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ROBOTIC ARM WITH COMPLIANT MECHANISM

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ABSTRACT– This review paper aims to highlight and describe the design and manufacturing of robotic arm with a compliant gripper. Robotic arms are being extensively used in various industries ranging from manufacturing to food industries as a way of reducing human errors and optimizing the performance. The employment of robotic arms has increased efficiency, productivity and precision of a particular operation. We have studied the optimized design of a traditional pick and place robotic arm by using a compliant gripper. A compliant mechanism is a flexible structure that deforms elastically to derive its mobility from the deflection of its flexible members rather than from movable joints only. Compliant mechanisms and its various systems are subject of active research. The compliance of the gripper can be put to use on the applications of a pick and place robotic arm. We have studied various aspects of the arm, gripper and referred several research papers to observe different methodologies of design such an arm.

KEYWORDS - Robotic arm, Compliant gripper, Pick and place robot, End-Effector, Compliant mechanism

1.1. INTRODUCTION

A robot is a mechanical device that performs automated tasks and movements, according to either pre-defined programs or a general set of guidelines and direct human supervision. Pick and place robots have been in use for many years now. A robotic arm is a type of mechanical or programmable arm with similar functions as that of a human arm. It consists of a combination of links attached with each other to perform a specific programmed task. A gripper is one of the mechanisms used as the end effector which in case of pick and place robots, is modelled as the fingers of the arm; it enables the holding, handling and releasing of an object. We can optimize the performance of a gripper if we can simplify its mechanism. This may be made possible by using a compliant gripper i.e., a flexible gripper.

1.2 Robotic Arm

The entirety of a robot has multiple facets such as the main frame, controller, manipulator, actuator, sensors, motors, arm etcetera. We will focus on the two main effectors of the robot – robotic arm and compliant gripper.

A robotic arm is the effector to which the gripper i.e., end-effector is attached. Generally driven by motor, the arm is often used for the rapid and consistent performance of highly repetitive procedures over an expansive period of time. It is a series of joints and manipulators that work in synchronization to carry out the functionality of a human arm.

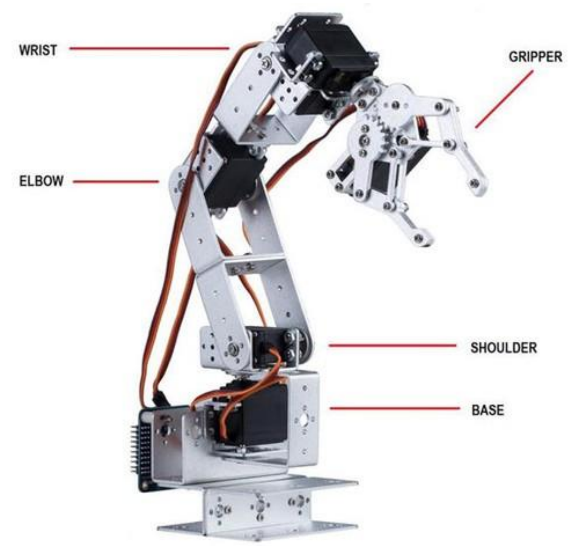

Fig 1. A 6 DOF Robotic Arm With Two-Jawed Gripper

1.2.1 Types

There are multiple types of robotic arms that have been developed based on the way their joints are designed to articulate a motion or work. The types can be listed as –

Cartesian robot – Based on Cartesian co-ordinate system (X, Y and Z axes). In this type, the end-effector is placed in a three-dimensional space and is manipulated through linear movements along these axes.

Cylindrical robot – Based on Cylindrical co-ordinate system. The movements take place within a cylindrical space, where rotary joints give the tool rotational as well as linear motion.

Spherical robot – Based on Polar co-ordinate system. The movements are achieved by a combination of rotational joints, rotary joints and linear joints.

SCARA (Selective Compliance Articulated Robot Arm) – This is a type with a degree of tolerable flexibility (compliance) along some axes while remaining rigid along the others.

Articulated robot – It is the robotic arm containing at least 3 rotary joints. It employs all three revolute joints to access its space. The joints are generally arranged in a chain, so that one joint aid the further in the chain.

1.2.2 Parts

The primary components of a robotic derive their names from the actual anatomical names of the human arm. The components are –

Base – It is the foundation on the which the further components are mounted. It forms the 1st joint of the arm.

Shoulder – The joint connected to the base is the shoulder, forming the 2nd joint of the arm.

Elbow – It forms the middle joint, connecting two links and joining the shoulder and wrist. It forms the 3rd joint of the arm.

Wrist – It is connected to the end-effector and is the 4th joint of the arm.

Gripper (End-effector) – It is the central element of the arm and is the part responsible to interact with the actual object. It often comprises of two or more claws.

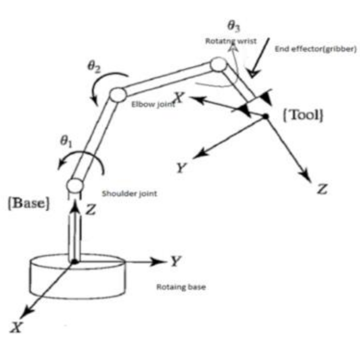

Fig 2. Structural representation of traditional robotic arm along with its parts

1.3 GRIPPER

Gripper is a device at the end of the robotic arm and is the very last link of the arm. It is a type of end-effector and is the most extensively used type. Generally used to hold, tilt and release an object. It has wide-ranging applications in various industries, in assembly units and packaging facilities.

In pick and place robotic arms, grippers and rotary actuators are two of the key elements which replicate the work of the wrist and hand.

1.3.1 Compliant gripper

Traditionally, grippers have always been rigid components, deriving motion and force from joints. But if a compliant (flexible) material is used as a gripper as shown, a simpler and lighter gripper mechanism could be possible to be fabricated. This endeavor, if succeeded, can reduce the friction and wear caused by a joint and thus optimize the performance and might even maximize it.

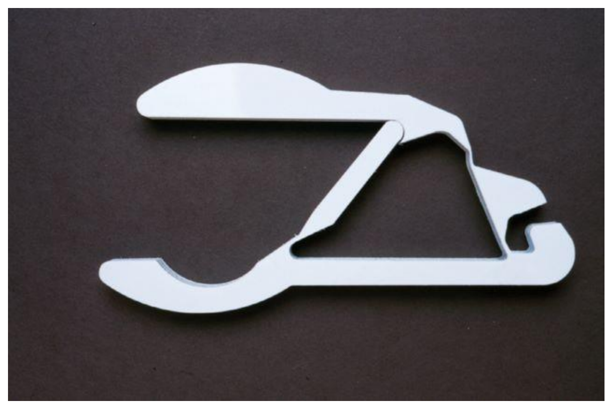

Fig 3. An actual compliant gripper

1.3.2 Compliant mechanisms

Compliant mechanisms are flexible mechanisms which derive force and motion from the deformation of its elastic body and achieve mobility from that derived force. It is generally a monolithic structure which stores strain energy in its flexible members. The most primitive example of this is the traditional bow and arrow. These flexible members are advantageous as they reduce the wear, otherwise resulting in heat and friction losses, and also reduces the part count of an assembly due to its single-structured body.

Design of compliant mechanisms can be typically done by two methods –

Kinematics method – A pseudo-rigid-body model (PRBM) can be made to analyse the mechanism. In this model, flexible elements are considered as rigid links connected to revolute joints with torsional springs.

Structural optimization method – In this method, topology optimization is carried out by taking load and force as input and weight and stress is optimized as output.

FEA method – It is used in more complex analysis where PRBM method does not suffice.

1.3.3 Advantages of compliant gripper

The advantages of compliant gripper can be considered in two main categories - cost reduction and increased performance. Cost reduction can be in terms of part count reduction, reduced assembly time and simplified manufacturing processes. In case of a compliant gripper, there is increased precision as there is reduction in backlash, increased reliability, reduced wear and maintenance as well as reduced wear.

The most prominent advantage of compliant gripper can be seen in the significant reduction in the part count of a mechanism. The total number of parts required to accomplish a specified task reduces dramatically as compliant gripper avoids the use of joints and rigid bodies. Compliant gripper, as a whole, can be mass produced by manufacturing methods such as injection molding or in the future, 3D printing and thus simplify a tedious task. Thus, only one monolithic design along with a tightening mechanism forms the whole structure. Due to this salient edge compliant gripper has over the traditional gripper, it has been the subject of much research in the last few years.

2. LITERATURE REVIEW

This review paper deals with the study of topics covered in the following research papers.

2.1 Study of robotic arm and its design

Jernej Preseren et al. [1] focused on detailed guidelines for designing grippers for use in various manufacturing industries. The guidelines have been divided into two categories: Those that help improve the throughput and those that increase the reliability. The paper also consists of thorough analysis of grippers that are designed using the stated guidelines and have been constructed successfully. One of the gripper assembly designs have been reviewed along with an example of the application of the guidelines. Although the grippers designed for these two operations are very different, the guidelines applied to both equally well.

Kemal Oltun Evliyaoğlu et al. [2] analyzed the variety of tasks which can be achieved by a robotic arm by just changing a few parameters of it. For instance, by changing the number of links, the arm can be made self-adaptable. He theorises multiple solutions to fulfill different applications of robotic arms with design optimization. His proposed design consists of two panels with their individual wiring arranged as per the application. Servo motors are connected to perform the desired task.

Gurudu Rishank Reddy et al. [3] demonstrated a successfully built 4 DOF robotic arm used for handling metal sheet in a conveyor system. The purpose of this arm was to reduce manual handling of sheet to shearing machine. Two pneumatic cylinders for the feeding mechanism, and a robotic arm for the workers' safety were designed. RCC control made it possible for the robot to interact with the surroundings. A self-optimized system was provided by the manipulator which ensured safety on site. This design successfully automated metal sheet bending operation by self-optimization of robotic arm.

Stafford Michahial et al. [4] put forth the design of an automated robotic arm based on an application. A functional prototype was created. The purpose was to simplify maintaining a strategic distance while dealing with unsafe and unstable objects and preventing danger. They developed a manipulator with 5 DOF. A microcontroller was installed which controlled the direction and motion of an electric motor. It issued orders to individual channels that made up the links. A proximity sensor was programmed such that it detected the presence of any obstacle in a 10cm radius. If the obstacle was not cleared, a feedback system such as a buzzer signaled the continuity of the problem.

Yagna Jadeja et al. [5] demonstrated a 5 DOF robotic arm with one cortex microcontroller which is M3 LPC1768 (Mbed). It could lift a maximum mass of 100g. Ultrasonic sensors were used to measure the distance of the object from the robotic system. Once the object was detected the microcontroller alerted the servo motors which initiated the pick and place mechanism of the robotic arm.

Rituparna Datta et al. [6] focuses on the multi objective design problem of a robot gripper. The modified design consists of an actuator in which the force is proportional to the voltage applied. The actuating element was modelled as a stack is actuators arranged in series and parallel. This condition led to the following cases –

a. Parallel modelling for the mechanical system and series modelling for the electrical system.
b. Parallel modelling for the electrical system and series modelling for the mechanical system.

c. Parallel modelling for both electrical and mechanical systems.
d. Series modelling for both electrical and mechanical systems.

2.2 Study of pick and place robotic arm

Prof G. K. Andurkar et al. [7] has demonstrated his own design of a pick and place robot system. This system offers benefits such as ergonomic design and reduction of cost, The system completes complex tasks faster and with more accuracy. The difficult task for him was to program the AVR microcontroller on the base station as well as the robot interface which would enable the wireless control of the robot. His design also includes a soft catching gripper which safely handles objects. He also demonstrated his own program of GUI application which enables the serial control of base station.

Kaustubh Ghadge et al. [8] combined the knowledge and applications of electronic as well as mechanical aspects to design and develop a "Robotic Arm for Pick and Place Application" using NodeMCU controller. He theorized a design of a more compact, usable and cheaper pick and place robotic arm which would be available for educational purposes. Input devices such as an Android application send a signal to NodeMCU which responded to the task. The practicality of the design was proven by its usefulness.

2.3 Study of robotic arm with modified gripper

Puran Singh et al. [9] designed a robotic arm specifically for the purpose of spot welding which consisted of 2 degrees of freedom. The end effector consisted of an arrangement of spur gears and threaded shafts along with an AC motor. The material used for the base of the robotic arm was plywood. The aims of this design were –

a. To have a rigid ergonomic structure.
b. Movement of parts at defined angles.
c. To attain consumption of power at optimum level.
d. To successfully perform spot welding with this particular end effector.

2.4 Study of theory of compliant mechanism

Arunkumar Gopal et al. [10] studied the theory of compliant mechanisms and conceptualized the various applications in which they could be used to the maximum of their potential. He narrated the applications of compliant mechanisms in new age industries like automobiles, aerospace etc. Numerical experiments were carried out to configure different designs. The analysis helped to decide the optimum design for compliant structures. Through various experiments, a design methodology was theorized.

Wenjing Wang et al. [11] presented investigation on the dymanic characteristics of compliant mechanisms. He attempted to improve the design of applied mechanisms. He tested strain, stress and elasticity of compliant mechanisms and showed the accuracy of the finite element method (FEM) for dynamic modelling. Using finite element analysis, a model for dynamic analysis of compliant mechanisms was developed. He concluded that the natural frequency of compliant mechanisms can be accurately calculated along with the sensitivities through FEM.

2.5 Study of compliant gripper

Sai Aswin Srikanth et al. [12] compared the structural performance of a four-bar compliant mechanism with the output of a four-bar rigid body mechanism. He showed an improvement in the design of flexure hinges after parameterization. The flexure hinges were originally considered as curved beams and later parameters were imposed to provide a better result.

Manpreet Kaur et al. [13] described the design and fabrication of a "Robotic finger based on 3D printed materials". Their design featured compliant joints with an embedded pressure sensor. He demonstrated how the mechanical stiffness of a body improves whike being flexible. The compliant joints enable bending of the aforementioned finger by undergoing expansion on the outer side and compression on the inner side. Sustainable manufacturing, cost-efficiency, mechanical durability and high repeatability were the prominent benefits proven by this design. The demonstrated fingercan have the flexibility and durability to be adapted in prosthetic hands with controlled pressure-sensing functions. They also showed how these structures can be miniaturized for small-scale applications.

Guangbo Hao et al. [14] proposed the design of a compliant gripper to be used in applications involving a variety of shaped and adaptations to specific requirements. He analyzed multiple operation modes of the gripper and analysis was done through FEM. The results complied with his analytical models with an acceptable range of discrepancy.

S. Yuvaraja et al. [15] demonstrated the design of a compliant clutch fork and showed compliant mechanisms by topology optimization as a great method of design approach. It reduced the mass and number of components while also maintaining the functions of a clutch fork. The fork still retained its mechanical strength as the original design and had good deformation while maintaining structural stiffness. His method reduced the mass as well as production costs because he used polymer-based materials, which are relatively lighter and cheaper than steel-based materials.

3. CONCLUSION

The study of various aspects of development and design of a multipurpose robotic arm with compliant gripper introduces a plethora of further avenues of research in the field of robotics and mechanics. The design optimization of a traditional gripper is a unique way of improving the performance of a robotic arm.

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