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A review of the flexible robotic arm

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Abstract. In the application of the robot, the gripper of the robot is an important medium between robot arm and target. The traditional manipulator hand is mostly rigid, which is easy to damage or unable to clamp the object in the operation process. What are demanded from robotics are no longer limited to just mechanical assistant, more efficient and precise target acquisition of robotics with self-adaptation and self-adjustment have become the tackle key in robot research and design. In this paper, the design of flexible materials, the AI real-time sensing and controlling of flexible manipulator are described, as well as the application and prospects are analyzed. It is intended to provide perspective and direction for the weak interaction between flexible robotic arm and environment, less adaptability and inflexibility in complex environment. In the future, a more advanced, flexible robotic arm can be created that goes even beyond the human arm and contributes to development of the world.

Keywords: flexible robotic arm, artificial intelligence, flexible manipulator.

1. Introduction

Date back to 1912, Dorrance et al. filed a U.S. patent for a two-finger linkage gripper on ducument[1]. Since Japanese researchers developed a relatively complete manipulator in the 1970s and named it Okada manipulator, more humanoid manipulator was introduced[2]. In the 1980s, with the advancement of computer and Internet technology, such as Stanford University's Stanford/JPL hand, which contains nine joints, three fingers [3] [4]. Later in the mid-1980s, the University of Utah and the Massachusetts Institute of Technology jointly developed a Utah/MIT manipulator [5]. In recent years, flexible robot technology has advanced rapidly with development of materials science, electromechanical and computer, the PISA/IIT Flexible Hand developed by PISA University is highly biomimetic and integrated [6].

Since the idea of intelligent machines from A. Chella in 2006 led to the notions of robots and robotics, self-adaptation, self-adjustment to handle tasks with more efficiency have become the core content of robot research and design [7][8]. At present, the development trend of the world's high-end flexible manipulator is high-speed, polyaxis, dexterous, and orientation system that can achieve micron-level accuracy [9]. Moreover, the flexible manufacturing system and unit have been initially adopted, creating conditions for the use of flexible manipulators in multi-degrees of freedom (DOF) and vacuum grippers, they have been playing more and more critical roles beyond the capabilities of humans and traditional rigid manipulators[10].There are rapid development and practical applications in industry, medical surgery performance precision agriculture harvest, food safety, electronic information, aerospace and other fields[11,12].

This paper reviews the research on the two most critical aspects of the 'flexibility or softness' of the flexible robotic arm. On one hand, the structure design of flexible robotic arm systems based on soft material selection, as well as the most effective number of DOF and fingers. On the other hand, the widespread use of artificial intelligence technology is also promoting the more varied adaptations to the 'gentle and precise control' of flexible robotic arms. This aspect includes progress not only in smart sensors and actuators, but also in more precise trackable modeling and feedback controlling mathematically.

2. Flexible material and structure design are the foundation support of flexible manipulator

With the development of materials science, control, electromechanical and other disciplines, flexible robotic arm technology is booming[8]. As an important medium for the robot to contact with the external environment, material, design and control of the gripper determines the degree of autonomy of the robot. In structure, the DF and the number of actuators determine the accuracy and flexibility of the flexible manipulator. A manipulator needs at least 6 DOF to grasp objects at any position in the reachable space; the corresponding structure is propelled by microscopic rubber hoses coated in Plastic Nets, known as "air-muscles" [12].

Shadow Robot in British, the founder of artificial Muscle, began with combining two Air muscles to form a flexible joint with two DOF, and applies this joint to Shadow Dexterous Hand, the first commercially available robot hand [13]. A kind of soft silicone gripper was developed, which can handle fragile objects like a chicken egg, by George M from Harvard University based on embedded pneumatic networks [14]. Velvet Fin-gers was developed by Vinicio Tincani and others from the University of Pisa, which has two fingers and 4 DOF freedom, and fingers' flex and bend are driven by a motor[15]. An underactuated humanoid manipulator has been developed by Ritsumeikan University in Japan, which is almost the same size as the human hand, with a total of 5 fingers and 20 DOF [16]. H Zhao, a researcher from Cornell University, has developed a kind of pneumatic flexible manipulator named Gentle Bot, which has five pneumatic fingers like human hands and is driven by four air bags to detect objects using light waves [17].

Artificial muscles supposed to be completely soft, as strong as biological muscles, and power-driven by pneumatic or electricity for easy combination with the rest of the robot [18, 19]. Pneumatic device is widely used because of its structure with advantage characteristics that can change its curvature from convex to concave, with the air pump filling and discharging gas, suitable for the needs of flexible gripper [14,19]. The term soft robot first appeared in 2000, describing a McKibben pneumatic artificial muscle[19]. For the exploration of materials for artificial muscles, H Zhao applies a high electric field to achieve the same contractile force as natural muscles by using a unique combination of nanoscale conducting particles and soft elastomers. These studies and explorations provide ideas for new surgical tools and flexible mechanical tentacles that mimic human functions [20]. Further, Biosensing three-dimensional and bio-inspired tactile sensors, give the capability to actuators with the potential to mimic biomimetic motions[22]. Further, essential functions of positioning and control are completed for the flexible manipulator by way of intelligent touch and visual recognition.

3. AI technology is the booster of controlling system of flexible manipulator

3.1. A critical way to analysis of actuation and feedback using data-driven AI

After the father of AI, John McCarthy, defines AI as the science and engineering of creating intelligent machines, particularly smart computer program, more and more AI technology is used in the field of robots [21]. AI techniques like data-driven machine learning and deep learning clinch precision and accuracy for bio-inspired sensor and actuator. The model-free modeling method of soft robot mainly

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uses artificial intelligence technology to find the mapping relationship between software system parameters and control results [23]. Developing those techniques would certainly lead to manufacture of flexible robotic arms, whose controlling system could be Interacted with the environment. Deep Learning techniques are being used to solve complex challenges in the task of controlling [24] The inherent properties of soft materials can result in complicate situations due to nonlinearity and hysteresis, which makes soft robots more difficult to model, verify, and operate than rigid robots, and several studies have used various machine learning-based methodologies to address these constraints[23].The applications include soft sensor calibrations, positioning control of soft actuators, and more complex tasks, such as grasping or motion planning of robots [25]. R. Morimoto propose a model-Free reinforcement learning network could establish control strategies for a continuum robot arm to place its tip at desired locations in both simulations and the actual reality. [26].

Hence, A new focus of research is the development of improved artificial biomimetic intelligence algorithms. and presents potential building smarter control systems in the research of soft robots. Through effective calculation and control of robot movement, body stiffness and deformation degree,it is more capable of dealing with things with distinct shapes and adjust to the environment's ever-changing conditions as well as build more intelligent robots [27].

3.2. Model construction

The analysis of the automation mechanism and the creation of a feedback system depend significantly on a statistically measurable model that tracks the actions of a flexible robot. Model-based controllers depend on models obtained from analytical kinematic methods, while model-free controllers use AI data-driven approach as mentioned early[28]. The main goal of the modeling process is to effectively construct the setup, drive, and task of the soft robot together through the constant curvature technique and the finite element method. Through the model, you can create an environment where complex changes can be made and keep it intelligently communicating [29,30]. In 2022, C. Armanini reviews the mathematically constructed classification models, and those infinite-dimensional soft robot systems are extremely nonlinear partial differential equations that are not analytically integrable [31]. Since developing high-order dynamic models for soft robots is difficult and computationally expensive for controllers, Learning-based techniques also proved to be successful in learning the dynamic models of soft robots. Learning-based techniques also showed success in learning the dynamic models of soft robots, which is advantageous because of models created is low down technology challenge and high throughput computing equipment costly [28].

4. Application of a flexible manipulator

4.1. Precise medical flexible mechanical arm

Medical consulting and remote medical procedures or examinations became more effective with the development of interactive audiovisual systems and remote mobile robotic platforms since 2010 [32].The system is called "Da Vinci" in part because Leonardo da Vinci's study of human anatomy eventually led to the design of the first known robot in history and the first model ‘Standard’ was launched in 1999[33]. There are evolving role of robotics in healthcare and allied areas with special concerns relating to the management and control of the spread of COVID-19 [34]. A flexible joint from a Xu K-based single-hole surgical robot was proposed, which was composed of a multi-segment 3 DOF distal and proximal structure and a set of rigid guiding cannulas but was limited by the narrow workspace[35]. Fujisawa Y proposed a 4 DOF compact medical tweezer mechanism using material deformation based on an elastic cylindrical curved body with a large incision to realize rotation [36]. As Zhang’s review, recent advancements of bionics, flexible actuation, sensing, and intelligent control algorithms as well as tunable stiffness have been referenced when soft and flexible robots are developed, as well as the bionic materials and structures that demonstrate the potential capabilities of the soft medical robot flexibility are the fundamental guarantee for clinical medical applications[37,38].

4.2. Soft agricultural picking manipulator grapple

Agricultural picking manipulator has been applied in practice without damaged as the first demand, and it is also one of the earliest fields in which flexible robots were put into production [39, 40]. Boa created a robotic pot seed transplanter installed on an implement that produced average seedling positions about 25 cm in 3 cm error with 5 DOF robot arm utilized for pepper plants in1986[39].

The proposed harvester is made up of two hands with four bars and flexible pneumatic muscles grab-hook and the system employs intelligent recognition system, identifies plants in the field through morphological calculations and chromatic aberration [41]. Another robotic arm to pluck a fruit or prune a branch was developed through capturing, processing and replicating human arm are in 3D space [42]. K. Rahul designed and developed a five-revolute joint (5R) With embedded chips and monitors that are readily accessible in the market, a 2DOF of handling paper container plants in a plant transport is used， also according to the research results, no pots were overlooked during lifting and releasing and there were no apparent cracks [43]. A collaborative human-robot strawberry harvesting system for identification and picking was deigned combining computer robotic control, the more human and computer interaction, the more robot functions are advanced and intelligent [40].

In summary, Agriculture is moving toward becoming Intelligent, large-scale and mechanized, with actuator-driven farm robots serving as the backbone of smart agriculture. As the fields of robotics and robotic arms develop quickly, humans will soon not only labor alongside robots but also use them as helpful assistants.

5. Conclusion

Although it is well known that the progress of flexible robotic arms depends on the joint development of multiple disciplines, numerous research projects are mainly carried out in their own research fields, as discussed. Mechanical, information and electrical engineering are paying attention to a highly integrated engineering technology for a smart, interactive, and economic manufacturing ecosystem, and flexible mechatronics and applications are the way leading to the creation of more dextrous, degrees of freedom, and capabilities devices. At the same time, how to develop and utilize the human-computer interaction system, the maximum potential capabilities of human-robot cooperation, is the future research direction.

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