Snake Robots for Rescue Operation

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Abstract. The motivation for snake robots originates from natural snakes. Snakes show better versatility abilities and can move over basically any kind of landscape, including limited and restricted spaces. Like a snake, robot has an exceptionally expressed robot controller arm with the capacity of giving its own drive. Wheel-less, limbless secluded Snake-like robot (Snake robot) has superior capacities in flexibility and adoptability to nature in examination with the most haggled vehicles. Some helpful highlights of snake-like robots incorporate smaller size of the cross-sectional regions, steadiness, capacity to work in troublesome landscape, great footing, high redundancy and complete fixing of the inside systems. Our model consists of multiple links joined together to create propulsion on its own in a spatial environment. The first link (head) can have various configurations like camera, gripper, etc. This makes the snake robot ideal for search and rescue operation.

Keywords: Snake robot, bio-inspired robotics, rescue, serpentine robot

1. Introduction and background study

Wheel is the mother of all invention, wheeled mechanism is the key to most of the ground-based transportation of today’s date. Comparatively in smooth surfaces, such mechanisms are performing well with high speeds and have sensible steering ability. Rougher terrain makes it tougher, if not possible, for wheeled mechanisms to maneuver. Snake is one amongst the creatures in nature that exhibit glorious quality in numerous terrains. It can move through slender passages and jump on rough ground. This unique mobility quality property is recreated in robots that look and move like snakes. These snake robots most frequently have a high variety of degrees of freedom (DOF) and they can move in the absence of active wheels or legs. At some point of time, snake robots might play a vital role in search and rescue operations, fire-fighting, examination and maintenance. The extremely articulated body permits the snake robot to traverse tough terrains like folded buildings or the chaotic situation caused by an automobile collision in tunnels. The snake robot could move through the intervals between collapsed buildings looking for people whereas at the same time transferal installation in conjunction with little amounts of food and water to anyone treed by the shattered building. Moreover, the snake robots will be used for examination and maintenance of complicated and probably risky areas of business plants like nuclear facilities. In urban areas, it might examine the sewage works searching for leaks or aid fighters.

The snake mechanism is a lot of sturdy to mechanical failures thanks to high redundancy and modularity. The drawback is its restricted payload capability, poor power potency and a really sizable amount of degrees of freedom that have to be compelled to be controlled. This desk work which manages dynamic and kinematic demonstrating of a wheel-less snake robot was proposed utilizing...
MATLAB/Simulink. This model can possibly adjust with nature. Also, the connection between the quantity of connections and the forward speed is examined in this investigation. The snake robot can move quicker in conditions where the erosion is huge and this can be proved from the re-enactment results. The outcome additionally shows that the forward speed is proportionately corresponding to the quantity of connections[1].

A snake robot which consists of enclosed actuators and has a modular architecture was designed [2]. It has a high torque output module and efficient usage of available power. It also has bi-stable brake to hold the robot in its position without drawing power. A series elastic actuated (SEA) snake robot which consists of 1-DOF modules in a series chain was developed. In this, each module allows a full 180 degree rotation [3]. Snake robots can be used to navigate through pipe networks which cannot be achieved using wheeled robots. Hence a snake robot which automatically adapts to the shape of its environment such as changes in pipe diameter and junctions was developed. A closed loop control is used in order to achieve high level robot behaviour. This provides a better result while traversing through pipes [4].

A method which deals with modelling the rolling motion of snake robot was proposed [5]. The rolling motion was represented by adopting Bel lows model. A rolling hump gait was designed using the concept of composing shapes which enables the snake robot to climb over obstacles and move on bumpy terrains. A design was created for the gait of snake robot which is useful to move in complicated environment [6]. Two strides were created in this work, one for moving over a rib on a line and another step called crawler walk which can move across harsh territory. A technique which permits the snake robot to ascend stepping stools was proposed [7]. The snake robot has a smooth surface shape which is created through development of pectinate - shaped pieces of the connections. The climbing movement is produced by mix of move control and hanging movement. The experiments proved that the robot can climb both straight and inclined ladders.

The dynamic and kinematics modelling of a planar, underwater snake robot was developed [8]. A simulation model of serpentine and eel-like motion pattern was presented which is modelled by considering the combinations of forces acting on the snake robot. The simulation is independent of number of robot links. A waterproof snake robot named Mamba was proposed [9]. It can quantify the natural contact powers acting along its body. This is accomplished by utilizing strain check based power/force sensors which are introduced in each joint module of the robot. A method in which a snake robot possess both snake-like and bipedal motion was modelled [10]. This reconfigurable robot can transform between snake and multiple walking configurations without any attachment or detachment of its modules. The goal is to achieve efficient walking along the rough and uneven terrains.

A control framework for snake robot which uses extend sensor information to stay away from crashes was proposed [11,12]. The administrator gives the ideal speed of the initial connection through a regulator, and at that point, the regulator naturally ascertains the impact shirking between ensuing connections and obstructions. A sound-based confinement technique which appraises the robot area and pipeline map with an IMU was created [14]. This technique finds beneficial as the GPS and other odometry-based confinement strategies are denied in a pipeline because of its exactness. The proposed strategy utilizes time of flight (ToF) of sound waves to gauge the separation. This technique at the same time gauges the area of the robot and pipeline map by consolidating the separation acquired by the ToF and direction assessed by the IMU.

Most of the snake robots described here are wheeled snake robots. Wheels cannot move between rubbles and rocky terrains. So, they cannot be used in rugged and uneven terrains. These robots have circular or cylindrical gaits which have higher possibilities to roll over in highly inclined surfaces. In addition to this, these robots do not have grippers to carry the necessary payloads.

During disasters like earthquake people struck in the rubbles lose their lives mainly due to suffocation and thirst. The rescue department needs to clear the rubbles to get the people out within a short period of time to save their lives. Due to this the rescue department has to take drastic measures to save them and even though they do their best service some people lose their liver due to suffocation. To avoid this the rescue department sends hose to the struck person to supply air and water. This is not possible if the path to reach the struck person is complex. In this case mobile robots can be employed to take the hose to the target through the gaps in the rubbles. Most of the mobile robot move by using wheels or legs. However, the wheels cannot roll in uneven terrains and legged robots with a
considerable payload are difficult to design in small size. Hence it is possible for a snake robot with a robust design and a gripper to carry the hose to the people who are struck between the rubbles.

2. Proposed method

2.1. Proposed solution
The objective of this project is to assist the rescue department in its operations. The snake robot can crawl through most of the small gaps in the rubbles. This ability will let it be more useful to the rescue operation than other mobile robots. The snake robot can have a camera and a gripper in its first link, this will allow the snake robot to search and find whether people are stuck inside the rubbles or not. The gripper will allow this robot to take a hose to the target for air and water through the gaps in the rubbles if necessary. The robot can be wired as well as wireless. The robot can be shielded from external environment by adding a cover or shield around its body. This will allow to bot to be operated in swamps or slurry environment. The robot can be operated or controlled wirelessly by using Bluetooth. The communication system can be changed to operate by using Wi-Fi or RF signals or ZigBee [13]. All components in this robot allow modularity. The robot is made of multiple links and joints controlled individually by separate servo motors. The movement of the robot is achieved by self-propulsion due to the movements of individual links in a specific method. The servo motors can be changed to more powerful motors to accommodate the user’s needs. The length of the robot can be changed on the spot in a short time based on the need of the rescue operation. The figure 1 shows the flow chart of the work.

![Flow Chart of the snake robot design](image)

2.2. Working principle
The snake robot consists of number of links and joints. Each link consists of a multipurpose servo bracket, short U-shaped clamp, L-shaped interlink and a servo motor. The brackets, clamps and interlinks are used for joining the multiple servo motors into a single robot. The servo motors are controlled individually to produce a self-propelling motion. The servo motors rotation must be perfectly coordinated in a specific pattern to create a self-propelling motion. Each motor of the robot is individually controlled by using the controller (ATmega 328p). Servo motors angle of rotation must be unique for each link. This is achieved by multitasking algorithm program.
2.2.1. Inch worm motion. This motion uses the movement of a worm as a model for the snake robots motion. A worm moves by moving its back end of its flexible body to create an arc and propagate that arc to its front end of its body. This allows the worm to move through tight gaps and move easily. The same concept is used in snake robots, First the last link is moved forward by rotating the send servo motor from the end while the two adjacent motors rotate to keep the stability. Next step the third motor from the end propagates the arch created by the previous motor while the last motor provides friction by aligning itself to the ground or base surface. This process is repeated until the created arch reaches the front link. The robot moves forward due to the friction created by the remaining links by aligning themselves to the base or surface. To move the robot in reverse direction the process is done in reverse order starting by creating an arch in the front end.

2.2.2. Sideway Motion. This model is derived from the actual motion of the snake. Snakes use their flexible spine to create motion mainly based on the friction between its body and surface. Sequence of the motion of the snake is as follows, First the snake creates an arch in the horizontal plane and lifts its front end and straightens its body. But an actual snake can create these multiple arches throughout its whole body. This allows it to move in a rapid motion. Snake robot can be programmed to move in this model as well. This movement is really a blend of the serpentine and rectilinear movements depicted previously. To accomplish this movement, the robot must be reconfigured. A side section interfacing one fragment to the C-section of the following portion is unscrewed and turned 90 degrees. This is done along the whole length of the snake. Hence servos 1, 3, 5 will be situated concerning serpentine movement and servos 2, 4, 6 will be situated with respect to rectilinear movement. Side winding movement is accomplished by sending a flat cosine wave down the odd numbered servos and a vertical cosine wave (balance from the level wave by 90 degrees) down the even numbered servos. Thus, the sideways movement is accomplished. The figure 2 shows the side way motion of a snake[16].

![Side Way Motion](image)

**Figure 2.** Side Way Motion

3. Components used and modelling

3.1. Arduino UNO (ATmega328p)
The Arduino UNO is a microcontroller board upheld with the chip ATmega328P microcontroller and created by Arduino.cc. The board is provided with sets of advanced and simple information/yield (I/O) pins which will be interfaced to change the broadening sheets (shields) and elective circuits. The board has six simple pins, fourteen advanced pins and programmable with the Arduino IDE (Integrated Development Environment) by means of a sort B USB link. It will be battery-fueled by a USB link or by an outer 9V battery, regardless of its acceptance of voltages somewhere in the range of seven and twenty volts. Furthermore, it is equivalent to the Arduino Nano and Leonardo.
The prearranged ATmega328 goes ahead the Arduino Uno with a boot loader that empowers transferring new code thereto while not the work of an outer equipment engineer. The correspondence is encouraged with the first STK500 convention.

3.2. **Servo motor (MG995)**
A servo engine is an electrical gadget which can push or pivot an item with accuracy. A servo engine is normally used if an object needs to be turned to a particular edge, or to be rotated. We can get an exceptionally high force servo engine in a little and light weight bundles. The number of servo motors is divided into 2 parts. Here, totally six servo motors are used, in which 3 of them are used to provide vertical movement and other 3 provide horizontal movement. These motors are controlled individually by Arduino. Based upon the commands given by Arduino to the servo, appropriate motion of the snake robot is achieved.

3.3. **HC-05**
HC - 05 is the Bluetooth module and complies as a MASTER/SLAVE module. Of course, the works setting is SLAVE. The Role of the module (Master or Slave) will be sorted out exclusively by AT COMMANDS. The slave modules can't start an alliance to an alternate Bluetooth gadget, anyway will make due with associations. Ace module will start a connection to elective gadgets. The client will utilize it simply for a port substitution to find out alliance between MCU and GPS, PC to an installed framework, and so forth.

3.4. **Camera**
Remote cameras will be cameras that communicate a video and sound sign to a remote collector through a radio band. Remote cameras require in any event one link or wire for power. Video can be taken to PC through Video catch/TV tuner for picture handling as well. The camera can be connected to any surface by utilizing fastener and nut or screws.

3.5. **Multipurpose servo brackets**
Multipurpose servo brackets are specially designed components made of aluminum or plastic to hold servo motors. Due to its design the servo motor gets a full support while it operates. This bracket is used for connecting the servo motor to the L shaped interconnect servo bracket. These brackets are made up of aluminum to reduce the weight of the snake robot’s mechanical structure. These brackets contain drilled holes to connect with the other components by using screws. The bracket is provided with large number of extra holes to provide modularity and allows the user to change its configuration easily.

3.6. **Short U-shaped servo bracket**
This section is utilized for associating one servo section to another. It is explicitly intended to append to a servo engine's pole. The short U-formed servo section is connected to the servo engine's pole by utilizing screws. This section is associated with the L formed interconnect servo section. This section is made of aluminum to lessen the heaviness of the robot.

3.7. **L-shaped interconnect servo bracket**
Interconnect servo sections are uniquely designed in aluminum to interface servo sections to short U-shaped servo sections. This section is utilized for associating the servo engine to short U-formed servo section. The L-formed interconnect servo section is appended to the multipurpose servo sections by utilizing screws. This section is made of aluminum to reduce the heaviness of the robot.

3.8. **Parallel jaw gripper**
Parallel Jaw Robotic Gripper gives the best grasp on load. It is adaptable with RKI-1204 and RKI-1211 servos [15]. Gripper is made of Aluminum Alloy having high elasticity with a general opening range of 55 mm.
3.9. **Bolts and nuts**

It is regular to utilize fasteners and nuts in numerous applications with an expectation to hold segments or things together tightly. Here and there the screw isn't utilized along with a nut, yet the nut is generally utilized alongside a fastener. Stray pieces fill in as the principal segments in a few development ventures as they give solid bonds that don't earn back the original investment under incredible measures of weight. Screws and nuts can have a few unique styles and types, each fit to coordinate the necessities of a specific application or the requirements of the activity.

3.10. **Kinematic modelling**

The snake robot comprises of N unbending connections of length 2l interconnected by N – 1 mechanized joints. The width of each connection isn’t considered in the model. All N joints have a similar mass m and snapshot of idleness J. The total mass of the snake robot is thus Nm. Uniform dispersion of weight is guaranteed in each connection so that the connection CM (Center of Mass) is arranged at its middle point (One length l ahead from the joint at each side). The figure 3 shows the kinematic model for snake robot’s movement. The figure 3 shows the kinematic model for snake robot’s motion.

![Figure 3. Kinematic Model for Snake Robot](image)

In the above equation, the robot’s global frame position i.e. p of the CM (Center of mass) is displayed by equation (1)

$$
\mathbf{p} = \begin{bmatrix} p_x \\ p_y \end{bmatrix} = \begin{bmatrix} \frac{1}{Nm} \sum_{i=1}^{N} m x_i \\ \frac{1}{Nm} \sum_{i=1}^{N} m y_i \end{bmatrix} = \frac{1}{N} \begin{bmatrix} e^T X \\ e^T Y \end{bmatrix},
$$

The heading (direction) of the snake robot is characterized as the normal of the connection edges which is given in the condition (2)

$$
\bar{\theta} = \frac{1}{N} \sum_{i=1}^{N} \theta_i.
$$

Every connection link in the system is fixed in the CM of the connection with x (divergent) and y (normal) axes and the same are aligned in such a way with the worldwide x and y axis when the connecting angle becomes zero. The rotation matrix from the worldwide edge to the casing of connection is given in the equation (3)
3.11. CAD modelling
The snake robot’s entire functionality depends on the design of its links and joints. These links must be interchangeable and must be able to connect with each other to form a complete structure. The figure 4 shows the design of individual links. The figure 5 shows the complete design of the snake robot.

\[
R_{\text{global}}^{\text{link},i} = \begin{bmatrix}
\cos \theta_i & -\sin \theta_i \\
\sin \theta_i & \cos \theta_i
\end{bmatrix}
\]

Figure 4. CAD Model of Links of the Snake Robot.

Figure 5. CAD Model of Snake Robot.
3.12. Assembly
The snake robot consists of multiple links and joints which must be joined to form a whole robot. The links are joined to each other by using fasteners (bolts and nuts) for modularity purposes. If there is any need to extend the size of the robot, then the links can be easily added by attaching extra links by using bolts and nuts. If there is any need to reduce the number of links in the robot, then links can be easily removed by disengaging the bolts and nuts holding them. The snake robot is modular because of its ability to integrate with many peripherals like gripper, camera, etc., to its links via bolt and nut. The figure 6 shows the snake robot when a gripper is attached to its first link. These peripherals can be controlled by using Arduino with appropriate program.

![Figure 6. Complete Assembly of Snake Robot.](image)

4. Feasibility study

4.1. Economic feasibility
The value of human life is more than any other things. Our government mobilizes large funds when disasters like building collapse, earthquake or a child falling inside a bore well accidentally. Even then sometimes the rescue team cannot save all lives because they don’t know where a person is struck and the person dies due to suffocation. Compared to the lives of people the cost of this project is too small to even bother with.

4.2. Operational feasibility
Any rescue bot must be very flexible, adaptable and must be able to move in any terrain through obstacles. Since the proposed project is flexible, adaptable, modular, self-propelling, the snake robot is the most suitable for rescue operation than any other robots ever designed. The robot is controlled wirelessly so this allows the robot to enter an environment where it is dangerous for living beings.

4.3. Technical feasibility
The robot consists of multiple links and joints which can be controlled individually by using a servo motor. The power supply for the robot can be used as wired as well as wireless. To control the motors Arduino uno is used so the robot’s program can be edited very easily. The robot can be attached with any wireless communication device for controlling the motion and to get the camera feeds.

5. Conclusion
The snake robot can assist the rescue department in rescue and surveillance operations because of its adaptability, flexibility and modularity. The aid of the snake robot will greatly increase the possibility of rescue of a being during disasters and the rescue department can use this robot in any environment. The snake robots design can be improved if a single link can provide 3D actuation (pitch yaw and roll). However, these links must be fabricated specifically for the snake robot. If that is done, snake robot will be more versatile and will be more useful. This robot cannot be used for underwater
applications but this can be achieved by providing sufficient casing for the gaits. Also it cannot carry heavy loads with it. The additional peripherals can be designed specifically for snake robot and any functionality can be achieved via snake robot. The snake robot can be used as an industrial manipulator that can hold objects without any specific shape or size. These robots due to their higher flexibility and adaptability can be used for inspection purposes in industries and pipelines. It can also be used for surveillance in forest and military purposes.

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