Soft Robotics

<u>f</u>luidic <u>r</u>escue <u>a</u>utonomous s<u>y</u>stem

into the f.r.a.y.

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ABSTRACT

When a disaster strikes, highly-trained response teams are immediately mobilized to conduct Search-and-Rescue (S&R) missions to locate survivors and safely extract them from high-risk areas. However, disaster zones require a lot of manpower and assistance to navigate, and the aftermath is always unpredictable and dangerous as rescue teams often have to enter without any on-the-ground intel. In order to minimize the danger posed to these S&R teams, many devices have been developed over the years to aid them in their jobs. While indeed, these traditional hard robots are thoroughly tested to perform in dangerous environments, their rigid structure prevents them from adapting effectively to their surroundings, and may in turn counterproductively put even more lives at risk. In this project, an innovative S&R soft robot has been developed with the potential to operate autonomously and replace traditional hard robots in their ability to adapt to their environment while collecting data. This soft robot comes in the form of an autonomous "walker" that is capable of locating survivors trapped under disaster debris, gathering environmental information, and transmitting it wirelessly. Initial test runs have proven the prototype highly effective in terms of balance, accessibility and environmental impact in navigating simulated "disaster" environments, which will be further discussed under the section "Testing". However, there are still areas that can be improved, such as the measure of its “stability”. Hence, we believe that further development of the prototype design may yield better environmental response, and the possible future evolution of the prototype will be explored in greater depth under "Results and Discussions".

1. INTRODUCTION AND LITERATURE REVIEW

Over the decade 2001–2010, an average of more than 700 natural and technological emergencies occurred globally every year, affecting approximately 270 million people and causing over 130 000 deaths annually. Twenty-five per cent of these emergencies, and 44 per cent of these deaths, occurred in less developed countries with limited capacities to prepare for and respond effectively to emergencies. These statistics do not include the high levels of mortality and morbidity associated with conflict-related emergencies (WHO, et al., 2013).

Here is where robots enter the S&R scene. S&R operations pose grave risk to human lives, both to victims and those sent in to save them - more than 700,000 people were killed as a result of disasters worldwide between 2005 and 2014 (UNISDR, et al., 2014). The Center for Robot-Assisted Search and Rescue (CRASAR), which has been researching and developing technology for disaster use for several years, has sent in many unmanned aerial, ground and marine vehicles to aid in SAR missions, including during Hurricane Katrina, and these machines are also now used in Italy and Germany. Human-robot teams, for both unmanned ground vehicles (UGVs) and unmanned aerial vehicles (UAVs), have shown a nine times increase in performance as opposed to human-only teams, according to the CRASAR (The Huffington Post - 11/23/2017 05:25 pm ET). However, some environments simply cannot be explored safely by humans.

Think of the core of a nuclear plant, a minefield, a collapsed building, or the surface of a faraway planet. Where humans cannot do anything in such scenarios, neither are hard-shelled metallic robots efficient for these tasks, as they cannot deal well with accidents in the terrain. Spirit, one of the two rovers sent to Mars in 2004, became stuck in 2009 and then stopped communicating (The Irish Times - Thu, Oct 2, 2014, 01:00).

This is where soft robots come in. A significant advantage of soft robots is that they are able to reduce impact on the disaster environment. An example is how hard robots may force their way through a tight spot in order to continue on their missions while a soft robot is able to simply squeeze through without colliding with the external environment, such as not to compromise the structural integrity of the wreckage.

Hence, to resolve the issue of environmental disturbance, this project aims to create a "walker" that can enter risky environments or small spaces with minimal disruption to the surroundings, using highly compliant materials, similar to those found in living organisms. This robot should be capable of searching for survivors and relaying footage back to communication operators who are then better equipped to direct search teams to locate the survivor and remove the rubble safely without endangering the life of the civilian trapped inside, or even that of the S&R teams.

2. EQUIPMENT AND MATERIALS

1 Hydraulic Pump

1 Modified Arduino Genuino Micro Circuit Board

1 USB Type A Male to USB Mini Cable

1 Polyethylene Robotic Frame

4 Jumper Cables

16 Silicone Tubes

4 Custom-designed, 3D-printed Ninjaflex Actuators

Various Polypropylene Connectors/Tapers (Including extensions, T-junctions, cross-junctions)

3. PROPOSED SOLUTION AND SOLUTION DESIGN

The intended goal of the prototype is for it to have the ability to crawl into tight spaces to gain intelligence in the form of images or a live feed of the situation under the rubble to ensure that controllers are constantly in the know of the on-the-ground situation, especially in highly inaccessible areas. The prototype is designed to be able to better assess tight or dangerous environments like structurally weakened buildings and architecture to allow operators to enter with better knowledge of their surroundings, avoiding potentially life-threatening situations. As our concern is that S&R teams (including men, dogs, et cetera...) run the risk of getting injured by falling debris, especially if they accidentally disturb the environment, causing their unstable surroundings to be even deadlier.

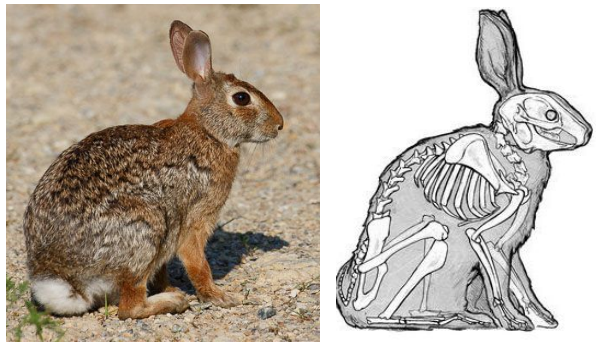

Fig. 1, 2 - Exterior and Skeletal Structure

of Cottontail rabbit (sylvilagus floridanus)

The prototype is modeled after the structure of a Cottontail rabbit in Figure 1. The movement of the prototype is characterised by the propulsion mainly being provided by the hind actuators, with the frontal actuators being coordinated to provide maximum balance, stability and control over movement, with reference to Figure 2.

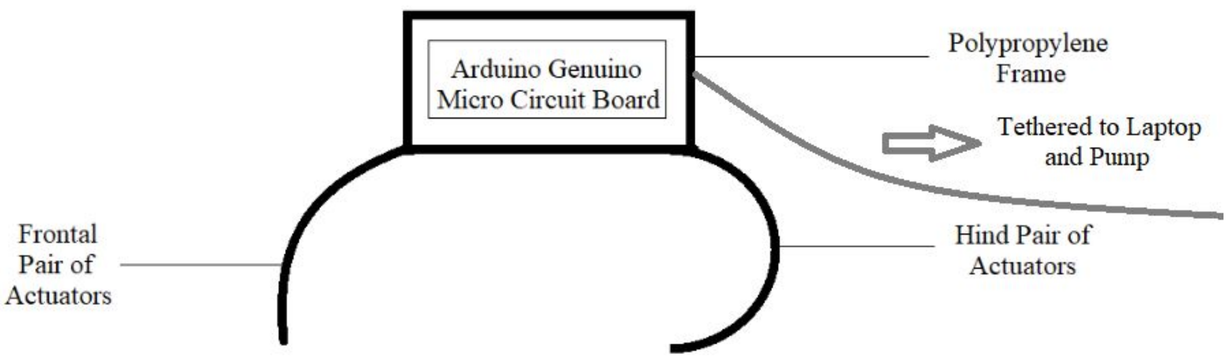

Fig. 3 - Plan of Prototype in Sagittal Plane

All coding for the prototype is done on Arduino and uploaded to the modified Arduino circuit board. The polyethylene frame of the prototype is in the shape of a rectangle to mount the Arduino circuit board upon. Considering the function of the prototype, the frame is designed to be closed-off to the outside environment in order to protect the delicate circuitry of the Arduino board. The unidirectional soft actuators are propelled by the use of a pneumatic system contained within the air capacitors of the actuators, the air pump and the silicone tubes as a closed system. The silicone tubes are connected to the custom pressure sensor that is welded onto the Arduino circuit board and provides a constant feedback of information to the connected computer that allows the prototype to move according to the commands entered on the computer. The exoskeleton has five holes to allow the four actuators to extend out of the frame and the wire to extend out from the Arduino board to the attached computer. (Take Figure 3 for reference purposes.)

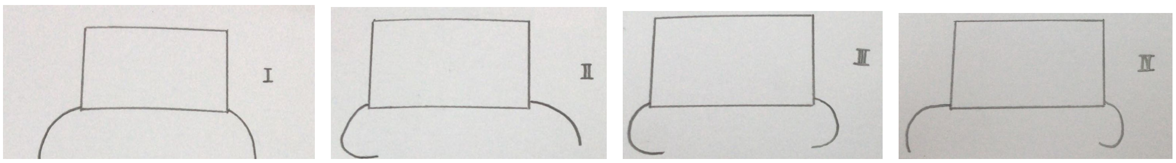

Fig. 4 - Movement of Prototype (Positions I through IV) in Sagittal Plane

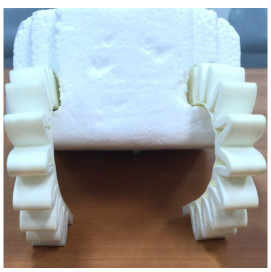

Fig. 5 - Image of Prototype in Frontal Plane

Fig. 6 - Image of Hydraulic Pump

As Figure 5 suggests, there are two pairs of actuators for the prototype, one on each side of the prototype. The prototype cycles through four main stages of motion, as detailed in Figure 4, oscillating between the frontal and hind actuators to propel itself forward. Figure 6 references the aforementioned hydraulic pump that controls the actuators, through a system of tubings.

4. TESTING

For the purpose of testing the prototype, after consultation with our research mentor at NUS and other leading experts in the field of Soft Robotics, a set of tests was devised in the form of disaster simulations and obstacle courses, in order to test the following set requirements: (a) “balance” - the ability of the prototype to remain upright on elevated ground; (b) “stability” - the ability of the prototype to navigate uneven terrain as successfully as compared to traditional hard robots; (c) “accessibility” - the ability of the prototype to squeeze through spaces or gaps that are smaller than the exoskeleton of the prototype; (d) “environmental impact” - the ability of the prototype to move through an area while causing minimal disturbance to its surroundings. Using the above tests, the degree of success of our prototype can be evaluated in order to find out whether the prototype is feasible and useable during S&R missions or not.

The test for “balance” is designed to take into account the ability of the prototype to remain upright on slopes. The incline/decline test is set by increments/decrements of 5 degrees. Success for the “balance” test is characterised by an ability to move up an incline/decline of at least 30 degrees.

The test for “stability” is designed to check the prototype’s ability to cross non-even ground. This is tested by an obstacle course, set by placing a variety of objects of increasing size in the path of the prototype moving in a straight line. Success for the “stability” test is characterised by an ability to crawl over obstacles of at least 3 cm in height.

The test for “accessibility” is designed by taking into account the ability of the robot to move through a cut-out gap on a wall. Success for the “accessibility” test is characterised by the robot being able to move through a space of which the area is a minimum of 80 % of the area of the prototype. This is calculated by the area of the gap (a) over the area of the height (h) and width (w) of the prototype as shown in the following formula: $100\ \% \times \frac{a}{h \cdot w}$.

The test for “environmental impact” is designed by testing the robot’s ability to move through an area littered with easily-disturbed “debris”. Success for the “environmental impact” test is characterised by an ability to displace not more than 20% of the “debris”.

5. RESULTS & DISCUSSIONS

According to preliminary testing, the prototype is: (a) Able to move up an incline of 30 degrees and a decline of 45 degrees; (b) Able to crawl over obstacles of up to 2 cm in height; (c) Able to crawl through gaps that are a minimum of 73.1% of the prototype exoskeleton; (d) Able to move through the obstacle course without displacing more than 18.0% of the “debris”.

The implications for the current experimental scale are as the following: the prototype is considered successful for the “balance” portion of the testing phase, the actuators of the prototype is considered not successful for the “stability” portion of the testing phase, the polyethylene frame is considered successful for the “accessibility” portion of the testing phase, the actuators of the prototype is considered successful for the “environmental impact” portion of the testing phase.

Based on gathered statistics, our prototype is mostly capable of navigating a simulated disaster zone. It is capable of scaling elevated ground and effectively navigating small spaces while causing minimal disruption to its physical surroundings. Thus, based on the properties demonstrated, our robot will be implementable and usable in realistic disaster response situations with further modifications, which will be discussed next.

In the other hand, in order to improve the prototype’s “stability”, gyroscopic function can be added to the Arduino input. The current soft actuators used can also be replaced with more advanced bidirectional soft actuators instead, allowing the prototype to more effectively “elevate” itself to move more efficiently over obstacles of different sizes.

This project notes that testing is only to a limited extent, and as all the saying goes, no plan survives first contact with the enemy. It is only until the prototype can be modified to be deployable then we can make a sure statement on its success. In the next section, the suitable applications to the prototype, and thus modifications, will discuss the feasibility of such a prototype on the ground.

6. CONCLUSION

The project had successfully fabricated an operational prototype with properties that surpass that of a traditional hard robot, capable of navigating dangerous rescue environment with minimal interference with its surroundings and flexible enough to obtain intelligence through tight spaces. It is also relatively lightweight, weighing no more than 600 g including all components (not inclusive of the pump, which was attached via a system of silicone tubings).

This is good news to the Search-and-Rescue operation as a whole, as current research in the S&R area focuses more on data-gathering to facilitate missions than the actual undertaking of such missions. First-responders, especially for earthquake and tsunami disasters, all around the world have given feedback that there is a need for adaptable remote robots that are able to enter disaster zones with minimal disturbance to the environment. This is one of the major reasons why ambitious hard-robot projects are rarely utilised in the actual S&R scene, mainly due to the reason that they are highly ineffective in actual situations, serving only to create more risk to both S&R teams and disaster victims.

However, current limitations include the current lack of a mounted surveillance device, as well as the non-adaptive Arduino algorithm and the need for physical tethering. These arise from a myriad of physical constraints, namely the lack of funding, the lack of resources and the lack of any prior technical expertise.

Should we choose to further this project, future developments may include adding a wireless surveillance device powerful enough to transmit information through layers of concrete or debris; programming the prototype with an adaptive algorithm using more advanced software, giving the prototype the ability to navigate disaster environments with a certain degree of non-control; as well as constructing the prototype out of more pliable, durable and lightweight material to facilitate motion. Communication systems could also be replaced with a wireless Bluetooth system, as the system is currently only supported by Arduino Genuino Micro, that will not only facilitate faster transfer of data, but also completely disregard the need for physical tethering, allowing for absolute mobility.

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