Survey For Soft Grippers and Manipulators*

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***Abstract*— This Survey is written for the Soft Robotics Class for Spring 2018. In this survey, I have done extensive research about the different Soft manipulators and Soft Grippers available right now. In this survey, I will talk about motivation behind using Soft Robots, the different types of actuators and techniques used to make soft robots and compare the soft robots with the conventional rigid robots.**

I. INTRODUCTION

Rigid conventional robots have limited abilities when it comes to elastically deform or to adopt their shape to the external environment and obstacles.As we know that these rigid robots have the potential to be incredibly powerful and precise, but they are highly specialized i.e. they don't display multi-functionality.As the field of robotics is advancing beyond manufacturing and industrial automation into the domain of health care,search and rescue, and most importantly service robots, the robots have to be less rigid so that we can achieve a safe functionality between the robots and human.

So as to achieve this safe harmony we have to tend towards robots made from soft materials. In contrast to rigid robots, soft robots have bodies made out of intrinsically soft and extensible materials that can easily deform and absorb much of the energy arising from a collision.Soft robots are highly adaptive to their surrounding environment and objects, so they can easily perform complex tasks with any extensive planning or controls.Furthermore, to achieve inherent compliance and adaptability, the soft robots could be combined with the conventional robotic designs.

Over the time, researchers have always taken inspiration from nature to design or build complex machines.Robotics has always been inspired from nature, like tongues, trunks and tentacles demonstrate an amazing variety of abilities by which the animals can dexterously perform manipulation and interact with their environment. For instance we can take inspiration from giraffe's tongue, which wraps around high tree branches to strip off leaves while avoiding thorns.Elephants show a wide range of strength from their trunks, as they can lift a heavy tree and also a tiny straw from their trunk. Squids have ten arms, two of which are tentacles with they use to catch their prey.Octopus has been the star for inspiration, as it has no rigid structure but it shows tremendous dexterousness.Also, human have always been they center as a source of biological inspiration for the design and application of robots.

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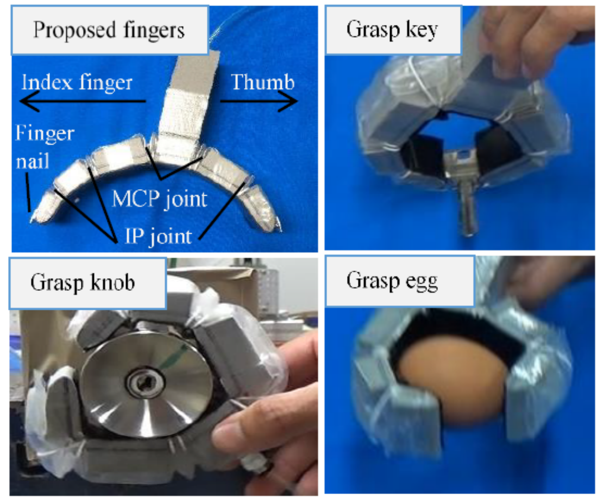

Fig. 1. Under-actuated Pneumatic Fingers

This survey report is organized as follow: Wide range of soft grippers are presented in section II, Section III is about soft manipulators , and the Section IV is about comparison between soft and rigid robots .

II. SOFT GRIPPERS

A. *Lightweight Under-actuated Pneumatic Fingers* [1]

In this paper, Dameitry et al. have proposed a new structure of finger actuator to perform grasping to hold various objects. The proposed fingers are inspired on the underactuated structured formed by an index finger and thumb. The proposed fingers are shown in Fig. 1. They have based their fingers on human finger and simplified their design with only thumb, index finger and a small portion of the palm. They have also added finger nail to the fingers for fingertip grasping. Here, the joints are made by flat tube pleated into zigzag structure covered by polyurethane foam and are connected together to all joints on one chamber of tube to produce one degree of freedom flexion motion for grasping.

For designing the zigzag structure of the tube, they have selected parameters like Uniformly Distributed Grasping Force, Joint Angle-Torque Formulation and Parameter Selection for the Finger.

From experimental results, they found that the torque distribution follows the uniformly distributed force, even though the force distribution is not exactly uniform. They also found that the torque increases as the size of grasped

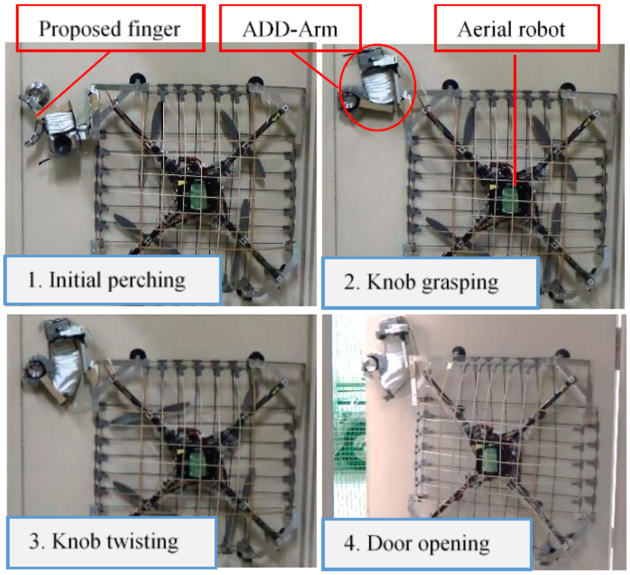

Fig. 2. Aerial Manipulator performing door opening mission

Fig. 3. Proposed Soft Gripper with Dual chambers

object increases and vice-versa. They have also compared their fingers with Rigid fingers which they had developed earlier and found the fingertip force pretty much same .Their fingers generated 11.07 N force and the rigid fingers had 15 N force.

They have made this fingers, so that they can attached them to the aerial manipulator as shown in Fig.2. They want to open the door knob using aerial manipulator, for that first they made a rigid finger type design but this design tends to make the total weight of the finger heavy so the force to weight ratio is low, so to overcome this limitation they have designed the soft fingers to open the door knob and they were successful in it.

B. *Soft-Robotic Gripper With Enhanced Object Adaptation and Grasping Reliability* [2]

In this paper, Zhou et al. have proposed a novel tri-fingered gripper (Fig. 3)comprising of three dual-chambered ellipse-profile soft pneumatic fingers and a novel palm design with a compliant chamber which is capable of holding 4 kg payload at an input pressure of 100 kPa.In the proposed design, they have made the fingers with soft bending actuator which comprises of two axially-aligned sections, where each section can be actuated independently, as shown in Fig.4,enables two modes of the finger as follows:

- If the the two chambers are pressurized with same pressure, the finger will behave similar as the single-chamber actuators.
- If the two sections are actuated independently, the actuator could reach larger area than the above mode, allowing the gripper to grasp complex-shaped objects.

The palm plays an important role in grasping, so they have proposed a design which consists of a passive air chamber with a soft material passive compliance surface supported by pillars, which are aligned in a hexagon pattern. The palm offers three modes as follows:

- Unsupported surface: lowest stiffness so easy to deform.
- Supporting surface: medium stiffness which is still deformable.
- Hard bottom surface: highest stiffness so non-deformable.

They have design the contact surface of the finger by taking into consideration the following things:

- Reducing input pressure.
- Improving the contact.
- Compensating the convex finger surface.

For the soft gripper, to achieve reliable grasping from the compliant nature of the proposed soft fingers, a tri-finger-single-palm setup in reference to the thumb,index and the middle finger. Here, the grasping volume of the gripper can be changed by changing the finger mounting angle.

For testing the proposed gripper, they have done five experiments for validating their hypothesis and they were successful in all of them, so the gripper is pretty solid according to their results and can be used for grasping most of the ADL (Activities of Daily living) objects easily. The five parameters they tested are as follows:

- Single Finger Motion in Free-Space.
- Finger Compliance and Force Test.
- Palm Feature and Palm Passive Adaptation Test.
- Gripper Grasping Force Test.
- Grasping Performance.

The proposed soft gripper can achieve 40 N grasping force in practice,at a very low actuation pressure below 100 kPa.

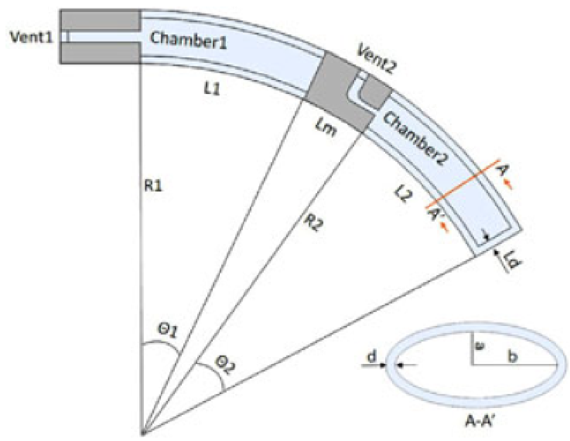

Fig. 4. Finger design with dual cambers

C. *Haptic Identification of Objects using a Modular Soft Robotic Gripper [3]*

In this paper, Homberg et al. have presented a new soft robotic gripper with proprioception by embedding a flex sensor inside the finger to get the curvature of a finger around a certain axis. They have made their gripper modular, it can be attached on top of an existing rigid finger as shown in Fig 5. Also, they have created an algorithm for the Haptic identification of objects.Their soft hand's compliance was able to pick up objects which the rigid hand was not able to pick up without extensive manipulation.

For design the Robotic hand they had the followings goals in mind:

- Ability to grasp a range of objects
- Ease of fabrication
- Modular interface to existing hardware

They were able to achieve all the proposed design goals, as they have shown that they are able grasp around 70 ADL objects, they have based the finger on Pneu-Nets and 3D printed parts which can be easily fabricated and also they have used this parts to screw on the soft hand to the existing rigid hand of Baxter. While fabricating the fingers, they had embedded a resistive flex sensor on the top of the finger's inextensible layer to get the bending of the fingers.

Apart from their goal of grasping objects, their goal is to identify the object on the base of internal sensing.As their hand interacts with the environment and grasps objects, it attains different configurations, so they record the data, but their sensor readings are noisy, so they represent the sensor readings as probability distribution. For object identification, when their hand grasps an object, it attains a certain configuration, so they use the sensor readings to predict the object.Here, they have considered two types of grasping,1) Enveloping grasps and 2) Pinch grasps.Here, in their experiments they have used K-means clustering to find the models of the probability distribution for different objects and grasps.

Fig. 5. Soft robotic hand, mounted to the wrist of a Baxter robot

In this paper, they did two experiments with the hand.First experiment characterized the resistive sensor of each finger, so through the change in resistor they were able to get the curvature of the each finger.Second experiment they performed grasping tests to cluster and identify the objects based on the sensor readings.In the paper, they have also given comparison between the rigid and soft hand.

D. *A Novel, Variable Stiffness Robotic Gripper Based on Integrated Soft Actuating and Particle Jamming[4]*

In this paper, Wei et al. have presented a soft robotic gripper with a variable stiffness for adaptive grasping and robust holding.The finger designed for the gripper combines a fiber-reinforced soft actuator and a particle pack.The proposed gripper is capable of handling objects with different shapes, weights and rigidities.

The finger design is based the Pneu-Net actuators and they have embedded a particle pack in the finger.Most robotics grippers tend to function well to a specific set of objects with relatively regular shapes but there's always a problem when it comes to irregular shapes.The paper is based upon solving this problem,the soft grippers though have compliance but they are not able to adapt to small features, so to solve this problem they have embedded a particle pack with the finger as shown in Fig 7. So the passive adaption driven by active actuation leads to closer contact between the fingers and the objects this provides fundamental advantages for stable and reliable grasping.

In the paper, they have done various experiments for finding the capabilities of the robotic gripper. They have done experiments for stiffness,compliance and Grasping for two

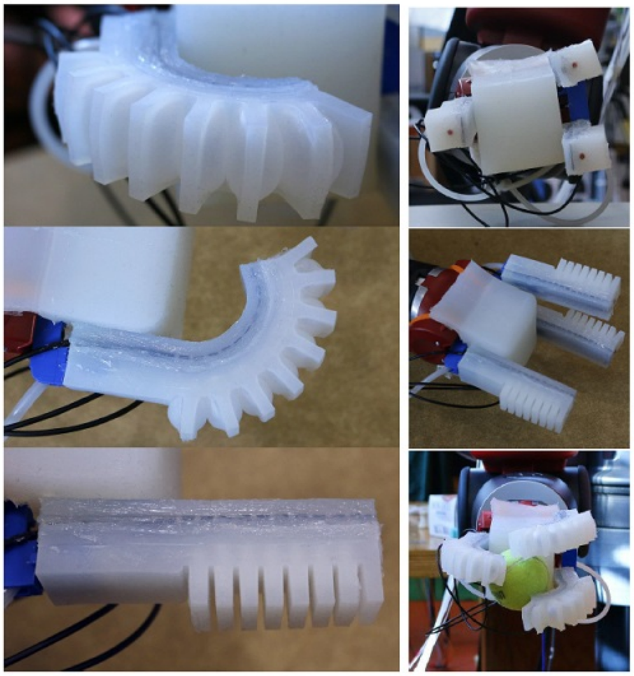

Fig. 6. Views of an individual finger and the entire hand with a view of the inside of the finger

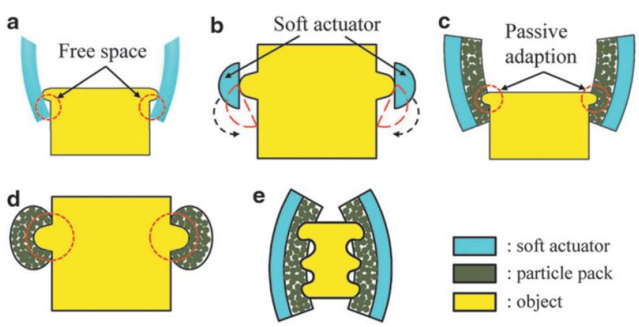

Fig. 7. Compliance and passive adaption

modes of the gripper i.e. one with the vacuum pressure for particle pack and one without it.They have also done a good experiment to show the importance of the variable stiffness of the finger.As shown in Fig 8, they grasp a bottle of water which has a weight of 748 g, which is a heavy load for a soft robot, The first example shows a grasping attempt without particle jamming, the results show that it was able to manipulate the bottle flexibly and can move it in a short distance, but not to large distance as water slides through the gripper. On the Contrary, when the same grasp is done with particle jamming, it can still manipulate the bottle flexibly and can also move it to large distance without the bottle slipping from the gripper.

The proposed gripper is based on the integration of two soft grasping principles, but it also has it own problems that may adversely affect its performance.1)In natural state, the particles can be jammed passively when the finger is being bent due to reduction of particle chamber. Consequently, the

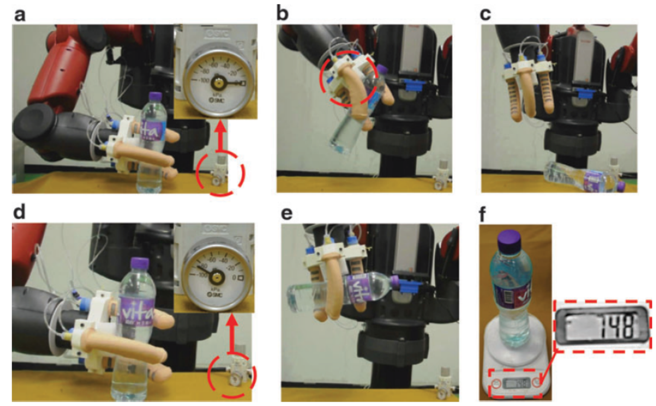

Fig. 8. Demonstration of grasping

bending range of a finger is affected. (2) The choice of an appropriate particle size is a challenge. A large size will greatly decrease the required particle quantity and weaken the compliance to object shape.

*E. **Soft Robotic Grippers for Biological Sampling on Deep Reefs**[5]*

In this paper, Galloway et al. have presented the development of an underwater gripper using soft actuators to delicately manipulate and sample fragile species on the deep reef.In this paper, they have demonstrated design principles for soft robot end effectors and talked about grasping performance and have also presented in situ testing at mesophotic depths. This work is the first use of soft robotics in the deep sea for the nondestructive sampling of benthic fauna.

In this paper, they have proposed a robotic gripper which can be attached to the Given ROV and manipulator platform as shown in Fig 9. So their design was based on two things: integration and operation, so for integration part their gripper should connect to the existing arm and use the ROV's hydraulic system for the actuation of gripper, and for the operation part, it has to be versatile by supporting the quick soft actuator installation, adjustment and removal and lastly the actuators should survive at high pressure at mesophotic depths under sea (i.e. greater than 300 m). So the soft gripper had to be designed for rapid and inexpensive customization. In the paper, they have explained how they did the customization for the soft gripper in the current design. For the actuation of the gripper, they needed the ability to distribute forces over a large area, conform to irregular shapes and the ability to change the surface texture, so they have used two types of soft actuators: 1) Boa-type fiber reinforced soft actuator and 2) Bellows-type soft actuator.The Boa-type actuator can wrap around an object to increase the surface area contact and distribute forces and it can wrap around objects as small as 12 mm in diameter.And the Bellow-type actuator is the one which creates asymmetric motion by unfolding the excess material in the bellows.

So for testing the grippers, they did a pilot study as shown in Fig 10, using the Bellows type actuator they

Fig. 9. Concept figure for Seaeye ROV with soft manipulator

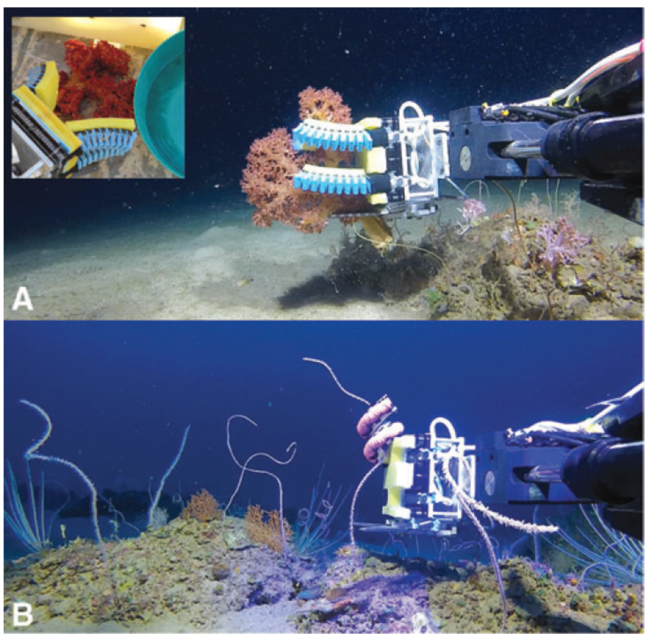

Fig. 10. Bellows-type and Boa-type actuators collecting soft coral under the sea

retrieved a red soft coral and the boa-type gripper was successful in wrapping around long and narrow coral whips.So they were successful in proving their concept of using soft grippers to retrieve coral reefs from under the sea.

III. Soft manipulators

A. *An Octopus-bioinspired solution to movement and manipulation for soft robots* [6]

In this paper, Dario et al. have designed and built an ad hoc robot, taking octopus as a reference, the robot has a silicone arm with cables embedded to replicate the functionality of the arm muscles of the octopus. This arm is capable of pushing-based locomotion and object grasping

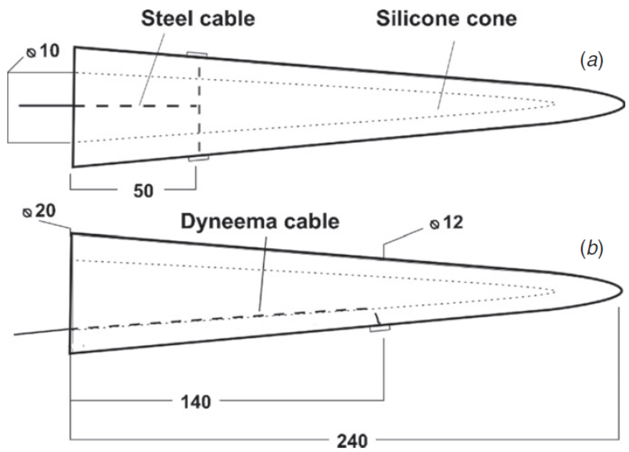

Fig. 11. Internal structure of the silicone limb

and it mimics the movements that octopus adopts while crawling.The purpose of this paper is to take inspirations from nature and find a suitable way to build a more complex soft robot that can perform diverse tasks with minimum control.This paper gives two aspects i.e. locomotion and manipulation, so I have focused more on the manipulation part of the paper.

Based on the biological observation of the octopus arm movements,they have built a bioinspired limb, which can elongate and shorten its proximal part to replicate arms motions like the octopus and the limb can bend to mimic the octopus' manipulation capability.So for mimicking the movements, the actuation system is made up of a steel cable that elongates and shortens the arm and one Dyneema fibre cable that bends the arm as shown in Fig 11.So the Dyneema cable mimics the function of the longitudinal muscles of the octopus , so they use this cable to attached on the tip of the arm can bend the arm to grasp an object.For controlling the cables they have made a platform that lodges two servomotors that actuates the two cables.

As shown in Fig 12, the whole arm is involved in the grasping activity, so when the Dyneema cables is coiled the arm bends with an incremental curvature from proximal to distal part. They have tested the grasping capability of the arm by grasping a pencil and six screws with incremental diameter and weight.The arm's grasps does not have high accuracy but it flexible so it can hold the object. So from the results, the arm was able to wrap around and hold objects with diameter from 4.9 mm to 7.7 mm and it was able to hold objects with diameter from 4.9 mm to 11.7 mm.

B. *Active Hose* [7]

In this paper Tsukagoshi et al. have presented a design concept and the driving mechanism of a flexible robot which can dive into debris and can be used in rescue operation. For this they took inspiration from the truck of an elephant which can bend into multiple degrees of freedom. So they have made a new type of robot"Active Hose (Fig 13)", which has multiple degrees of freedom by connecting ubenits of two

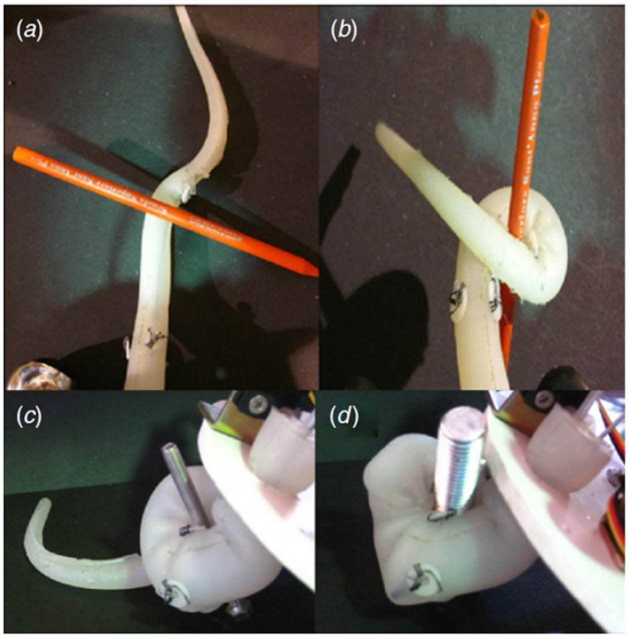

Fig. 12. Grasping Examples from the paper

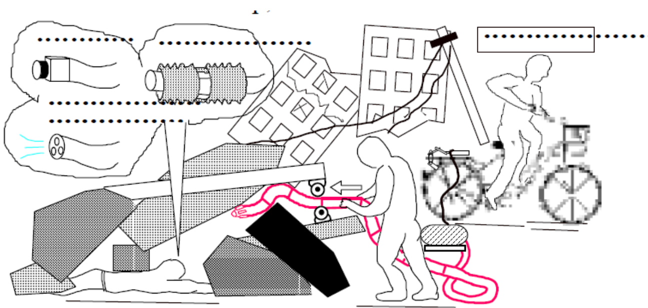

Fig. 13. Rescue operation by using the Artificial Elephant nose

degrees of freedom in series and can achieve high bending moment.

Their design is based on the biology of elephant's nose because of the followings functionalities, 1) is has multiple degrees of freedom with flexibility, 2)it can curve and grasp the object with small curvature 3) it can carry fluid just like a hose. So to achieve this can flexibility they had to consider a couple of things, as mentioned in above that active hose is made up of small units connected in series which gives two rotational degrees of freedom around its pitch and yaw, so it necessary for a single unit to possess some structure to reinforce the bending moment, so for that they have installed a spinal structure to the center of the unit to provide that strength.

For the actuation of the unit they have proposed a new actuator called Wound Tube actuator, it is a spiral tube surrounding the unit like a coil and its cross section forms a flat ellipse, when its inside is pressurized the tube pushes each other to its radius direction as its cross section changes gradually to a circle.Also, it possess the following advantages

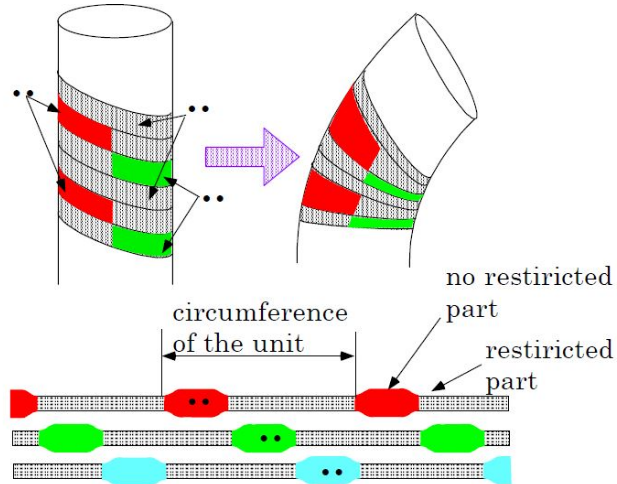

Fig. 14. Driving Method of an unit by using three WT actuators

1) It can stretch the object easily after winding around it,2)It takes the advantage of the force to the radius direction, so a tube of high resistance to pressure can be used and 3) it acts as a virtual spring, as the contact area to the next tube decreases in proportion to displacement, as the pressure remains constant.

As shown in Fig 14. each Wound tube is made up of a restricted part and non-restricted part as a cycle of circumference of the unit. The restricted part occupies 2/3 length and the rest of the circumference is covered by the non-restricted part. Three Wound tubes can make the single unit bend in arbitrary direction, When one Wound tube is pressurized, it swells 120 degrees, so simultaneously pressurizing the tubes we can get arbitrary bending of the unit.

C. Robotic Tentacles with Three-Dimensional Mobility Based on Flexible Elastomers[8]

The pneumatic based actuators when actuated by the expansion of the elastomeric networks, have a disadvantage as they have been limited to a single bending direction, in this work by Whitesides et al. they have proposed a design to improve the motion capabilities and fabricate a soft robotic actuator with three-dimensional motion and which are low in cost and can be control easily.

So for achieving this three dimensional motion they have made a silicone tentacle as shown in Fig 15, it has three individual channels, when pressurized, the pneumatic channels expand in the regions that are most compliant, so at the beginning of the actuation the bending concentrates at the free end of the tentacle, as the force to initiate the deformation is less than in the center. Once the end of the tentacle reaches the snap-through instability, the deformation at the end of the channel saturates and the center of bending motion then propagetes towards to root of the tentacle, bending the tentacle in a circular pattern. So have more complex bending and more range of motion, they have added

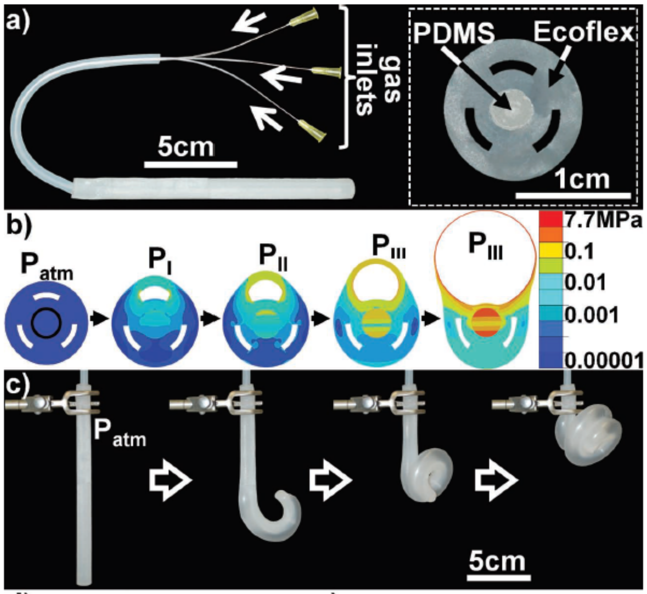

Fig. 15. Movement of tentacle with internal structures

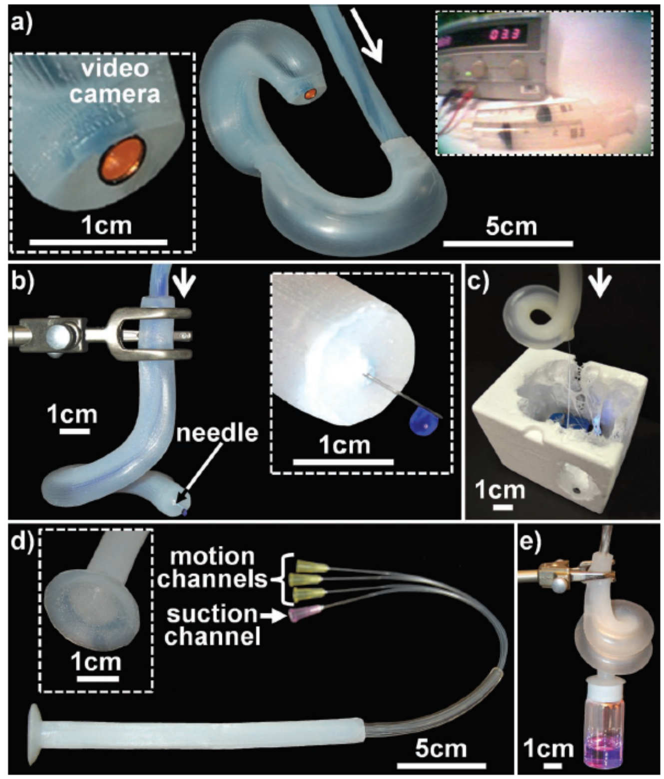

Fig. 16. Tentacles with Embedded Functionality

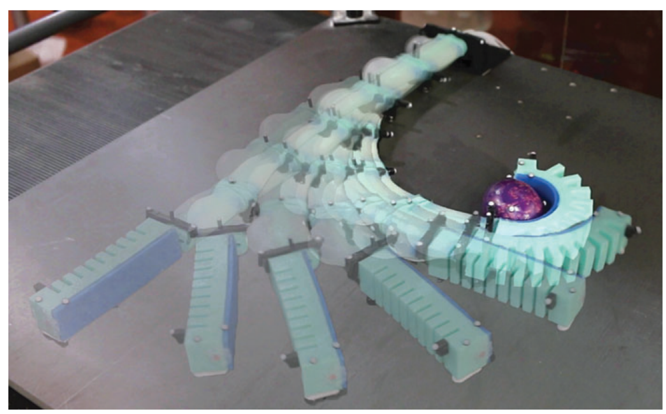

Fig. 17. The Soft manipulator

mutiple sections to the tentacles, each having three pneumatic channels. Pressurization of channels from different sections allows multiple bending modes, which allows the tentacles to adpot complex shapes.

To add more functionality to the tentacle, they have added flexible components in the central channel;these components do not affect the mobility of the tentacle but add more function to it.For example Fig 16a shows a tentacle with a video camera implated at the root,16b shows a tentacle that has additional tubing embedded along its central channel, Fig 16c shows a similar tentacle used to deactivate a circuit and Fig 16d shows a suction cup attached at the end of the tentacle.They have also made a tentacle with different surface texture, which is able to grasp more slippery objects.

D. Autonomous Object Manipulation Using a Soft Planar Grasping Manipulator [9]

In this paper Rus et al. have proposed a soft 2D manipulator with a planning algorithm to grasp-and-place randomly positioned objects on a planar surface using a Seven Degrees of Freedom soft manipulator.They have done experiments for autonomous manipulation with various objects of unknown geometry placed randomly in the working space of the manipulator without requiring force sensing or accurate sensing.

As shown in Fig 17 the manipulator has six bidirectional segments with cylindrical cavities forming the arm and a soft gripper inspired by the Pneumatic Networks for soft actuation of the gripper as the end effector, the arm and gripper can be actuated independently through an array of 13 fluidic drive cylinders.Here each cylindrical segment of the arm can be actuated up to a bend angle of 60 degrees, so it requires several segments to be combined together to allow the arm to work in a large workspace to perform the manipulation task.

For the planning and control of the manipulator they have made an algorithm for autonomous grasp and place operation. Fig 18 shows the state diagram the sensing,planning and execution states. Here, the object planner receives the coordinates and radius of the object and with the current curvature of the arm it solves a series of constrained nonlinear optimization problems to generate the end effector poses for approaching the object.

For experimenting the arm with the planning algorithm, they have made an experimental platform. They have evaluated the manipulator system for repeatability and ability to handle uncertainty and the experiments consisted of picking

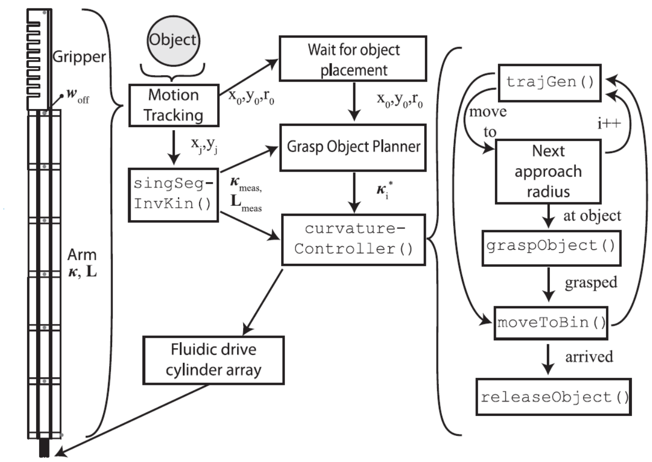

Fig. 18. State Flow diagram for the planning algorithm

and placing several objects of unknown location and geometry.They have performed over 200 trials at randomly chosen positions within the workspace of the manipulator.They were able to picked up various objects like eggs,shuttlecocks, bakery items, cups, light bulbs and tape holders. The objects had an enclosing diameter in the range of 2-5 cm.

IV. Comparison of Soft manipulator with rigid manipulators

In his paper, Alici[10] has made a detailed comparison between soft and rigid robots, as indicated in the paper, the following table makes a comparison between soft and rigid robots.

TABLE I
Comparison between Soft and rigid robots

Soft Robots	Rigid Robots
Made of soft, flexible, stretchable materials with reversible and variable properties	Made of hard materials with invariable properties
Inherent Compliance match with its environment	Smooth contact with its environment facilitated by advanced feedback control strategies and sensors
Infinite Degrees of Freedom	Finite Degrees of Freedom
Inherently Safe for Human-robot interaction	Unsafe for Human-robot interaction
Highly Adaptive	Limited Adaptability
Low Accuracy	High Accuracy
Low Speed actuation	High speed operations
Low weight and cost	High weight and cost

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