International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 6 Issue 3, March-April 2022 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Soft Robotics: An Overview

Matthew N. O. Sadiku[1], Uwakwe C. Chukwu[2], Abayomi Ajayi-Majebi[3], Sarhan M. Musa[1]

[1]Roy G. Perry College of Engineering, Prairie View A&M University, Prairie View, TX, USA
[2]Department of Engineering Technology, South Carolina State University, Orangeburg, SC, USA
[3]Department of Manufacturing Engineering, Central State University, Wilberforce, OH, USA

ABSTRACT

Robotics is an interdisciplinary discipline embracing mechanical engineering, electrical engineering, computer science, and others. The goal of robotics is to create intelligent machines (called robots) that behave and think like humans. Soft robotics is an emerging branch of robotics that combines mechatronics, control, chemistry, plastics engineering, material science, computer science, and biomimetics. It involves the design, control, and fabrication of robots composed of compliant materials, instead of rigid links. It is one of the fastest growing issues in the robotic community. It has the potential to revolutionize the role of robotics in society and industry. The paper provides a concise overview of soft robots and their diverse applications.

KEYWORDS: *robots, robotics, bio-inspired robotics, soft material, soft sensors, soft matter*

How to cite this paper: Matthew N. O. Sadiku | Uwakwe C. Chukwu | Abayomi Ajayi-Majebi | Sarhan M. Musa "Soft Robotics: An Overview" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-6 | Issue-3, April 2022, pp.2139-2145, URL: www.ijtsrd.com/papers/ijtsrd49924.pdf

IJTSRD49924

Copyright © 2022 by author (s) and International Journal of Trend in Scientific Research and Development Journal. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0) (http://creativecommons.org/licenses/by/4.0)

International Journal of Trend in Scientific Research and Development
IJTSRD
International Journal of Trend in Scientific Research and Development
ISSN: 2456-6470

INTRODUCTION

Robots are all around us and their uses are increasing every day. They are taking over the world. Robots have moved from science fiction to your local hospital, where they are changing healthcare. Today, robots perform vital functions in homes, industries, outer space, hospitals, and on military settings. Robots can support, assist, and extend the services of healthcare professionals. Robotics and autonomous systems are regarded as the fourth industrial revolution.

A robot is a system that contains sensors, control systems, power supplies, and software all working together to perform a task. It functions as an intelligent machine, meaning that, it can be programmed to take actions or make choices based on input from sensors. Robots are commonly used in dangerous environments where humans cannot survive such as defusing bombs, finding survivors in unstable ruins, welding, and exploring mines and shipwrecks. They are designed to perform a wide variety of programmed tasks. They may help manufacturers increase precision, repeatability, and productivity [1].

Robotics is a branch of engineering and computer science that involves the conception, design, manufacture, and operation of robots. It involves using electronics, computer science, artificial intelligence, mechatronics, and bioengineering. Traditionally, robotic systems are usually made of rigid materials such as steel and aluminum. Material rigidity is often determined by the modulus of elasticity, or Young's modulus. Elasticity dictates the reliability of soft robots.

Today, robots generally make use of soft, elastic, and flexible materials in order to survive in complex unstructured environments. There has been a growing interest in the use of unconventional materials in robotic systems due to their underlying mechanical properties such as body shapes, elasticity, viscosity, softness, density and stickiness. The goal is to design and construct robots with physically flexible-bodies and electronics. This will make actuators and sensors smaller, softer, and deformable [2]. Soft robots have some inherent advantages over conventional "hard" robots. These include safe human-machine interaction, adaptability to wearable devices, and simple gripping system. Some soft robots often use pneumatics or hydraulics to actuate their bodies.

WHAT IS A ROBOT?

The word "robot" was coined by Czech writer Karel Čapek in his play in 1920. Isaac Asimov coined the term "robotics" in 1942 and came up with three rules to guide the behavior of robots [3]:

1. Robots must never harm human beings;
2. Robots must follow instructions from humans without violating rule 1,
3. Robots must protect themselves without violating the other rules.

Robotics has advanced and taken many forms including fixed robots, collaborative robots, mobile robots, industrial robots, medical robots, police robots, military robots, officer robots, service robots, space robots, social robots, personal robots, and rehabilitation robots [4,5]. Robots are becoming increasingly prevalent in almost every industry, from healthcare to manufacturing.

Although there are many types of robots designed for different environments and for different purposes/applications, they all share four basic similarities [6]: (1) All robots have some form of mechanical construction designed to achieve a particular task; (2) They have electrical components which power and control the machinery; (3) All robots must be able to sense its surroundings; a robot may have light sensors (eyes), touch and pressure sensors (hands), chemical sensors (nose), hearing and sonar sensors (ears), etc. (4) All robots contain some level of computer programming code. An autonomous robot must have a basic body structure (the chassis), sensors, a central control system (microprocessor), actuators (motors), a power supply and an overall program for its behavior. Programs are the core essence of a robot since they provide intelligence. There are three different types of robotic programs: remote control, artificial intelligence, and hybrid. Some robots are programmed to faithfully carry out specific actions over and over again (repetitive actions) without variation and with a high degree of accuracy. Some advantages and disadvantages of robots are shown in Figure 1 [7].

The advantages of robotics include heavy-duty jobs with precision and repeatability. Despite these advantages, there are certain skills to which humans will be better suited than machines for some time to come. Humans have the advantages of creativity, decision-making, flexibility and adaptability.

BACKGROUND ON SOFT ROBOTICS

Early robots were simple mechanical automated machines. Modern robots employ microprocessors and computer technology. They can be programmed and "taught" to perform certain tasks. They are taking on more "human" traits such as sensing, dexterity, remembering, and trainability. Conventional robots have rigid underlying structures that limit their ability to interact with their environment. They find it difficult to operate in unstructured and highly congested environments

Started in the years 2006-2008 as a niche of robotics, soft robotics has become a well-known sector and can be a game changer. Soft robotics is still at its infancy as far as technological maturity is concerned. Efforts in soft robotics are connected to progress in the broader field of soft-matter engineering, which creates machines and robotic systems out of fluids, elastomers, gels, and other soft materials. Progress made by additive manufacturing techniques like 3D- and 4D-printing allows the design of complex structures used in soft robotics. Recently, 3D printing has been used as a key technology to fabricate soft robots because of high quality and printing multiple materials [8]. For example, Figure 2 shows a soft robotic gripper developed using 3D printing [9]. A soft robot is an engineered mobile machine which is constructed from soft materials.

Robotics evolved to allow human- or animal-like functions to be carried out by machines, with greater strength, speed, and accuracy, in a roughly human- or animal-shaped machine. All robots to some degree and soft robots in particular are inspired from biological systems which consist of soft materials. Biological inspiration means that we understand the principles underlying the behavior of animals and humans and transfer them to the development of robots. Figure 3 illustrates bioinspiration [10]. Soft robotics enables the use of soft materials in designing soft machines and devices with large scale flexibility, deformability, and adaptability. Soft robots are characterized by actuation, sensing, structure, control and electronics, materials, fabrication system, and applications. Most of them are inspired by flexible creatures like octopus and caterpillars. Since soft robots are made of compliant materials, the effect of temperature must be considered. Earlier versions of soft robots were all tethered, which works fine in some applications.

Figure 4 depicts various soft robots with different degree of stiffness [11].

"Hard" robotic engineers incorporate soft technologies into their designs with the objective of endowing robots with new, bioinspired capabilities that permit adaptive, flexible interactions with unpredictable environments. Incorporating soft technologies can reduce the mechanical and algorithmic complexity in robot design. This will expedite the evolution of robots that can safely interact with humans and natural environments [12,13].

The field of soft robotics is a heterogeneous, multi-disciplinary field. The community of soft robotics consists of robotics engineers, biologists, computer scientists, mathematicians, to mention a few. Soft robotics engineer need to think completely differently, employ different materials, and use different energy sources.

Manufacturing a soft robotic system requiring using the proper innovative material, applying the appropriate manufacturing methods, and adapting the architecture of the system. Soft and deformable structures are crucial in the systems that deal with uncertain and dynamic task-environments.

APPLICATIONS OF SOFT ROBOTS

Soft robots can perform feats no current machines can accomplish. Soft robotics is expected to play an important role in moving robots into people's daily life. Soft robotics systems are being applied to real-world situations. Applications of soft robotics include locomotion, manipulation, exploration, manufacturing, human-robot interaction, biomedicine, medical devices, and wearable devices. Some of these applications are discussed as follows.

- **Biomedicine:** Soft robots are used for biomedical applications, such as in surgery, diagnosis and drug delivery, wearable and assistive devices, prostheses, artificial organs and tissue-mimicking simulators [14]. Magnetically actuated soft robots are promising tools to access delicate and narrow regions of the body and perform minimally invasive disease diagnosis and treatments. Soft surgical robots have been developed for minimally invasive surgery.
- **Wearable Devices:** Since soft robots are modeled after biological systems, soft robotics are useful for medical and wearable devices. Soft robotics technologies could be used in a wearable pair of human wings. They provide physical assistance to those humans who have motor impairments or are engaged in strenuous tasks. Figure 5 shows some wearable soft robots [15].
- **Rehabilitation:** Soft medical devices have been developed for rehabilitation and assistance. Soft robotics have been used in the field of medical applications such as in medical/rehabilitation devices. Soft robots can assist stroke patients to improve their hand function, providing a personalized and affordable solution for stroke rehabilitation [16].
- **Human-robot Interface:** Soft robots that are flexible and controlled by air or water rather than electricity are safer for human interactions. They provide solution to human-robot interfaces in a safe and effective manner and serve a multitude of functions in medical, industrial, or commercial applications. Their compliant bodies allow safe human-robot interactions and make them resilient to impacts and collisions. They can work shoulder-to-shoulder with humans. Co-robots (or assistive robots) cooperate with humans. Since they will physically interact with human partners, they must be adequately soft and lightweight in order to prevent injuries during collisions.
- **Marine:** Marine robotics allows difficult underwater operations, dramatically increasing our ability to explore and understand the oceans from a scientific perspective. These underwater soft robots can pioneer a new breed of underwater vehicles which will move over underwater structures without disturbing the environment, perform long-time monitoring and high definition photography [17].
- **Locomotion:** Locomotion strategies include crawling, swimming, and borrowing. The principles of locomotion of soft robots are shared with traditional mobile robots. Crawling soft robots, owing to their simple locomotion, have been mostly inspired by the inchworms and caterpillars. This motion pattern allows forward, backward, and sideway motions in the robot. Locomotion is employed by many worms. The locomotion of animals is deeply studied and covers a wide range of different gaits. Crawling locomotion includes several different gaits, and possibly refers also to unorganized body motions which provide locomotion.

Soft robots are also used in construction industry, textile industry, and military settings.

BENEFITS

Traditional robots have some disadvantages due to their stiffness and rigidity. Soft robots outclass conventional robots in cooperation and coexistence with humans, undertaking tasks without being given absolute environment information. They have advantages ove8 rigid-bodied robots for operations in unstructured environments. Soft robots have inherently infinited of (degrees of freedom) in their mechanical system but only a limited number of actuation can be introduced to the system [18]. They have substantial benefits of safety, adaptability, and cost efficiency compared to traditional robots. They do not have to calculate their movements as precisely as hard robots. Attempts have been made to make soft robots more controllable, more predictable, more robust, and more manufacturable. Soft robots do not replace traditional robots but add some features for softer robotic applications.

1. **Flexibility:** The flexibility, potential low cost, and good match with human tasks makes soft robots very attractive. Owing to a high flexibility, soft robots can interact with their environment quite easily.
2. **Lightweight:** Soft robotics have the benefits of higher flexibility, safer operations, lightweight, and simplified production, which reduce the manufacturing cost. Soft robots can be used in space exploration, where weight is important.
3. **Wide Applications:** Robotics has benefited a wide range of industries, from car manufacturing to space exploration. They have been playing an increasingly important role in our daily life. In many fields such as child education, healthcare, cognitive science, and sociology, the demand for robots is rapidly increasing.

CHALLENGES

As with all innovations in healthcare, robotics has faced numerous challenges, notably questions regarding efficacy, safety, and cost-effectiveness. Soft robots encounter some challenges such as miniaturization, efficiency of the locomotion, carrying-load capacity, and obstacle-crossing capability. Some see them as intrusive and controlling. They need some regulation due to the new legal and ethical issues they raise. Soft Robotics faces a number of fundamental scientific challenges [19]:

1. Mostsoft robots reported to date are laboratory prototypes. Approaches in design and construction of soft robots are still rudimentary.
2. It is yet to be fully clarified what materials are available and useful for robotic applications.
3. Tools and methods for fabrication and assembly of soft robots are not established. Wee do not have broadly agreed methods of modeling and simulation of soft continuum bodies.
4. We are still exploring what are the good ways to test, evaluate, and communicate the soft robotics technologies.
5. The development of soft robotics is closely dependent on advanced manufacturing processes.
6. Roboticists are prejudiced toward rigid structures, for which algorithms can be inherited from the well-established factory robot industry.
7. The effort and funding invested in soft robotics is very small compared to what is been invested in hard robots.
8. Fabrication of soft robots is is a major challenge. Some soft robots are more complex and need more steps for their fabrication.

CONCLUSION

Soft robotics concerns with the design, fabrication, locomotion, control, and applications of robots composed of soft materials. It is an emerging branch of robotics that deals with the construction of robots from highly compliant materials that mimic living organisms. It is of growing interest in the robot community. The interest and enthusiasm generated by soft robotics is justified by the need to evolve toward human friendly robotics. Soft robots may redefine the future of robotics itself. Since the concept is new, we are yet to witness the full potential of the soft robots.

Soft robots constitute a new class of robots that has taken the community of robotics by storm. This generation of robots are expected to elastically soft and capable of safely interacting with humans and navigating easily through constrained environments. As the field of soft robotics improves, the supporting soft matter technologies used in sensing, electronics, and actuation will grow in maturity. The global soft robotics market may reach 3.41 billion by 2027. However, in order for soft robotics to take root and be an impactful field in the next decade, we must move beyond "soft for soft's sake" and ensure that each study makes a meaningful contribution. More information about soft robotics can be found in the books in [16,20-25] and the following journals devoted to robot-related issues:

1. Soft Robotics
2. Robotica
3. Robitics and Autonomous Systems
4. Advanced Robotics
5. Journal of Robotic Systems
6. Journal of Robotics
7. Journal of Robotic Surgery
8. Journal of Intelligent & Robotic Systems
9. Journal of Mechanisms and Robotics-Transactions of the ASME
10. Intelligent Service Robotics
11. IEEE Journal on Robotics and Automation
12. IEEE Robotics & Automation Magazine
13. IEEE Robotics and Automation Letters

14. IEEE Transactions on Robotics
15. International Journal of Medical Robotics and Computer Assisted Surgery
16. International Journal of Robotics Research
17. International Journal of Social Robotics
18. International Journal of Humanoid Robotics
19. International *Journal of Robotics Research*

REFERENCES

[1] M. N. O. Sadiku, Y. Wang, S. Cui, and S.M. Musa, "Healthcare robotics: A primer," *International Journal of Advanced Research in Computer Science and Software Engineering,* vol. 8, no. 2, Feb. 2018, pp. 26-29.

[2] F. Iida and C. Laschi, "Soft robotics: Challenges and perspectives," *Procedia Computer Science*, vol. 7, 2011, pp. 99-102.

[3] "Human–robot interaction," *Wikipedia,* the free encyclopediahttps://en.wikipedia.org/wiki/Human–robot_interaction

[4] R. D. Davenport, "Robotics," in W. C. Mann (ed.), *Smart Technology for Aging, Disability, and Independenc*e. John Wiley & Sons, 2005, Chapter 3, pp. 67-109.

[5] M. N. O. Sadiku, S. Alam, and S.M. Musa, "Intelligent robotics and applications," *International Journal of Trends in Research and Development*, vol. 5, no. 1, January-February 2018, pp. 101-103.

[6] "Robotics," *Wikipedia*, the free encyclopedia https://en.wikipedia.org/wiki/Robotics

[7] L. Calderone, "Robots in manufacturing applications," August 2016, https://www.manufacturingtomorrow.com/article/2016/07/robots-in-manufacturing-applications/8333

[8] J. Z. Gul et al, "3D printing for soft robotics – A review," *Science and Technology of Advanced Materials*, vol. 19, no. 1, 2018, pp. 243-262.

[9] S. Crowe, "3D Printing Soft Robotics with Embedded Sensors," March 2018, https://www.therobotreport.com/97810-2/

[10] "Neuro based soft robots," https://mathewlab.com/iv-soft-robotics/

[11] "Soft robotics: Future of robotics?" https://www.ft.lk/IT-Telecom-Tech/Soft-robotics-Future-of-robotics/50-653878

[12] S. Kim, C. Laschi, and B. Trimmer, "Soft robotics: A bioinspired evolution in robotics," *Trends in Biotechnology,* vol. 31, no. 5, May 2013, pp.287-294.

[13] G. Bao et al., "Soft robotics: Academic insights and perspectives through bibliometric analysis," *Soft Robotics,* vol. 5, no. 3, June 2018, pp. 229-241.

[14] M. Cianchetti et al., "Biomedical applications of soft robotics," *Nature Reviews Materials*, vol. 3, May 2018, pp.143–153.

[15] "Wearable soft robotics," https://undergraduate-research.engineering.asu.edu/project/wearable-soft-robotics/

[16] A. Jafari and N. Ebrahimi (eds.), *Soft Robotics in Rehabilitation.* Academic Press, 2021.

[17] B. Mazzolai, "Roadmap on soft robotics: Multifunctionality, adaptability and growth without borders," *Multifunctional Materials*, 2022.

[18] V.A. Ho et al., "Special issue on 'morphological computation in soft robotics'," *Advanced Robotics*, vol. 32, no. 7, 2018, pp. 339-339.

[19] "Technical committee for soft robotics,", https://www.ieee-ras.org/soft-robotics

[20] K. Kim, *Microscale Soft Robotics: Motivations, Progress, and Outlook.* Springer, 2016.

[21] A. Verl et al. (eds.), *Soft Robotics: Transferring Theory to Application.* Springer 2015.

[22] M. Borgatti and K. Love, *Introduction to Squishy, Stretchy, and Flexible Robots.* Make Community, 2018.

[23] G. J. Monkman, *Soft Robotics.* Bentham Science Publishers, 2022.

[24] C. Laschi et al. (eds.), *Soft Robotics: Trends, Applications and Challenges: Proceedings of the Soft Robotics Week, April 25-30, 2016, Livorno*. Springer 2016.

[25] D. A. Paley and N. M. Wereley (eds.), *Bioinspired Sensing, Actuation, and Control in Underwater Soft Robotic Systems.* Springer 2021.

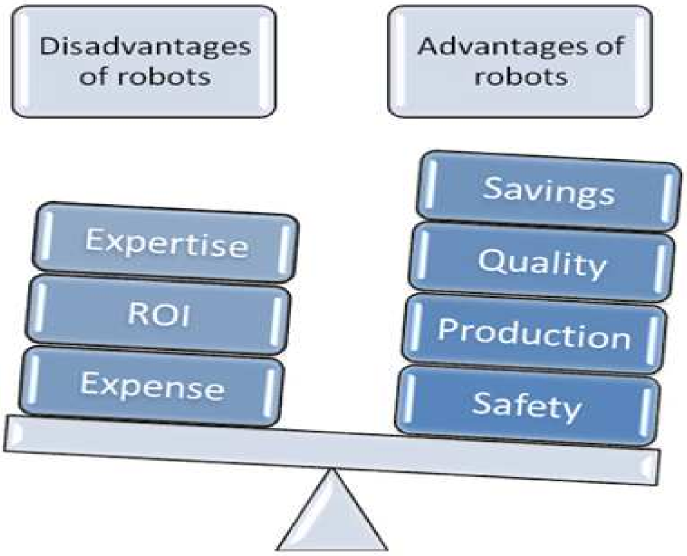

Figure 1Some advantages and disadvantages of robots [7].

Figure 2 Soft robotic gripper developed using 3D printing [9].

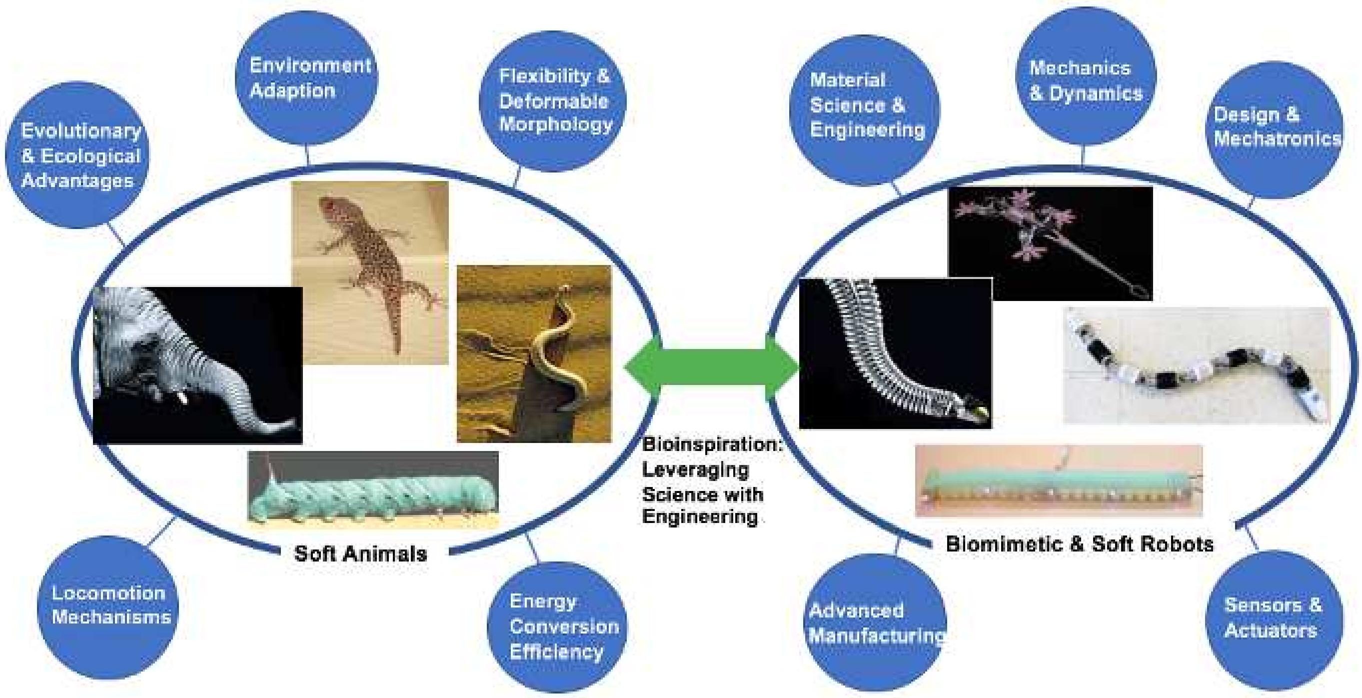

Figure 3 Bioinspiration [10].

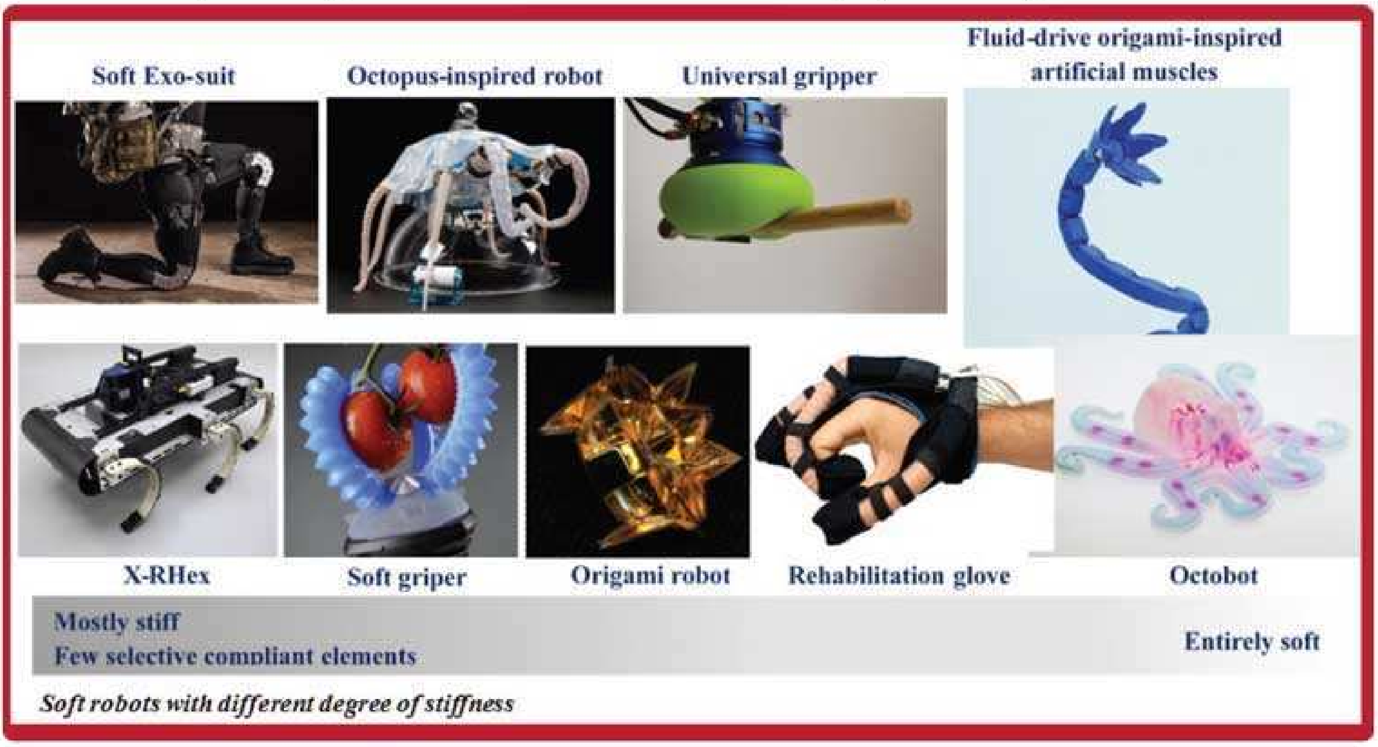

Figure 4Various soft robots with different degree of stiffness [11].

Figure 5 Wearable soft robots [15]