JOURNAL LA MULTIAPP

VOL. 06 ISSUE 03 (508-523), 2025
DOI: 10.37899/journallamultiapp.v6i3.1924

A Survey of Soft Robot Actuation, Sensing, and Application

Areej Ghazi Abdulshaheed[1], **Suhair Ghazi Mahdi**[1]

[1]AL-Furat AL-Awsat Technical University, Technical Institute of AL-Diwaniyah, Iraq

**Corresponding Author: Areej Ghazi Abdulshaheed*
Email: areej.ghazy.idi25@atu.edu.i

Article Info

Article history:
Received 13 January 2025
Received in revised form 6 June 2025
Accepted 21 June 2025

Keywords:
Soft Robot
Actuators
Sensing Technology
Manipulator
Pneumatic Robot

Abstract

Because of their fundamentally high adaptability, high compliance, excellent flexibility, and safe and natural interactive features, soft robotics technologies are pointing the path toward robotic capabilities that are essential for a wide range of applications, including manufacturing, manipulation, gripping, human-machine interaction, locomotion, and more. Soft robots are incredibly versatile and lightweight, making them ideal for interacting with delicate things and navigating unstructured spaces. Soft robots have not yet reached their full potential, though; in many aspects, including manipulation and movement, nature still possesses considerably greater sophistication. Future research should concentrate on comprehending the concepts behind the design and operation of soft robots in order to identify what constrains the way they function and impedes their transfer from the lab to real-world settings. Through an analysis of the operation of sophisticated actuation and sensor technologies, this paper offers a current overview of the area. Lastly, examples of the different soft actuators and possibilities for future development are reviewed, along with a number of prospective implementations.

Introduction

Even though a standard rigid robot is capable of performing intricate and precise movements, multi-redundant motion control frequently requires a significant number of stiff link joints. Redundant or hyper-redundant robots are the standard terms used to describe this kind of rigid connection robot (Guan et al., 2020; Abdulshaheed et al., 2022). For the robot to perform the work without breaking delicate things or human bodies, it must have considerable flexibility. Because traditional robots usually use rigid motors and rigid joints, the industry usually needs a number of associated sensors or technologies such as position, force feedback, and image recognition, to execute compatible control of the power produced to improve the safety of rigid robots. These kinds of robots were first referred to as "soft robots" Albu-Schaffer et al. (2008) when discussing the aforementioned difficulties. However, the idea of soft robots—that is, robots whose primary body is composed of soft materials and whose mobility is mostly produced by flexible deformation of the framework itself—is becoming increasingly prominent as bionics, soft materials, and manufacturing technologies advance. In theory, the soft robot has an endless number of degrees of freedom in contrast to the conventional rigid robot. Its exceptional flexibility and safety compensate for the drawbacks of a rigid robot, demonstrating previously unheard-of levels of adaptability, safety, and sensitivity while continuously broadening the robots' application areas. As a result, one of the key developments in robotics has been the soft robot. Because they may simply deform in contrast to their stiff cousin, soft robots are of considerable interest. Nonetheless, the concept of "soft robots," or robots with a primarily soft material body and whose The structure's elasticity is

ISSN: 2716-3865 (Print), 2721-1290 (Online)

the primary source of mobility, and it is becoming increasingly prominent as bionics, soft materials, and manufacturing technologies advance. In theory, the soft robot has an endless number of degrees of freedom in contrast to the conventional rigid robot. Its exceptional flexibility and safety compensate for the drawbacks of a rigid robot, demonstrating previously unheard-of levels of adaptability, safety, and sensitivity while continuously broadening the robots' application areas. As a result, one of the key developments in robotics has been the soft robot. These hold great promise for use in microrobots, micro-manipulators , and artificial muscles (Greco et al., 2022). The field of soft robotics, which primarily draws on material science, can be implemented via a range of mechanisms, including heat activation, electrostatic, pneumatic (Walker et al., 2020), and magnetic actuations (Ebrahimi et al., 2021). These soft robots' ability to move delicately, precisely, and continuously allows them to perform tasks including gripping fragile objects and moving ahead on different substrates in varying conditions (Liu et al., 2022; Huang et al., 2020). For this purpose, active and soft materials show promise since they can be activated by a variety of external stimuli, including light, heat, magnetic fields, and/or electric fields. Particles, polymers (either shape-memory or electroactive), liquid metals, sheets, shape-memory alloys (SMAs), fluids, hydrogels, two-dimensional materials, and combinations of these are examples of such materials (Mishra et al., 2020; Huang et al., 2020; McCracken et al., 2020; Jing et al., 2020). Soft robots have shown promise in altering our daily routines. For instance, in industrial contexts, the combination of soft robotic systems and conventional rigid-bodied robots has been applied to tasks requiring dexterous item manipulation (Wang et al., 2021). Moreover, delicate deep-sea species have been investigated by soft robots to further our understanding of the world (Coulson et al., 2022). Additionally, studies have looked into the use of soft robots with low invasiveness for medical procedures like delivery of medication (Hu et al., 2018), endoscopy (Bernth et al., 2017), and operation (Abidi et al., 2018) in sensitive body areas.

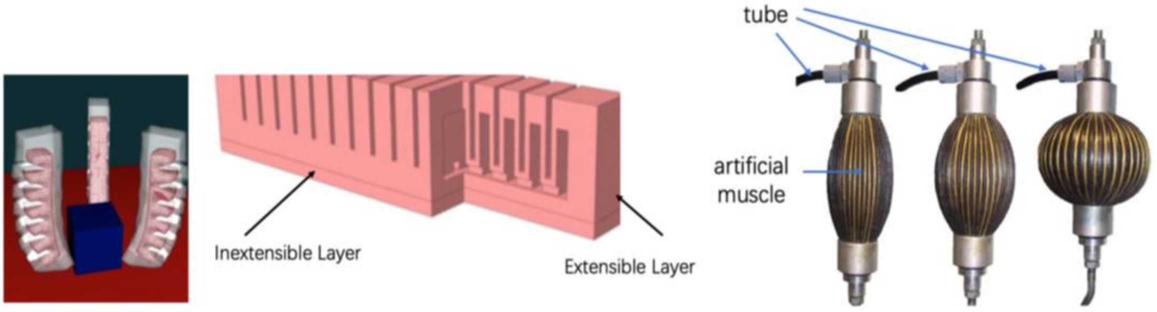
The structure of this paper is organized as follows: the motivation and types of the soft robots are provided in Sections 1. Section 2 introduces the operation of the soft robotic actuation types that are most frequently utilized. Section 3 describes sensor technologies that could be applied to develop soft robots with greater proprioception. Section 4 discusses the challenges and benefits involved in different applications. Finally, the conclusion is drawn in Section 5.

Actuator

Pneumatic Soft Actuators

There are two types of pneumatic drives used in soft robots: positive and negative pressure drives. The soft actuator is driven by applying positive pressure, which causes it to move, deform, and fill the cavity with compressed gas, which causes the major body to expand. On the other hand, the negative one involves using vacuuming to remove air from the cavity, which causes the cavity to contract, to regulate the deformation and movement of the soft actuators (Zaidi et al., 2021). Pneumatic Networks (PneuNets) and fiber-constrained actuators are the two primary categories into which typical pneumatic actuators can be separated based on structural differences as seen in Figure 1.

The two layers that make up the framework of a pneumatic Networks actuator are the confined layer at the bottom and the extended layer at the top. An air duct connects the inside of the upper layer's linear array of air chambers. Elastomers with many hollow channels built into them, or a novel architecture known as Honeycomb Pneumatic Networks, comprise PneuNets (Hongjun et al., 2024). Structural deformation actuation refers to the process of creating robot movements using the folding-extension deformation of several hexagonal structures using a honeycomb aerodynamic network.



(a) *(b)*

Figure 1. Pneumatic actuator types (Su et al., 2022) (a) The structure of a typical pneumatic network , b) McKibben artificial muscle

Electrically Responsive Actuation

Many pliable, elastic, and soft materials are available that can convert electrical energy into mechanical energy. These consist of liquid metals, memory alloys, paper, polymers, gels, and even carbon-based materials like carbon nanotubes (CNTs) on their own. Phase, amplitude, and frequency of the impulses may be easily and quickly modulated thanks to the electronic signals powering the actuators. Furthermore, these actuators may be simply integrated with energy devices and electric drivers because they are compatible with conventional electronic equipment. The possibilities are endless; among the most exciting areas of research include microscale item manipulation (Jager et al., 2000), microfluidic systems (Tony et al., 2021), microrobots (Kim et al., 2020), and artificial muscles (Wang etal., 2021).

Shape Memory Actuators

Actuators, the primary part of a soft robotics device, are commonly made of SMPs, or smart materials that "remember" their original shape. These materials can revert to their original form when a certain trigger is applied after being manually distorted into a temporary shape. The most researched SMP varieties are thermally responsive SMP (Scalet, 2020), while there are many more types that are activated by other stimuli, including chemical, light, and thermal. Two crucial physicochemical conditions must be met for a polymer to exhibit a thermal shape memory response: the polymer must undergo chemical or physical crosslinking to establish its permanent shape, and it must have a glass transition temperature (Tg) or melting temperature (Tm) to serve as a molecular switch, fixing its temporary shape. 3D printable SMPs have been created during the past ten years for a variety of printing processes, such as vat polymerization, polyjet, and FDM.

Fluidic Actuation

One of the most popular modalities for controlling the deformation of soft robots is fluidic actuation. It controls the fluidic pressure in the interior expandable pockets (i.e., chambers and channels) of a soft robot in space and time to produce motion. When using this method for driving soft robots, the primary material used is elastomeric, and around some of their internal inflated chambers, they include one or more layers of inextensible reinforcement, including fibres, textiles, or stiffer materials. To produce the desired deformation and motion, the path of distortion is restricted by these reinforcements. Pumps use fluids like air or water to pressurise and depressurise the inside inflatable chambers.

This process creates internal fluidic stress, Which leads the robot's body to distort (Figure 2). By adjusting the duration and amplitude of the fluidic pressure within every chamber, the deformation rate may be adjusted. the intended motion and distortion. Pumps use fluids like water or air to pressurise and depressurise the internal inflatable chambers. This process creates inside fluidic stress, which deforms the robot's body (Figure 2a). By altering the fluidic pressure's duration and amplitude within each hollow, the deformation rate may be adjusted. Depending on the planned robotic activities (Feng et al., 2002), There are several designs and segment morphologies that the inflated chambers and surrounding construction can have, including ribbed, pleated, and cylindrical. The actuation speed of a soft robot is determined by its design.

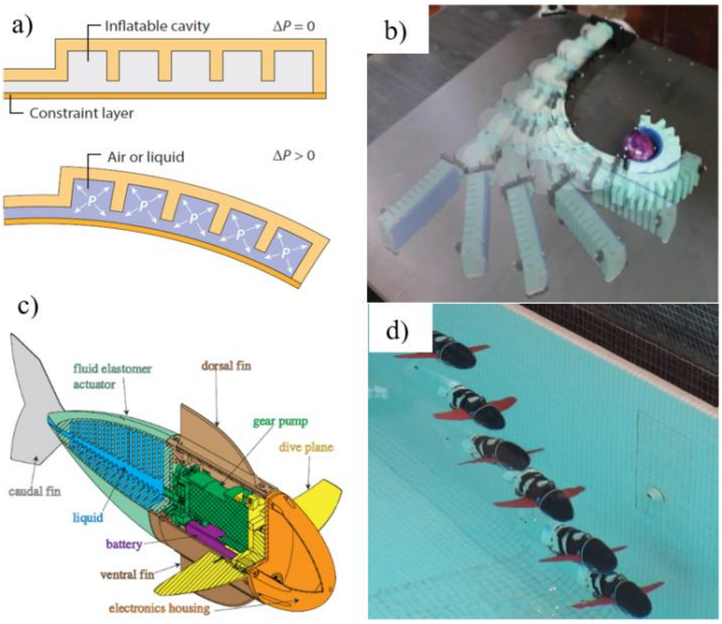


Figure 2. Actuation using fluids. (a) Actuation is produced by the spatiotemporal regulation of the fluidic pressure P inside the interior inflatable chambers of soft robots (Yasa et al., 2023). (b) soft manipulator with gripper (Katzschmann et al., 2015). (c, d) structure of soft fish robot and real experiment of the hydraulic fish in a pool (Katzschmann et al., 2015).

Magnetically Responsive Actuators Editors

In addition to its capacity to pass through most materials, magnetic stimulation is thought to be particularly attractive since it is simple to alter the direction and strength of the magnetic field fast and accurately. Magnetic fillers and particles have been included into polymers, gels, papers, and fluids so they can be activated by an applied external magnetic field. Variable amplitude and direction magnetisation profiles are produced when discrete magnetic fillers are inserted into soft materials (Kim & & Zhao, 2022). Magnetic fillers seek alignment with a magnetic field when exposed to it, which produces a variety of actuation modes, including contraction, elongation, bending, and deformation.

These actuation modes are often produced when the magnetic fillers interact with the field spatial gradients. Nonetheless, in compact regions, it is possible to generate the field and its spatial gradients separately, enabling the two distinct actuation modes required for intricate movements (Hwang et al., 2002). A multitude of parameters, such as the actuation signals, the magnetisation profiles, and the stiffness and shape of the materials, can be adjusted to produce a variety of distortion patterns. This kind of actuator is promise for applications limited to enclosed spaces, like targeted drug administration, microfluidics, and microsurgery, since magnetic fields may pass through a variety of materials.

Furthermore, these actuators respond quickly in comparison to other actuation modalities, where stated speeds of 100 Hz have been seen (Dong & Sitti, 2020). As a result, magnetic actuators have been effectively employed in the creation of several swimmers, micropumps, and crawling apparatuses. It is important to note, though, that external magnetic coils—which are used to create magnetic fields—are usually huge and power-hungry. Still, the zones where the magnetic field is sufficiently powerful and controllable are normally limited.

Photo-Responsive Actuation

The wireless feature and compact size and controllability of light-stimulated soft actuators make them attractive (Di Martino et al., 2023). Photochromic molecules, the basis of photo-responsive materials, are molecules that absorb light and change their properties accordingly. These molecules can be incorporated into gels, polymers, and fluids, among other soft actuators. The photo-responsive actuators are categorised in this area according to the light spectrum that determines the appropriate applications: visible light (such as sunlight) or NIR.

Explosive-Based Actuators

Using actuators based on explosives is a further method of producing motion. Actually, high-temperature gas pulses could be produced by explosive chemical processes and used for PneuNet actuation. It has been reported that several techniques, such as multi-material 3D printing, can be used to construct such a soft robot (Sachyani Keneth et al., 2021). Shepherd et al., for example, devised a method to allow a robot that can leap in less than 0.2 seconds more than thirty times its height, or about 30 cm (speed 3.6ms_1). The soft robot was made to jump by PneuNet actuation, which was made possible by the explosive chemical reactions that occurred between hydrocarbons and an electrical spark. The inability to regulate the jump's orientation or direction was one of this method's drawbacks. Loepfe et al. showed the directed jump of a 2.1 kg soft robot by the explosive burning of butane in order to get over this restriction. The combustion chamber is seen in Figures 3a,b both before and after the combustion. With a linear speed of 0.9 cm s_1, the robot can thus leap 7.5 times its body height in 20 seconds. But if it lands on its back, the claimed robot can't get ready for the next jump (Loepfe et al., 2015). Directed hopping in 3D-printed soft robots driven by butane and oxygen combustion was described by Bartlett et al. Pneumatic legs, which assist the robot in tilting before jumping, were used to enable directed jumping (up to 1.12 meters in height for 100 cycles) (Bartlett et al., 2015). However, explosive material-based actuators have a short lifespan due to the requirement for chemical replenishment; they are also non-scalable, have a narrow range of applications, and require extremely robust mechanical resilience in order to withstand an explosive impact event.

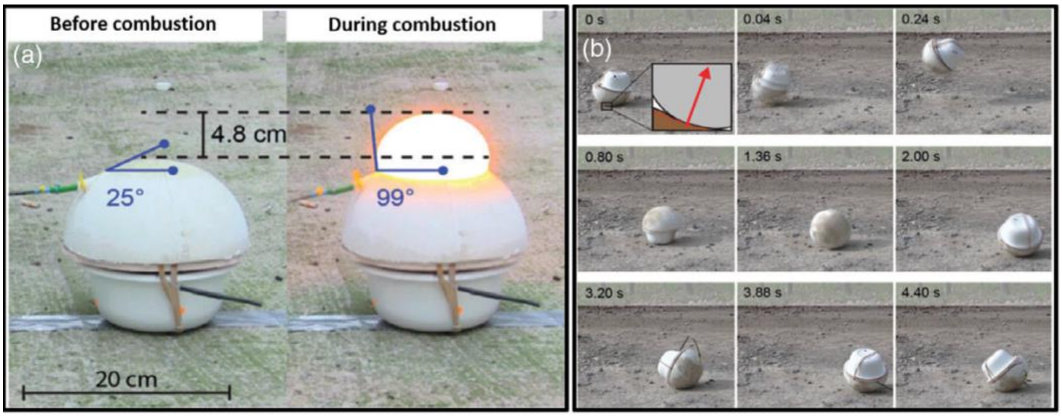


Figure 3. Illustrations of soft robots with explosive propulsion. a) Images taken prior to and during combustion that show how the combustion chamber deforms. b) The explosive-based soft robot's reorientation behaviour is shown

Biohybrid Actuation

By incorporating the sophisticated qualities of cells into soft robotics, we may be able to take advantage of the properties and capabilities of living materials. By adding skeletal muscle cells and cardiomyocytes, two types of contractile eukaryotic cells, to soft robot designs, biohybrid actuation in soft robotics can be accomplished (Won et al., 2020). These cells have a natural softness and compliance, and when mixed with biodegradable materials, they offer a sustainable and environmentally friendly supply of engineering materials for the creation of soft robots (Mazzolai & Laschi, 2020). Living-material soft robots have a better power-to-weight ratio than other actuation technologies and carry their own fuel source, which is the nutrients in their environment (Trimmer, 2020). Furthermore, live cells have the ability to multiply in order to reconstruct missing pieces of their assemblies; as a result, soft robots constructed from living materials are capable of effective self-healing (Roels et al., 2022). Biohybrid soft robots can be made with either nonmammalian (Akiyama et al., 2012) or mammalian (Xi et al., 2005) contractile cells. The top-down method of creating these soft robots involves taking functional contractile tissue directly from living things, On the other hand, the bottom-up approach uses main cells or lines of cells to generate tissues in an incubator for cells.

Sensor technology

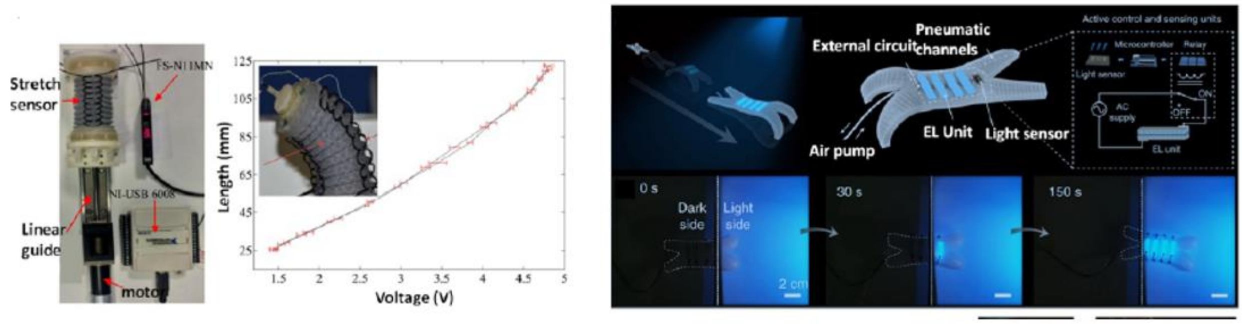
Proprioceptive and tactile sensing capabilities in soft robotics can be made possible by utilising various sensor technologies, as previously mentioned. The performance parameters for object identification, deformation type, nonlinearity, and hysteresis vary among these sensor technologies. Thus, it is essential to assess these parameters and select the optimal technology for sensors for the soft robot's desired structure.

Resistive and piezoresistive sensors

Depending on their state of deformation, elastic conductive materials have different resistances. The actuation states of soft robots can be recognised by comparing the variations in resistance as these materials undergo distortion. As a result, the variation in resistance can be used by resistive and piezoresistive sensors to signal the bending condition or external pressure applied to the soft robotic body. To put it another way, these sensors measure the robot's bending state, which gives soft robots proprioception in addition to providing them with more tactile information when they make touch with their surroundings (Banerjee et al., 2021). However, because to hysteresis in their reading, measurements of dynamic movements might not be precise. Resistive sensors and soft robot bodies can be printed jointly using 3D printing technology, allowing for sophisticated sensor placements through integrated sensor-actuator systems (Georgopoulou et al., 2022).

Furthermore, resistive sensors can be set up to recognise contact rather than self-induced bending . As a result, a soft gripper equipped with touch sensors and resistive flex may haptically detect the objects it is grasping (Homberg et al., 2019). The piezoelectric effect governs the operation of piezoresistive sensors; the resistivity of the materials varies with applied strain or pressure. But to translate the raw measurements into results for pose estimation, a trained recurrent neural network is needed due to piezoresistive sensor hysteresis characteristics and nonlinear outputs (Truby et al., 2020). Soft robot proprioception can be solved with a resistive sensor, however modelling and forecasting soft robotic systems is challenging due to their nonlinear behaviour. Macrobend optical sensors were employed by Althoefer's group (Sareh et al., 2015) to measure the soft robotic arm's attitude. An optical fibre serving as the macrobend stretch sensor in this instance adjusts the transmitted light's intensity in response to bend, stretch, and compression forces. Along the soft arm's perimeter, three macrobend sensors (Figure 4a) were sewed with equal orientations, 120 degrees apart.

Based on the difference in intensity caused by transmission loss at the macrobends, the sensor could discriminate between the arm's bend, stretch, and compression with accuracy. Another class of optical sensing techniques that can be integrated into the sensing of soft robots is electroluminescence. A soft quadrupedal robot with an electroluminescent (EL) coating that can blend in with three different background colors—orange, green, and blue—was created by Liu's group (Zhang et al., 2022). The quadrupedal robot has a light sensor installed, as seen in Figure 4b. This sensor detects the wavelength of the surrounding light and turns on the appropriate layer of EL material. The creation of such a sophisticated design for the smart soft robot was made possible by the use of multimaterial 3D printing with in-house developed ion conducting, electroluminescent, and dielectric inks.



(a) *(b)*

Figure 4. Soft robotics using optical sensors. (a) Left: A macrobend strain sensor for pose measurement using a soft arm with sewed optical fibres. Right: The stretch sensor's voltage vs. length connection (Zhang et al., 2020). (b) Quadrupedal soft-camouflage robot. Top: Sensor and EL skin integration in the soft robot design. Bottom: The robot uses selective illumination on its EL skin to blend in with its surroundings while it moves (Tapia et al., 2020).

Conductive Liquid Sensors

Within the soft robots' interior changeable cavities, conductive liquids, such as liquid metals (Tapia et al., 2020) or ionic liquids (Kaneko et al., 2023), can be employed to assess changes in resistance in accordance with the deformation states of the soft robots. Following the measurement of these resistance changes, Pouillet's rule (Tapia et al., 2020) utilised to reconstruct the states of deformation of the robots. These sensors, like resistive sensors, are prone to hysteresis. However, During the manufacturing phase, pathways for the conductive inks can be added to maximise the flexibility of positioning the sensors (Truby et al., 2018), allowing for the creation of complicated sensor combinations. To choose the best sensor path to detect deformation and validate the sensor's sensing ability on a real sensing element, an optimisation technique can be applied.

Capacitive Sensors

Proprioceptively measuring soft robots' postures and exteroceptively measuring their interaction with their environment are both possible with capacitive sensors. For haptic sensing, they can function in either of two modes: mutual-capacitance mode or self-capacitance mode (Navarro et al., 2020). The self-capacitance mode senses things in the vicinity that drain the produced electric fields by applying an alternating current to a single electrode. A pair of electrodes is needed for the mutual capacitance mode in order for transmitting and receiving signals; in this state, a coupling effect is created when physical contact brings the electrodes closely to one another, while an approaching conductive item causes a shielding effect (Teyssier et al., 2021). Using capacitive sensors to detect nonconductive items is challenging. Nonetheless, the mutual-capacitive mode's coupling effect is dependent on physical deformation, which means it may be applied to detect nonconductive objects.

In order to forecast the location and strength of the contact force given to soft robots, a numerical optimisation technique has been utilised to combine measurements from capacitive and pressure sensors using a FEM model in the SOFA simulator. Many stretchy and conductive materials, including composites , conductive polymers, and thin films, are employed to create electrodes in the development of flexible capacitive sensors. Sensitivity is another measure of capacitive sensor performance that is mostly influenced by dielectric layer deformation. Many techniques have been used to boost the sensor's sensitivity, including the use of porous structures (Yang et al., 2019), tailored surfaces (Ruth et al., 2002), textiles (Xu et al., 2022), and nanowire networks (Lee et al., 2020). Moreover, another challenge with soft capacitive sensors is the trade-off between pressure range and sensitivity. Qu et al. (2021) overcame this difficulty by creating a hybrid piezoresistive and piezocapacitive sensor that has good sensitivity across a broad pressure range and shows promise for accurate robot control.

Application

Soft robots make it possible to do intricate tasks including safe interaction with delicate objects and navigation in unstructured surroundings. They have previously demonstrated their ability to help with search and rescue operations, investigate underwater environments, handle delicate items in industrial environments, and carry out noninvasive medical procedures. This section looks at many soft robots for healthcare, exploration, and manipulation applications.

Manipulation

Without requiring substantial sensorization to assess deformation, touch, or force, the majority of soft robots can manage delicate objects and interact with their environment by utilising their inherent compliance and softness. Three different approaches can be used to manipulate soft robots: adhesion, stiffness, or actuation control (Shintakeet al., 2018) (Figure 5a). By managing the actuation of soft robots, the majority of soft robotic actuation modalities can be used to manipulate objects (Toshimitsu et al., 2021). However, soft robots that use controllable adhesion ought to have special structural elements (like pillars modelled after geckos) that allow them to engage with the target item (Morimoto et al., 2018) or provide physical forces that are attractive to the target's surface (like electroadhesion forces) (Shintake et al., 2016). Furthermore, soft robots can be manufactured with a variety of actuation mechanisms and configurations while manipulating items by altering their stiffness. The most prospective soft robots in this category are those that use a jamming mechanism to manipulate heavy things with little force applied (Jacob & Secco, 2022). Generally speaking, fragile, light objects have been delicately manipulated by soft robots. However, the majority of soft robots are unable to handle large objects. Creating soft robots that can adjust their stiffness based on the weights of the objects they are aiming for would be one way to address this problem (Zhang et al., 2019). This approach can improve soft robots' performance and increase their range of applications.

(a) *(b)*

Figure 5. Multi types of manpulators (a) manipulation. Soft robots' compliance and softness make them suitable for handling fragile goods (Shintake et al., 2016)[62]. (b) OctArm VI - continuum manipulators (McMahan et al., 2006)

ISSN: 2716-3865 (Print), 2721-1290 (Online)

Bionic Applications

Soft robots use their motor patterns to simulate the behaviour of living things. Soft actuators, a crucial component of soft robotic systems, enable the actuation and mobility of soft robots. Figure 6 depicts the BionicSoftArm (Müller et al., 2002), a lightweight, modular pneumatic robot. The robot's modular design allows it to be utilised in a multitude of ways. With a variety of adjustable pneumatic grippers, it can grasp and control a broad variety of items and forms. With up to seven pneumatic actuators, the BionicSoftArm's length may be adjusted to suit specific needs, offering the greatest possible range and mobility.

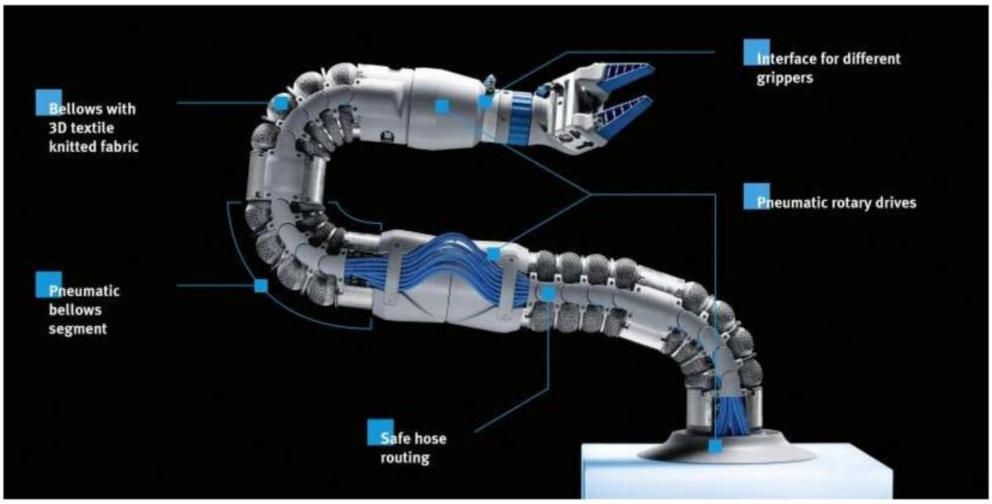


Figure 6. Bionicsoftarm [66].

Applications that are challenging to implement with a regular robot are now relatively simple to implement. Figures 8(a)–(b) of a study conducted in Terryn et al. (2017) demonstrate the construction of a robotic hand, gripper, and self-healing soft pneumatic artificial muscle composed of Diels-Alders polymers. Diels Alders polymers, supported by their thermoreversible characteristics, create covalent networks. Diels Alder elastomers were used to produce the soft robotic devices shown in figures 8(a)–(b), which have the potential to heal themselves.

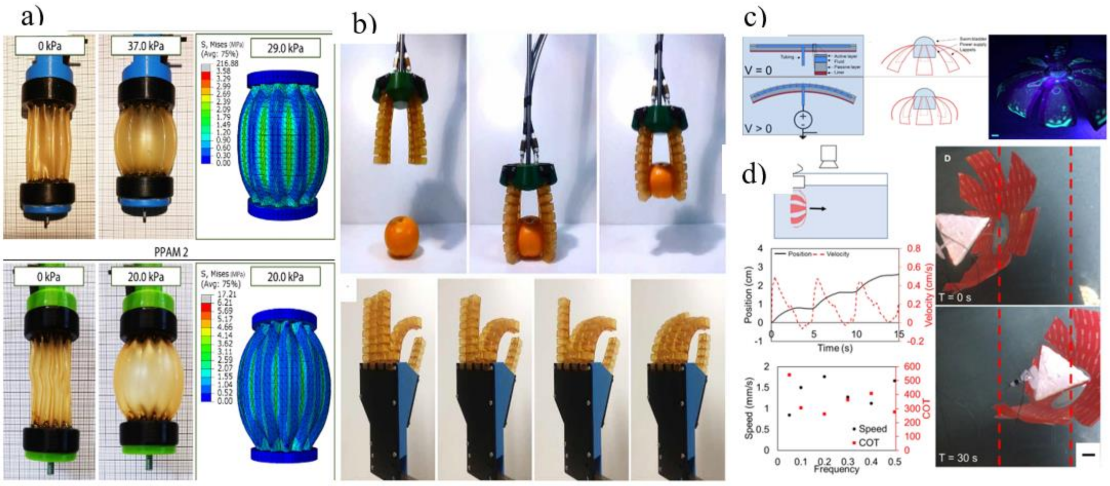


Figure 7. (a)–(b) Simulation and experimental contraction, deformation, and functionality as well as characteristics of four-BSPAs. (Terryn et al., 2017)[67]. (c), (d) Jelly fish inspired un-tethered soft robot for under water monitoring (Christianson et al., 2019).

On the other hand, the overpressure test was conducted to validate the developed work's ability to repair seals, while the air pressure functions to activate them. In Liu et al. (2021), a brand-new soft gripper design is put forth. It is possible for the suggested design to manage objects with varying sizes, weights, orientations, and shapes. The actuator's flexible fingers that are powered by pneumatics are organised in a modular fashion. The gripper has four chambers that are connected so that it can be adjusted to fit around various objects.

Until recently, all robots intended for underwater applications were mostly inflexible and equipped with jet propellers or thrusters with large power ratings, which hindered the development of lightweight and compact robot designs. Soft robots inspired by biology offer a solution to this issue. One study, described in Christianson et al. (2019), was inspired by the jellyfish depicted in figures 7(c) and (d). It is likewise composed of flexible materials that can adapt to their surroundings. Figure 7(d) depicts the robot's schematic and fundamental design. Therefore, the untethered soft robot, which was inspired by jellyfish, was equipped with an onboard water-proof power source for frameless dielectric elastomer actuators (DEAs).

Medical Application

According to the theory of continuous passive motion (CPM) (Noviyanto et al., 2021), which is based on rehabilitation medicine, patients with motor dysfunction may benefit from CPM therapy by helping to heal injured motor nerves. This can effectively lower the risk of disability in these patients. Exoskeleton robots for rehabilitation have been developed in a number of ways to allow patients to engage in physical interaction or go out on their own in the community (Yu et al., 2020; Zhou et al., 2021).

(a) *(b)* *(c)*

Figure 8. Soft robot that used for medical applications. (a) Medical robots that are soft. In an in vivo pig model of heart failure. (b) A soft hand exoskeleton composed of continuously changeable pieces. (c) A soft robot intended for minimally invasive surgery.

In addition to helping patients with flexion, extension, and twisting motions, exoskeletal rehabilitation robots gradually restore motor function to the body portion that has been deviated throughout continual wearing training. Pneumatic soft rehabilitation exoskeletons are among the most notable because of their high level of safety and straightforward design. They play a significant role in the rehabilitation robotics sector. Soft robots' docile characteristics allow for its implementation in a variety of healthcare settings, including as targeted drug delivery, minimally invasive surgery, and rehabilitation. Soft robots in rehabilitation help patients heal by cooperating with them in a safe manner.

Because of their innate compliance and softness, soft robots can follow motion trajectories that are kinematically comparable to those of humans. Because of their softness, they may also adapt to the bodies of their patients and avoid applying nonphysiological loads during rehabilitation that might harm the musculoskeletal system.The majority of efforts have been focused on hand function restoration, despite the fact that soft robots have been created for use in the therapy of the majority of the body's main joints. Soft hand devices, which resemble gloves in shape, facilitate finger bending for the purpose of performing assistive tasks or rehabilitation exercises (Gu et al., 2023) (Figure 9). Various methods, such as fluidic, shape-memory, and electrostatic actuators, have been used to power these gloves.

Conclusion

Appropriate reactions between a body and its surroundings are necessary for robotic actuation. Usually, nondeformable parts and precise controls have been used by robots to apply forces and regulate system motion. This conventional approach, which is predicated on rigid bodies, is being challenged by soft robots, who are cogently establishing novel concepts for accomplishing robotic actuation with soft bodies. In this article, we discussed a few of the actuation mechanisms found in soft robots. In soft robotics, actuation is generally a significant difficulty because the intended function cannot be realised without appropriate actuation technology.

However, the device's delicate nature shouldn't be impacted by its mechanical construction. This also applies to soft grippers and manipulators; a trade-off is required. Pneumatic networks embedded into polymeric materials are used in the majority of soft robots today to accomplish actuation or propulsion. These actuators respond quickly and don't have any friction issues. It is also easier to regulate, which is why it is employed more frequently than the alternative techniques. However, they are hard to miniaturise, and leaks easily cause them to fail in experiments. The most noteworthy or current findings from the literature consulted for this study were presented, with an emphasis on both the soft robotics application and the fundamental concepts guiding the motions attained in the soft robots.

The primary finding was that the majority of soft grippers and manipulators—especially those used for pick-and-place tasks and the handling of intricately formed objects—are primarily evaluated in lab settings. Not many of them arrived at the pitch. Thus, there is still more work to be done in order to build soft grippers and manipulators for usage in factories. It is also important to note that the increased usage of vacuum and pneumatic actuations by researchers, which has increased their reliability, is due to their greater advantages over alternative technologies. SMAs, Electo-Response, photo-response, and Magnetically responsive actuators are just a few of the emerging technologies that will take some time to reach maturity. Nonetheless, they can be combined with vacuum and pneumatic systems to create a technology that is more dependable and effective. The field of soft robotics is currently primarily driven by the requirement for its applications in biomedical systems, which are necessary for precise manipulation, therapy, and surgery on soft natural materials. Consequently, there has been a surge in interest in the study of biocompatible and biodegradable soft actuators.

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ISSN: 2716-3865 (Print), 2721-1290 (Online)