Toward the sense of touch in snake modular robots for search and rescue operations

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Figure 1. Typical urban scenario after an earthquake. A highly unstructured and chaotic environment with a lot of pieces of rumble. Likely, there are people inside that should be rescued immediately. City of Puerto Principe, Haiti. Photo courtesy of tumundovirutal.wordpress.com

***Abstract*—Snakes modular robots are good candidates for being used in Urban Search And Rescue (USAR) operations because of their flexibility, good adaptation to the terrain and small section. We propose to design and build snake robots that combine three capabilities: locomotion, climbing and grasping. The last one allows the robot to remove objects for clearing the path to the trapped people. The sense of touch is key to achieving these three capabilities. To implement it, our novel approach is based on the idea of touch rings and touch strips. In this paper some preliminary ideas are presented.**

I. Introduction

Unfortunately disasters caused by earthquakes, floods, tsunamis or hurricanes are very often in the news. In these scenarios the priority is to find survivals quickly, otherwise they will die. In urban disasters the environment is extremely unstructured, chaotic and full of pieces of rubble everywhere (fig. 1). This makes very difficult and dangerous for the USAR (Urban Search And Rescue) teams to move and locate people. Besides, it is clear that if a building has collapsed, there will be likely people inside that should be rescued as soon as possible.

During the last decade, researchers around the world have been facing the problem of designing tele-operated robots capable of moving in such environments and to assist the USAR teams. Properties such as versatility, adaptability and flexibility are taken into account when designing these robots.

Yim et al.[1] were the first to propose modular robots for this purpose, due to their three promises of versatility, robustness and low cost. Miller[2] suggested snakes robots (consisting of yaw modules with passive wheels) as good candidates for moving in unstructured terrains, in a similar manner than real snakes do. Wolf et al.[3] from the Department of Mechanics at CMU developed a new concept consisting of an elephant trunk-like robot mounted on a mobile base. A camera located at the end of the trunk was used for inspecting unreachable areas such as small cracks and pipes.

The Japanese government is specially interested in USAR applications. They are funding and promoting research for the development of practical search-and-rescue robots. Prof. Hirose and their colleagues at the Tokyo Institute of Technology have been working on these robots for many years [4]. They have developed robots with tracks and wheels, such as Souryu, Genbu, Kohga, Gunryu and the latest Helios VIII[5]. They have also proposed the snake robots as candidates for USAR applications because of their advanced motion capabilities: their bodies can act as “legs”, “arms” or “fingers” depending on the situation. Since mid 70’s they have been working on the ACM snake-like robot family[6]. The ACM-R3 and R4 have passive wheels larger than the profile of the link that fully cover the whole body. This enables the snake to slide smoothly among the rubble.

In the Institute of Robotics at Beihang University, Zhang et al. have developed the JL-I robot[7]. It is composed of three identical autonomous modules with 3 DOF joints. It can climb obstacles, stairs and recover itself in case of turning over.

One of the latest USAR robots is Amoeba-I[8] developed at the Shenyang Institute of Automation in China. It is composed of three tracked modules and has nine locomotion configurations. It can change its configuration automatically to adapt to the environment.

Modular robots with a 1D topology can be divided into two groups: serpentine and snake robots. The former use active tracks or wheels for self-propulsion while the latter use body motions in a similar manner than their biological counterparts. A very successful serpentine robot is Omnithread developed by Granosik, Hansen and Borenstein at the Mobile Robotics Laboratory in the University of Michigan. It is a novel design

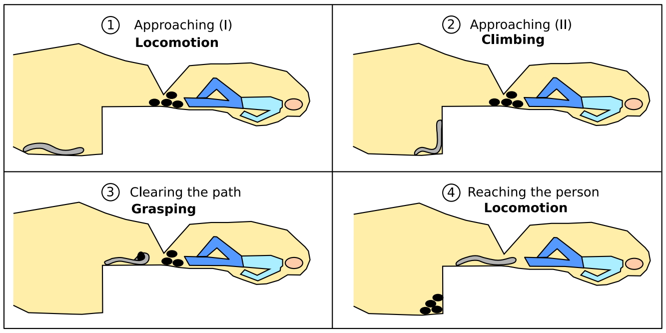

Figure 2. A general scenario where there is a trapped person and the access is blocked by pieces of rumble.

consisting of 5 segments with moving tracks on all their four sides to assure propulsion even when the vehicle rolls over. The latest prototype is OT-4[9]. Rimassa et al. [10] have developed a serpentine robot with climbing abilities.

Even though serpentine robots are very promising for USAR applications, they lack the flexibility of real snakes and it is difficult to attach to them artificial skins because of their wheels or tracks. Snake robots, on the contrary, are similar to real snakes and inherit some of their properties. Perambulator[11], developed by Ye et al. at the Shenyang Institute of Automation in China, is able to perform a powerful propulsion and a high mobility. Every segment contains a kind of omni-directional wheel with free rollers that enables this robot to perform the serpentine locomotion (like real snakes).

Another modular robot with high locomotion capabilities is Hypercube[12], developed in our group. It can perform at least 5 different gaits: moving in a straight line (forward and backward), moving in a circular path, side-winding, rotating and rolling.

Our goal is to develop a new snake modular robot for search and rescue applications. In this paper we propose a preliminary novel design of its tactile system that will be used for improving the robot locomotion as well as its climbing and graping capabilities.

II. Snake modular robots for search and rescue operations

Modular snake robots have a lot of potential for search and rescue operations. Consider the scenario shown in figure 1 where there is a collapsed building (image of Puerto Principe, in Haiti). A USAR robot would be very helpful to explore inside the house and searching for people. The are two possible alternatives. On one hand, the robot can go through the bars of the window if its size is small enough. On the other hand, it can climb the wall and enter through the upper hole, but the robot should be flexible and have climbing capabilities. Snake robots could meet these requirements.

Now let's consider a general scenario as the one shown in figure 2 where there is a person trapped inside a house. First (fig. 2-1) the snake robot approaches the zone. Obviously, locomotion capabilities are needed. Second (fig. 2-2), the snake arrives to a wall and has to climb it. Therefore, climbing capabilities are necessary. Third (fig. 2-3), there are some pieces of rubble blocking the access to the person. The snake clears the path by grasping the objects and getting rid of them. Grasping capabilities are required. Finally (fig. 2-4), the robot reaches the person.

This scenario suggests that the robot should have at least locomotion, climbing and grasping capabilities. In previous work, our group has researched on these three areas. The locomotion of snake modular robots of any length has been widely studied and implemented on real robots[13] using sinusoidal oscillators that can be programmed with low cost 8-bit micro-controllers. A novel inspired modular climbing caterpillar that combines climbing techniques with locomotion capabilities was designed and tested in [14]. For climbing, a low-frequency vibrating passive attachment principle was successfully developed. Moreover, grasping capabilities are being studied and simulated[15].

The sense of touch is key to achieve these three capabilities. For locomotion, touch sensors provide the necessary feedback for enabling the robot to adapt its body to the terrain and therefore moving more efficiently. In addition, situations in which the robot get caught on the ground can be detected. For climbing, the attaching forces can be measured to guarantee that the robot will not fall down. Finally, the sense of touch in grasping allows the robot to apply the necessary force to remove objects from the path as well as optionally detecting the shape of these objects.

III. Sense of touch

A. Introduction

Perceiving the environment in animals needs multimodal sensing capabilities. Humans combine sensory information from different sources as touch, vision, and hearing. If not using any of them, there is a gap in knowledge that makes differences between what is sensed and what is perceived[16]. Simple experiments of exploring objects after putting hands on an ice block for a while, therefore anesthetizing the skin, shows the difficulty of achieving stable grasp[17]. This occurs even when participants can see what they were doing.

There are several technologies and transduction principles that have been traditionally employed for the development of tactile sensing for robots, such as resistive, force, magnetic, optical, piezoelectric and capacitive based sensors[18]. Among them, capacitive sensors are commonly used in robotics applications. Despite their two major drawbacks, stray capacity and severe hysteresis, they are very small and sensitive. In addition they can be easily arranged in dense arrays. As an example of their high degree of integration, Gray et al. developed in 1996 an 8x8 capacitive tactile sensing array with 1 mm^2 area and spatial resolution at least 10 times better than the human limit of 1 mm. Schmidt et at. [19] designed a novel array of capacitive sensors for grasping purposes, which couple to the object by means of little brushes of fiber. Maggliali et at.[20] proposed the novel idea of using a mesh of triangles for covering three-dimensional surfaces. They have designed a triangle module witch contains 16 capacitive sensors and all the electronics.

Currently, it can be found commercially capacitive based touch array sensors such as the ones provided by 'RoboTouch'

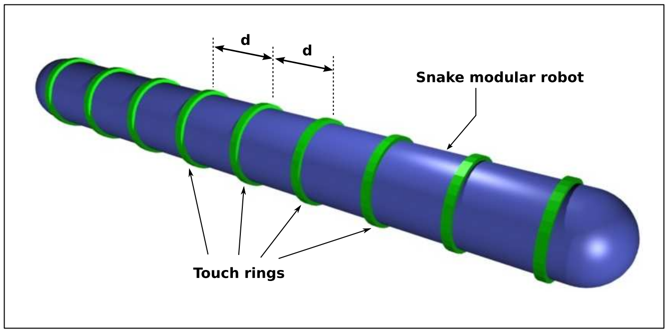

Figure 3. The touch rings approach for the implementation of the sense of touch in snake robots

and 'DigiTacts' [1]. Also, there exists various commercial 'capacitance to digital converter' chips such as the AD7147 'Captouch' chip from Analog Devices. It have been successfully employed for the triangle module implementation[20].

B. Touch rings

Real snakes have a continuous skin, like the mammals, in which the sense of touch is distributed uniformly throughout the whole body. Designing an artificial skin similar to that of the snakes, with the same flexibility and equipped with touch sensors, is a big challenge. It still has not been realized, to the best of our knowledge. In our approach, we propose the idea of touch rings (figure 3) located at fixed positions along the body axis. Therefore, the sense of touch is not continuous and uniformly distributed but discrete and concentrated in touch zones. Although it is not continuous, the distance between two consecutive rings (d) can be set according to the application. If higher touch resolution is required, this distance can be reduced. Thus, this approach is very versatile giving the designer the possibility of changing it.

In our opinion, USAR operations do not require a very high resolution. It should be high enough to allow the robot to perform the locomotion, climbing and grasping efficiently. As a starting point we are planning to use one touch ring per module.

C. Touch strips

Each touch ring consist of a flexible capacitive strip that is bended (figure 4). One advantage of this design is that it can be fitted into different snakes with different sections of the body trunk, due to the fact that the strip is flexible. In the example of figure 3 the section is circular, but it can also be applied to snakes with other section shape, like a square. The strip will fit regardless of the shape of the body section.

Therefore, our design is very versatile and it is valid for a lot of different snakes. Moreover, the width and length of the strip can also be changed according the application. The wider it is, the more capacitive sensors can be embedded.

[1]http://www.pressureprofile.com

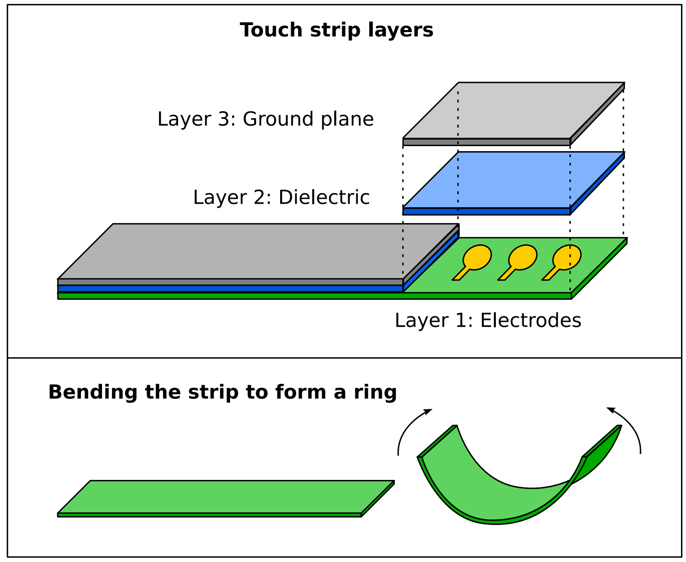

Figure 4. The capacitive touch strips used for implementing the touch rings

D. Capacitive sensor principle

The touch strips are based on capacitive sensors. The strip is composed of three layers (figure 4). The total thickness is expected to be less than 1mm. The first layer is a flexible printed circuit board (PCB) containing the electrodes for the capacitors. The second layer is the dielectric. This material should be compressible and expandable. We are testing different candidates, such as silicone (S60) and polyester (PEPT) based ones. The third layer is the ground plane.

When normal forces are applied to the strip surface, the dielectric layer is compressed and the distance between the electrodes and the ground plates is reduced. Therefore there is a change in the capacitance of the capacitors that can be measured. The material in the second layer must recover its initial thickness when no forces are applied.

E. Electronics

Various commercial capacitive-to-digital converters chips are available. In this work, we are using the MPR121 from Freescale[2] because of its low cost and I^2C bus compatibility. Its main features are summed up in table I. It can measure capacitance ranging from 10 pF to 2000 pF. Minimum size of the electrodes should be less than 0.25 cm, if high dielectric materials are used. Once capacitance is calculated, it runs through a couple of levels of digital filtering allowing for good noise immunity in different environments without sacrificing response time or power consumption.

Some of the major advantages comparing with the AD7147 chip include an increased electrode count, a hardware configurable I2C address, an expanded filtering system, and completely independent electrodes with auto-configuration built in. Regardless every chip can read only 12 capacitive sensors, bigger arrays can be made by connecting different MPR121 chips through I^2C bus. When bandwidth is not enough for

[2]http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MPR121

Table I
FEATURES OF THE MPR121 CHIP

Feature	Value
Number of electrodes	12 electrodes
Measurement range	10 pF to 2000 pF
Sensitivity range	-0.01953 to -0.19531 pF / ADC count
I2c bandwidth	400 Khz
Size	3x3x0.6 mm^3

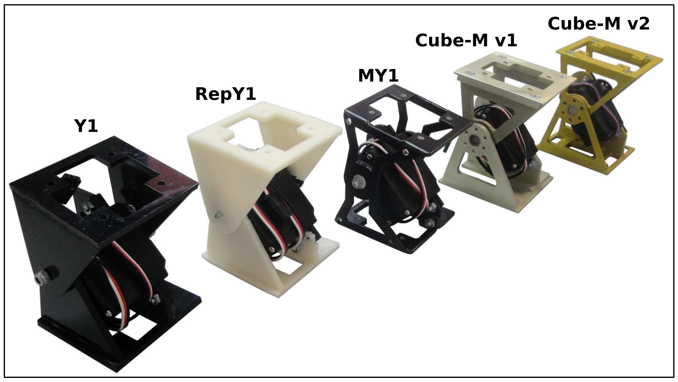

Figure 5. The Y1 and Cube-M families of modules

Figure 6. Some of the modular robot prototypes. a) Dr. Zhang and Dr. Gonzalez-Gomez sitting by their modular robots b) Hypercube snake, composed of 8 pitch-yaw Y1 modules. c) Cube Revolutions: a caterpillar with 8 pitch Y1 modules. d) A 2D topology star robot. e) A 5 pitch-yaw Cube-M module snake. f) A four MY-1 module pitch caterpillar going through a tube.

transmitting all chip readings, digital multiplexers for communications or other microcontrollers should be used.

IV. MECHANICS

A. Modules

Since 2004 our groups have been working on modular robots. We have designed different modules, grouped into two families: Y1 and Cube-M (figure 5). The Y1 family is very cheap and very easy to build. It is intended for fast-prototyping, testings and educational purposes. The modules have one DOF actuated by a low-end RC servo (futaba 3003). The electronics (not shown in the figure) includes an 8-bit PIC16F876A microcontroller. This family is composed of three modules: Y1, RepY1 and MY1. The Y1 consist of 6 laser-cut pieces of plastic glued together. It is mainly intended for educational purposes as it is very cheap and easy to build by students. RepY1 modules are the "printable" version that can be manufactured using a commercial 3D printer or a low-cost open Reprap machine[3]. The MY1 version is made of aluminum. It has three pieces that are joined together using screws and nuts.

The Cube-M family[21] is an improvement over Y1. These modules are made of aluminum and are designed to carry more weight and to build bigger modular robots with 1D and 2D topologies. The electronics has been improved and embedded into the modules.

B. Robot prototypes

Some of the modular robots we have built are shown in figure 6. We have mainly concentrated on studying the locomotion of modular robots with 1D topology. This group can be divided into two subgroups: pitch-pitch and pitch-yaw connecting modular robots. The former is composed of those robots in which all the modules pitch up and down (fig. 6c and 6f). This configuration is kinematically similar to that of the caterpillars in nature. Therefore, these robots are very useful for studying the climbing capabilities, even though they only can move forward and backward. The later comprises the robots with pitch and yaw modules. These snakes can move on a plane (fig. 6b and 6e). When sinusoidal oscillators are used for their control, they can perform at least five different locomotion gaits[13]: moving in a straight line, circular path, side-winding, rotating and rolling. The relationships between the oscillator's parameters (amplitudes and phase differences) determine the type of movement that will be executed.

Modular robots with a 2D topology have also been developed (fig6d) but their use for search and rescue operations is left for future work.

[3]http://reprap.org/wiki/Main_Page

C. Touch strip prototype

The first prototype of touch strip is being made and designed, but a preliminary proof of concept has been built. It it is shown in figure 7a. It consist of one layer with 12 electrodes in a flexible PCB, which has been taken from a commercial flexible keyboard. The strip containing the 12 electrodes has been cut and three wires have been soldered for performing preliminary tests. The total strip length is 208mm.

In figure 7b the strip is placed around one MY1 module, which has a square section. As the strip is flexible, it can be fitted to any shape. There are three electrodes per side, but only the three at the bottom are currently being tested. The proof of concept is being done with the pitch-pitch minimum configuration robot consisting of two MY1 modules. This is the minimum modular robot with locomotion capabilities[13].

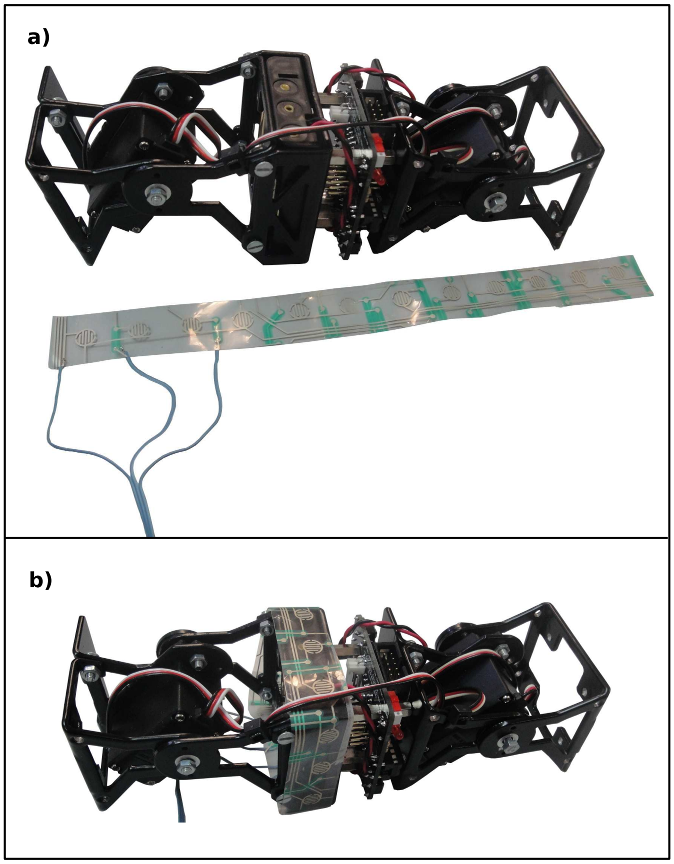

Figure 7. Preliminary touch strip prototype. Only one layer is being tested. a) The touch strip with 12 electrodes along with the pitch-pitch minimum configuration robot. Only three electrodes are connected. b) The touch strip is placed around one module to form a square "touch ring"

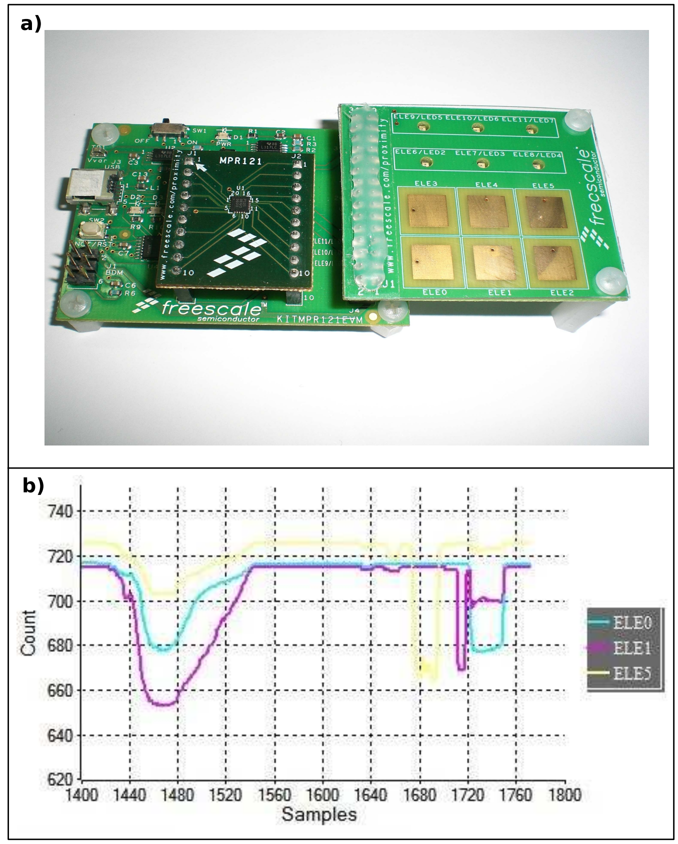

Figure 8. Testing the touch strip with the Freescale Sensor Toolbox MPR121 Evaluation Kit. a) The kit is connected to the standard electrodes supplied by the manufacturer. b) Screenshot of the measures taken from the three electrodes of the touch strip, using the software provided by Freescale

V. Experiments

A. Touch strip experiments

First, we have tested and measured standard capacitive sensors provided by the Freescale Sensor Toolbox MPR121 Evaluation Kit shown in figure 8a. Then we have replaced them by our touch strip prototype to test the viability of our idea. Even if these preliminary electrodes are not meant for being used as capacitive sensors, because the come from a flexible commercial keyboard, they are working good enough and the MPR121 chip is able to perform measurements. The pressure exerted with the fingers is detected, as shown in fig. 8b. As can be seen, the idea is working. These results are very promising and let us continue to the next step: building another touch strip prototype that includes the three layers and the 12 electrodes.

B. Modular Grasping simulation

Some preliminary grasping experiments have been performed in simulation. The OpenRave simulator[22] has been used along with our OpenMR[4] plugin for modular robots. The testing program obtain the contact points between the snake and the cylinder, as well as the applied forces. In figure 9a a

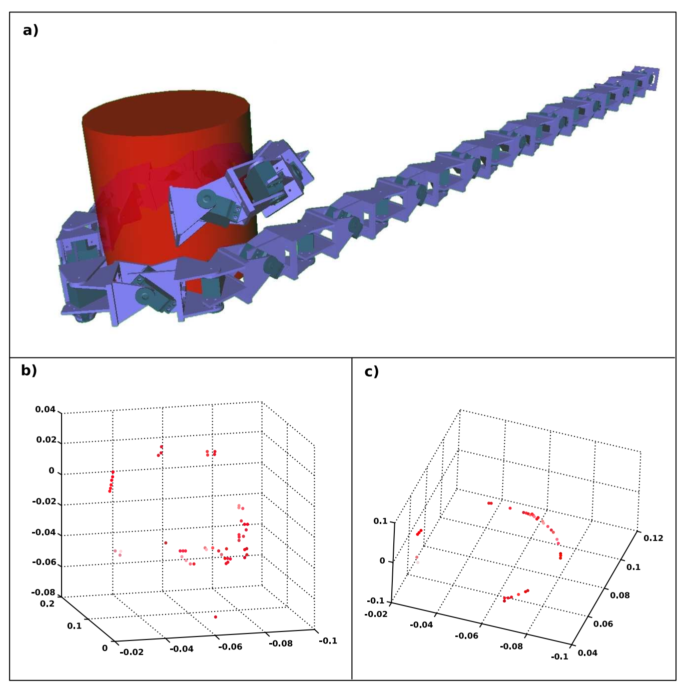

Figure 9. Simulation of a 30 module snake robot grasping a cylinder. a) Simulation in OpenRave. b) The contact point cloud obtained from the simulation. c) The contact point cloud view from another angle, so that the cylinder contour can be seen

[4]OpenRave Modular Robots plugin: http://bit.ly/9a3fXk

30 module snake robot grasping the cylinder can be seen. The contact point cloud is shown in fig. 9b. When the orientation of these points is aligned with the observer, the cylinder contour can be glimpsed.

VI. Conclusions

We have presented a novel idea for implementing the sense of touch in snake modular robots. It is based on touch strips placed around the snake section, forming touch rings with embedded capacitive sensors. Even if this work is in a very preliminary stage of development, the experiments carried out confirm the viability of this design. In addition, experiments on modular grasping have been simulated for obtaining the contact point and forces applied when a snake robot grasp an object.

Currently we are working in combining the locomotion, climbing and grasping capabilities with the sense of touch for the realization of a modular snake robot for urban search and rescue operations.

VII. Acknowledgments

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