Modular Snake Robot with Mapping and Navigation

Urban Search and Rescue (USAR) Robot

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***Abstract*-This paper focuses on the design of a hyper redundant snake robot inspired from a real biological snake. Snakes have unique capabilities for moving on a wide range of terrain. The snake robot, rather than wheeled and legged mobile mechanisms, offers high stability. The paper presents a design of a snake robot that possesses the ability to map and navigate in its surroundings and also to find the possibility of human life. The snake robot is designed using sensors such as Ultrasonic sensors, PIR sensor and is designed to a moderate size segments so that easy locomotion is possible. The most effective movement pattern, flexible locomotion gaits such as sidewinding, crawling, plunging and leaping can be implemented on a snake robot. The snake robot can be used for many applications such as search and rescue operations in collapsed structure and inspection of tightly packed space that people and conventional machinery cannot access. To make the snake robot work or function like a real biological snake, it is constructed using many joints that enables the robot to have various degrees of bends, and gives the robot ability to be flexible enough to reach or approach different terrains. This ability of snake robot enables it to move around in complex environments.**

Keywords— Biological snake, modular snake robot, locomotion gait, mapping and navigation, search and rescue.

I. INTRODUCTION

In the tremendously advancing field of electronics which mainly focuses on the communication sector and the automation industry little has been done in the area of non-profiting applications such as in the case of a disaster to conduct search and rescue operations, industrial surveillance and exploration of cluttered areas. Also, from the time of development of robotic mechanisms, the locomotion and obstacle avoidance robots still have many limitations. The robots operating on wheels do not operate well in all type of terrains [7]. The snake movements have dynamic characteristics that make it capable of crawling in different types of terrains. To design a robot which acts as a real biological snake is very complex with some issues such as [3]. An essential issue is to provide snake's locomotion to the snake robot [1]. The snake robot should satisfy prototypical advantages that include terrain ability, good stability and effectiveness.

This paper provides complete design of a modular snake robot based on principles of mapping and navigation. Basic idea of this paper is to explain a method or a way of using the modern technical advancement in case of emergency where humans cannot work and the time frame to complete the job is small [6]. The snake robot is made of a prototype which is made up of many modules connected one after the other and is capable of taking shapes in more than one plane. The robustness and stability of biological snake locomotion inspires modular snake robot to meet the ever demanding need of robotic mobility on irregular and challenging environments [4]. For the application of the snake robot based on the presented design, it may include several fields such as:

1) In search and rescue operations, the snake robot can help us in finding blockages and detecting live humans under debris as in case of earthquakes [6]. It can generate a map of its surrounding and send environmental parameters to the PC [11].
2) In our survey we found out that the snake robot is suitable to explore unknown environment; this is possible due to the support achieved from the distribution of mass of the snake robot over a wide area.
3) To camouflage its identity with real animals so that animal behaviour could be studied better as the snake robot can be modelled exactly as a real biological snakes if the number of modules is increased and the appropriate locomotion of snakes is achieved. [11].
4) Snake robots can also be implemented in areas of military application where it can help in knowing the whereabouts of the enemy by sneaking into their territory.

II. RELATED WORKS

Sheigo Horse introduced in early 70's snake inspired robots and since then a number of developments have taken place over the design which have been prototyped for practical

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purposes. Early designs consisted of snake robots with big or huge wheels and thus locomotion ability of the snake was limited making it suitable to run only on even terrains due to which locomotion on uneven terrains was a major limitation. Some designs which were initially built were ACM- Active Card Mechanism and Amphibionic designs [1] [9]. ACM design worked on the principle of wheel based modules i.e. having massive or big wheels on each segment or module and an Amphibionic or Amphibot is an arrangement of many similar looking modules or segments [5]. The main intention of an Amphibot was to create a robot which can swim or crawl.

The second category of robots was the one which used active wheels for locomotion purpose basically to obtain propulsion for example Korya II. Klaseen and Paap designed the GMD- SNAKE 2 in the year 1999 which was an improvement over the previous developed model GMD-SNAKE. With increasing scope due to major developments in the area of snake robots need for search and rescue operations with the help of robots emerged and this gave birth to third category of robots which includes robots like Kary-1 and OmiTred [10].

A fourth category of snake robots was also developed which could completely mimic the actions or locomotion capabilities of a snake robot, some of these robots used pure undulation techniques and some used complete change in body forms for serving the application needs some examples of this category of robots are CONRO, NEC Quake Snake. The fifth category of snake robots is completely based on undulation techniques but using methods of linear expansion. Example of these kinds of robots is a Slim Slime robot [10]. Other major developments include worm like robot developed in the year 1996 by Chen Et Al. Also, a reconfigurable robot called Telecubes which can show the locomotion of a real biological snake.

III. SYSTEM ARCHITECTURE

A complete control system architecture system was designed as follows: each module was designed with a local power control, meaning an on/off switch. Furthermore, it is desirable to have an operating mode where the battery could be charged while still inside of the module. Finally, there should be one master control that starts the entire sequence so that each of the modules actuation sequence is synchronized. The overall system architecture is shown in Fig. 1.

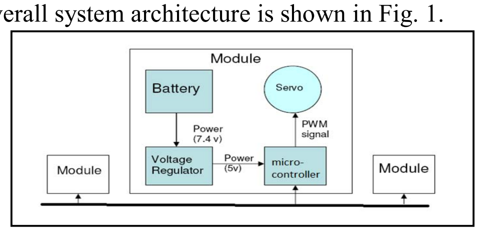

Fig.1.Modular circuit architecture

A. Block Diagram

The snake in this type of application requires real time response and thus a ZigBee module is used to send real time data from the sensors to the user, i.e., computer at the user side and to also take control response from the user and carry the control information to the snake for processing [5]. The user can control the snake from the pc or laptop. The processor used here is an ARM 7 processor (LPC 2138). Power supply is given through a battery connected to the snake module. The ARM controller has two sensors attached to it which do the work of collecting the information. The sensors are ultrasonic and PIR sensors for mapping and detection of human life in the form of motion movement shown by humans.

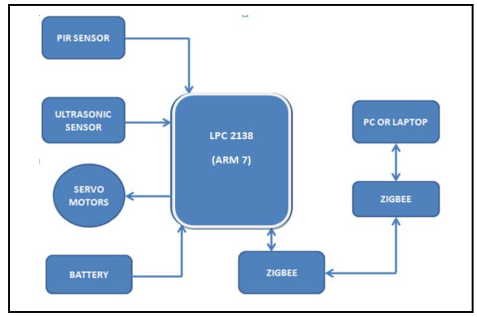

Fig. 2. Block diagram of overall robotic mechanism

B. Kinematic and Dynamic Model

In order to design a snake robot that utilizes a concertina gait, it would be advantageous to have a kinematics and dynamics model for a multi-linked snake robot that is moving in such a fashion [2] [11]. By being able to compute the torque as a function of time during the entire course of motion for the gait, relevant information about the snake robot design (metrics such as effort) can be [5] extracted. In order to develop functional modular snake robots, they must be designed to optimize certain functional requirements and performance characteristics.

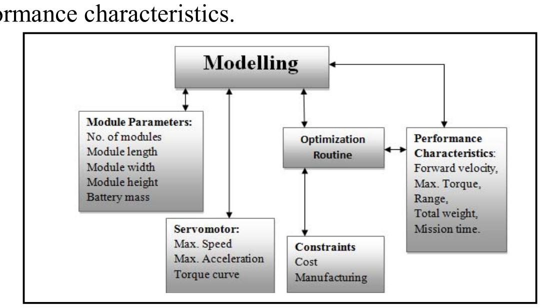

Fig 3.Kinematic and Dynamic Model.

C. Gait Design

While implementing concertina gait we found out that it is required to construct a framework for generating gaits with desirable performance of various characteristics such as mechanical movements and the speed of the snake robot [7] [9]. A gait design having various parameters that can be expressed or calculated is needed such that path of the snake or its trajectory can be easily manipulated by the end user. By using joint trajectories that are highly tunable, the gait design can then be integrated with the dynamics model to design gaits that are optimal [3].In Fig. 4, small circles are the representations of motors, i.e., servo motors and the big circles indicate the big gear. The horizontal lines after every big gear represent the segments or the modules of the snake robot. In the first phase a wave is produced by moving the two gears 1 and 2. During this period the end of the snake robot will move ahead with a distance equals to Δx. After the first phase the wave will continue to propagate reaching gear 3 and 4 to push the head of the snake forward. Thus the waves which are generated move the snake robot in the forward direction with a distance equal to Δx [7].

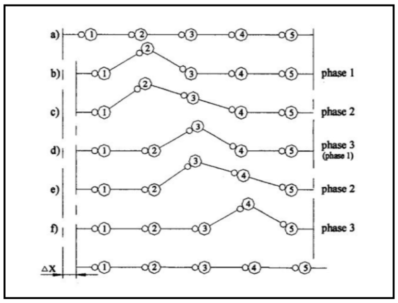

Fig 4.Propagation of modules

IV. MECHANICAL OVERVIEW

A considerable barrier in the development of snake-inspired robots is that they are currently expensive to produce, as they require manual assembly of many small parts because of the many sections and joints. This is especially important since one of the probable uses for snake robots, dangerous search and rescue applications, would place the robots in locations where it is likely that they would be destroyed. We have used an alloy of aluminum and steel called GI and is chosen because it was dumped by a local workshop house as their waste materials which helped in reducing waste and also helped us reduce the net cost. GI is strong can be screwed up using nuts and bolts, provides a solid mechanical body to the snake which prevents or protects the electronic parts which are sensitive to the external environment. The snake robot consists of 6 modules and a head, each module is driven by a servo motor. Modules are aligned alternately, i.e., the first module moves sideways, i.e., in a horizontal motion and the second module moves in an upright, i.e., vertical motion. This arrangement repeats for all the six modules and the head as shown in fig. 5

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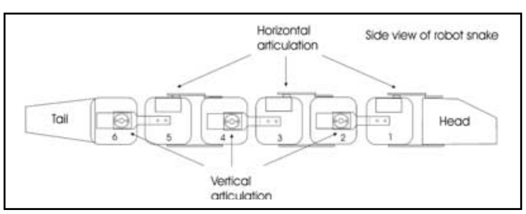

Fig. 5. Snake robot's movement capabilities.

A. Constructing the body sections and the head

To cut the pieces used in making the modules of snake robot to the required dimensions refer Fig. 6 to Fig. 8[13]. After cutting the pieces, use a 0.16 inch drill bit to drill the holes, as shown. File any uneven edges from the pieces. Fold each piece as per the angles indicated.

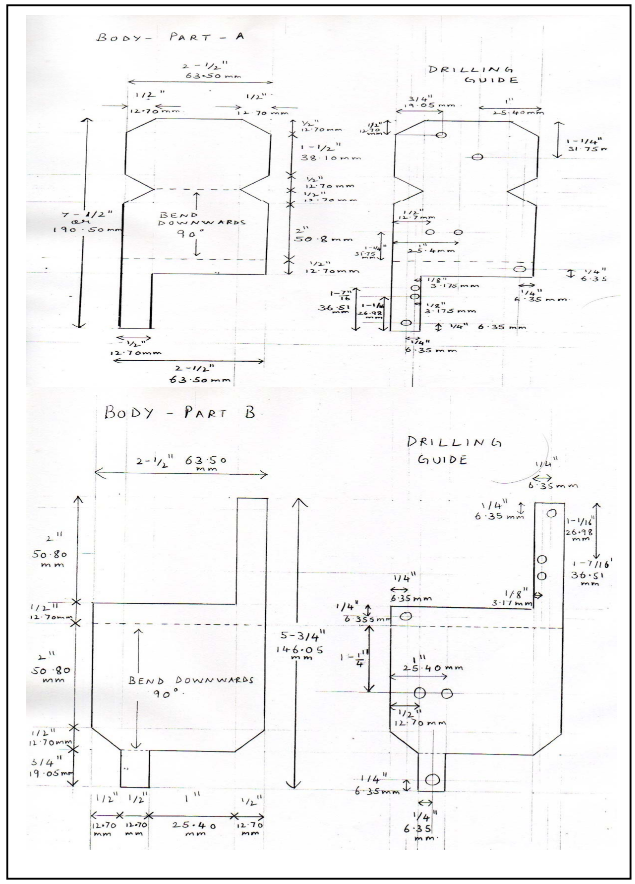

Fig. 6.a) Body part A b) Body part B

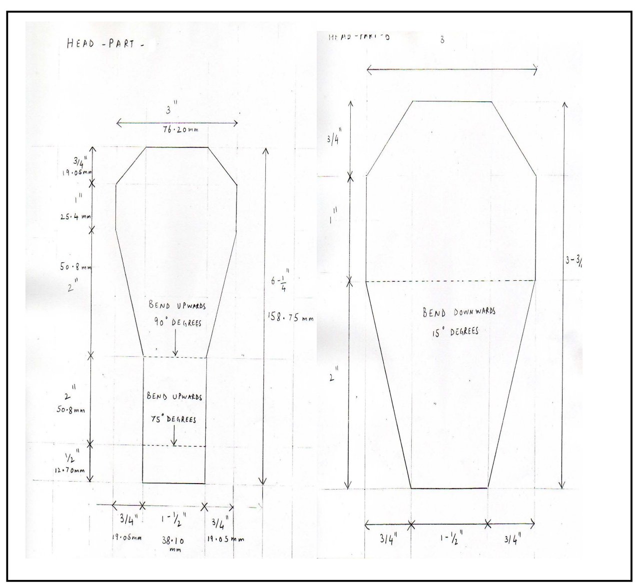

Fig. 7.a) Head part A b) Head part B.

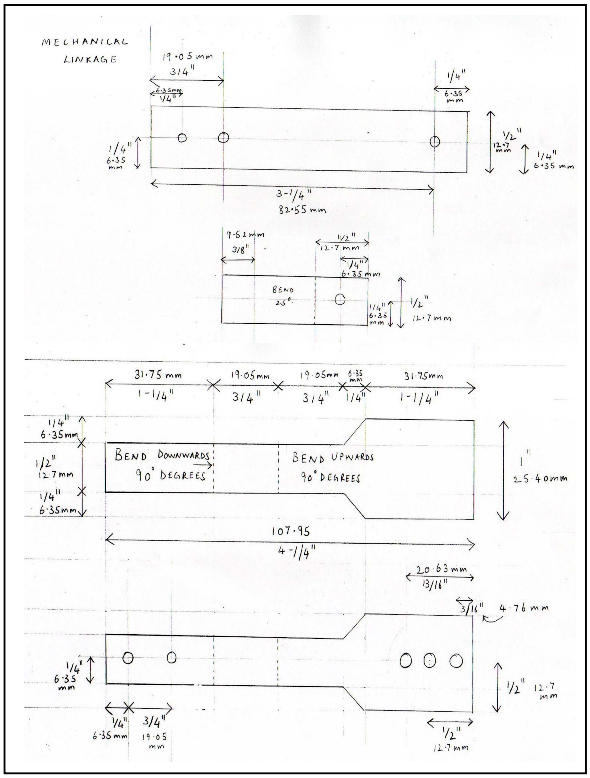

Fig. 8. Mechanical linkages.

B. Servo *Mechanism*

For the actuation of this snake-inspired robot, servomotors are selected. Servomotors are selected because of their size, cost, and simplicity. Servomotors are a conventional and proven technology, and many control platforms currently exist for their implementation. Servomotors are readily available and come in many different shapes and sizes. Servomotors are chosen as opposed to newer, experimental technologies, and other conventional motors [12]. Servomotors can be contrasted with new, novel actuation technologies such as artificial muscles and shape memory alloys; technologies that may be ideal for snake-inspired robot actuation in the future, but currently they would require too much study in order to incorporate them into this design [12].

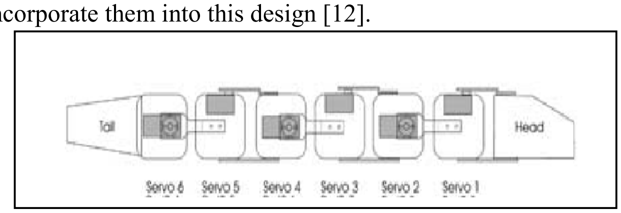

Fig. 9.Servo connection diagram.

V. ELECTRONICS OVERVIEW

A. Controller

Requirements of the snake robot are satisfied by using a fully capable microcontroller [9] i.e. the use of ARM7TDMI microcontroller and its features provides the snake with all the required controlling action. Various processor manufacturing companies are manufacturing these cores, among them one is Philips LPC2138 microcontroller. ARM processor used is a 32 bit microcontroller with real time processing and has support of a high speed flash memory of 512 kb, also has an on chip static RAM which is of 32 kb and is helpful in implementing functional embedded systems. The size of the chip is very small and thus consumes less power for its operation making it an ideal device for embedded systems where the size of the chip is a prime concern. It has two 32 bit timers, 14 ten bit analog to digital converter channels and also has a single ten bit digital to analog converter which provides analog output over a large range, also it can be used by the program for implementing several applications.

In this design, the functions carried out by LPC2138 are:(1) It processes the data collected from the sensors and makes it available at the user end (2) The generation of PWM signals using motor driver (IC L293d) which helps the servo motor to rotate at required torque.

B. Driving Circuit and Sensors

Locomotion of the snake robot depends mainly on motor movements [2] and is controlled with the help of a motor driving L293d IC; in which simultaneous running of two motors is possible. To make the designed robot work in a desired way and making it fully functional, various sensors are attached to the robot body. The snake robot is equipped with PIR and ultrasonic sensors.

A PIR sensor also known as passive infrared sensor is a sensor which measures the infrared radiations of objects coming in its field view or its specified range. PIR sensors work entirely by detecting the energy given off by other objects in its range and hence it can be used to find live humans. Ultrasonic sensors are also known as transceivers as they both send and receive, and referred as transducers. The working of ultrasonic sensors depends on the principle similar to as SONAR or RADAR, by evaluating attributes of a distant object.

VI. MONITORING SECTION

The monitoring section is responsible for controlling and monitoring the robot and is done with the help of a PC at the user side. Monitoring section sends the control signals and receives the acknowledge signal through ZigBee technology a java application is developed to make it easy for the user to interact with the robotic snake [13].

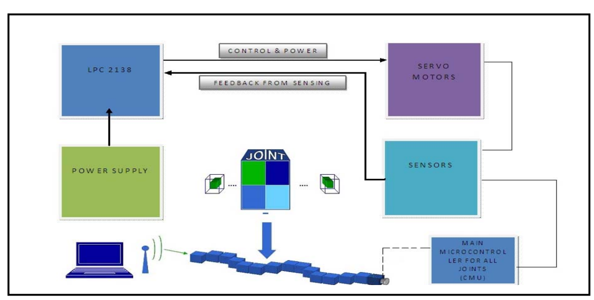

Fig 10. Structure of monitoring section.

The microcontroller receives information from its sensors as it is the processing head, when an appropriate action needs to be taken the robot is directed using controlling action by the microcontroller on the snake. The movement of the snake is controlled by the end user through a PC [6] or a laptop by running a simple JAVA application on it. The GUI for the JAVA application is shown in the Fig. 11.

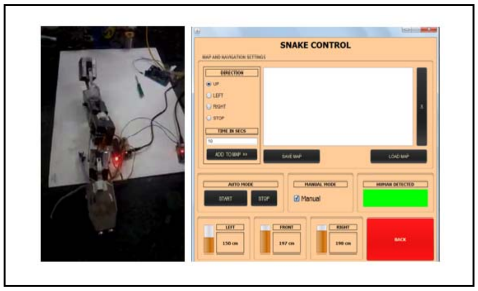

Fig. 11.GUI for java application.

VII. TEST RESULTS

Through various tests and techniques conducted, many characteristics or functioning of this project were improved. Basic features of the snake robot were tested so to ensure that every component is functional and required modifications and adjustments were made to the main circuits so they functioned according to the design keeping practical considerations in check. The component values used in the designing of the circuits initially were not easily available, so components with values within the range of 0-5% tolerances were used. The servo motors are used to give the degree of freedom to move the snake according to the user requirement. The ultrasonic sensors are used to calculate the distance between snake and obstacle or surrounding area of snake body and PIR sensor is used to show the detection of around a snake. The ZigBee module is used to transmit and receive the data. Using Graphical user interface designed in Visual Basic we have observed the readings.

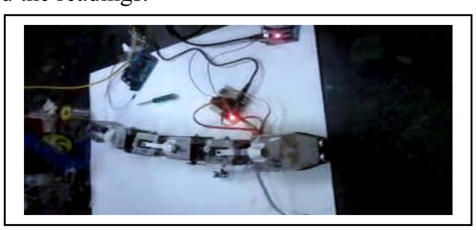

Fig. 12.Fully assembled Snake robot.

VIII. CONCLUSION

Modular snake robot designed from the presented paper possesses the ability to traverse complex and difficult terrains, such as pipes, small holes and gaps, and generate mapping information of the surrounding environment. The robotic mechanism is controlled by using ZigBee wireless technology. The design of the snake robot is implemented by considering several design metrics such as reliability, size, weight and performance. The objective of our work is to provide a powerful embedded real time system for search and rescue operations, surveillance, exploration of planet and several other applications where it is difficult for humans and conventional machinery to approach. The model designed conforms the locomotion of a real biological snake by understanding specific class of gaits. Finally, a full modular architecture of a snake robot was designed and implemented using an innovative manufacturing process aimed at reducing costs.

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