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Wearable Robots

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ABSTRACT

A wearable device is any device that is worn comfortably on the body and enables user interaction. It is typically integrated into the clothing or attached to the body of a person to enhance human performance. A wearable robot is a type of robot that is used to enhance a person's motion and/or physical abilities. Wearable robots are constructed of typical robotic components such as actuators, sensors, and control algorithms. They aim at providing assistance to impaired limbs, augment human ability, help with the rehabilitation, or enable increased personal mobility. This paper provides an introduction to wearable robotics, including active orthotics (exoskeleton) and active prosthetics.

KEYWORDS: *robots, robotics, wearable robots, wearable sensors, exoskeletons*

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INTRODUCTION

Wearables and hearables are everywhere. They have become an inherent part of our daily lives. Wearable devices or systems are usually lightweight, miniature electronic or digital devices. They are worn on the wrist, in clothing such as vests, footwear, headwear, earwear, and eyewear. A wearable computer is computer-powered device that is never-sleeping ever-present network-connected electronic system that can be used at anytime and anywhere and does not in any way disturb the user's interaction with the real world. It should be worn, much as eyeglasses or clothing are worn, and interact with the user [1]. It includes all manner of technology that is on or in the body such as fitness trackers, smartwatches, smart clothing, smart rings, smart glasses, wearable mobile sensors, smart jewelry, and smart ECG (electrocardiogram) monitors. There has been a proliferation of wearables from consumer gadgets to medical devices that are approved by the Food and Drug Administration (FDA). Typical wearable devices are shown in Figure 1 [2].

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. Robots were originally intended for use in industrial environments to replace humans in tedious and repetitive tasks. Wearable robots are robotic systems characterized by suitable shape, kinematic, and weight factors to be worn on the human body with the aim assisting humans. They are person-oriented robots and can be worn by human operators, whether to supplement the function of a limb or to replace it completely. They arise as of-vital-importance tools for home assistance targeting people affected by motor disabilities.

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.

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 WEARABLE ROBOTICS

A wearable device essentially consists of two different components: wearable and body sensors. It incorporates sensors, memory, solar cells, and batteries. It stays in contact with the body for extended periods of time. Traditional materials for wearables are mostly metals and semiconductors with relatively poor mechanical flexibility. Modern wearable technologies are characterized by body-worn devices, as smart clothing, e-textiles, and accessories [8]. Wearable devices can be used to collect various data to support a series of innovative applications. Today, wearable devices have numerous applications due to their integration with artificial intelligence. Wearable devices can be attached to shoes, eyeglasses, earrings, clothing, gloves, and wrist watches [9].

Wearable robots, also known as exoskeletons or bionic robots, are machines that are developed with the intention to suit the shape and function of the human body. The robots are meant to enhance body movements. Wearable robotics is highly interdisciplinary field that combines safety, ergonomics, control, autonomy, human-machine interaction, soft robotics, wearable sensors, and material science. It involves experts from different fields such as medical, social, caregivers and industrials. Sensors acting as controllers or monitors of the wearer's movements are integrated into the wearable. There are different types of wearable robots depending on the application and user. Figure 2 shows a worker wearing the Hyundai Rotem's wearable robot [10].

APPLICATIONS OF WEARABLE ROBOTS

Wearable robots have been used in automobile, heavy industry, shipbuilding, logistics and distribution fields, agriculture, healthcare, rehabilitation engineering, assistive robotics, and power augmentation. The following applications are typical.

- **Wearable robotic exoskeleton:** Robotic exoskeletons augment human physical strength. It allows humans to have more physical freedom by wearing robots. Traditional exoskeletons are large systems that require big battery packs. There are different types of exoskeletons: (1) hip modular exoskeleton, (2) knee modular exoskeleton, (3) life-caring exoskeleton, (4) medical exoskeleton. Exoskeleton can serve as an industrial robot which can reduce workers' fatigue. They can be used in application in back support, skiing, arm support, upper body rehabilitation, and the legs support. Future exoskeleton robotics will be based on wireless technology. A typical robotic exoskeleton is shown in Figure 3 [11].
- **Soft wearable robots:** From a design perspective, wearable robots can be generally classified as rigid or soft. Rigid wearable robots are known for their excessive mass and high impedance. Soft robotics combines robotics and soft materials. Soft mechatronic technologies have become an attractive solution for wearable robotic technologies. Soft wearable robots provide active methods of actuation for assistive and augmentative purposes. The term "soft" is typically used in robotics to describe materials that conform to existing surroundings. Compared to rigid robots, soft robotic systems demonstrate

potential for safer, more comfortable, and lower cost alternatives. Soft robots are effective for human–robot interaction, improved durability, and increased user comfort. Several soft wearable robots have been used for human assistance [12].

- **Elderly assistant:** The ageing worldwide population is causing a growing demand for wearable robotics. There is an increasing interest in the use of robotic devices to assist the elderly people to accomplish their main daily living activities. Wearable robots can be used as a device to help the elderly with walking difficulties. Wearable exoskeleton robots can assist the elderly and patients with spinal cord injuries.
- **Healthcare:** Wearable robots represent an exciting application in the medical field. They can provide support for patients, healthcare workers, and the healthcare system. They can be used to assist healthcare workers with any other task that is labor-intensive, time-consuming, and repetitive. The use of wearable robots is helping the paralytic or disabled individuals in the movement. They provide more stable walking compared to using crutches. Figure 4 shows a wearable robot in healthcare [13].
- **Military:** Wearables have been used in the military. The army uses the wearable robots when carrying heavy equipment over a long distance. Battery-powered wearable robots are attached to the legs of solders to increase their efficiency.
- **Manufacturing:** Wearable robots offer various advantages in manufacturing sectors such as lowering work fatigue and reducing work-related injuries, thereby increasing productivity and work quality [14].
- **Agriculture:** Wearable robots are used in a variety of ways in agricultural fields, such as harvesting fruits, transporting heavy crops, and managing crops.

Other applications of wearable robotics include walking assistance, workout assistant, rehabilitation, upper body support, paralyzed patients, fight pandemics, factories, and warehouses.

BENEFITS

Compared to traditional robots, wearable robots have the potential to be fully portable and lightweight. The technology opens up new possibilities that are not possible with rigid robotic components. Wearable robotics has the potential to offer easy and unobtrusive assistance to individuals with physical disabilities. Wearable robots assist the gait of workers, soldiers, athletes, and hobbyists. Physically weak individuals due to age, injure, or handicapped situations have been identified as the primary beneficiaries of this technology. In healthcare, wearable robots can perform as assistive aids to those with physical challenges. Consumers and medical professionals are increasingly using wearables for fitness, fashion, and medical purposes. They desire continuous monitoring of health and vital sign parameters. They support manual labor tasks in construction sites, factory labor, and warehouses. In addition to healthcare, wearable robotics hold promise for the improvement of quality of life for other users.

CHALLENGES

In wearable robotics, physical interfacing between the human body and a robot causes various engineering issues. Some questions remain regarding human augmentation and assistance control for wearable robots. Different nations apply different compliance standards in order for wearable robots to be sold in the market. Other challenges include:

- **Ethical, legal and social implications (ELSI):** There is a general concern of some legal and regulatory aspects, such as health and safety or data security. It is important that people have a thorough medical evaluation before using wearable robots. Wearable technologies may require safety and regulatory testing to achieve market access. ELSI considerations have received increased attention from governance bodies and professional organizations. Education about ELSI in wearable robotic design helps to prepare the groundwork for engineers and designers to comply with the legal frameworks. Being ELSI-sensitive will ultimately lead to more acceptable, safer, and successful wearable robots [15].
- **Human-robot interaction:** The design of the physical human-robot interface is critical because it determines the efficacy of the robot and the kinematic compatibility of the device with the human skeleton. Controlling the physical human-robot interaction at the joint level poses some challenges in the design of exoskeletons [16].
- **Complexity:** In order to achieve complex tasks in wearable robotics, the complexity of the control algorithms increases significantly. The number of sensors and actuators increases significantly to achieve more complex tasks in robotics, and the complexity of the control algorithms increases exponentially [17].

- **Performance evaluation:** This is becoming an urgent issue in wearable robotics. Consumers and distributors have difficulty comparing the performance of wearable robots because it is currently not measured in a standardized manner. The robotics community needs reliable and replicable testing methods to verify and compare the performance of the numerous robots available in the market. Without clear and quantitative measures, this rapidly expanding market runs the risk of losing sight of real users' needs [18].

CONCLUSION

A wearable robot is a wearable device used to enhance a person's motion and physical abilities. Wearable robots are designed to assist humans in different situations. They effectively integrate the cognitive ability of human being and the advantage of robotic devices to assist the users to accomplish their desired activities. Wearable robots are increasingly moving out of the laboratories toward real-world applications. We are witnessing a rapid growth in the demand of wearable robotics due to its increased use in the therapy of patients suffering from musculoskeletal disorders. More information about soft robotics can be found in the books in [19-21] and the following journals devoted to robot-related issues:

1. Robotica
2. Robitics and Autonomous Systems
3. Advanced Robotics
4. Journal of Robotic Systems
5. Journal of Robotics
6. Journal of Robotic Surgery
7. Journal of Intelligent & Robotic Systes
8. Journal of Mechanisms and Robotics-Transactions of the ASME
9. Intelligent Service Robotics
10. IEEE Journal on Robotics and Automation
11. IEEE Robotics & Automation Magazine
12. IEEE Robotics and Automation Letters
13. IEEE Transactions on Robotics
14. International Journal of Medical Robotics and Computer Assisted Surgery
15. International Journal of Robotics Research
16. International Journal of Social Robotics
17. International Journal of Humanoid Robotics
18. International Journal of Robotics Research

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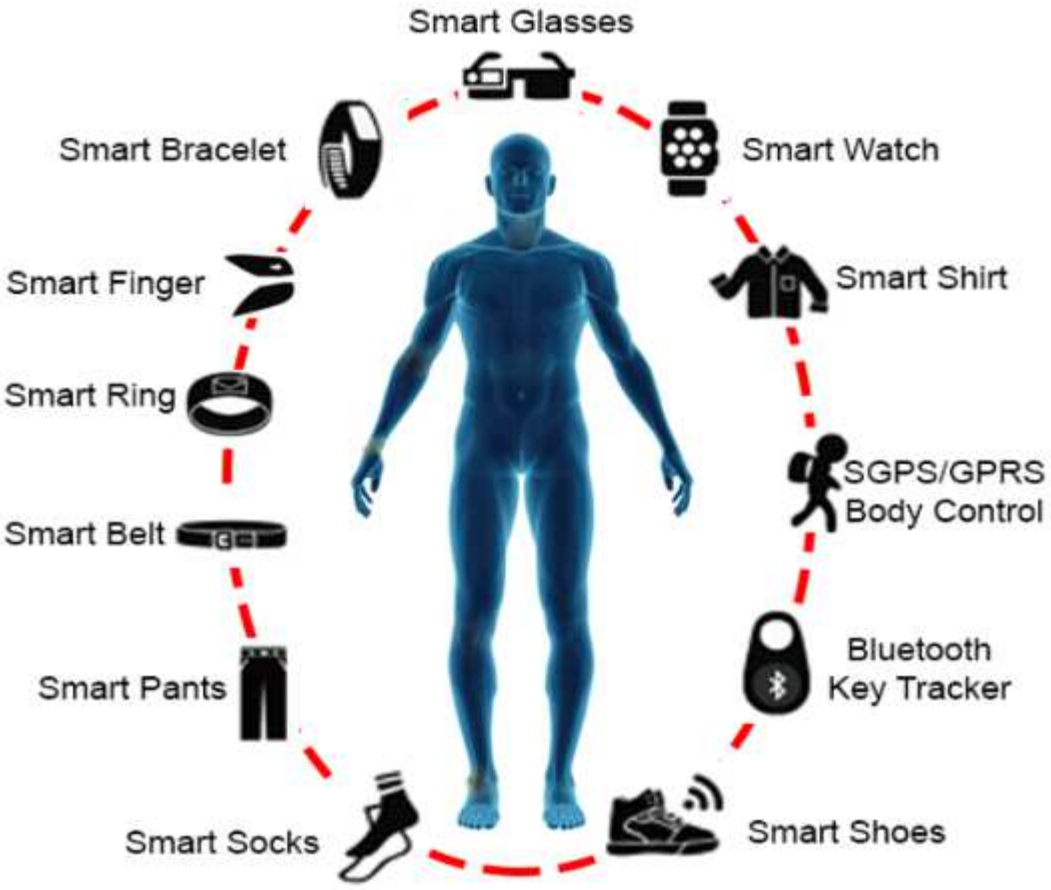

Figure 1 Different types of wearable devices on human body [2].

Figure 2 A worker wearing the Hyundai Rotem's wearable robot [10].

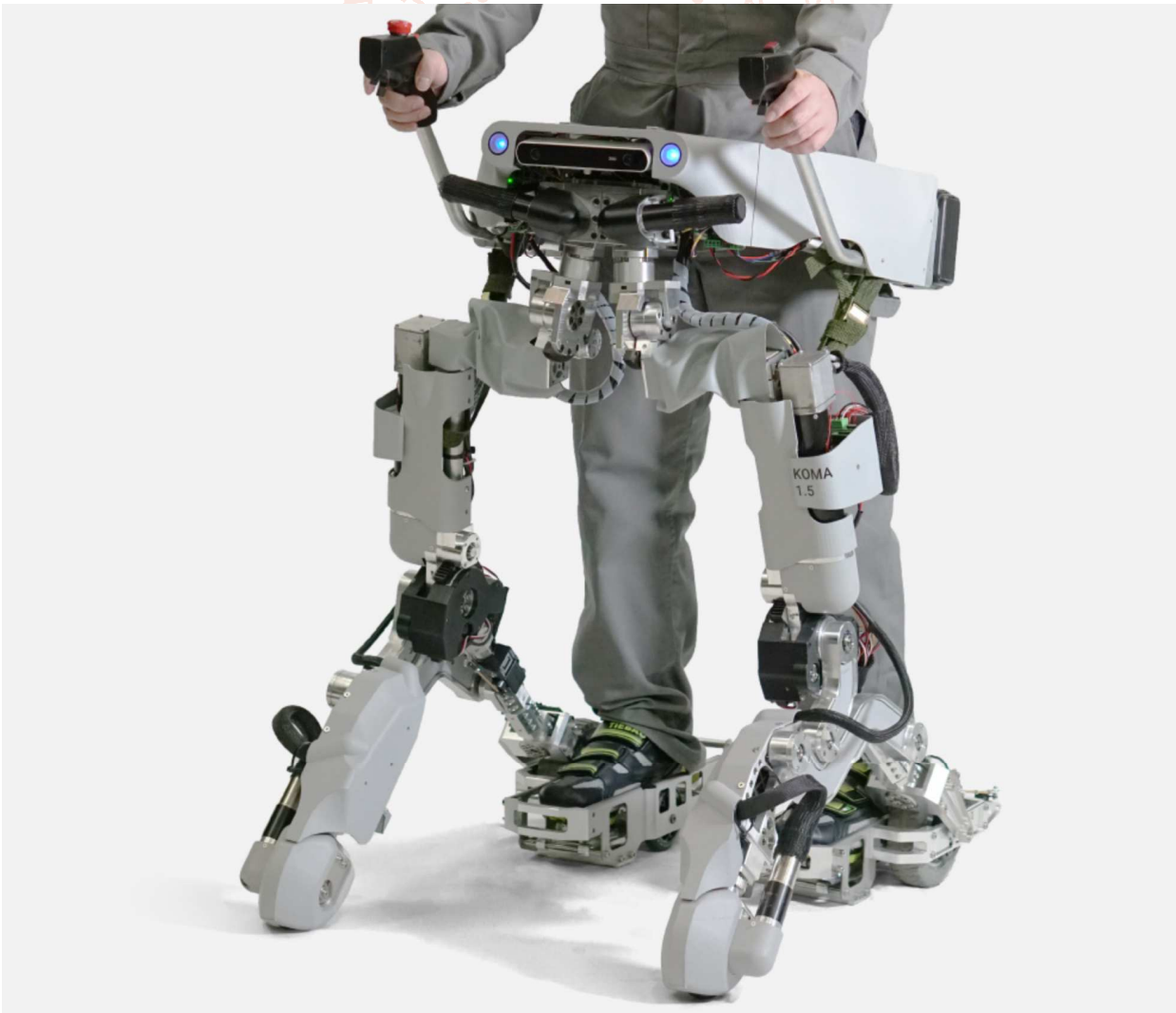

Figure 3 A typical robotic exoskeleton [11].

Figure 4 Wearable robot in healthcare [13].