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The Impact of Development and Application of Soft Material and Novel Actuators in Soft Robotics Technology on Future Biomedical Engineering

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ABSTRACT

The goal of the robotics industry has been to build devices that mirror the remarkable powers of the human body ever since it was founded. In an attempt to emulate the compliance and deformability of genuine biological tissue, efforts have been made to construct actuators and electronics out of elastomers, textiles, and other soft materials as early as the 1940s. Since then, the field of soft robotics has advanced extraordinarily, with recent work concentrating on actuation, sensing, and application. In this review, recent advancement in the soft robotically field from the perspective of soft actuators, soft material, and biomedical application is highlighted. Soft actuators had gone decent development along with different advantages and setbacks. The need for chemistry and material science has been increasingly large in recent years and the material for 4D printing manufacturing is a major focus. Biomedical applications can be advanced by introducing soft robotics combined with existing technology. The biocompatibility issue is a major challenge to be faced, and perspectives on such regard will be discussed.

Introduction

Robotics is currently at a technical stage that is maybe akin to the very beginnings of the internet. It occurs when robots and people start to collaborate or even merge. Soft robotics will play an important role in this stage and transformation. The chance to participate in it should not be passed up by chemistry and materials science (Whitesides, 2018). Different scales of soft machines and gadgets may be designed thanks to soft robotics. Soft robots are particularly intriguing for medical applications because of their compliance and mechanical characteristics. To ensure system operation and body acceptability, soft robotics materials must be somewhat compatible with the human body and tissues; nevertheless, the degree of compatibility will vary depending on the particular biomedical application. Allergies and touch reactions must be addressed for infrequent exterior usage, acute immunological responses must be taken into consideration for brief internal use, and long-term implantation of soft robotic devices impacts the long-term immune response and may potentially result in rejection (Cianchetti et al., 2018). Additionally, the materials must, to some extent, mimic the mechanical characteristics of human tissues. For instance, replicating the mechanical characteristics and operation of human tissues is necessary for the application of soft robots as simulators, organs, or prostheses. Moreover, collections of sensors and actuators must be incorporated into the system for robots to communicate with the outside world and carry out activities. Because its sensing and actuation components are typically tightly interwoven with the body of the robot and its overall functioning, soft robots in particular face significant hurdles. As the sensing, power, and data processing units are relocated off-board, these difficulties become even more pressing when the soft robot is shrunk to a size of just a few hundred nanometers. Miniaturized soft actuators that respond to a variety of stimuli, exhibit significant deformations, and show mechanical robustness are therefore essential. In the four sections of my essay, I will briefly talk about the actuation method of soft robotics, the evaluation of different kinds of materials, the possible application in the medical field, and my perspective on the future of soft robotics.

Soft Actuators: The Fundament of Soft Robotics

Electrically Responsive

Electrically responsive actuation works by using electronic signals to rapidly and conveniently modify the signal's phase, amplitude, and frequency. Dielectric Elastomer Actuator is a specific type of electrically responsive actuator that works with two electrodes that are located on separate ends of a compressible membrane and are separated by a Coulombic attraction which granted it high energy density, self-sensing characteristic, and biological application (Kwon et al., 2008). Hydraulically amplified self-healing electrostatic (HASEL) is a recent electric polymer design that mimics human muscle as shown in Figure 1A (Acome et al., 2018). The electric polymer actuator, just like human muscle, endures the strain of 0.3 MPa; since they are controlled by voltage, it is easy to accurate the degree of actuation. Using this actuation, it is possible to irregularly deform the surface of a thin sheet of the dielectric elastomer in a controlled manner (Shian & Clarke, 2016) and develop a multifunctional electrical adhesive soft gripper (Shintake et al., 2016). Other types of external physical stimulation electrically responsive actuators including piezoelectric-based and mechanical servomotor-based takes a similar approach. However, a special kind of electrically responsive actuator is Neuro-stimulation based actuator. Typically, the process of using Neuro-stimulation actuators for a prothesis works as the following: electrical impulses are the basis for neuronal communication, making this actuator particularly ideal for actuating prosthetics; feeling can be sent to the brain and the electrodes of the interface nerve can be stabilized by decoding the electrical activity of the muscle and stimulating the nerves electrically; then a sense of ownership over a prosthetic limb will emerge after the user is accustomed to and comfortable with the sensor feedback (El-Atab et al., 2020).

Magnetic Responsive

Magnetically responsive actuators control the direction and strength of the magnetic field swiftly and precisely by magnetic stimulation while also being capable to permeate most materials. Magnetic filters and particles have been included in polymers, gels, papers, and fluids in order for them to function when an external magnetic field is applied (El-Atab et al., 2020). The creation of various actuation modes, including deformation, bending, elongation, and contraction, occurs when magnetic fillers are exposed to a magnetic field. These actuation modes are often produced when the magnetic fillers interact with the field spatial gradients. This kind of actuator is best used for applications confined to enclosed spaces including targeted medication delivery, microfluidics, and microsurgery since magnetic fields may penetrate a variety of materials (Diller et al., 2016). Additionally, magnetic actuators respond quickly where speeds of 100 Hz have been documented (Diller et al., 2012). Hence, they are also suitable for the application of crawling devices or micropumps.

Thermally Responsive

Thermally responsive actuators are activated by heat application. Shape Memory Alloy (SMA) is a branch of thermally responsive actuators which utilize the thermal expansion property to work (Otsuka & Kakeshita, 2002). SMA can be composed of a variety of elements and each has its unique advantage depending on the field of application. For example, iron-based SMA is more cost-efficient while NiTi-based SMA has higher stability. When producing an electrical current and using the material’s electric resistance, heat is created for SMA to deform (Mohd Jani et al., 2014). The advantage of SMA actuators is their ability to be free of reliance on changes in temperature; in other words, it doesn’t need to work in a controlled environment. Moreover, Shape memory polymer (SMP) is a smart actuator that can be programmed into different shapes and reverted back by stimulation such as heat. PU and thermoplastic polyurethane are the most prevalent SMP kinds created for biomedical purposes (Small et al., 2010). SMP contributes the most to the self-holding technology which converts 2D flat material into a 3D structure as shown in Figure 1C(Felton et al., 2013). Devices including sensors, medication delivery systems, reconfigurable electronics, and solar cells, have been developed using this method (Loepfe et al., 2015). Furthermore, rubber's elasticity and liquid crystals' orientationally order combine to create a special class of materials known as Liquid Crystal Elastomer (LCE), which hold promise for applications requiring stimulus response (Kularatne et al., 2017). LCE bilayers with orthogonal director orientation and various nematicon-to-isotropic transition temperatures constitute the soft composite matter (El-Atab et al., 2020). When heated beyond their respective actuation temperatures, the printed LCE hinges have a reversible bending reaction. Similar to the SMP, LCE can use its computational hinges to actuate at different temperatures. Hinges made by using LCE technology can lift objects 450 times heavier compared to normal ones. Due to its working density and stress, it has the advantage to be controlled by low voltage from 1 to 3V. However, this actuator is much slower and has a low energy efficiency (Lendlein & Kelch, 2002). The self-holding technique is also achievable using the LCE, but unlike the SMP, a fully soft system using this actuator would be unable to fold reversibly. Lastly, the synthetic hydrogel is a 3D structure of polymer structure that is composed of mostly water. As the water exposes to light or temperature, the percentage of the water in hydrogel changes which causes it to bend. Additionally, due to their sensitivity to biologically related stimuli, hydrogels are particularly appealing for biomedical applications such as tissue engineering and medicine administration (Jeon et al., 2017). Poly nisopropylacrylamide (pNIPAM), which has been shown to be a soft actuator in a variety of applications, including grippers, is one of the most notable stimuli-responsive hydrogels (Wang et al., 2013). A reliable gripping tool that can latch onto tissues and cells at body temperature has recently been developed for use in medication delivery (Malachowski et al., 2014). In order to precisely shape the stiff material into sharp ends that may safely pierce tissue to secure the position of the theragrippers and deliver the medicine, the researchers invented a photolithographic approach which made it possible to precisely shape the stiff material so that sharp ends could be formed, which could then be used to distribute the medicine and secure the position of the theragrippers by digging harmlessly into the tissue. The method of processing is appropriate for use with actual medications. The researchers demonstrated how to use grippers to distribute an anti-inflammatory medicine over the course of a week as a proof of concept.

Photo Responsive

Photo-Responsive Actuation can be controlled wireless even in small sizes. The photo-responsive materials recognize optical signals and transform them using photochromic molecules to produce various movements and modifications (Jiang et al., 2006). Photo-responsive actuators can be divided into visible-light-driven or non-visible light-driven. The visible-light-driven actuation method can use sunlight as a natural source of energy to operate. Recently, visible light actuators are liquid crystal polymer networks (LCNs) or carbon-based materials (El-Atab et al., 2020). Both of them need a large intensity of light in order to perform simple and small movements. One approach to movement is to use the self-shadowing effect which let the actuators to bend as a flying motion, similar to that of butterflies, and it is achievable under a frequency of 2.7 Hz (Dong et al., 2020). Another approach to movement is using the laser-induced graphene (LIG) structures; by light stimulation under a 150W lamp, a bending curve of 1.8 cm is reached within 5 seconds and 5.5 seconds are needed for the actuator to recover its original flat shape (Deng et al., 2018). Moreover, Visible light actuators can achieve self-folding by giving the light of different wavelengths which means a 2D structure such as a thin paper can be transformed into a 3D structure through bending. Speaking of the Near Infrared (NIR)-Driven actuators, which work by exploiting invisible light, have gained large attention due to their capacity to penetrate biomaterial using long wavelength and low cost. It is considered the best wireless biocompatible actuation technique for biomedical devices. NIR-stimulated soft actuators are fabricated by doping polymers with a variety of photothermal agents. The photothermal agents, such as metal nanoparticles, transformed the NIR light into thermal energy thus creating polymer property transformation or thermal expansion (X. Liu et al., 2015). However, using photothermal agents has the disadvantage that adding the amount and variety of material to its composition leads to a decrease in its mechanical properties. In order to improve the mechanical property, a group of researchers revealed a cross-linking strategy of two-step acyclic diene metathesis to produce single axially aligned main-chain LCEs along with chemically linked NIR light that absorbs four-alkenyl-tailed croconaine-core cross-linkers (L. Liu et al., 2017). The result is when the actuator shrank by up to 110 percent, it is able to lift objects 5600 times heavier than it was.

Pressure-driven

Pressure-Driven actuators can be driven by pressure to produce the appropriate deformations, but they must spatially design their stiffness qualities to offer effective actuation. Pressure-driven actuators can generate high force with lightweight and can be classified as pneumatic driven and hydraulic driven. Pneumatic actuators convert energy into either linear or rotational motion using pressured gas or air, making them extremely effective and secure sources for controlling motion. They are particularly well suited for usage in repetitive valve opening and closing, extreme environments, or industrial applications where alternative electric or magnetic actuators might interfere. A pneumatically stimulated implanted reservoir has been developed using this technique (Dolan et al., 2019). By stopping the flow of fluid and preimplant tissue cell activity, the reservoir alters the biotic abiotic interface's biomechanics. The pressure and volume of the chamber rise as the stimulating reservoir become pressured across the stimulation line. As a result, the middle and lower membranes could deflect downward. The tension brought on by the membrane deflection causes the fluid at the tissue interface to shift, which inhibits the activity of the cells. This method employs mechanical stimulation to elicit the desired biological response, which would also lessen the fibrotic encapsulation of the implantable medical device (Dolan et al., 2019). Hydraulic actuators work by inserting fluid into a pre-designed chamber which can be used to perform the desired movement such as bending or twisting. Just like pneumatically soft robotics, it is hard for hydraulic soft robotics to reduce its size due to the necessity of connecting to a rigid control or powering system. An application of biomimicry fish is designed by Katzschmann as shown in Figure 1B (R. K. Katzschmann et al., 2016). The fish consists of two lateral cavities and a bending tail using hydraulic actuators. The actuator is designed in a rib-like structure with a center for the influx of liquid; based on the pressure given, positive or negative, the outer skin will inflate or deflate which causes the bending of the central part that leads the fish to swim (R. K. Katzschmann et al., 2016).

Explosive

Explosive-based actuators function by the pulse of high-temperature gas created by the chemical explosive reaction(Shepherd et al., 2013). This actuation method has very limited application due to its working principle.

To this day, it may seem that soft robotics have undergone considerable development; however, most soft actuation needs to be tethered to a rigid control system for its movement. For those actuators that are untethered, they need to be connected with a rigid energy source. SMAs and SMPs need to be pre-programmed for actuation and their material is costly. DEA-based actuators need large voltage which is a hinder force for many applications. Additionally, hydraulic actuation needs a pneumatic system for it to operate large forces quickly. In general, soft actuators are steadily progressing with different varieties providing many choices used for different fields and possessing many advantages; however, there is still a long way to go for perfect actuators to develop that is suitable for everything. The general pros and cons for some recent and mostly used actuator types are summarized in Table 1 to give perspectives when comparing advantages and disadvantages (Boyraz et al., 2018).

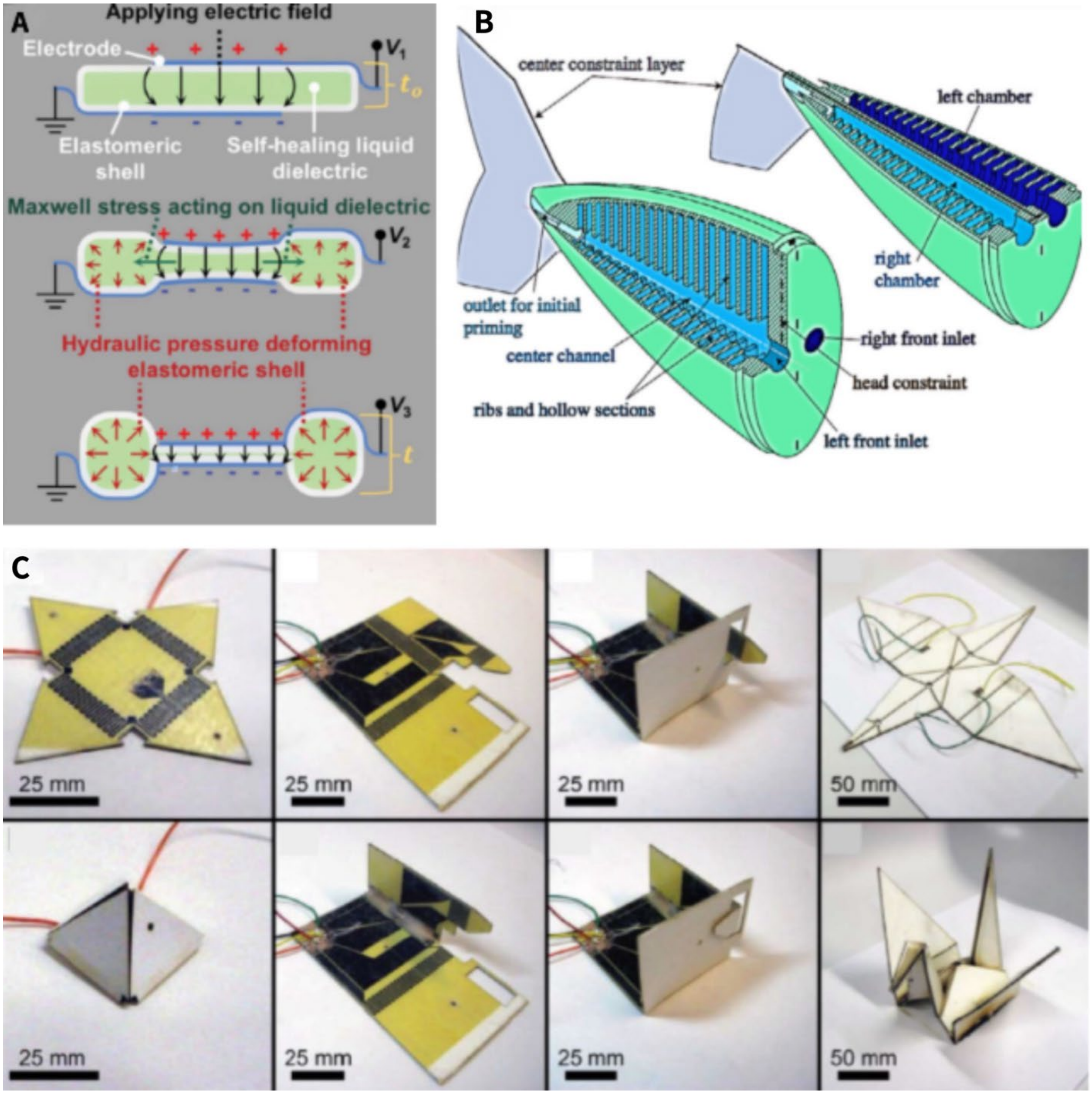

Figure 1. A) HASEL actuator shown at three different voltages (Acome et al., 2018). B) Fish soft tail consist of an elastomer-based hydraulic actuator with two fluidic chambers (R. K. Katzschmann et al., 2016). C) Self-folding pyramid created by simultaneously actuating the four hinges with a 2A supplied current (Felton et al., 2013).

Table 1. Advantage and Disadvantage of Types of Actuators

Actuator Type	Advantages	Disadvantage
Dielectric-Electrically	Flexible and scalable Stores kinetic energy Inherent compliant Support light weight structure	Slow responsive time Low payload capacities Need to avoid high-voltage circuit Require amplification of feed voltage in order for better efficiency Electrical break-down limits, mechanical strain limits, and durability limits
Shape Memory Alloys	Flexible naturally Provide large frequency responsive Low actuation temperature Capable to achieve light-weight construction	Hysteresis, slow responsive time Low efficiency with high power consumption Need to be pre-programed Almost no inherited compliance Difficult heat transfer in a Marco-scale The larger the SMA structure the worse the energy conversion dynamics would be handled
Shape Memory Polymers	Low Cost Biodegradable Endurable from temperature (+-150C) Highly deformable Can be used in very specific applications	Strict requirement of processing method Rigid component in order to repair back to original shape Scalability is a limiting factor Controlling is usually non-linear and often unidentified behavior
Magnetic	Precise output Quick Responsive Capable to penetrate different materials	Large Dimension Not suitable for therapy-inflection Complex manufacturing process Limited mechanic compliance due to its coil and particle Operation range is not suitable for all environments due to its need for remote regulation of magnetic field Small-scale dimensions, magnetic interference
Photo-Responsive	Environment as a source of energy Remote control Control and tuning of response strength are easy	Requirement of intense light Limited deformations Requirement of sophisticated materials
Pneumatic	Low Cost Fast Working Cycle Free from temperature effect No need for electronic	Not suitable for high load Limitation in separating energy source and system Requirement of auxiliary energy source

Types of New Material and Their Usages

The soft polymers and elastomers make up the majority of the soft robotic material discussed in this paragraph. The robot's housing or transport medium for integrated electrical circuitry, as well as the robot's limbs or fingers, are frequently made of elastomers. Additionally, fluids for actuation or flexible electronics are frequently seen in soft robots. These liquids can be dispersed inside an elastomer matrix or gel, added to chambers, used as microfluidic channels, or poured into chambers. Moreover, Liquid crystal elastomers and shape-memory alloys, which alter the shape in response to heat or electrical current, may be used in soft robotics

Elastomer

To start with, Elastomer is a rubbery polymer that has been commonly used as a material for soft robotics. Material is elastic if it can return to its original shape after an applied tensile is loaded. Elastomers are hyperplastic materials because they have elastic responsiveness when giving a broad range of strains (Marckmann & Verron, 2006). Elastomer is a popular material in soft robotics because of its compliance and elastic property. As a result of their low modulus, high strain limit, and relatively low hysteresis between loading and unloading, polysiloxanes such as PDMS have become a common material in soft microfluidics and robotics (Majidi, 2019).

Polymer Composite

A second common type of soft material is polymer composite, a special form of elastomer. Because the elastomer is insulated, they are often filled with Nanoparticles or special fluid to give them thermal conductivity and electric permittivity that is caused by the dispersion phase; when given high filler concentration, the composite will have electric conductivity. When given the filler, nanoparticles tend to form a scaled gap. With an increasing gap, the interparticle resistance increases dramatically, decreasing the composite's effective volumetric conductivity (Knite et al., 2004). Using this method, a soft sensing skin could be created by carbon-filled elastomers as shown in Figure 2A (Charalambides & Bergbreiter, 2017).

Air

In addition to elastomer and polymers, early actuation methods use pneumatic artificial muscles which use compressed air as materials. When air is added, the elastomer shell contracts which mimics the movement of muscles. Additionally, combustion and fuel decomposition could create pressurized air that can soft pneumatic actuators. Another method is the Whitney strain gauge which is made of a rubber tube that is filled with Liquid Metal (LM) (Whitney, 1953). When the tube is stretched by measuring the change of conductivity of LM, the strain gauge would perform contraction or joint motion. Recently, fluid as a material is more commonly used along with the LM and compressed air. In soft actuators, fluids play a similar role as in pneumatics and hydraulics machines. Water is a fluidic material that can allow great load bearing and triggers more rapid actuator responses (Marchese et al., 2015). Water is uncompressible so when slight movements to the boundaries happen, the fluidic pressure and actuator stiffness will change. Another kind of material of fluid often used tis conductive fluid. Conductive grease made up of carbon mixed with silicone oil has been used for dielectric elastomer actuators (Carpi et al., 2010).

Gel

Furthermore, gels are fluid-solid binary structures that contain micrometer-scale distances between the fluid and solid phases. Gels can be thought of as a combining material of polymers and fluids. They can be filled with many fluids including gas, hydrogels, water, and ionic solution (Majidi, 2019). Gels with ionic solutions could be used to create tactile skin, as shown in Figure 2B (Sun et al., 2014). The solid phase of gels has elastic properties which allow it to swell and deform. Gels have high potential in soft robotics materials because of their capacity to combine great tear resistance, skin-like suppleness, and ionic conductivity (Sun et al., 2012).

Liquid

Finally, while gels are composed of mostly fluid with solid, it is possible to make fluid-elastomer composites with minorly fluid. One of these approaches is the Ga-based LM microdroplets (Figure 2C) (Bartlett et al., 2017). Unlike the conductive polymer composites mentioned above that have rigid fillers, these LM-Embedded Elastomers (LMEEs) show greatly reduced electromechanical coupling (Fassler & Majidi, 2015). Depending on the proportion or the type of LM liquid given, the composite can be thermally conductive, electrically conductive, or electrically insulated. For example, when an LMEE is electrically conductive, the droplets will make direct physical contact which means that the liquid metal could direct flow between the droplets. Since, when stretching the material, the number of contacts does not change, the electric resistance remains unchanged (Majidi, 2019).

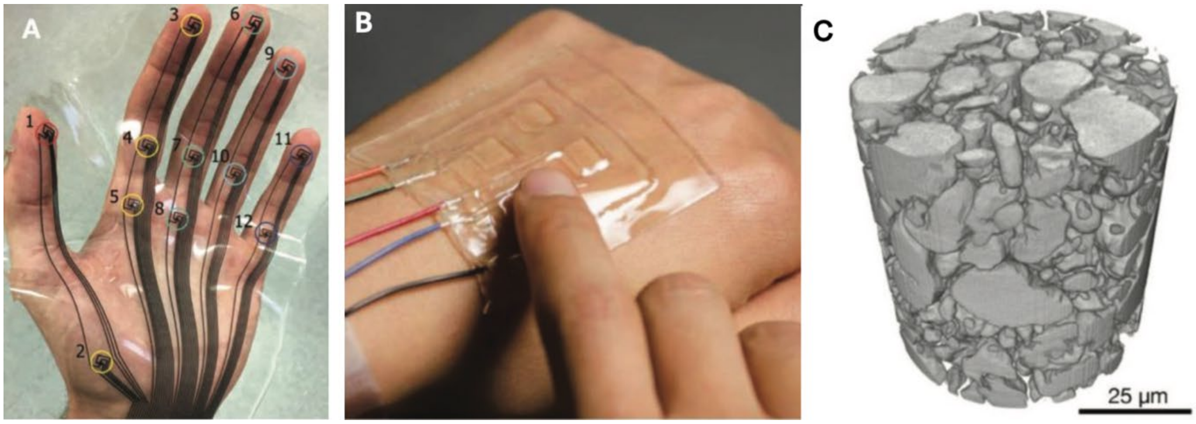

Figure 2. A) Soft sensing skin with traces of carbon-filled conductive elastomer (Charalambides & Bergbreiter, 2017). B) Tactile skin with ionically conductive gel (Sun et al., 2014). C) Liquid metal embedded elastomer composite with high electrical permittivity and thermal conductivity (Bartlett et al., 2017).

4D Printing Technology

In the recent five years, there has been a significant increase in research interest in four-dimensional printing, which was first introduced in 2013—roughly 30 years after the invention for three-dimensional printing. A wide number of applications are developing in the disciplines of bioengineering, material science, and engineering as a result of the fusion of the two rapidly developing technologies of soft robotics and 4D printing

Even though there isn't a standard definition for 4D printing, the main concept is that the object printed is dynamic or can be transformed according to the environment and different stimuli. 4D printing is inseparable from 3D printing technology and it is an extension of 3D printing: the 4D printing method is based on the concept to add a time-dependent component to the 3D printing method (Cui et al., 2019). Figure 3 provide an example comparing 3D printed object and 4D printing object using near-infrared light (Cui et al., 2019). Due to the maturing and mainstreaming of 4D printing, it is possible to provide an innovative solution to many medical needs such as precise positioning of drug delivery systems, designing and manufacturing tools for minimally invasive surgery, or engineering artificial tissue for repairing. Stereolithography (SLA) is one of the 4D printing methods for biomedical applications (Melchels et al., 2010). In this method, photosensitive ink materials are crosslinked into a desired 3D design using laser light in the visible or ultraviolet (UV) wavelengths. High-resolution printing is made possible by the comparatively limited surface area of emitted light which drives the photo-crosslinking process (Melchels et al., 2010). Moreover, the SLA method does not need to use syringes that do not give pressure on the printed material. As is usual for extrusion-based printing technologies like bioplotting, this nozzle-free printing technology efficiently reduces the possibility of clogging problems and the mortality of resident bioink (Melchels et al., 2010). Similar to the SLA, digital light processing (DLP) uses projectors and UV light to crosslink photosensitive inks into 3D geometries (Zhang et al., 2019). DLP has the capacity to efficiently reflect light over micro-mirror arrays which allows for the seamless construction of 3D and 4D architecture. Furthermore, researchers have described a technique for adjusting a DLP printer's light output using grayscale patterning to create cross-link densities for different structures to demonstrate reversible shape-changing characteristics (Wu et al., 2018). DLP will be the best printing method for mass production of dynamic materials in the future (Agarwal et al., 2021). Additionally, extrusion-based printing technologies like direct ink writing (DIW) and fused deposition modeling (FDM) are the best-characterized 3D printing techniques due to their ease of operation, portability, and low cost (Wan et al., 2020). DIW operates by the extrusion of liquid which offers choices in material selection and allows shape preservation of the ink after printing is finished; on the other hand, FDM is operated by giving heat to transform the state of the materials (Penumakala et al., 2020). FDM has the potential to reach 4D printing by adding Shape Memory Material filament.

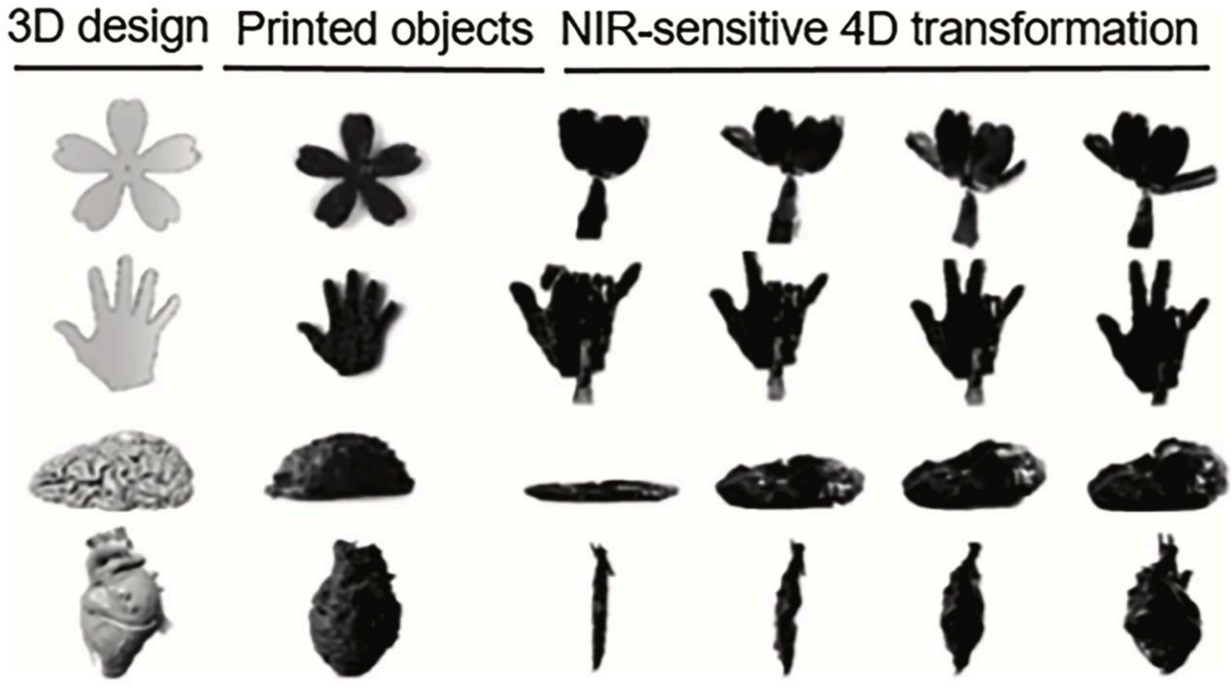

Figure 3. Transformation process for blooming flower, human hand gesture, and dilated brain and heart (Cui et al., 2019).

4D Printing Materials

The material used for 4D printing technology can be generalized as stimuli-responsive material (SRM); shape memory material is a large and major branch of SRM including shape memory alloys, shape memory hydrogels, shape memory composites, and liquid crystal elastomers (Kuang et al., 2019). The inclusion of SRM is the fundamental approach to transforming 3D printed statically objects into a 4D printed dynamic project. To start with shape memory polymers is the most used 4D printing material in biomedical application. As mentioned in the previous sections, SSP is highly biodegradable, biocompatible, and responsive to various stimuli, including light, chemicals, and heat. An individual SMP is first changed at a temperature higher than its typical transition temperature. Depending on the kind of polymer, this temperature may be the glass transition or the melting point. The SMP is then cooled below the transition temperature in order to fix the preset form. By heating the SMP enough above the transition point, the original form may then be recovered. The material's capacity for stretching at higher temperatures plays a critical role in deciding how well it can change into 4D printing shapes (Kuang et al., 2019). The shape memory alloy, which is also discussed in the previous section, is a material that requires programming to be transformed into different phases. Austenite, detwinned martensite, and twinned martensite are the three specific crystal forms in which SMAs may occur, and they each have one-way, two-way, and pseudoelasticity shape memory properties (Zhou et al., 2020). When a load is applied, a naturally occurring SMA that is twinned martensite can transform into a detwinned martensite crystal structure. The detwinned martensite construct transforms to the austenite phase as the temperature rises over the austenite transition point, providing shape recovery. Since the pseudoelasticity phase is not a thermally dependent property, it is often associated with the state of SMAs as a type of SMMs (Zhou et al., 2020). Shape memory hydrogels (SMHs) and composites (SMCs) have also emerged as candidates for 4D printing. SMHs can be used in 4D printing technology because of their swelling and deswelling characteristics; as a smart material, hydrogel could also respond to external stimuli. Achieving shape-changing activities, such as reversible folding or crimping, requires either hydrogels with different compositions to generate an unbalanced swelling property or a single hydrogel showing different swelling behaviors within the structure caused by different crosslink densities (Ding et al., 2019). Moreover, SMCs combine composite with the SMPs to improve 4D shape transformation. For example, graphene acts as a photo absorber that controls light penetration to create laser-induced internal stress which is needed to bring about a 4D metamorphosis in the printed structures. Graphene combined into thermos-responsive structures can reduce their shape recovery time while also making them able to go through NIR light-responsive 4D transformation (Miao et al., 2018). Liquid crystal elastomers (LCEs) are an extension of SMPs. Liquid crystal chain units, which make up the majority of LCEs, are capable of starting the phase transformation from mesomorphic to isotropic phases (Chen et al., 2020). The distinctive characteristics of LCEs are higher reversibility, quick deformation, and dominating amplitude.

Biomedical Application

Surgical Device

Over the past 30 years, there has been a significant advancement in surgery, moving from open surgery to minimally invasive methods that provide benefits including increased safety and less access stress, leading to quicker healing and scar minimization. Robotic technology can aid surgeons in enhancing their precision, predictability, and reproducibility. The utilization of stiff instruments, conventional mechanical coupling, and cable-actuated solutions are the primary methods for achieving accuracy in surgery (Cianchetti et al., 2018). Flexible instruments that are less exact but more appropriate are needed for endoscopy and catheter-like treatments in order to maneuver over difficult terrain and avoid barriers in order to access distant organs. Both strategies are merged in the realm of surgical endoscopy, making endoscopic operations as precise and efficient as conventional minimally invasive spine procedures (Cianchetti et al., 2018). Moreover, traditional endoscopic, surgical, and catheter-like treatments that need for downsizing can potentially benefit from smart materials. SMAs, for instance, have received a lot of attention due to their great qualities, which include good corrosion resistance and biocompatibility. Additionally, they may be manufactured in a variety of forms and dimensions. In an effort to discover the ideal balance between actuation speed and controllability, a number of catheters, active endoscopic capsules, and one-shot tiny surgical instruments (Ovesco) have been created (Menciassi et al., 2005). Superelastic materials have also been used in continuous and cannula-like robots. These medical gadgets extend the operating area and extend the reach of small-diameter catheters (Burgner-Kahrs et al., 2015). The initial use of FFAs, which are based on shrinkable polymers, is in colonoscopy (Phee et al., 2002). The ones made of inflating balloons enhance friction between the contraption and the gut walls, while those built of pneumatic bellows allow for self-propelled propulsion. These devices have been incorporated into active colonoscopy systems that resemble inchworms. There are various benefits to using current FFAs in surgical instruments. Due to their elastomeric makeup and lack of a direct electric source, they may be used in situations where there is radioactivity or magnetic fields, making them suitable for magnetic resonance imaging. Furthermore, since there is no stiff motion, leakages from the chambers that come into contact with tissues can be reduced (Cianchetti et al., 2018). FFAs have recently been employed as actuators for needle insertion and controlling cannula robots, as well as in surgical tools and manipulators (Comber et al., 2016).

Drug Delivery

Endoscopic and surgical instruments cannot be employed if the target location for a therapeutic process is extremely far away, as is the case for the inner portions of the brain and liver or if the therapy is based on the continuous release of medication by implanted devices for chronic diseases. Wired surgical instruments cannot navigate the capillaries to approach small target regions or give medications with a precise dosing profile. Therefore, many soft materials in soft robotics that are based on hydrogels and polymers that break down over time can be employed for medication delivery. The medicine can be delivered either passively or actively utilizing such soft robots, for instance by employing external stimuli like magnetic fields or temperature. In recent years, the science of soft micro-robotics has developed microscale medication delivery systems using hydrogels consisting of magnetic particles as demonstrated in Figure 4A (Fusco et al., 2014). Such sensitive nanomaterials can be used for diagnostics or therapy, and using a soft covering lowers the body's immunological reaction. An example could be the targeted delivery of biological agents using an untethered, self-folding, soft micro-robotic platform. Within a bilayer hydrogel matrix that reacts to near-infrared light are magnetic alginate microbeads in this device. When the ambient temperature hits 40°C, the hydrogel framework will open and discharge the beads after sealing and safeguarding them (Breger et al., 2015). The photo-crosslinked hydrogel is given a stiff fragmented polymer to increase its gripping abilities, and iron oxide nanoparticles are included to allow for remote magnetic steering. Furthermore, manufacturing techniques based on soft materials, including hydrogels and silicones, have partially supplanted classic lithography and allow for the microscale production of a variety of soft device geometries (Ricotti et al., 2017).

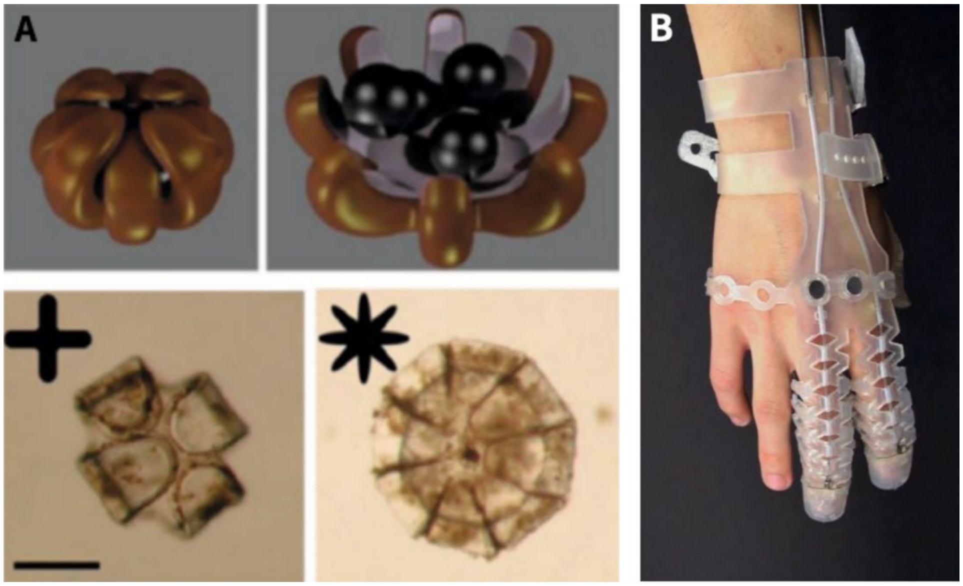

Figure 4. A) A soft device for drug delivery(Fusco et al., 2014). B) Exo-Glove Polymer(Kang et al., 2016).

Assistive Devices and Rehabilitation Equipments

An aging society's demands can be effectively met by assistive robots. While rigid robots can aid a human with daily tasks, soft robotics opens up new opportunities for secure and safe interaction. Robotic systems for help and rehabilitation rapidly evolved from stiff interfaces coupled with bioinspired actuators to fully soft wearable systems, with dynamically adjustable portions meant to maintain close contact and interact with those who need it. Supportive devices for the lower limbs are based on stiff interfaces and rotational joints that are mounted to the patient's body and operated by soft actuators, such as McKibben-like actuators, to enable ankle and hip recovery for bipedal locomotion (Gordon et al., 2006). With alternative kinds of soft actuators, such as FFAs, whose restraint technique is based on linear, rigid fibers, the same interface strategy may be applied (Kawamura et al., 2013).

Pneumatic actuators, on the other hand, can be used to create more conformable robotic systems for ankle and foot rehabilitation (Park et al., 2014). For tension and deformation detection, various sensors can be integrated into wearable devices; for example, elastomer-based sensors have been effectively installed on a soft exosuit (Wehner et al., 2013). These sensors are constructed of liquid metals inserted in the elastomeric chamber. Elongation of the chamber causes a difference in the cross-section, which causes variations in the sensor's electrical resistance.

Gloves can be used as exomusculature by opening and closing the patient's hand using an attached cable system (Delph et al., 2013). A Bowden system is utilized to send tensile force produced by servomotors mounted in a backpack to the fingers, assisting with flexion and extension. To improve comfort, each wire is routed through a different type of conduit. Each finger is separately activated to ensure design flexibility, with a total of five servomotors controlling ten tendons. A system based on this concept is the Exo-Glove as shown in Figure 4B(Kang et al., 2016).

Soft robotic technology's inherent benefits in standalone systems can also be used in rehabilitation equipment. A haptic device for hand neuromuscular therapy, for example, has been devised to provide adjustable stiffness in both hospital and residential situations (Yap et al., 2017). This handle is built on a pneumatic soft structure comprised of extremely flexible materials that operate as haptic interface actuators. Pressure increases in a closed or open circuit, as well as the use of replaceable sleeves that may be tailored to contain materials of varied stiffness, can be used to adjust the stiffness. Soft robotic technology can potentially be utilized to control tremors. The tremor power can be selectively reduced by using polymers that can modify their viscoelastic characteristics when magnetic fields are applied (Manto et al., 2003).

Prostheses and Artificial Organ

Soft robotic technologies have the potential to significantly enhance the use and acceptance of limb prosthesis. Similar to assistive and rehabilitative devices, soft robotic prosthetics must be portable and controllable in order to be developed. As a result, similar technical options for prosthetic devices have been researched. For instance, prosthetic hands composed of soft or flexible materials can have their fingers flexed using cable-driven methods. Finite element method models may be used for their design to maximize material properties (Mutlu et al., 2016). Elastomeric fingers can be 3D printed, which is an affordable and repeatable production technique. The way a prosthesis is made and used, as well as the patient's attitude and behavior, are all factors in how pleasant it is to wear. Research is being done to create prostheses that are more comfortable. By proactively or passively assisting the adaptation to body changes, soft robotic technologies can increase the conformability of conventional prostheses, such as artificial limbs made of stiff materials.

To recreate physiological processes in artificial organs, bioactive materials are required. It is the same requirements as endoscopic or surgical soft equipment applied to artificial organs or organ support devices, but because they are implanted, their material and production processes must be developed in a way that minimizes the fibrotic reaction of the human body (Cianchetti et al., 2018). Due to its use of a pump, softness, and the serious effects of organ malfunction on human health, the heart has been the focus of study into soft robotics. The mechanical functionality of the cardiac can be recovered with artificial supports.

It has also been investigated to totally replace the native organ with soft artificial hearts. Devices made using 3D printing are capable of mimicking the heart's structure and functionality. The soft design, shown in Figure 5, enables the recreation of biological blood flow and the movement of the human heart while pumping (Cohrs et al., 2017). Three distinct elastomeric chambers—a left ventricle, a right ventricle, and an expansion chamber—make up the design. When the expansion chamber is inflated by an external pump, the two ventricles are compressed and the blood is displaced as a result, creating a pulsatile flow. The majority of research on soft robotic technology used to create artificial hearts has been on the mechanical specifications, such as pressure, frequency, and occasionally operating cycles, that can be reached. However, biocompatibility and sustainability still need to be considered and enhanced in order to construct a long-lasting implanted device.

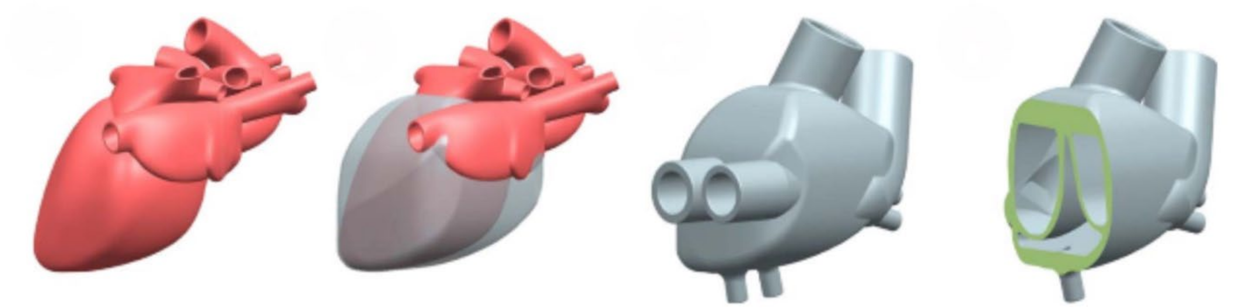

Figure 5. Illustration of the design procedure for the soft total artificial heart(Cohrs et al., 2017).

Body-Part Simulators

The development of body-part simulators is made possible by the combination of soft materials, elastic actuators, and flexible sensors in soft robotics. Normal body simulators have been created for the training of experts in increased healthcare simulation analysis and for the examination of body physiology with the aim of eliminating animal or patient experiments and are driven by the demand for standardized medical procedures. For instance, software simulators may be used to create realistic simulators for surgical training that react to external inputs. As a result, operators control virtual tools by using a master interface to operate on virtual surroundings that are particularly made to respond to pressures, torque multiplication, and deformations. To track touch and gauge the operator's force during inhalation or endoscopy, the soft sensor can be incorporated into the simulator. The Bionic Humanoid is a program that aims to create a human model using sensors and actuators to replace animal testing. In order to practice stripping the outer surface of the retina, a lifelike eye surgery simulator has been created as a part of this study. It is based on a polyhydrogel that has undergone chemical crosslinking (Someya et al., 2016).

Discussion

Soft robotics is mature enough for biomedical applications. However, there are many changes that need to be made. The capacity of materials for biomedical soft robots to meet biomedical needs that conventional rigid robots cannot perform includes controllability and adjustability of the mechanical characteristics, a manageable reaction to environmental stimulation, and structural adaptability to biological conditions. Therefore, advancements in the design of intelligent soft materials are essential for the creation of biomedical soft robots in the future. To 4D print active, multimaterial components into a single package for usage, in the end, is the next hurdle. Even while the scientific community has reached a new high with the advent of 4D printing, it is important to note that, in contrast to traditional rigid robots, soft robots require whole new designs and manufacturing processes, making knowledge transfer essential. For instance, there aren't many soft materials with good characteristics that can be utilized widely for 4D printing. As a result, new polymer discoveries by chemists in the future can flourish in the field of soft robotics.

The most often employed actuation method in soft robotics is fluidic actuation, which has received much research. In order to create soft actuators, fluidic actuation and elastomeric chambers have been coupled over the past ten years. Due to their adaptability and simplicity of manufacture, FFAs have emerged as the industry standard for soft robotic actuation in the majority of applications. A significant step towards biomimicry, which is crucial for surgical devices, assistive and rehabilitative robots, and realistic simulations, has been made possible by the mixing of elastomers and fluids with various configurations and elastomeric chamber alterations. Not only FFAs become the main trend, but SMAs will also be the most commonly used material and actuator, the elastic property is suitable for a robot to be soft and its low manufacture cost along with some matured design indicated it is for real ready for applicable use.

One of the most important aspects and challenges of biomedical soft robotics is biocompatibility and power source. The majority of new actuation technologies do not work well with biological applications. Clinical translation is frequently hindered by high temperatures, powerful electric fields, and high currents. One of the possible solutions that can be adopted in the future may be to power wearable technology or prosthetics with ATP, the human body's natural energy source (Roseman et al., 2015). For the sensing and management of prostheses, electrical signals are currently used in both artificial and natural systems; alternatively, the user might supply a chemical power source (Roseman et al., 2015). To create such new energy sources, biology, materials engineering, and chemistry will need to work together.

Currently, biocompatibility issues are mostly dealt with by using inert substances that don't trigger an immune reaction, such as silicones or hydrogels. However, better active materials and innovative actuation and sensing concepts are needed to integrate biocompatibility, biomimicry, mobility, and usefulness. Combining tissue engineering methods with materials science for surgical instruments and implants would be a significant advancement. Moreover, a significant revolution in equipment design is necessary to keep up with the worldwide trend toward personalized medicine and patient-specific medical treatments.

Conclusion

It should be clear that soft robots offer the next generation a fresh perspective on robotics that will entice investors and businesses to launch new products. The definitive momentum can be gained by soft robotics since the latter can address and solve a number of issues that current technologies have not been able to address, rather than competing with conventional robots.

Suitable interactions between the environment and the body are necessary for robotic actuation. Robots often apply pressures and regulate the movement of the system using nondeformable parts and precise controls. This conventional approach, which is based on rigid bodies, is being contested by soft robots, who are cogently establishing new principles for attaining robotic actuation with soft bodies. In this essay, I discussed a few of the soft robot actuation methods, which vary from micrometer to centimeter size and greater. With an emphasis on the basic concepts that underlie the motions accomplished in the soft robots, as well as the soft robotics biomedical application, the most current or most noteworthy achievements, were given. A broad variety of materials that may be stimulated thermally, hydraulically, magnetically, pneumatically, or electrically have been examined. Chemicals and pressure differences had an effect on other materials. The soft actuators under discussion were either based on polymers, fluids, organic material, pressure, or even hybrid materials that combine biological cells and matter. The examples reported in this paper about the possible actuators and materials currently suitable to build them is a proof that soft robotics is mature enough to pave the way to the next generation of biomedical applications, opening up brand new horizons for prosthetics and artificial organs.

Limitations

Most sources are from recent ten years. However, the development of soft robotics is speeding which might causes the novel actuators or materials discussed in the article to be outdated.

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