M. Tech. Dissertation Report
on
Bluetooth Control Based Origami Snake Robot

is submitted in partial fulfillment of the
Master of Technology in Embedded Systems

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Abstract

An Origami snake robot is an example of implementation of soft robotics where the robot imitates the characteristics of the snake. In recent years, use of soft materials to make robots has become prominent since use of softer materials for robots has widely helped to overcome the flaws that use to previously occur due to the rigidity of the robots. In this project, an attempt has been made to build a robot that could be controller using an android mobile Bluetooth controller application and is essential for obstacle detection. The aim is to make the robot locomote similar to that of a living snake , take turns, and detect obstacles. The entire robot is an array of three separate modules ,each module comprising an Arduino board as main controller ,with one of them being the master and other two being the slaves. The data communication between the modules in order to make them take the desired gait is done over an I2C bus.

Keywords: Bluetooth Controller, Arduino, I2C Bus

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List of Abbreviations

Table 1: Specifications of IC 7805

1	DC	Direct Current
2	PWM	Pulse Width Modulation
3	IC	Integrated Circuit
4	I2C	Inter-Integrated Circuit
5	PCB	Printed Circuit Board
6	IR	Infrared Radiations
7	CM	Centimeter
8	MM	Millimeter
9	V	Volts
10	2D	Two Dimensional
11	3D	Three Dimensional
12	GND	Ground

Chapter 1

Introduction

1.1 Motivation

Soft robotics is an evolving branch of robotics and automation. This stream of robotics emerged as an alternative to those frameworks of the robots where the rigidity is a major constraint. Soft robotics draws heavily from the way in which living organisms move and adapt to their surroundings[11]. Materials like silicone and polyethylene terephthalate sheets, bubble wraps, and foams. Robots that replicate the living organisms like snakes, spiders and worms have been attempted previously forming an array of multiple small rigid links so as to make it appear and function like a real organism, soft robots are best suited for the applications which involve the obstacle detection, and various aspects of search and rescue operations. classification. Here a snake robot has been built so as to perform the regular gait as an actual snake does, along with obstacle detection. The inspiration for the same is taken from a previously made soft robotic snake which was built to perform different gaits. This robot is based on the same idea with distinct hardware and working principles.

1.2 Background

Small and compact robots are considered to be significant in performing search and rescue operations, places where it is humanly impossible to reach, small-sized robot's built is essential to perform such tasks where space for movement is limited. Yet, not being able to take turns in compact places and not climbing above a certain height were the limitations of the small-sized robots, to meet these constrains, robots were designed as continuum manipulators were made, the body is constructed by making an array of smaller limbs, construction made similar to that of a trunk or snake so as to make the robot flexible enough in order to make it take those difficult turns in compact spaces. These robots were the pioneer of the idea of soft robotics. Soft robotics was introduced in the year 2012 by Prof.George Whitesides.

The whole idea behind inventing this method was to make the robots the meet the needs of flexibility replicate exactly like the invertebrates that they are supposed to represent. ex. a snake or a worm. The soft robotics emerged to be a best suited option for making the outer bodies of the robots since it reduced the overall weight of the modules, also had enough strength to be able lift up weights multiple times more than the body itself was. Fig 1.1 shows a soft robotic arm prototype model. Fig 1.2 shows a soft robot lifting up an egg, which is a delicate object).
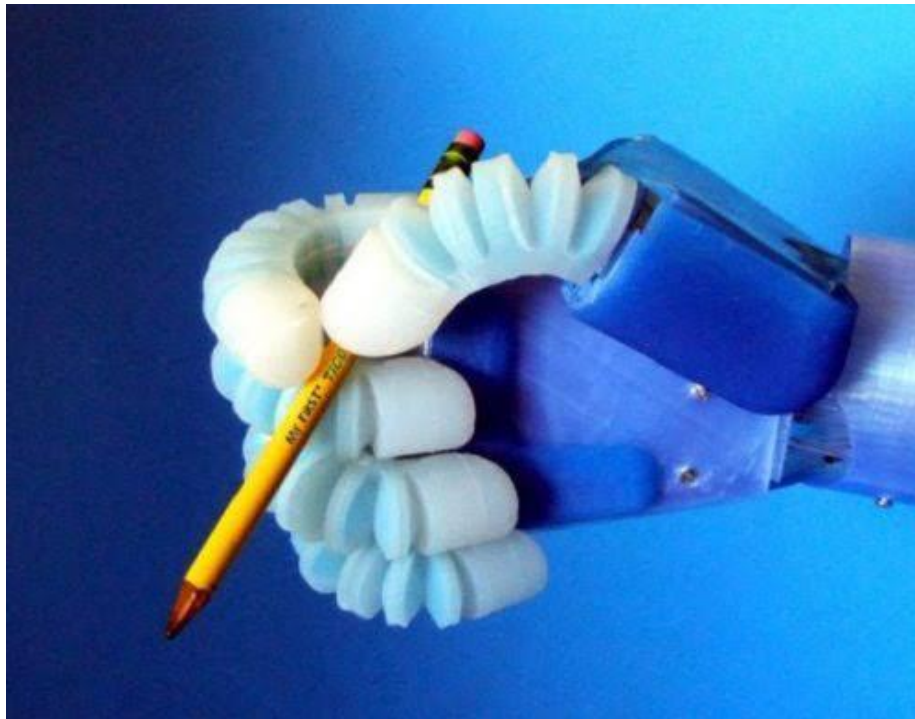
Figure 1.1: Soft robotic arm prototype model

Techniques used to manufacture soft robots include Shape Deposition Manufacturing (SDM), Smart Composite Microstructure(SCM) process[11], 3D Multi-material printing and pressure actuators. Soft robots are majorly made out of liquid silicone, where the silicone is poured into different molds and the respective shape is obtained by subjecting these mold to any of the methods of actuation, viz. hydraulic, electric, pneumatic and mechanical.

The liquid silicone is easy to mold into desired shape using these pressure techniques. Soft robots provide the flexibility required for the robot to represent the attributes of the invertebrates that they are supposed to replicate. Soft robots not only reduced the overall weight of the robot but also made the use of smaller electric and digital components more resourceful. Soft robots give the benefit of lifting and manipulating objects, they have the advantage
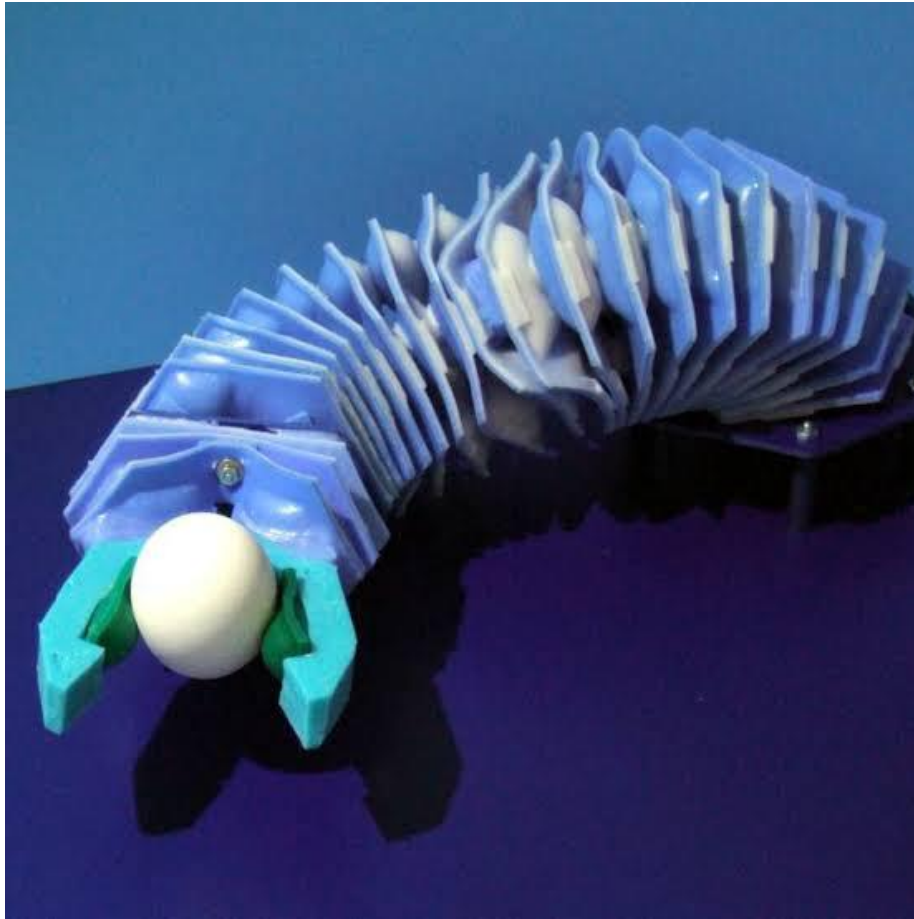
Figure 1.2: Soft robot holding an egg

of generating low force that is essential to holding up the delicate and fragile objects without breaking them. The other method that was later developed was making a planar model of the robot body and then folding it into a 3D model. The material used to do the same were PET sheets and polymer sheets[1] [2]. The greatest benefit of making a 3D robot by using a 2D planar design is that the robot can be built and dismantled as per ones requirements. The 2D model on the sheet is made using different folding patterns one uses in origami. One such technique is Yashimura crease pattern.

The 3D model is made by folding the 2D planar sheet along the crease that are marked on the sheet using laser techniques. The crease is basically an engraving on the sheet where specific type of crease pattern demonstrates the valley folds(inward) and mountain folds(outward). Until today different types of robots that represent the characteristics of various invertebrates have been

built and implemented. These include snakes and worms pre-dominantly. Also, different continuum modules have been developed in order to test the bending stiffness of the soft robot. Turns out that the soft robots are capable of lifting up to 100 times of weight of its own. Different types of study robots are made using soft robotics techniques.

One such robot is made by WPI called the Origami Snake Robot. This robot is an extension of a previously made continuum module that was a study module built to test the torsional strength. The origami snake made earlier is a robot that replicates different gaits of the snake, viz. lateral undulation, side-winding motion and rectilinear motion. All these were the study robots where different aspects of soft robots were tested and possibilities of areas of commercial implementation and execution were discussed. A newer version of the same has been implemented in this dissertation where the main objective is to make the robot engage in search and rescue operations.

The robot is based on the previous idea of making independent modules and using Arduino board as the main controller and then allowing them to communicate over the I2C bus by assigning one of the modules as a master and rest as slaves. The other mode of motion added here is Autonomous motion, where the robot decides which way to turn and continue the serpentine motion based on detecting the obstacle.

1.3 Literature Survey

Figure 1.3: Crawling Robot

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In 2012, Soft robotics was invented by George Whitesides[18], who is a chemistry professor in Harvard University, America. He came up with the idea of soft nanotechnology so as to make use of soft materials to function parallel to automation. Many soft robots that imitate the behavior of living organisms have been made until today. The living organisms who have genuinely flexible bodies like snakes, spiders, octopuses, snails and many other vertebrates are considered ideal to be rebuild in the form of soft robots. The soft robot made by George Whitesides[19], was a crawling robot with four legs and a central body. The robot inflated from the body would make the robot arch and the robot inflated from the legs would make the robot crawl. Fig 1.3 shows the crawling robot.

Later, many advancements came in with respect to using different materials made of variable chemical compositions so as to replicate the nature and behavior of the soft living organisms. The greater challenge was to attain the behavioral aspects of those living bodies along with the flexibility of their bodies. In 2014, a snake robot was built using the techniques of soft robotics[11], this robot that looked like a snake, was capable of having variable gaits like an actual snake. All these soft robots until then were made using liquid silicone of different viscosity and were molded using various pressure techniques. In 2017, J. Santoso and E. Skorin came up with the idea of using the polyethylene terephthalate sheets for building a soft robot. Instead of using the pressure actuators, it simply required a 2D planar model of the body that would be designed using a laser cutting machine and folded into a 3D model. Using this technique, they made a continuum module that was constructed using a PET sheet folded using Origami techniques[2]. In 2017, using this idea of making a continuum module
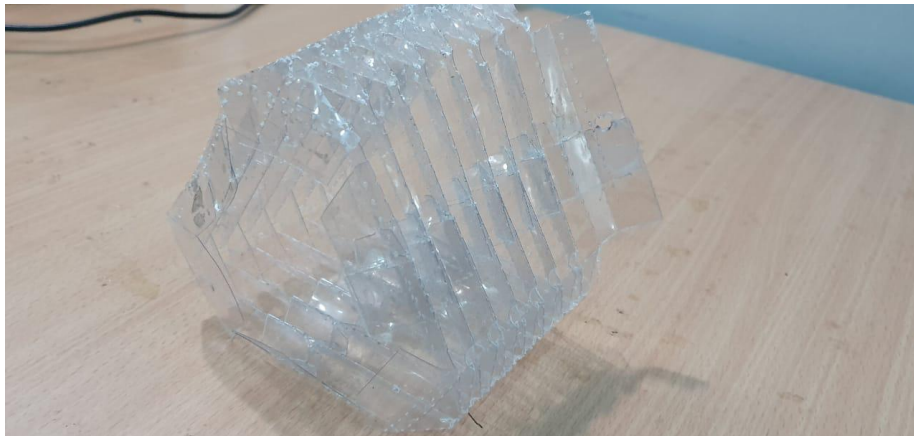

Figure 1.4: Yashimura crease pattern 3D model

using a PET sheet was applied to make a soft robotic snake that had four independent modules, clamped to one another from the back end and forming a trail[1]. The independent continuum modules were attached to each other by clips and they shared a single communication bus. The I2C protocol was used

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for data communication. Fig 1.4 shows the single continuum module made by J Santoso. Use of PET sheets reduced the overall cost of construction of the body since no actuators were required. A laser cutting tool was sufficient to do the same.
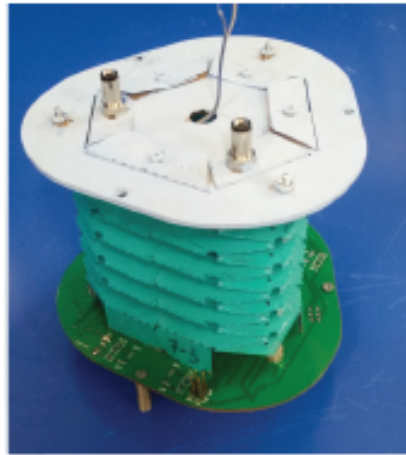

Figure 1.5: Continuum Model

1.4   Outline of the project

In this dissertation, a snake robot has been introduced based on the idea of soft robotics. The inspiration is taken from the IEEE conference paper launched by WPI.viz. "OriSnake: Design, Fabrication, and Experimental Analysis of a 3-D Origami Snake Robot"[1] The implemented model is a 2-D soft robotic snake that is capable of performing different types of motions similar to the gait of an actual snake. The robot has been implemented based on the idea similar to that of the previously made soft robotic snake. A snake robot with an outer body as flexible as the real snake, along with the ability of different angles of motion has been studied and implemented in this project. The soft robotics is an evolving branch of robotics and different ways to execute the same have been implemented so far. One of those techniques to make the outer body of the snake has been used here.

The robot is a study based robot and with a few modifications the same design could become fit to be implemented on commercial level. Being a soft snake robot it has its own advantages and disadvantages with respect to ease of implementation in the actual surroundings. The purpose of this robot is to introduce a cost efficient way to implement the soft robotic snake made previously. The main purpose of the snake robots is its use for search and rescue operations. A newer way to change the locomotion and the gait of the snake has been introduced along with a feature of obstacle detection.

The motion of the robot is initiated and controlled using a Bluetooth device placed on the robot that is linked with a mobile app. The entire snake robot is made using three independent similar looking and functioning modules that are juxtaposed, the main component used here is ARDUINO NANO and the mode of communication used is I2C, with head being the master and the other two modules being the slaves. Each module has servo motors with an extended shaft that has nylon string rolled over it, which when the motor rotates, compresses and expands the body making it appear like the movement of a snake. Instructions of activation are sent to the robot from the mobile app, the head (master) module has its own locomotion to perform accordingly, subsequently, it passes the commands of execution to other two slave modules to perform their gait. Every instruction is sent from the mobile app to the master and master performs its own set along with sending respective commands to the slaves. The IR sensors are fixed on the master, based on the obstacle detected, the path of the robot is changed via the decision made by the robot. The entire project is based on the idea of the previously made model , with significant number of changes in the hardware and functioning.

Chapter 2

Hardware and Software Used

2.1 Hardware Used

2.1.1 Arduino NANO

Arduino NANO is used as the main controller in all the three modules where one is the master and rest two are the slaves. The full specifications of the system are shown in the Table 2.1.

Table 2.1: Specifications of Arduino NANO

Pin No.	Name	Type	Description
1-2, 5-16	D0-D13	I/O	Digital input/output port 0 to 13
3,28	RESET	Input	Reset (active low)
4,29	GND	PWR	Supply ground
17	3V3	Output	+3.3V output (from FTDI)
18	AREF	Input	ADC reference
19-26	A7-A0	Input	Analog input channel 0 to 7
27	+5V	Output or Input	+5V output (from on-board regulator) or +5V (input from external power supply)
30	VIN	PWR	Supply voltage

The image below describes the pin out of the Arduino NANO 3.0 board. Fig 2.1 describes the pins of the arduino board.5
The sole objective to select the Arduino NANO was to choose a microcontroller board that is compact in size and provides the required pins and specifications to fulfill the needs of the robot.
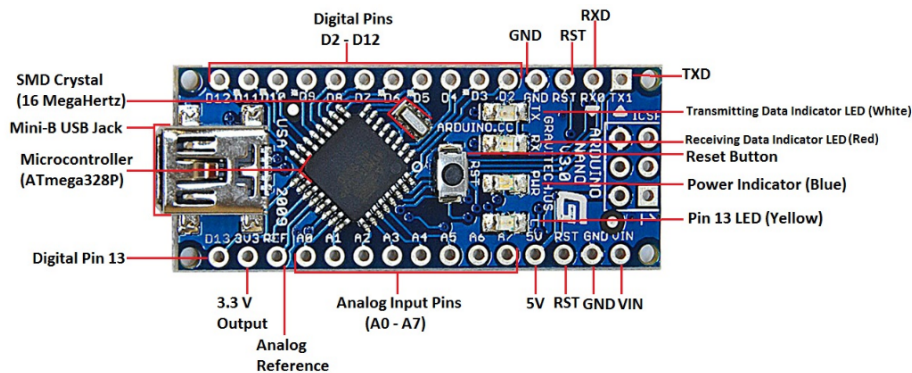Arduino NANO is 43mm x 18mm in size and has a mini USB port. It has 6

Figure 2.1: Pin-out of Arduino NANO 3.0 board

PWM I/O pins out of total 14 digital I/O pins. It has 6 analog inputs. Aurdino NANO is best suited for this robot since the size of the robot is a major issue of concern here. It is a study board with all the basic functions available on it hence it eases the implementation of the task that has to be performed. Below is a diagram (Fig 2.1) of the pin configuration and specification of arduino NANO. Arduino NANO is a study microcontroller that comes with a package of pins and functions that are necessary to perform a certain operation. With regards to this project, any other microcontroller could have been used to perform the same function as NANO here. The reason why this particular board was chosen was the small compact size of it. ProMini is a smaller arduino board but has no USB port to upload the code. Every time one has to upload the code , a string of 6 wires is to be connected. In this particular robot, the hardware placement is on both the sides of a PCB. The back panel of one module is a front face for another module and the gap between two modules is approximately 1.2 cm. In that case, uploading code in the promini becomes a tedious task.

Other microcontroller boards like ATMega packages which are extremely small and compact in size could be used by designing a custom PCB board. These microcontrollers would require that fine soldering and connections which in impossible to attain manually. That is the reason why an arduino NANO is chosen here which suits right for the size of the robot designed, and fulfills all the necessary requirements of the hardware connections that are needed.

2.1.2 MG996 Servo Motor

The MG 996 Servo motors are the heavy duty gear motors that are specifically built to meet the needs of essential torque and precise angular displacement. They are best known for the high torque providence and compact shape and size. Servo motors are widely used in automation machines where the requirement of angular motion is prominent. Servo motors since capable of doing so with the help of the hardware that it is comprised of (DC motor with voltage regulator
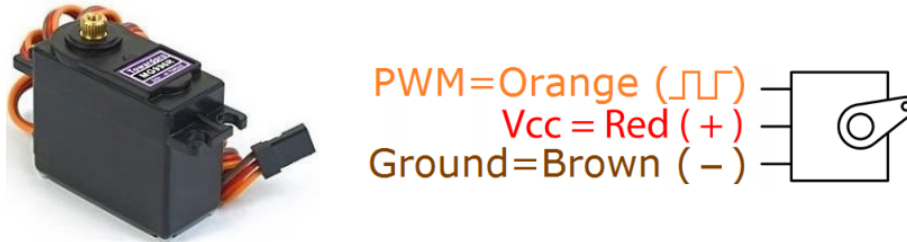
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Figure 2.2: MG996 Servo Motor and the wiring

potentiometer), is widely used to attain agular motion. In this project, every module is to be contracted and expanded alternately on each of it's sides, to achieve this kind of movement, servo motors have been used. The servo motor coding allows one to set the angle for deflection as well. The freedom of angle given by a servo motor is upto 180°.

Table 2.2: Specifications of MG996 Servo Motors

Pin No.	Name
Model	MG 996
Rated Voltage	4.8V-6V
Operating speed	GND
Weight	3V3
Stall Torque	AREF
Dimensions	A7-A0
Temperature range	0°-55°
gear Material	Full Metal
Shaft Size	4x60mm (D*L)
Running Current	500mA-900mA(60V)

In this project, the required angular motion is in between 45 degrees to 75 degrees. The motor is placed vertically on the PCB board on the inner side of the robot , it lies covered under the PET sheet 3D model, The motor shaft is connected to the other end of the module i.e. the acrylic sheet with the help of a nylon string. Two such strings are used to connect the two ends of the module. The servo motor being a heavy duty motor, is capable to move the overall weight of the single module and provide the desired push the to the adjacent modules.

Any other servo or DC motors that are capable of giving heavy duty performance and are small in size, can be used in the hardware for this robot. The DC motors that are small in size and have metal or plastic gears can be used in this case. The DC motors should have a good torque so that it is capable of pulling enough weight. These motors needed to be attached with a feedback system so that

the independent module's position remains updated. The first choice of motors made was N20 DC miniature gear motors for this robot. But a good number of motors were found to have broken gears when the motor shaft would start rotating. Hence the switch to using servo motors was made. The reason servo motors are used is because they already are comprised of a setup of DC motor and potentiometer and this particular servo motor is the right size for the design of the robot that has been built.

The detailed specifications of the servo motors are shown in the Table 2.2.

2.1.3 L293D Motor driving IC

It is motor driver IC capable of handling the working of up to two motors. The L293D IC is used on each of the three modules. The specifications of the Raspberry Pi 3 Model B+ are shown in the Table 1.4.

Pin Functions

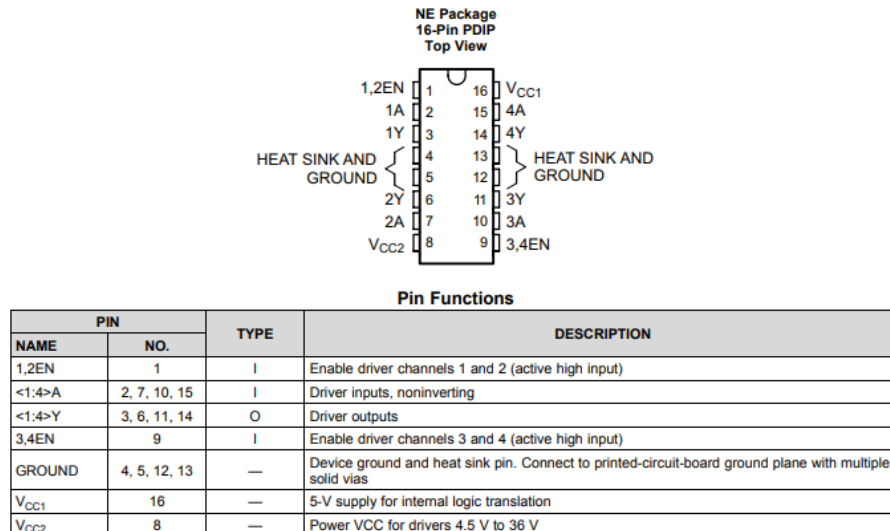| PIN		TYPE	DESCRIPTION
NAME	**NO.**		
1,2EN	1	I	Enable driver channels 1 and 2 (active high input)
<1:4>A	2, 7, 10, 15	I	Driver inputs, noninverting
<1:4>Y	3, 6, 11, 14	O	Driver outputs
3,4EN	9	I	Enable driver channels 3 and 4 (active high input)
GROUND	4, 5, 12, 13	—	Device ground and heat sink pin. Connect to printed-circuit-board ground plane with multiple solid vias
V$_{CC1}$	16	—	5-V supply for internal logic translation
V$_{CC2}$	8	—	Power VCC for drivers 4.5 V to 36 V

Figure 2.3: Specifications of L293D motor driver IC

L293D is a cost efficient IC capable of making run 2 motors at a time. The use of this IC is done in order to power up the servo motor that has been used.

2.1.4 7805 Voltage Regulator IC

IC 7805 is used to generate 5V power supply for the motor driver IC. It is connected to the 5V pin of Arduino NANO and to the VCC pins of the L293D. IC 7805 is used here to generate the required 5V output voltage for the components to work smoothly. This voltage regulator IC is a small 3 pin IC and is essential in this case for it is fixed under the NANO board and that is a space saver.
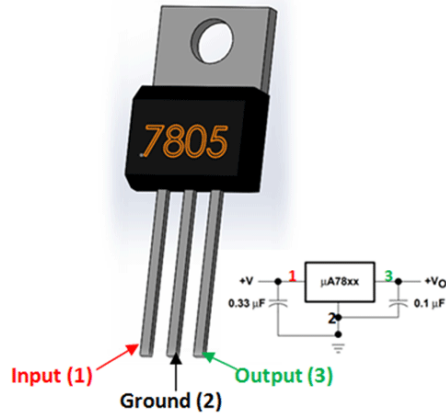
Figure 2.4: Specifications of 7805 Voltage Regulator IC

Fig 2.4 shows the pin configuration of IC 7805. Table 2.3 below shows the pin specifications of the IC.

Table 2.3: Specifications of IC 7805

Pin No.	Name
Input Pin	Pin 1; positive unregulated voltage given
Ground Pin	Pin 2; common to I/P and O/P
Output Pin	Pin 3; regulated 5 volt taken from here

2.1.5 Extended Plastic Shaft

The extended plastic shaft is the replacement of the shaft that is provided along with the servo motor. The already provided shaft is inefficient to provide the pattern of compression that is needed to contract the module on each side. Thus, the smaller shaft is replaced by a slightly longer shaft which is 4 x 50 mm. This shaft is designed on SolidWorks software and is printed using a 3D printer. This shaft is tied along the pre-existing shaft with the help of a bare wire.

2.1.6 Plastic base for motor

The fixing of Servo motors on the PCB makes it necessary to provide a base support for the motor to stay fixed on the surface of it. A base is designed on SolidWorks software and the model is printed using a 3D printer. The height of this base is 7mm. The motor is fixed on this base. The base is bolted on

the PCB. This is a rectangle wave shaped clamp that is fixed to the fron of the motor. Another cylindrical base that will give a height of 7mm is fixed at the rear of the motor.

2.1.7   HC05 Bluetooth Transceiver module

The HC05 bluetooth module is a transmitter receiver module. The default communication of the module is as slave. It is best suited for two way communication between two Arduinos or any devices with microcontrollers. It can also be used to communicate with any devices with Bluetooth functionality like a phone or a laptop. The module has two modes of operation. One is the data mode, here it sends and receives data from other Bluetooth devices. The other on is the AT command where the default settings of he device can be changed. The Fig 2.5 below shows the pin configuration and the specifications of the Bluetooth module.
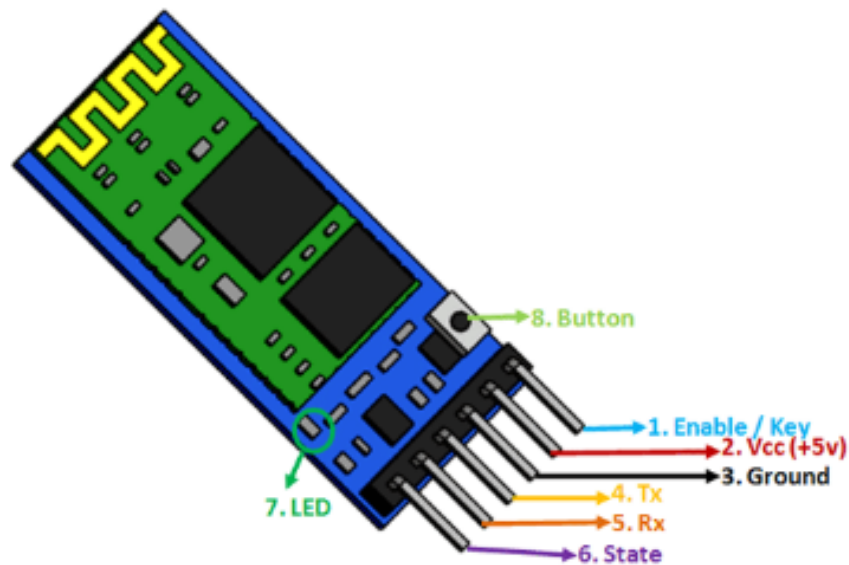

Figure 2.5: Pin configuration and specification of the HC05 Bluetooth module

2.1.8   IR Sensor

IR sensor is a passive transmitter-receiver device that is used to detect objects in it's radar. The IR transmitter transmits an infrared light signal. This signal when strikes with an object in it's radar, bounces back in multiple directions including the direction in which the IR receiver exists. In this project, the IR sensor is used to detect obstacles that might come in front of the robot. Three

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IR sensors are placed on the head module one in each corner in order to detect the obstacles that will come in front of the robot.

2.2 Software Libraries and Frameworks Used

2.2.1 SolidWorks 2019 SP0.0

SolidWorks is a computer-aided engineering program and computer-aided design that is used to generate 3D models. This software here is used to generate the 3D model for the constructing the base for the motors to rest on the PCB. All the bases and clamps that are required for the motor placement are made using the solidworks application. The designs that are made using this software are then printed using a 3D printer.

2.2.2 CorelDRAW Graphics Suite 2019

CorelDRAW is a vector graphics editor. It is used to generate digital designs. The designs can be abstract or geometric. This software provides a wide range of specification so as to provide greater palette to select minute dimensions that are important in designing the geometric models. This software here is used to model the Yashimura crease pattern to make the outer body of the robot. This crease pattern is then uploaded on the PET sheet using a CNC machine. The input to the CNC machine is the soft copy of the planar model created using this tool and the pattern is engraved on the PET sheet accordingly. The Fig. 1.4 shows the 3D model that has been made using this software.

2.2.3 Arduino IDE

Arduino IDE is the tool on which the code to program the Arduino is built. The Arduino IDE is the platform on which the entire code for the master module and the slave modules has been designed. Arduino IDE supports the programming languages like C and C++. It has a specific set of rules for constructing the code. The code written for this project is in C language. Arduino IDE is essential here since the controller board used here is arduino NANO. This tool provides set of libraries that is needed in wiring the project.

2.2.4 Bluetooth controller Mobile Application

The Bluetooth controller mobile application is used as a remote control for controlling the motion of the robot. The application supports the android version 4.0.4 and onwards. The Bluetooth application has pre-set tools that look like the buttons of a remote control viz. up-arrow , down-arrow, left-arrow, right-arrow, start, stop and pause buttons. The Bluetooth device that is placed on the robot is paired with the mobile phone application in order to make the robot accessible to the application. The Bluetooth device that is placed on the robot is connected to the arduino NANO and the microcontroller is coded so as to

allow the mobile application monitor the robot. The Fig. 2.6 shows the control panel of the Bluetooth application.

Figure 2.6: Motor Control Panel of Bluetooth application
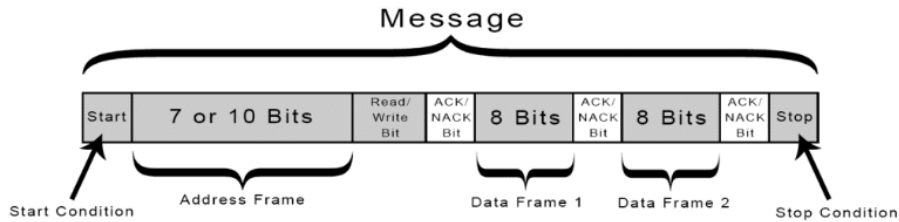
2.3   I2C Protocol

Figure 2.7: I2C Protocol

I2C communication stands for inter-integrated communication, it is one of the protocols which allows the use to establish master-slave communication between the microcontrollers. It is the combinations of best of features of both SPI and UARTs[19]. I2C allows us to have multiple master to multiple slave communication as well. Unlike SPI, the number of connections / wirings that are needed for the I2C are less. This communication when used on aurdino, the only requied connections are A4-A4, A5-A5, and GND-GND pins. The A4 pin on the aurdino is the SDA pin which stands for serial data line and A5 is the SCL which stands for the serial clock line.
The SDA line is used to send and receive data between the master and slaves. The SCL line gives the clock signal. The number of masters that can be connected over I2C bus are unlimited and the number of slaves that can be con-

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nected is 1008.

The data over the I2C bus is transferred in the form of messages. The messages are sent in packages of frames. Every message has an address frame and every frame contains the binary address of the slave. One or more than one frames that contain data are been sent. The message also includes start and stop conditions. It includes the ACK(acknowledgement) bits between two data frames. Fig 2.7 shows the communication process in the I2C communication.

Chapter 3

Introduction To Soft Robotics & Techniques To Built Them

Since its advent, Robotics play a major role in the industrial and commercial areas. Robotics is basically automation, something that reduces human efforts and perform the task with precision and with lesser manpower. In today's advancing world, robotics is largely flourishing branch which is responsible for giving precision in work to the industries where large scale production is required. Every machine that gives ease of function along with precision and is automatic is a robot. Industrial robots, humanoids, spy robots and many other types of robots are been constructed these days. To perfectly match with the species the robot is trying to represent, especially the invertebrates, who are enormously flexible, soft robotics emerged to fulfill the needs of flexibility. Continuum modules were previously made using rigid elements, these elements are now replaced by the soft links giving the continuum modules the required freedom of movement.

3.1   What is Soft Robotics?

Soft Robotics is that branch of robotics where the robots are built with highly compliant materials, similar to the ones found in the living organisms. Soft robotics highly emerges from the way the living organisms adapt and move in the surroundings. Soft robots allow increased flexibility in accomplishing tasks and provide improved safety while working around humans as well. Many robots representing the invertebrates have been made till the date.

3.1.1 Challenges

As per the soft robotic snake built previously[1], the robot is built out of 4 individual continuum modules juxtaposed, head module being the master and the rest being the slaves. Each module had a microcontroller , two DC miniature gear motors, magnetic encoder for feedback, nylon string with one of the ends rolled along the shaft of the motor and the other one attached to the other end of the module viz. acrylic sheet. Each module has custom made PCB with miniature components mount on it. That reduced the overall size of the module and make the built look neat and compact. The complete design of the previously made soft robotic snake had really compact hardware, which is difficult to find in the local market.

The component used for feedback purpose is magnetic disc with encoder sensor the magnetic disc and encoder sensor that will accurately mount on the shaft of the miniature dc motors. Since those magnetic encoders are not available in our market and the sole purpose to use them was to count the number of rotations of the motor and give the exact position of the motor, this requirement is now fulfilled using a 10K Rotary potentiometer.

The shaft of the rotary potentiometer is calibrated along with the shaft of the motor and the connection is established by fixing a T-shaped shaft on it. The use of the rotary potentiometer increases the size of the module and puts extra load on the motor since the motor has to rotate the shaft of the potentiometer juxtaposed and the T-shaped shaft. This led to breakdown of the gearbox of the miniature DC gear motors. Hence in the entire design, the two DC gear motors per module were replaced by heavy duty servo motors.

The entire system is based on making a robot effectively compact so as to make it work in the natural surroundings and make it be an effective option for search and rescue operation purposes. Since not all miniature electric components are available to us here, and there are other alternatives in the market. The entire setup of using the DC miniature gear motors along with the potentiometer or any other feedback devices led to put extra weight on the motors to pull off to that level with the amount of torque they provide. The entire system hence needed to be replaced with the components that could bear the weight of the overall increased size and weight of the module with all the materials that are used for it. Thus, heavy duty servo motors were preferably chosen for performing the given task. The basic algorithm that has to be followed with all these new hardware changes is as follows:

- Bluetooth Controller mobile application instructs the robot to activate

- Master module starts it's functioning

- Sends activation command to slave1

- Sends activation command to slave2

- Master module in parallel checks for obstacle with the help of IR sensors mounted

- If obstacle found, keeps looking to the left of it for free path

- If free path found, turns that way and resumes regular gait

- If no free path found, turns right and searches for free path

- If free path found, turns that way and resumes the regular gait

- If no free path found, aborts
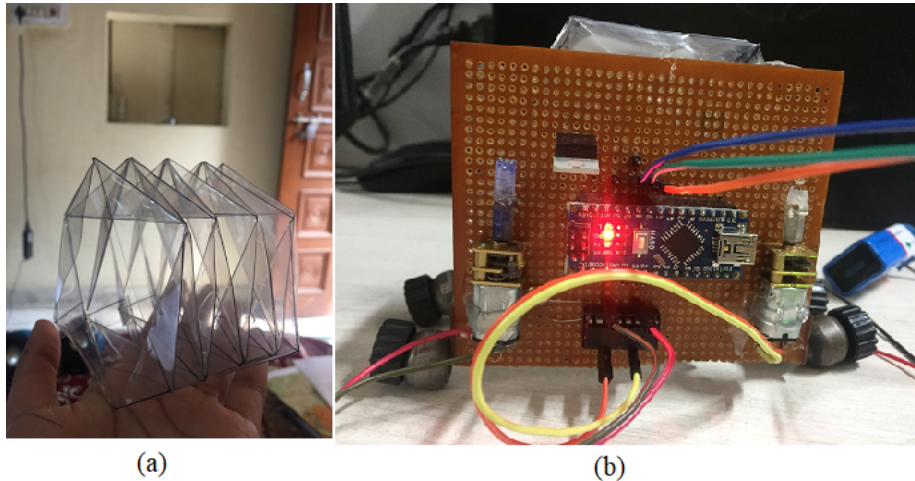
3.1.2 Approaches

First method

Figure 3.1: (a) Hand marked and folded hexagon (b) Single module construction

To built a single module without making use of feedback mechanism; with one Arduino NANO on the module as the slave, and one Arduino UNO as the master that was used as a master, wired with the NANO for I2C communication. The outer body of the module was built by folding PET sheet alongside the cuts marked manually on the sheet. This constituted the outer body of the snake robot.

The markings were made as per the required dimensions of the PCB board. Accordingly, a hexagonal shaped origami structure was made.

The drawback was that since it was only one module, the forward motion was hardly visible in it, also, the PET sheet since was manually marked for folds, failed to provide enough strength. Fig 3.1(a) shows the outer body of the module previously made for trial purpose and Fig 3.1(b) shows the module hardware placing.

Second Method

The method that we chose to build the outer body was printing the folding pattern on the planar sheet and folding it along the crease. The planar sheet used for this purpose was PET sheet. The pattern generated over it was Yashimura Crease Pattern. Using this, the pattern generated on the sheet is then folded along the mountain folds and valley folds.
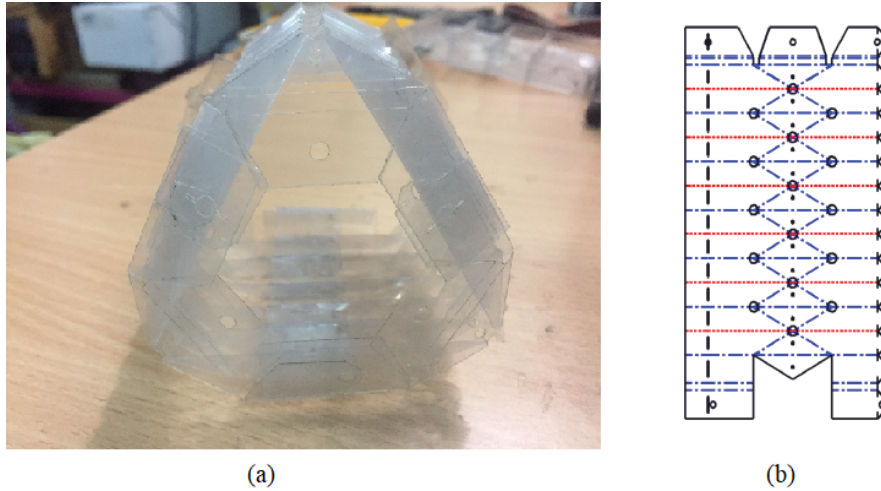

Figure 3.2: (a) Yashimura design (3D) (b) Crease pattern for PET sheet

The crease pattern (Fig 3.2(b)) was generated on the planar sheet using the laser cut machine and the dimensions of the sheet are (14.1*8.2)cms and two modules were built and connected to each other with screws and bolts. These modules since had no feedback mechanism, the functioning of the modules was restricted when the system was to be paused and resumed. The code would start from the beginning and if the motors were turned already, the code's execution since beginning from up top, the nylon strings attached to the motors would either be loosened or stretched too tight leading them to break down. The outer body of the robot created is shown in Fig 3.2(a), the modules connected to each other are shown in Fig 3.3.

Third Method

The feedback mechanism was inserted in the system by making the use of the potentiometer. This was not a direct way to gain the feedback, but since the potentiometer was essential to count the rotations and give that data to the controller and controller would convert the analog data to digital data and this data which is the position information of the motor would make it essential for the master module to thereby control the positioning of the motors of the slave. This attempt was basically based on creating a custom servo motor since the
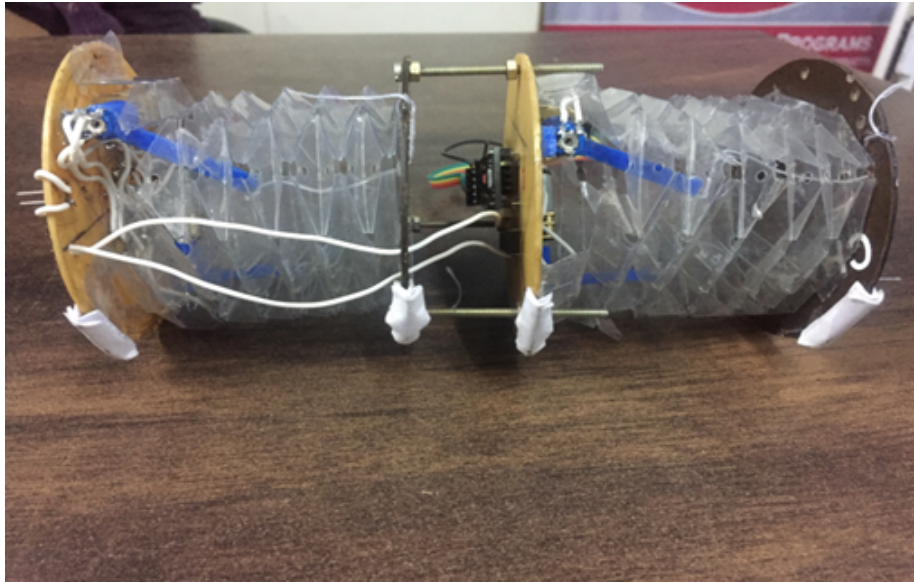
Figure 3.3: Two independent slave modules linked together

servo motor itself is a DC motor connected to a voltage regulator and works on PWM. The entire module dimensions were changed due to the increased hardware.

The typical analog rotary potentiometer with a shaft was used of 10K value. This shaft was cut down to 8mm and was placed in alignment to the shaft of the N20 DC gear motor. These two shafts were then supported with another T-shaped shaft that was turned vertical which had a length of 3.7 cm. The shaft was designed using solidworks software and printed using a 3D printer. Fig. 3.10(a) shows the plastic shaft 3D image. Along with that, a motor base and a motor clamp were also designed so as to support the motor gear box and to bring up the motor to the height of the potentiometer. Fig 3.10(c) shows the motor base and Fig. 3.10(b) show the motor gear box clamp. Every module had two such fixes and due to this the entire PCB size and acrylic sheet size had to be changed.

Also, previously Arduino NANO was used as master and Arduino PROmini was used as slave, in the new set up, all the controllers were Arduino NANO. The change was made because the Arduino pro mini needs an external USB connector to upload the code; since the gap in between every two modules was considerably less, the connecting and removing was wires every time to make changes in the code was exhausting and time taking. Arduino NANO already being having a USB slot, it erased the problem of uploading code unlike pro mini where we required connecting 6 different wires every time you want to upload a code.

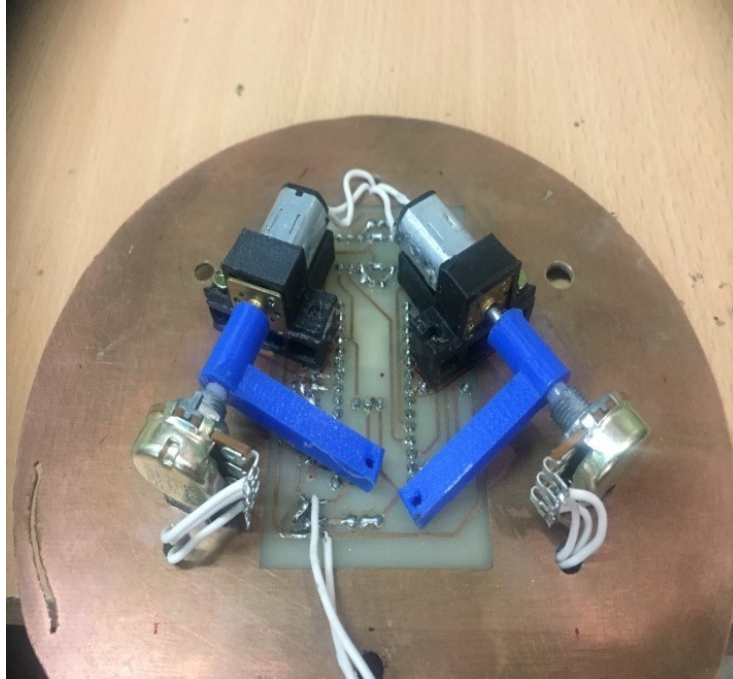The dimensions taken for the PCB are 14.4 cm width and 12 cm height. This

Figure 3.4: Motor-shaft-potentiometer placement on PCB

huge size of the PCB was decided for allowing the plastic shaft a free motion as per the need of contracting and releasing the nylon thread pierced through it. The entire set up of motor-potentiometer-plastic shaft is 6 cm long. They are placed diagonally on the PCB as shown in the Fig. 3.4. Fig 3.7(a) shows the PCB layout of the master module. Fig 3.7(b) shows the PCB layout of the slave module. The white acrylic sheet is cut in the same shape and with same dimensions as the PCB board.

The side view of the module is shown in Fig. 3.5.

The PET sheet dimensions also were changed as per the increased size of the module. The dimensions taken now were 4.5cm, 3.5cm, 5.8cm (from)left to right. The shape of the new design slightly differs when folded into a 3D model. Previously made model looked like a hexagon, the later one looked like a blunt edged triangle. The total number of modules made were 3. Each module carrying two DC motors with potentiometer, an Arduino NANO, L293D motor driving IC. The master module had slightly greater arrangement of components. Along with these, there were 3 IR sensors used so as to detect the obstacles around the robot. A Bluetooth device is fixed on the module so as to connect with the android phone to take the initialization instructions from the mobile Bluetooth app controller. The arrangement of the IR on the PCB is as shown in the Fig 3.6(a).

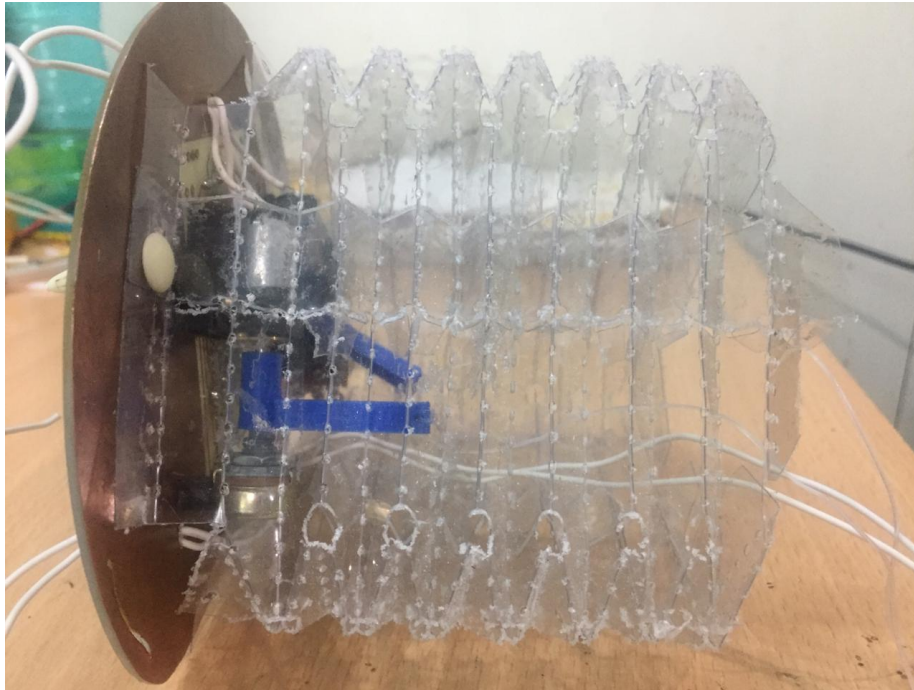On installing the respective codes for the respective modules and on starting

Figure 3.5: Motor Control Panel of Bluetooth application

the power supply, it was observed that only the master module was functioning well.

The I2C bus was checked for the same to see if there were any issues there. No issues were found there. After checking all the connections and hardware components, the problem was found in the gear box of the motors. 2 out of six motor gear box were found broken. One motor coil was found burnt. Immediate replacement of the motors was not possible since the motors were not available in the local market and it would take a long time to make them available, also, since there was an issue of breakdown of the gear box reoccurring again and again, better alternative was to replace the entire dc motor-potentiometer system with a high torque servo motor. In every module, the set up of 2 dc motors along with potentiometer was replaced by one servo motor per module. All other dimensions were kept the same.

3.1.3 Problem Solution

Soft robotics has emerged as that stream of automation where the technology has got a new aspect of attaining the texture and locomotion very much relevant to the living beings. Giving such close relevance to the natural living creatures around, the soft robots are majorly used in search and rescue operations. Not just that, even in the medical field, the use of soft robotics has become prominent
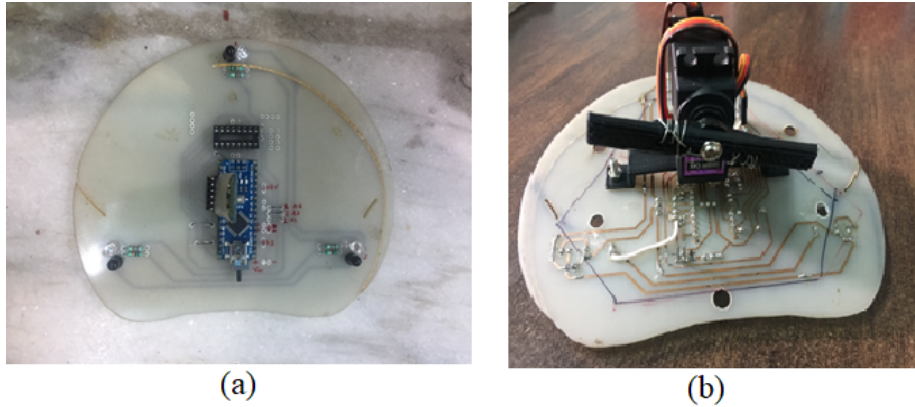
Figure 3.6: (a) Master module hardware placement (b) Servo motor placement

in order to build artificial human body parts and ligaments, since it provides wider range for angular movement, resembles more with the actual body parts, ex. Artificial hand. Along with this, automation units to lift up fragile or delicate products, the use of soft robots for the purpose is prominent these days. That is because, the soft robots are extremely flexible and at the same time are strong enough to lift up weights up to 100 times more than their own. This benefit is because of the material composition with which they are made. Materials used are liquid silicone, different types of polymers, and polyethylene terephthalate sheets.

After the previous failed attempt to achieve the feedback system using an analog potentiometer, the motor is now replaced with servo motors. The servo motors are basically heavy duty motors which are a combination of DC motors and potentiometers. The use of servo motor here is a solution to the problem initially faced for pause and resume of the model. The servo motors used here are MG996 Servo Motors. Rest of the hardware is kept exactly the same, only the motor-potentiometer-shaft system is replaced with a single servo motor per module. Fig. 3.6(a) shows the master module hardware, Fig 3.6(b) shows the placement of the servo motor on the modules. The torque provided by these servo motors is high, also the servo motors work on the input pulse that is given to them to change the angle of the shaft fixed on it accordingly.

The angles are so set, that the modules when placed together, it appears like the motion of the snake. As per the previous paper, different was of locomotion of snake are shown[1]. In this dissertation, one of the applications mentioned in the paper[1], viz. search and rescue operations, has been attempted to implement by making the robot efficient to detect the obstacles.

For this purpose, 3 IR sensors and one Bluetooth modem are mounted on the master module. The IR sensors will detect the object when it comes in-front of the snake and the snake will change its direction by measuring the length of the object first to the left and then to the right of it and turn accordingly. The
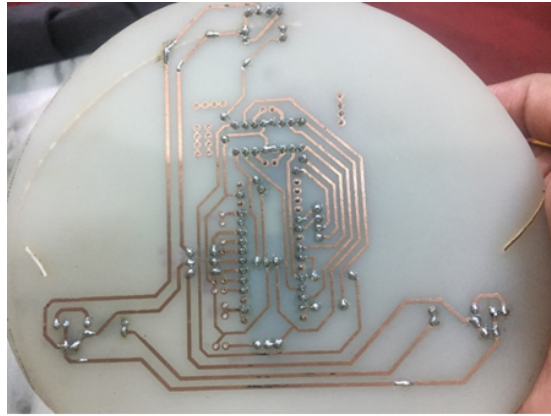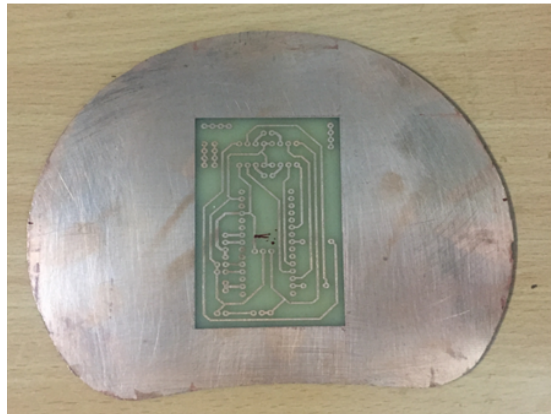
Figure 3.7: (a) Master and (b) Slave PCB Layout

Bluetooth modem is used to establish connectivity in between the robot and an android Bluetooth controller application. The robot is been controlled using the mobile application. The initial instructions of activation and motion are given using the application. The master module receives the instructions from the android application via the Bluetooth. Accordingly, the master activates and starts the execution of the code which initializes the slaves activation since the commands to the slaves are received from the master module. The modules all together move in a way that replicates the gait of a snake.

When an obstacle comes in between, it is detected by the IR sensors. That sends an interrupt signal to the master and the master initiates the function to measure the length of the object on the left and turns accordingly. Similarly, sends the instruction to the slaves modules and they change their gait as per the command received from the master. Fig 3.8 shows the entire robot along
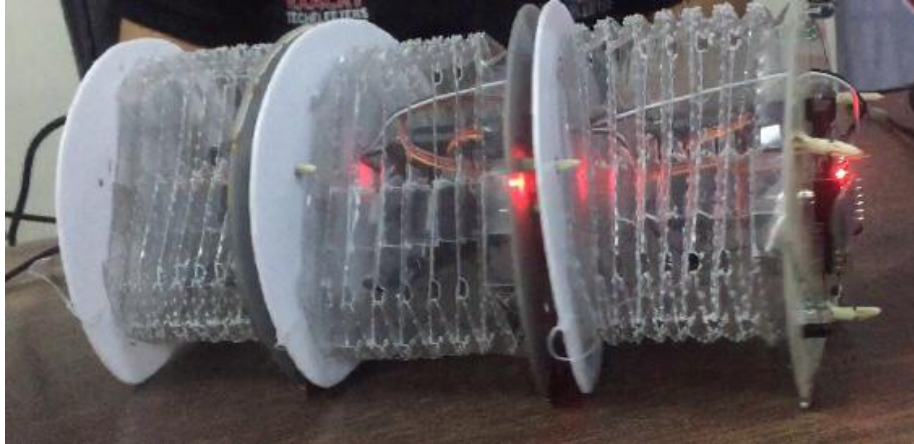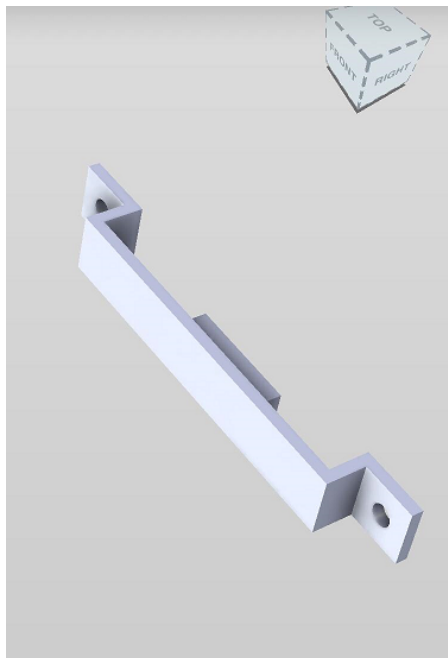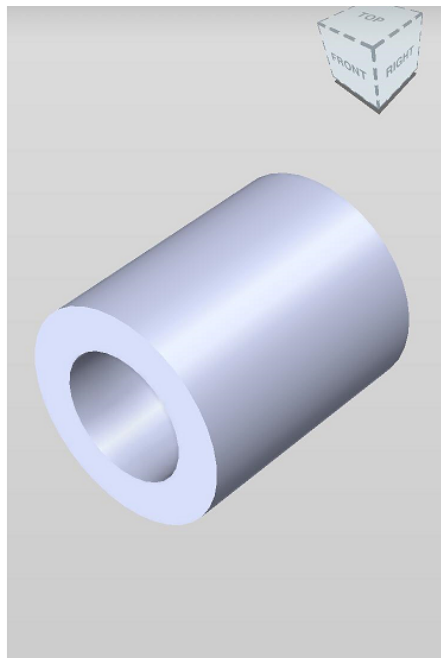
with the gait taken by it.

Figure 3.8: The fully constructed snake robot with servo motors

Below are the figures of the 3D modules designed for the base and head of the servo motors. The Fig 3.9(a) and Fig 3.9(b) shows the 3D model of the base clamp and base for the servo motors. The shaft that has been redesigned as per the need is shown in Fig. 3.9(c).
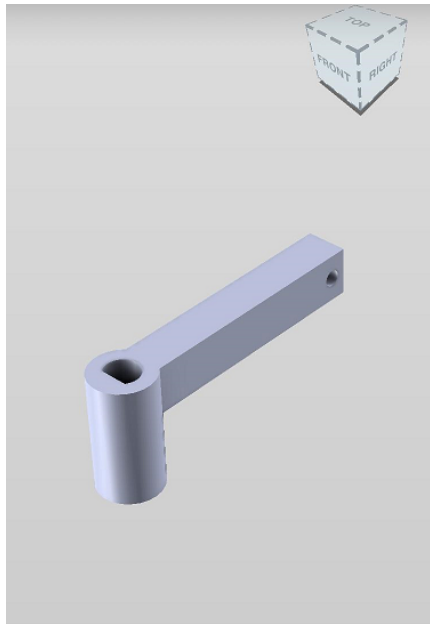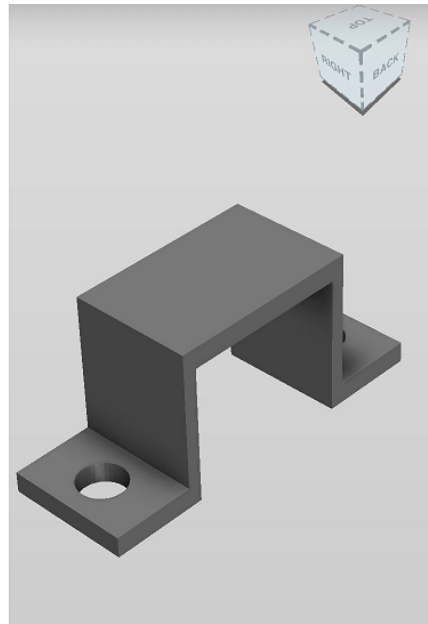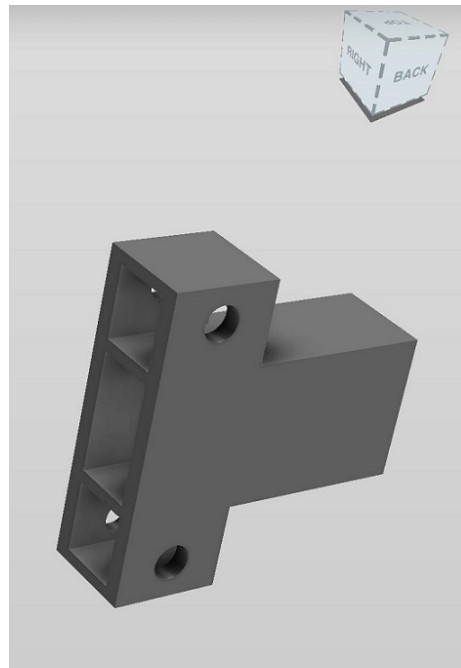
(a)

(b)

(c)

Figure 3.9: (a) Base clamp of servo motor (b) Base of servo motor (c) Shaft of servo motor

(a)

(b)

(c)

Figure 3.10: (a) Extended plastic shaft (b) DC motor base 3D design (c) DC motor gearbox case

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Chapter 4

Model Tuning and Results

4.1   Model Tuning

The robot is tried and tested in the room environments by placing the obstacles. The obstacles are chosen are of different length and widths so as to test the motion of robot. The initial instructions to start the gait are provided via the Bluetooth Controller application.

The 'start ' command is given to the robot from the mobile phone application . On Initialization , The robot is expected to start the gait and then as per the hurdles in the way, it is expected to change it's direction of locomotion. The IR sensors are placed on the head(master) module with the help of which the obstacles will be detected. The Bluetooth device on the robot is paired with the Bluetooth of the android mobile phone. The Bluetooth module on the robot is configured with respect to the Bluetooth controller application, the controls of the robot from the application are coded in the Arduino code.

The servo motor's shaft is a rest i.e. 0 degrees deflection. The I2C communication is established between one master and two slave modules. I2C communication is the main element responsible for the overall data communication between the master and the slaves. A4, A5 and GND pins of all the Arduino NANOs are connected over one bus for data transfer. The power supply is given via the lithium ion batteries placed at the tail end. Three such batteries with value 3.7V are series connected to to give overall 9V.

4.2   Steps of Working of the System

- The android mobile application named "Bluetooth controller" is used to initialize the robot.

- The master module starts initialization of itself and the slave modules

- The servo motors take 45 degree angle turns towards left and right alternately.

- The motion of the master starts first, succeeded by the tail module and lastly moves.

- The master module is continuously checking for the obstacles or hurdles with the help of the IR sensors mounted on it.

- If the master module is detecting an obstacle, the module checks free path towards the left of the hurdle.

- Keeps checking until a free path is found. The master bends in that direction accordingly. The master also sends the instructions to slave modules to change gait accordingly.

- If free path is found, master resumes to the regular locomotion and commands the same to the two slave modules.

- If no free path is found to the left, the master starts checking the free path to the right of the obstacle.

- If free path is found, master returns back to the regular locomotion and notifies the slaves modules to do the same.

- If no free path is found in either of the directions, the master module aborts the motion and commands the slaves to do the same.

- The algorithm for the master-slave modules compression and expansion for serpentine locomotion is as follows:

    - Master-Right Compress
    - Slave2-Left Compress
    - Slave1-Right Compress
    - Master-Right Expand
    - Slave2-Left Expand
    - Slave1-Right Expand
    - Master-Left Compress
    - Slave2-Right Compress
    - Slave1-Left Compress
    - Master-left Expand
    - Slave2-Right Expand
    - Slave1-Left Expand

4.3 Flowchart of the system

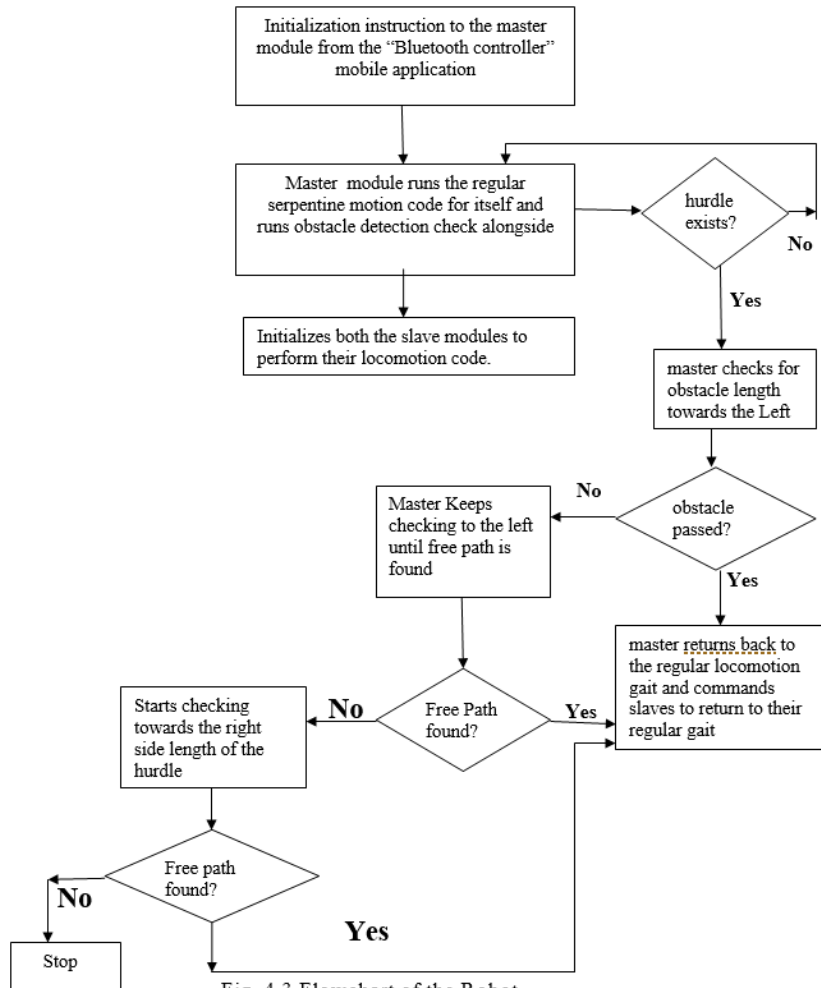Fig 4.1 shows the flowchart of the working of robot

Fig. 4.3 Flowchart of the Robot

Figure 4.1: Flowchart of the Robot

4.4   Test Results

- The module height is 8 cm when in reset mode.

- The master module and slave modules together make the snake robot 24 cm long.

- The servo motors deflect from origin with an angle of 45 degree to the left and the right alternatively.

- The master moves first, then the tail and lastly the mid module.

- The entire robot moves with a speed of 6mm/s.

- The maximum compression occurring on each side of the module is in between 60 degree to 75 degrees.

- When an obstacle is detected the maximum compression occurred in the module is upto 40 degrees

- When a hurdle comes, the master module deflects more towards left and subsequently the slave modules too.

- When free path is found, the master module returns to the regular gait and also commands the slaves to do the same.

- When no free path found on the left side, the module moves towards the right side.

- When free path found on the right, the module starts moving on that free path by returning to the original gait.
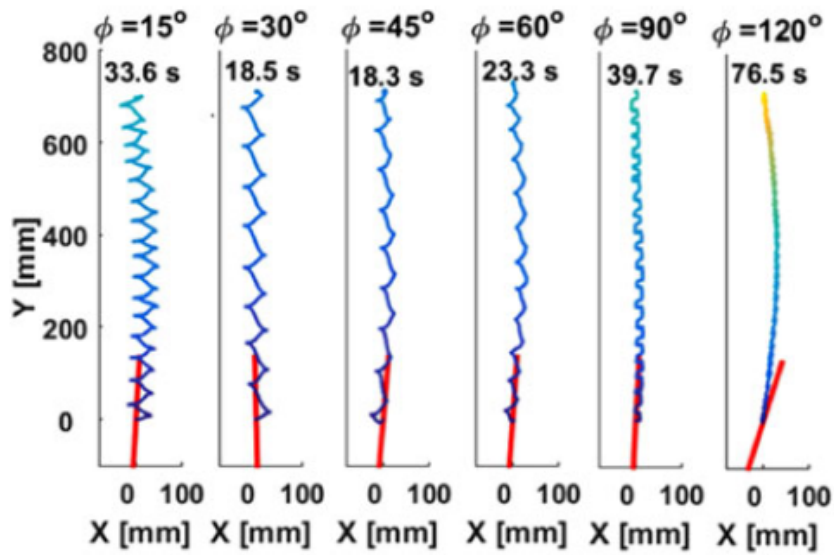
The supposed angular deflections of the robot from the straight path are shown in the Fig 4.2(a)

The supposed change in the gait of the robot on detecting obstacle is shown in Fig. 4.2(b)

The images of the actual motion of the snake are shown in the Fig. 4.3.
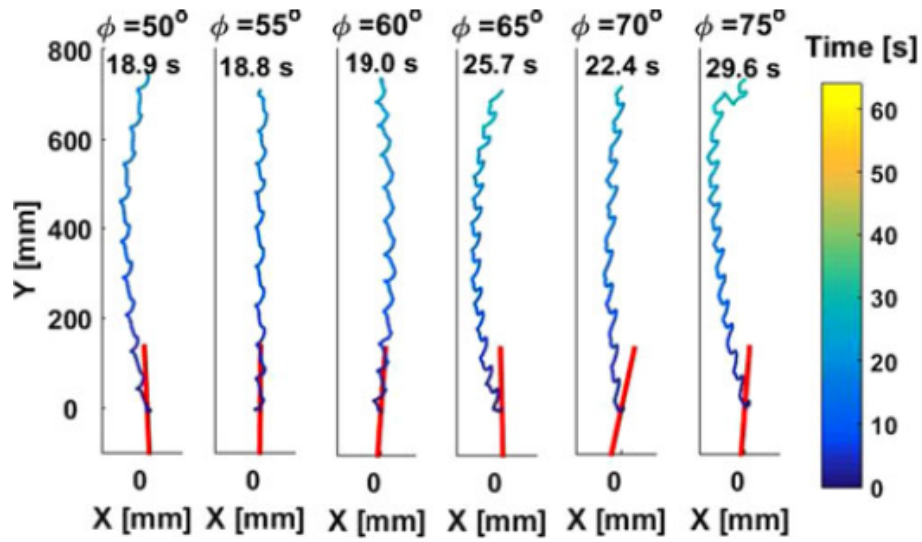
Figure 4.2: (a) Angular deflection of the snake robot (b) Deflection in angle on obstacle detection

(a)

(b)

(c)

(d)

Figure 4.3: Motion of the robot at (a) 2 sec (b) 2.5 sec (c) 3 sec (4) 3.75 sec

Chapter 5

Conclusion & Future Enhancements

5.1   Conclusion

This robot is efficient in giving a resultant serpentine locomotion and moves at the rate of 6mm/s. The robot is capable of doing the locomotion with minimum angle of deflection as low as 45 degrees and maximum of the angle as 75 degrees. The height of a module on maximum compression goes down to 3.5 cm from 9 cm.

When the robot occurs in a deadlock condition, i.e. when there is no place to go either the right or the left, the robot aborts in function and resets itself. The mobile application used for this purpose can initialize and stop the robot.

The previously built robot is capable of moving with different gaits, i.e. serpentine motion, side-winding motion, snail like motion. This robot was restricted only to showing different types of gaits. The power supply given to the previously built robot is a wired power supply. This restricts the range in which the robot can move. In this project, we have achieved a regular serpentine motion. Along with that, we are controlling the robot with the help of a mobile application which makes this robot independent of the dependency on a laptop or a computer to send the instructions of locomotion to it. 3.7 volt rechargeable batteries are mounted on the back panel of the module, thus ruling out the restriction of range of movement for the same. The only care that is to be taken is that the robot stays in the range of the Bluetooth model that is used, in this case it is approximately 10 m here. This makes it a mobile robot that one can carry to any place and can be used for getting into places with a diameter as mall as 14 cm and also for obstacle detection.

The snake robot is capable of moving like an actual snake in terms of attaining the serpentine locomotion. The robot fails to detect the overall length of the hurdle when it occurs, but moves in one direction at a time and then in the other. Just as a snake needs to take a U-turn when wants to return back to the

path that has been crossed, it does not move backwards.

The robot is taking the turns based on how wide the obstacle has been detected. The robot since checks for only one direction at one time, it is slightly time taking when the hurdle towards the left gives no free path and the robot has to take a U-turn and return towards backward direction.

5.2 Future Enhancements

- The robot can enhance better functionality in terms of becoming a commercial robot for performing search and rescue operations.

- For that, the devices and components used on the robot must chosen so as to

- reduce the overall size of the robot. This will enable the robot to move through small and compact places.

- The robot can be enhanced with multiple sensors like cameras and wifi modules, so that the direct access of the robot's location will be granted to the user.

- The robot can be equipped with other functionalities like detecting human bodies or animals by fixing heat sensors on it.

- Many commercial applications are possible using this soft robotic snake. It will benefit in giving the precise results for the tasks that it is meant to perform based on the components that it is built with.

- Use of custom made PCB with microcontrollers instead of using Arduinos will provide a better functioning robot that what it is at present.

- The master module can be programmed in such a way that when it checks for obstacles or objects, it can measure the width of them by simultaneously scanning the object length on both the sides.

- When the hardware selected is so that the overall size of the robot reduces, along with making the outer body a compact and waterproof structure, this robot can be used to move in the sewage pipes and underground mining.

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