Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 08, August-2024

# Review of Soft Robots using Artificial Intelligence (AI)

Authors Name:Prashant Jadhav,Sandeep Thorat,Bhumeshwar Patle,Nishigandha Patel
Department of Robotics Engineering.
MIT ADT University Pune.
Pune, India

***Abstract-*** **In recent years, breakthrough has been made in the field of artificial intelligence (AI), which has also revolutionized the industry of robotics. Soft robots featured with high-level safety, less weight, lower power consumption have always been one of the research hotspots. Recently, multifunctional sensors for perception of soft robotics have been rapidly developed, while more algorithms and models of machine learning with high accuracy have been optimized and proposed. Designs of soft robots with AI have also been advanced ranging from multimodal sensing, human–machine interaction to effective actuation in robotic systems. Nonetheless, comprehensive reviews concerning the new developments and strategies for the ingenious design of the soft robotic systems equipped with AI are rare. Here, the new development is systematically reviewed in the feld of soft robots with AI. First, background and mechanisms of soft robotic systems are briefed, after which development focused on how to endow the soft robots with AI, including the aspects of feeling, thought and reaction, is illustrated. Next, applications of soft robots with AI are systematically summarized and discussed together with advanced strategies proposed for performance enhancement. Design thoughts for future intelligent soft robotics are pointed out. Finally, some perspectives are put forward.**

Keywords— ***Soft robotic systems; Artificial intelligence;Soft robot Design tactics; Review and perspective, Electroactive polymers***

## INTRODUCTION

Robots can be classified hard or soft on the basis of material used.Soft robotics is subfield of robotics that concerns with the deisgn ,control, and fabricationof robots composed of compliant materials instead of rigid links.Ceramics and hard palstic is used as material

Soft robots provide an opportunity to bridge the gap between machines and people. In contrast to hard bodied robots, soft robots have bodies made out of intrinsically soft and/or extensible materials (e.g. silicone rubbers) that can deform and absorb much of the energy arising from a collision. Soft robots have a continuously deformable structure with muscle-like actuation that emulates biological systems and results in a relatively large number of degrees of freedom as compared to their hard-bodied counterparts.

Soft robots (Fig. 1) have the potential to exhibit unprecedented adaptation, sensitivity, and agility. Soft bodied robots promise to

1) Move with the ability to bend and twist with high curvatures and thus can be used in confined spaces; 2) Deform their bodies in a continuous way and thus achieve motions that emulate biology; 3) Adapt their shape to the environment employing compliant motion and thus manipulate objects, or move on rough terrain and exhibit resilience;4) Execute rapid, agile maneuvers, such as the escape maneuver in fish

Robots with soft bodies have tremendous potential where rigid bodies can not work useful in disaster relief scenarios Generally leans towards machines that are dominantly entirely soft.Nature is source of inspiration for soft robot design

Animals are composed of soft components and they appear to exploit their softness for efficient movement in complex environment.Soft robots are designed to link familiar creatures especially soft organisms like octopus.Their flexibility and compliance makes them difficult to control.

Therefore,they can carry soft and fragile payloads without causing damage. Using large strain deformation, they can squeeze through openings smaller than their nominal dimensions.

This makes them ideal for applications such as personal robots that interact with people without causing injury,service and painting robots that need high dexterity to reach confined spaces, medical robots, especially for use in surgery, and defence and rescue robots that operate in unstructured environments.

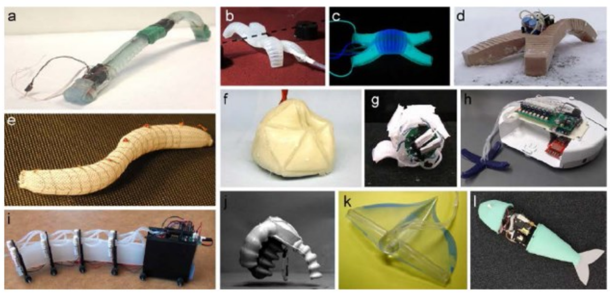


Figure 1: Mobile soft robotic systems inspired by a range of biological systems, demonstrating a) caterpillar-inspired locomotion[20], b) a multi-gait quadruped[29], c) active camouflage[35], d) walking in hazardous environments[10], e) worm-inspired locomotion[88], f) particle jamming-based actuation[42], g) rolling powered by a pneumatic battery[28], h) a hybrid hard/soft robot[89], i) snake-inspired locomotion[8], j) jumping powered by internal combustion[58], k) manta-ray inspired locomotion[100], and l) an autonomous fish[11].

Fig. 1. Soft Robotic System

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 08, August-2024

The main objective of this document is to give an overview of the current state of the art of the field and to draw the attention on the main challenges that researchers could tackle to advance the area with both scientific and technological impacts.

Soft robotics is still in its first ramp-up phase of research in terms of technological maturity and systems applicability. Since the first years, the field has been characterized by a multi-facet scenario, investigating unconventional materials, studying the relations between morphologies and functionalities, challenging problems of self-organizations, self-stability and self-assembly.

Soft robotics can be a game changer to effectively design artificial systems with a null impact in the biological world. Soft bioinspired robots of the future will be able to adapt and evolve, will be made of recyclable or biodegradable or biohybrid materials, and will use renewable forms of energy without weighing on the natural eco systems energy balance. Similarly to natural systems, these green soft robots will be developed to follow a life-like circle and to better integrate into the natural ecosystem, creating a new wave of environmentally-responsible machines

It is observed that when introducing AI into soft robotic systems, the soft robots can be good at self learning, problem-solving and decision-making which are important features for self-regulating behaviors, and are qualified to be applied in the dynamic environment of the real world (Fig. 1). Despite of the fact that the introducing of AI into the traditional rigid robots can also bring about a lot of advantages, the combination of AI and soft robots can realize many other effects which cannot accomplished by rigid robots with AI. Compared with their counterparts of the traditional robots fabricated from the rigid materials, the soft robots have the advantages of compliance, dexterity, softness, deform ability, high-level safety, less weight, lower power consumption, less manufacturing costs and safer contact to live tissues, which have been regarded as the bridge between machines and biological organism

## I..ACTUATION

### A. Actuator:

While most soft robot prototypes have used pneumatic or hydraulic actuation, a great deal of research has focused on the development of electrically activated soft actuators composed of electroactive polymers (EAPs), which have also led to prototype systems. Since energy is typically most readily stored in electrical form, and computation is usually done on electronic circuits, it may be more efficient to directly use electrical potential to actuate soft robots. Types of EAPs include Dielectric EAPs, ferroelectric polymers, electroactive graft polymers, liquid crystal polymers, ionic EAPs, electrorheological fluids, ionic polymer-metal composites, and stimuli-responsive gels.

### B. Sensors

The compliance and morphology of soft robots precludes the use of many traditional sensors including encoders, metal or semiconductor strain gages, or inertial measurement units (IMUs). While flexible-bending sensors based on piezoelectric polymers are available as commercial products, these may not be appropriate due to the need for all elements of the system to be both bendable and stretchable. Soft, stretchable electronics may enable new sensing modalities The basis of proprioceptive sensors (fig no: 2)for a soft robot is usually either non-contact sensors or very low modulus elastomers combined with liquid-phase materials. Since soft robots are actuated by generating curvatures, proprioception relies on curvature sensors. The low modulus of proposed elastomer sensors (which have characteristic moduli in the range of 105-106 Pa) impart minimal change on the impedance of the underlying structures. These sensors generally have layered structures, where multiple thin elastomer layers are patterned with microfluidic channels by soft lithography. The channels are subsequently filled with a liquid conductor (e.g. gallium-containing alloys such as eutectic gallium-indium or eGaIn). With layered channel geometries, it is possible to tailor sensors for measuring various strains including tensile, shear, or curvature.

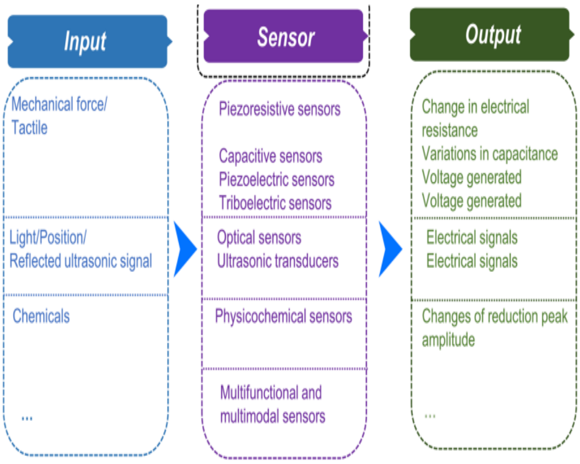


Fig no 2:Working mechanism of sensors

## II.MACHINE LEARNING

the soft robots with AI are managed to learn from the history data and deal with new situations. In a typical ML process, frstly, the vast amount of history data in the working environment detected by the sensors can be learned, during which process a variety of algorithms can be selected for extracting useful information from large quantities of data. Inspired by biological processes, more suitable algorithms and architectures for analogous tasks in soft robots can be developed. It is during the learning process that the information is processed to knowledge which is put into the repository. Since various information is provided by the external environment to the learning systems, the quality of information can exert an important effect on the complexity of the learning realization.

In the soft robotic system, the data collected by the sensors are applied as input, such as tactile, temperature, chemicals and so on. Various goals can be reached by the soft robots by making use of ML, including but not limited to object recognition, classifcation, detection of touch modalities and perception of surface textures and material types. ML algorithms are able to learn from experiences without being programmed. For instance, k Nearest Neighbor (kNN) algorithm is a classification algorithm, as data points are grouped into several classes, and

this algorithm tries to classify the sample data point supplied to it. This algorithm is features with simpleness and easy implementation. The deep neural network (DNN), which is also known as a feedforward network, is an artificial neural network (ANN) with multiple fully connected layers inside it.

The features are extracted from the data, and the most optimal way by which the input can be converted into the output is acquired. A significant amount of data is worked on by the DNN. Convolutional neural network (CNN) is another deep network that is inspired by visual perception and managed to extract features from data with convolution structures. CNN has a series of advantages. For example, each neuron in CNN is connected to only a small number of neurons of the previous layer, as a result of which parameters are reduced and convergence is speeded up

## III.APPLICATION

In this section we review some of the systems and that have been developed to date to address a variety of potential applications to locomotion, manipulation, and human-machine interaction.

### A.Locomotion

Recent work has explored the modes of locomotion possible with (or enabled by) soft bodies . Notably, studies of caterpillars have led to a soft robotic systems, as well as a further understanding of the control of motion in these animals. An understanding of worm biomechanics also led to a bioinspired worm design composed of flexible materials and actuated by shape memory actuators (SMAs), and an annelid inspired robot actuated by dielectric elastomer. A European initiative studied the biomechanics and control of the octopus to produce a soft robotic prototype,. Likewise, a self-contained, autonomous robotic fish actuated by soft fluidic actuators was demonstrated to be capable of forward swimming, turning, and depth adjustment.

This robot can execute a c-turn escape maneuver in 100 milliseconds, which is on par with its biological counterpart, enabling the use of this robot as an instrument (i.e. a physical model) for biological studies. Soft robotics projects have also explored quadrupedal locomotion,, rolling, and snake-like undulation. Jumping has also been achieved using internal combustion of hydrocarbon fuels to achieve rapid energy release.

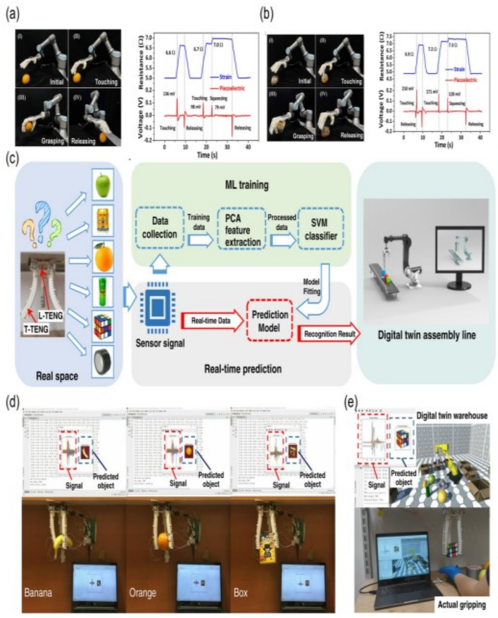


Fig No:3 – a) Photographs of the process illustrating how the fresh orange was sorted by a manipulator, and the resistance and voltage output obtained from the sensors. b) Photographs of the process illustrating how the rotten orange was sorted by a manipulator, and the corresponding signals from the sensors. c) Flow diagram illustrating how the soft robot worked in digital twin system. d) Object prediction efect provided by this system, and e) the system interface for object recognition and digital twin warehouse application

Published by :
http://www.ijert.org
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 08, August-2024

Many of the exciting applications for soft robotics (e.g. search-and-rescue, environmental monitoring), require an autonomous, mobile system. However, most experimental soft robotic systems rely on power and/or control signals delivered through pneumatic and/or electrical tethers. Since typical actuation power sources (e.g. air compressors, batteries) are relatively heavy (e.g. 1.2 kg10), tethers greatly simplify system design by significantly reducing the required carrying capacity. One approach to achieving mobile systems is to tether a soft robot to a mobile rigid robot with a greater carrying capacity. Untethered mobile systems have circumvented the challenge of carrying heavy power sources by operating underwater or rolling on a surface, such that actuation system masses do not have to be lifted against gravity. Another approach has developed materials and designs tailored to operate at working pressures high enough to carry large payloads.

B.Manipulation

Manipulation is one of the canonical challenges for robotics. Soft systems have a natural advantage over rigid robots in grasping an manipulating unknown objects since the compliance of soft grippers allows them to adapt to a variety of objects with simple control schemes. Grippers which employ isothermal phase change due to granular jamming have taken advantage of this feature of soft systems. Underactuated grippers composed of silicone elastomers with embedded pneumatic channels have also demonstrated impressive adaptability. Commercially developed systems have also demonstrated manipulation with lightweight grippers composed of inflated flexible (but not extensible) material. As one of the more mature applications of soft robotic technology, companies have begun to produce soft robotic manipulators (e.g. Pneubotics an Otherlab Company, Empire Robotics Inc., Soft Robotics Inc.).

## C.Medical/Wearable Applications

One of the natural advantages of soft robotic systems is the compatibility of their moduli with those of natural tissues for medical and wearable applications. Rigid medical devices or orthoses run the risk of causing damage or discomfort to human or animal tissue.

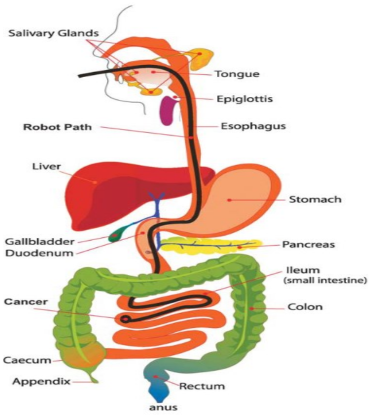


Fig:No 4:Path planning for reaching a cancer in small intestine from oral cavity

Additionally, it can be difficult to perfectly replicate the motion of natural joints with rigid orthodics. One possibility is to integrate a degree of compliance into wearable devices, Recently, researchers have begun to look at medical wearable applications for soft robotics including soft wearable input devices (e.g. wearable keyboards), soft orthodics for human ankle-foot rehabilitation, soft sensing suits for lower limb measurement, soft actuated systems for gait rehabilitation of rodents who have had their spinal cord surgically cut, and a soft system for simulation of cardiac actuation

D.Soft Cyborgs

Recent work has begun to investigate robotic systems that directly integrate biological (as opposed to artificial, biologically compatible) materials. Since biological materials are often very soft, the resulting systems are soft robotic systems (or perhaps they would be more aptly named soft cyborgs). For example, microbes which digest organic material and produce electricity have powered artificial muscles for autonomous robots96, and cardiomyocytes have been used to power a jellyfish inspired swimming cyborg97. One challenge with using swarms of inexpensive soft robots for exploration is that of retrieving the robots once the task is completed. One way to avoid this problem is to develop biodegradable and the soft robots powered by gelatin actuators98. Since gelatin is edible, there may also be medical applications for this technology.

E.Underwater robots

Soft materials are an important direction of progress for robotics . Soft robotics technologies contribute to a sustainable progress and enable further abilities in underwater robots. Inspired by benthic marine species, soft robots can negotiate the interaction with the seabed and other underwater structures. Based on embodied intelligence principles, they gain unprecedent locomotion ability, with self-stabilizing gaits, efficient computationally and energetically.Such abilities enable a plethora of applications, underwater. Benthic soft robots can explore the seabed,which is of great interest for studies in biology, ecology, oceanography, and for other scientific purposes. It is of interest for monitoring and management of environmental resources and meteorological services.

Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 08, August-2024

## IV.FUTURE SCOPE

### A.To Be Fully Learned from Nature

The real-world application has put forward more abundant and higher standard demands for the soft robots. A lot of work has been carried out via fully learning from the living creatures which can endow the soft robotic systems with various advantages and make them more qualified for the realworld applications The behaviors of living creatures, ranging from land animals, aquatic animals, to aerial animals have been carefully observed, and researchers have come up with many ideas inspired by the outstanding features in actuation of these living creature. Efforts have been made from several levels, including the design of soft materials, the preparation of flexible electronics, the improvement of the fabrication method and so on

### B.To Be Autonomously Operated

It is desirable for the components of the soft robots to be able to work without the consumption of the external power for the purpose of saving energy. To address this challenge, one approach is to design the systems with self-powered abilities, and some other method, like to make full use of the external stimuli, can also be adopted. In regard to the former method, a diversity of technology can be taken advantages of, including but not limited to triboelectric, piezoelectric and hygroscopic technology. The latter approach refers to those soft robots that can get the energy for their operation from the manipulated objects

### C.To Be Combined with Virtual Reality

The rapid advancements of AIoT have stimulate the development of smart soft robots for the digital-twin-based remote interactive applications, like robotic-assisted industrial automation and virtual shopping with immersed experiences . The up-to-date status of the physical objects distributed sensory network, which include but not limit to the size, color, shapes, position and movement, can be detected and collected . This cyber-physical system makes it possible for people to get advanced interaction virtually and remotely, so that real-time parallel control in unmanned working spaces can come true. Additionally, when introducing the augmented reality (AR) or virtual reality (VR) to the soft robots with AI, the robotic VR can make it possible for people to interact with robots in a combined manner,

## V.CONCLUSION:

Overall, the recent development, including but not limited to intelligence solutions to the sensing devices, ML and actuation systems of the soft robotics, is reviewed in depth. With the rapid development in the AI area, significant progress has also been made in the field of smart soft robots owing to their high-level safety, lower power consumption, less manufacturing costs and so on.

## REFERENCES

[1] Advanced Design of Soft Robots with Artificial Intelligence Ying Cao, Bingang Xu, Bin Li , Hong Fu
[2] Nano-Micro Lett. (2024) 16:214
[3] Daerden F, Lefeber D. Pneumatic artificial muscles: actuators for robotics and automation. Euro J Mech Environ Eng 2002;47:11–21.
[4] Ilievski F, Mazzeo AD, Shepherd RF, Chen X, Whitesides GM. Soft robotics for chemists. Angew Chem Int Ed 2011;50:1890–1895.
[5] Suzumori K, Iikura S, Tanaka H. Development of flexible icroactuator and its applications to robotics mechanisms.Proceedings of 1991 IEEE International Conference on Ro-
[6] botics and Automation, Sacramento, CA.
[7] Lacour SP, Wagner S, Huang Z, Suo Z. Stretchable gold conductors on elastomeric substrates. Appl Phys Lett 2003;82:2404–2406.
[8] Rogers JA, Someya T, Huang Y. Materials and mechanics for stretchable electronics. Science 2010;327:1603–1607.
[9] Cheng S, Wu Z. Microfluidic electronics. Lab Chip 2012;12:2782–2791.
[10] Quake SR, Scherer A. From micro- to nanofabrication with soft materials. Science 2000;290:1536–1539.
[11] Xia Y, Whitesides GM. Soft lithography. Angew Chem Int Ed 1998;37:550–575.
[12] Unger MA, Chou H-P, Thorsen T, Scherer A, Quake SR.Monolithic microfabricated valves and pumps by multilayer soft lithography. Science 2000;288:113–116.
[13] Madden JDW, Vandesteeg NA, Anquetil PAA, Madden PGA, Takshi A, Pytel RZ, et al. Artificial muscle technology:physical principles and naval prospects. IEEE J Ocean Eng 2004;29:706–728.
[14] Qian B, McKinley GH, Hosoi AE. Structure evolution in electrorheological fluids flowing through microchannels. Soft Matter 2013;9:2889–2898.
[15] Alici G, Huynh NN. 2006. A robotic gripper based on conducting polymer actuators. Paper presented at: AMC'06. Istanbul, Turkey: IEEE, pp. 472–477.
[16] Alici G, Huynh NN. 2007. Performance quantification of conducting polymer actuators for real applications: a microgripping system. IEEE/ASME Trans Mechatron. 12:73–84+
[17] .Anshelevich E, Owens S, Lamiraux F, Kavraki LE. 2000. Deformable volumes in path planning applications. Int Conf Robotics Automation. 3:2290–2295.
[18] .Arena P, Bonomo C, Fortuna L, Frasca M, Graziani S. 2006. Design and control of an ipmc wormlike robot. IEEE Tran Sys Man Cybernet—Part B: Cybernet. 36(5):1044–1052.
[19] Trivedi, Deepak, Rahn, Christopher D., Kier, William M. and Walker, Ian D.(2008)'Soft robotics: Biological inspiration, state of the art, and future research',Applied Bionics and Biomechanics,5:3,99 — 117
[20] Liu J, Hu H, Gu D. 2006. A layered control architecture for autonomous robotic fish. In: Proc. IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems. 9–15 October 2006; Beijing, China: IEEE, p. 312–317.
[21] Madden JDW, Vandesteeg NA, Anquetil PA, Madden PGA, Takshi A, Pytel RZ, Lafontaine SR, Wieringa PA, Hunter IW. 2004. Artificial muscle technology: physical principles and naval prospects. IEEE J. Oceanic Eng. 29:706–728.
[22] Madden J, Genereux N, Shkuratoff K, Star AVD, Poon D, Irwin D, Cheng P, Hsu G, Filipozzi, L. 2007. Electroactive polymer actuator online database. In. Proceedings of SPIE—The International Society for Optical Engineering. Bellingham, WA: SPIE Press p. 65240P.
[23] . Mangan E, Kingsley D, Quinn R, Chiel H. 2002. Development of a peristaltic endoscope. IEEE Int Conf on Robot Automat. Washington DC, USA: IEEE, 1:347–352.

[24] Markenscoff X, Ni L, Papadimitriou CH, 1990. The geometry of grasping. Int J Robot Res. 9:61–74. McCurley RS, Kier WM. 1995. The functional morphology of starfish tube feet: the role of a crossed-fiber helical array in movement. Biol Bull. 188:197–209.
[25] McIsaac K, Ostrowski J. 2003. Motion planning for anguilliform locomotion. Robot. Automat. IEEE Trans. 19(4):637– 652. Meijer K, Bar-Cohen Y, Full RJ. 2003. Biological inspiration for musclelike actuators of robots and biologically inspired intelligent robots.
[26] Bellingham, WA: SPIE Press, pp. 25– 46. Meijer K, Rosenthal M, Full RJ. 2001. Muscle-like actuators? A comparison between three electroactive polymers. Proc SPIE—Inter Soc Optical Eng. 4329. Bellingham WA: SPIE Press, 7–15.
[27] .Menciassi A, Dario P. 2003. Bio-inspired solutions for locomotion in the gastrointestinal tract: background and perspectives. Philos Trans R Soc. 361(1811):2287–2298.
[28] Meyers JJ, O'Reilly JC, Monroy JA, Nishikawa KC. 1999. Mechanism of tongue protraction in microhylid frogs. J Exp Biol. 207:21–31.
[29] Micromuscle. 2007. Available from: www.micromuscle.com 17 October 2008.