the primary achievements of this work.

10. FURTHER MODIFICATIONS

For any further modification of the project automation of the system can be developed with the latest available technology. Modification can be done by designing high performance robotic arm with rotary hydraulic actuators. Wireless communication of the system can be developed by replacing the RF (Radio Frequency) modules with any Bluetooth or Wi-Fi module.

11. REFERENCES

[1] F. Arif, M. F. Ismail, M. S. Alam, and M. A. R. Sarkar, "Modeling and Implementation of Autonomous Robotic Vehicles with Locally Available Materials", *in Proc. of 6th International Mechanical Engineering Conference & 14th Annual Paper Meet*, Dhaka, Bangladesh, September 28-29, 2012.

[2] M. F. Ismail, F. Arif, M. E. Amin, J. Mojumdar, and M. A. R. Sarkar, "Fabrication of a Stair Climbing Vehicle for Industrial and Rescue applications Using Appropriate Technology," *in Proc. of 7th International Conference on Electrical and Computer Engineering, 2012*.

[3] http://machinedesign.com/technologies/protecting-servomotors-self-destruction. (14-07-2013)

[4] http://en.wikipedia.org/wiki. (14-07-2013)

[5] J. G. Keramas, *Robot Technology Fundamentals*, Delmar: a part of Cengage Learning, 1999.

[6] M. T. Das, and L. C. Dulger, "Mathematical modeling, simulation and experimental verification of a scara robot", *Journal of Simulation Modeling Practice and Theory*, Vol. 13, Issue 3, pp. 257-271, April 2005.

[7] J. J. Craig, *Introduction to Robotics*, Addison Wesley Longman, 1986.

[8] R. K. Saha, M. M. Islam, P. V. Biswas, S. D. Nath, S. Das, and K. M. M. Rahman, *Design and fabrication of Autonomous Mobile Robots*, Undergraduate Thesis, Bangladesh University Of Engineering and Technology, 2009.

12. NOMENCLATURE

Symbol	Meaning	Unit
θ	Angle	degree
L	Distance	(m)
τ	Torque	(Kg-m)