Soft Robots in Search and Rescue

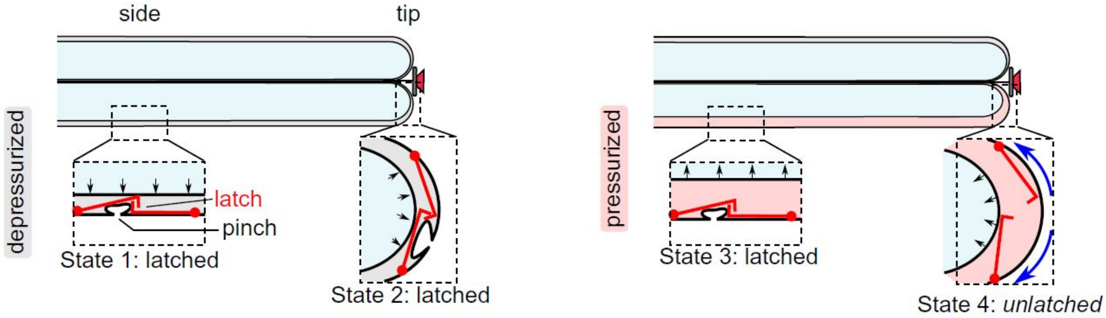
Soft robots are a tip extending robot which movement is through growth, unlike most robots which movement is through locomotion. Inspired by fungus, neurons and trailing plants [1] the Soft Robot lengthens itself via a reel of plastic and a pressurised air flow which fills up the body of the robot. There are many functionalities for this type of robot, that could be very beneficial to the search and rescue situations due to its unique navigation, its resistant to hazard terrain/obstatales and antenna deployment.

The benefits of using growth instead of locomotion is that we can have a stationary power source and no sliding friction, as the movement of the soft robot will not be dependent on its environment. [1] The movement is done through internal pressure, which pushes out the material to the length of the robot. The pressure forces the inverted material that is within the robot through its tip and is further supplied with more material by the centre of the robot through a reel which sits at the base of the robot [2].

The material itself needs to be thin and withhold pressure, in most cases it's a thin membrane of polyethylene [2]. The thickness of the material depends on the diameter of the robot, which allows the robot to be scalaby, meaning we can have soft robots of 1.8mm diameter to 36cm [2]. There are many different methods to turn a soft robot. One method is to have a robot with asymmetric lengthening of the robots a pneumatic backbone, also by having a constant curvature bending provided by artificial muscles along the backbone [1].

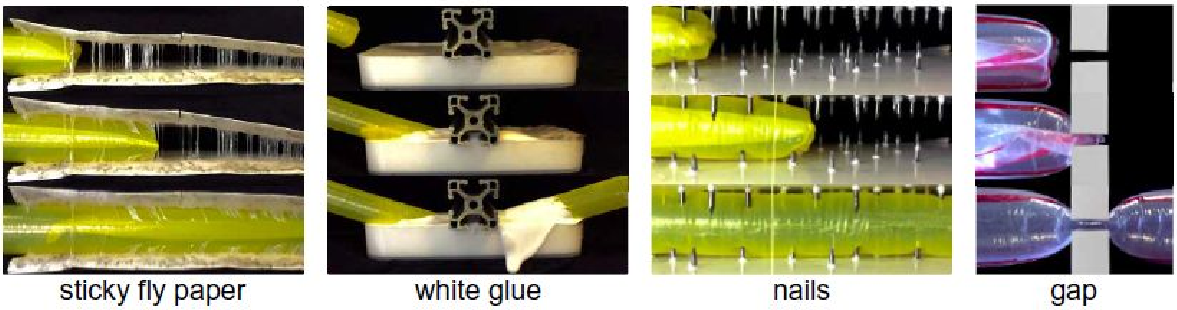
Another method is to have control chambers which limit the pressures to a specific side of the robot. When a side or channel is pressurised, that side of the tip will be lengthened resulting in a curve. If the left side is inflated, the left side will be lengthened and will turn right [2]. Besides the control signal, turning does not require any more power (or pressure) thus making it efficient. To control the chamber flow, the membrane has a series of pinched material along the insides of the robot. There are also latches which can unpinch the material, resulting in an increased length of the material on that side [2]. When the latch is in a depressurized state it is unable to unpinch any material. However when it is pressurized it can latch into the pinch and remove it [2]. This results in a turning mechanism for the soft robot.

Figure 1.1 - Control Chambers [2]



The soft robots key advantage is its insensitivity to obstacles or different surfaces. Hawkes tested the soft robot through a series of harsh environments, fly paper, glue, nails and small gaps [2]. The soft robot was able to easily pass all of these obstacles and the pressure required to pass through these obstacles stayed constant. Which means that the soft robot can easily adapt to its surroundings, without the need of more power or tools. Even though the soft robot was punctured from the nails, it was able to use its internal pressure and create a seal around the nail.

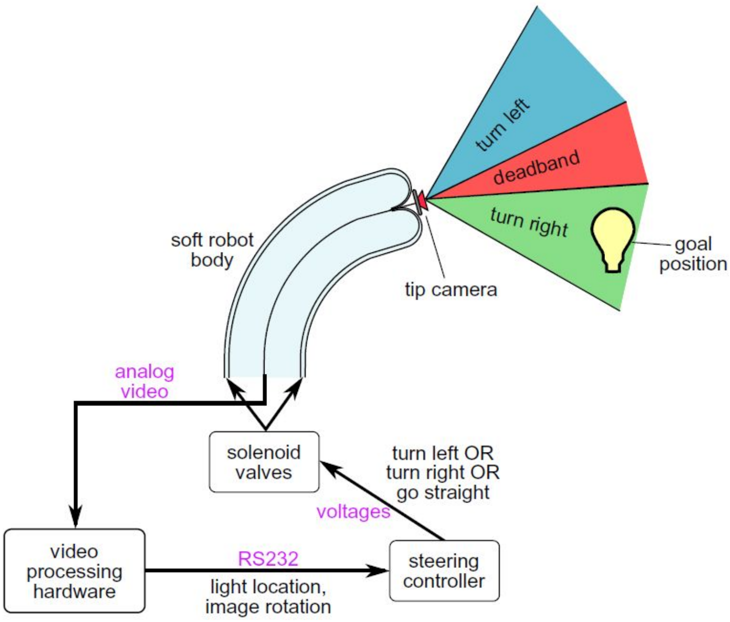
Figure 1.2 - Soft robot through hazardous terrain [2]



Stanford also tested soft robots and showed how they can be used to lift up objects, allowing either for the robot to pass the obstacle or to possibly free someone or something from underneath a heavy object [3]. This further shows the advantages of soft robots in navigation and possibly in search and rescue operations.

A possible method for autonomous navigation is the use of a camera placed at the tip of the robot. Data from the camera was able to calculate the location of a light source and the camera's rotation about its optical axis. This was done by the use of template-based object tracking, and distinguishing between the different frames. Using this method they were able to make the robot have the light source centered on the camera, and would turn or go straight depending on its relativity to the light source [2].

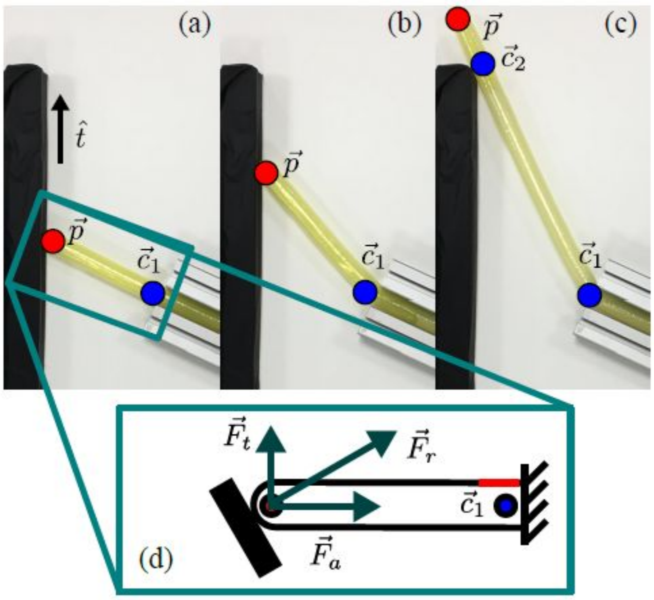
Figure 1.3 - Light focused steering [2]



Normally in navigational robots, obstacles are a problem. When the robot collides with an object there is a risk of damage to the robot or obstacle. In most navigational scenarios, obstacle avoidance is essential. However with our soft robots obstacle, can be used to benefit and guide the movement of the robot. Geer stated that there are two states the soft robot is in when in motion [1]. Firstly is free growth, which is when the soft robot is moving/growing and it is not being affected by any obstacle. Secondly is Obstacle Contact, which is the state to describe when the robot has encountered an obstacle [1].

When the soft robot comes into contact with an obstacle, it will buckle. This is due to the reaction force being both transverse and parallel to the backbone of the robot. The robot will move up the obstacle if the reaction force is greater than the pressure within the robot. The pressure also forces the tip of the robot to be in contact with the obstacle until has push up the length of it [1]. The tip being in contact with the wall means that once the robot has pushed past the obstacle, it will not move in the parallel direction. Once it has past the wall, the robot will change states from Obstacle Contact to Free Growth.

Figure 1.4 - Obstacle Interaction [1]



Equations 1.1 and 1.2 denote how Geer represents each state [1]:

Equation 1.1 - Free Growth Differential Kinematics:

$$\dot{\vec{p}} = u \frac{1}{||\vec{p} - \vec{c}_n||} (\vec{p} - \vec{c}_n)$$

Where p = *tip of the robot* ; $c_1, \ldots, c_n$ = *contact points along the backbone* ; u = *growth speed*

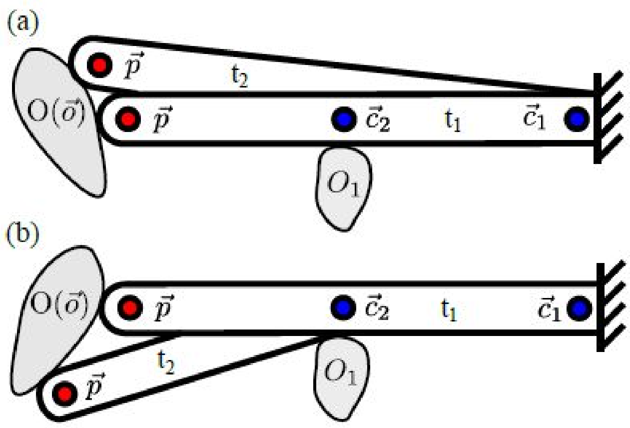
Equation 1.2 - Obstacle Interaction Differential Kinematics:

$$\dot{\vec{p}} = u\frac{||\vec{p} - \vec{c}_n||}{\hat{t} \cdot (\vec{p} - \vec{c}_n)}\hat{t}$$

Where t = *direction of movement up the obstacle*

Using these equations, they were able to create recursive algorithms to allow the robot to autonomously explore and move around a two dimensional space efficiently. The first algorithm inputs the initial state and the desired length the robot will reach. Using these it will output the robots tip position once it has grown to the given desired length. They use this first algorithm to express the high-level recursive movement of the robot, and the free growth state [1]. The second algorithm is used in the contact state, where it takes the same arguments as in the first algorithm, and in addition it also takes the obstacle contact point. It will then make the robot move up the obstacle, and check if it has reached the end point of the obstacle. Algorithm 1 is recursively called to move up the obstacle.

Figure 1.5 - Glancing Contact [1]



Case b in figure 1.5 is a example of glancing contact, and that state is dealt with using algorithm 3. Instead of finding the most distal point of O_1, it finds the distal point of $O(o)$. and if $O(o)$ distal point p is more distal than the original p it will move towards the new, more distal p. Again algorithm 1 is recursively called with algorithm 3 to move and update the model state [1]. Figure 1.5 shows the difference in reaching for the most distal point (a) veres simply overpassing the obstacle O1 and using it as a pivot point (b). Model (b) is achieved using only algorithm 1 and 2, while (a) uses all 3. In (a) contact point c_2 is dismissed and it is not the most distal point, and instead turns with t_2. Algorithm 2 is used to update the tip point and contact points for algorithm one to make the robot move.

From these algorithms they tested a robot in a crowded space. There goal was to see if the robot will find all possible exists if they place them at different starting orientations. They did testing with solely algorithm one, and with all three. Both tests correctly predicted all exit location.

Figure 1.6 - Robot navigating using algorithm 1 [1]

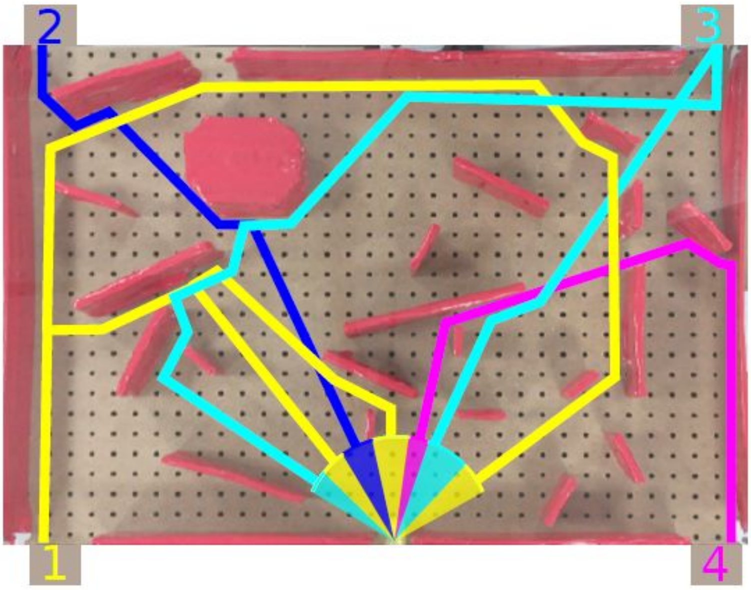
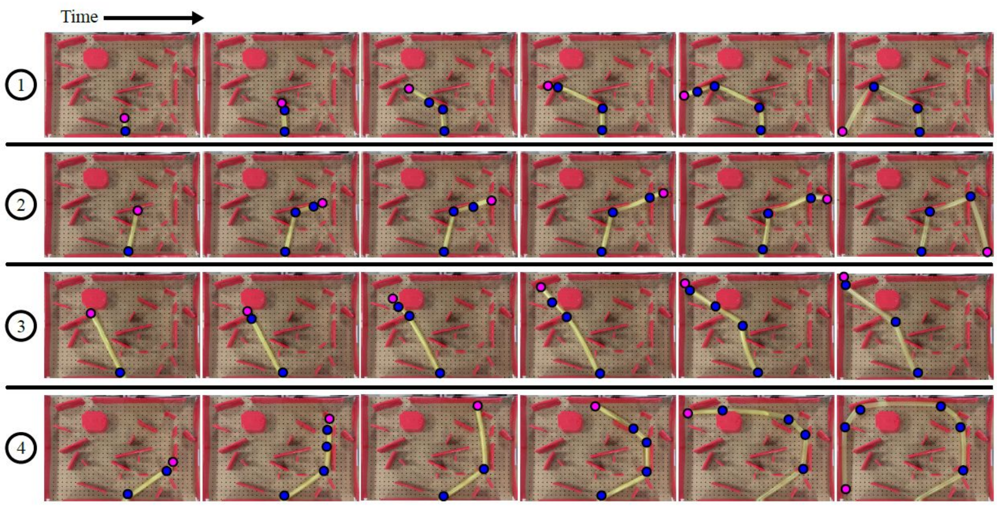


Figure 1.7 - Robot navigating using all algorithms [1]

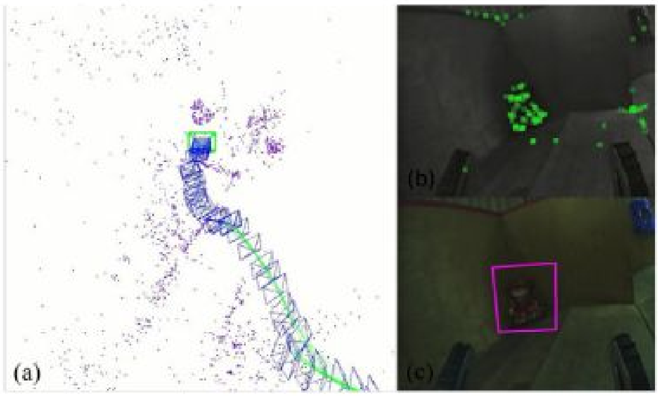


These test showed that the soft robots had a good potential to be useful and successful in searching or navigational tasks, as unlike other robots they used obstacles to their navigational advantage. It was also suggested that using a branching soft robot would be able to cover a larger area [2] and each branching tip could individually find all exit points, thus having a single robot which could map and search a large area. Greer concluded that their open-loop control algorithm that some active steering would be needed as the robot does not reach all location depending on the scenario, but they were planning on improving it [1].

Soft robots ability to easily navigate and pass through difficult scenarios, soft robots have the potential to be great search and rescue robots, however they are lacking in a sophisticated mapping software, like SLAM. Chen used SLAM and LiDAR to design and test an urban search and rescue (USAR) robot which one best in class small robot in 2016 RoboCup Germany [4]. The combination of Chen's work and soft robot could possibly design a high performing USAR robot.

SLAM has 2 main branches: feature-based and direct approaches. Feature-based approaches has 2 steps, firstly the camera identifies features from the environment, secondly the robots camera pose is recorded, combing both steps creates a map. To reduce the computation cost, this approach is based on frames which are identified as key frames. However the maps constructed solely from this method are difficult to understand for the human eye (Figure 1.8). Direct approaches try to create more visually understandable mappings by focusing on the geometry of the images intensities. This approach is poor in identifying objects however which means that for USAR SLAM robots badly identifies hazards, and objects of interest [4].

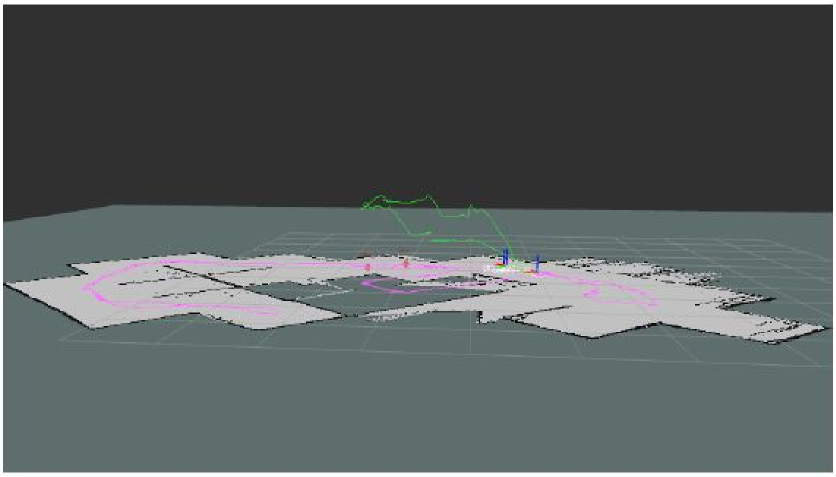
Figure 1.8 - Map generated by SLAM



To improve SLAM they combined it with LiDAR. LiDAR is used to identify the camera pose and the scale of its environment. This is done by the use of scan matching, a particle filter and graph optimization. It will collect and match a series of scans, it uses gmapping odometry to remove unuseful particles, these techniques improve the accuracy of SLAM. Lastly it combine these scans and constructs a node graph, with each node representing a pose.

When they combined SLAM and LiDAR they were able to create a robot which could generate a easy readable map of the surrounding area (Figure 1.9), and was able to identify the hazards in real scale. When they combined the localization tracking and LiDAR they were able to help the robot when it climbed up stairs, this allowing for a better 3D effectiveness of the robot. Obviously in the soft robot current state when compared to Chen's USAR robot was highly more sophisticated and better suited for the task. However soft robots have an unique approach to movement and obstacle avoidance, and possible which the combination of SLAM and LiDAR with the soft robot it could provide a better solution. Also with the free range of mobility of the soft robot, it would fully utilize the 3D mapping of the combined SLAM and LiDAR.

Figure 1.9 - Final map generated using both SLAM and LiDAR

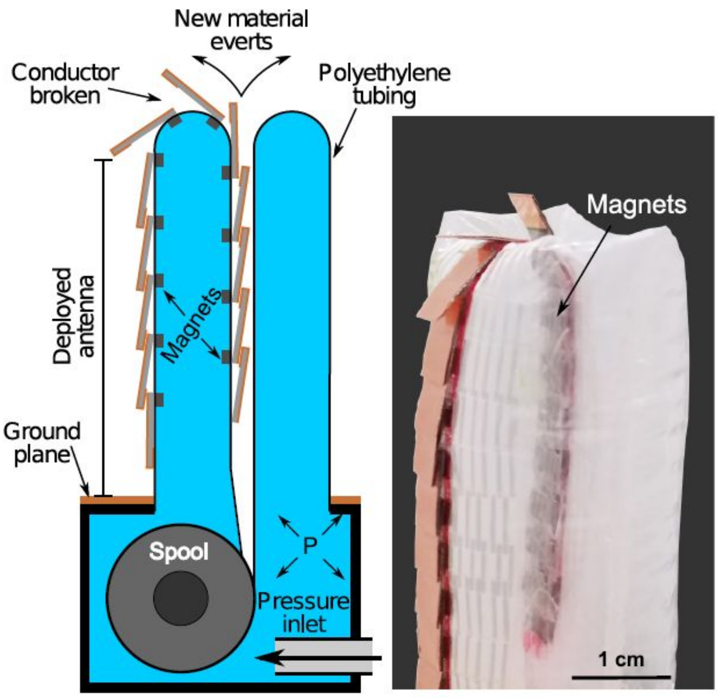


For USAR the soft robot can change its shape depending on the situation. Hawkes experimented on utilizing the free form body of the soft robot to create useful 3D shapes. They were able to create hooks, which could open or retrieve items. Due to the hollow body the robot could be a vessel for water to become a fire hose or to provide water to trapped victims [2]. You can also have the inner lining of the soft robot be filled with conductive matter to create deployable antennas [5].

Retractable and deployable antennas can be greatly useful for search and rescue, as the antenna would be compact and easy to transport. Soft robots are able to create a deployable antenna which are cheap, lightweight and portable. Blumenschein designed a quarter-wave monopole antenna. Changing the length of the monopole you are able to resonant different frequencies. In their soft robot grow was controlled by a brushed DC gearmotor which was attached to the inner inverted material. The gearmotor allowed for the total retraction or the changing the length of the robot [5].

To make the antenna work, the robot needing a lining of an highly conductive material. Due to the flexibility of the soft robot, the material did not need to stretch, therefore they used copper which is a cheap conductor. To allow for the copper to be flexible they overlapped copper strips along the whole length of the robot body, meaning that if the robot were to curve the overlapping strips would still connect and cover the area. They were able to keep the outside of the robot connected while the inside was electrically disconnected from the outer copper by having a break in the conductor at the tip of the robot. They sandwiched the copper with a steel which provided a stiffness for the break connection and to to create a strong backbone for the robot. Magnets were also used to align the overlapping plates, and to keep the structure of the antenna[5].

Figure 1.10 - Schematic of antenna



To control the frequencies they had a closed-loop tuning, similar to PID, The tuning was based on the feedback provided by the robots change of size. The frequency was inputted, and the returned loss is collected by its internal vector network analyzer, which MatLab used to calculate the resonant frequency of the antenna. The difference in the input frequency and the actual frequency was then used to calculate the error and it changed the antenna length accordingly. Due to the flexibility of the soft robot and the inner workings the robot is able to safely make these multiple changes [5].

Dynamically changing antennas has been done before with tuning mechanisms, however most of them like RF-MEMS antennas were complex to design and build, expensive, and used a high voltage. Soft robots however using there free form body with infinite degrees of freedom can allow for the same tuning mechanisms, while being much cheaper [5].

The many implementations of the versatile soft robots can create a well rounded team for search and rescue. Soft antennas can be deployed to open communication, and a branching navigational soft robot can map the area and find hazards and victims. When victims are found the robot would funnel through water, oxygen, food or medical supplies. While lifting hazards off them, or putting out fires. There could even to possibility of large soft robots to create a safe passageway for the survivors or medical staff to pass through. With further designing and with more sophisticated AI the soft robot could be the future for robot technology and especially search and rescue situations.

References

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