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Developing a Robotic Kit for Mechatronic Engineering Education

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Development of a Robotic Kit for Mechatronic Engineering Education

Abstract

This paper discusses the development of a robotic kit for the courses in the Mechatronic Engineering program. Mechatronics is a discipline that combines elements of Mechanical Engineering, Electrical Engineering, Computer Engineering and Control Engineering. Students in the program are required to possess not only broad multi-disciplinary knowledge but also strong hands-on technical skills. To achieve the program's educational objective, a robotic kit - the VEX® robotic arm[1] with a granular jamming gripper has been developed. Using the robotic arm and gripper system, students can visually understand the design process of a robotic manipulator based on the theorem they learned from the classes, such as forward and inverse kinematics, robotic dynamics and trajectory planning. Particularly, the granular jamming gripper is a creative and universal solution for robotic gripper designs. The flexible VEX® robotic arm in combination with the gripper can be used as an ideal educational platform. The easily implemented robotic system with the creative gripper design can inspire students to explore more novel and feasible solutions in their future careers in engineering.

Introduction

Robotic arms are a popular educational tool for mechatronic engineering students to learn system design by combining the knowledge learned from Electrical Engineering, Mechanical Engineering and Computer Engineering. However, current robotic manipulators on the market are expensive. Small colleges cannot afford to spend thousands of dollars on a single basic platform. Educators who are attempting to improve manipulator to student ratio, for example two or three students per manipulator, are even more constrained. Furthermore, the fixed setup of commercial manipulators makes it difficult to explain the internals of a robotic arm, which discourages students from modifying the current system and developing a new system by themselves. Among several affordable robotic arm platforms, such as VEX® robotic tool box[1] and LEGO® robotic tool box[2], the VEX® robotic arm is a better choice due to the robust parts for repeated usage. Therefore, the robotic platform under investigation has been built using most VEX® robotic parts.

For the robotic arm, besides designing a robot shoulder and elbow to send the end effector to a desired position and orientation, how to implement a robotic hand to “grasp” an object is also very important. Traditionally, most robotic hands are exploited by embodying human hand structure [3,4]. As a result, the robotic hands with up to 18 DOF (degrees of freedom) and elastic, flexible, and deformable materials have been developed. In addition, force control needs to be applied so that the robotic arm can pick up both hard and soft objects. Such a requirement for the knowledge in mechanics, materials, and control theory makes teaching robotic manipulators in the courses at an undergraduate-level complicated.

Recently, a research on robotic hands for "grasping" has emerged a completely different strategy called universal grippers or granular jamming grippers[5]. The method utilizes a latex membrane (as the gripper) containing granular material to enwrap an object and then evacuate air from the gripper so that the granular material jam and stabilize the “grasp”. A robotic gripper built in this way needs neither complex hand structure and materials nor sensory feedback. Therefore, it not only provides a revolutionary solution in the research area, but also brings a viable way for the robotic education for undergraduates.

In this paper, we will introduce a robotic platform that combines a VEX® robotic arm with a granular jamming gripper. The VEX® robotic arm has three DOF with three encoders to measure the joint angles and four DC (direct current) motors to control joint angular positions and orientations. A granular jamming gripper consists of a latex balloon which contains the granular material and a vacuum which is used to interact with an object. The developed robotic arm and gripper system are designed for the senior-level course, Mechatronics II – Robotics. In the course, students will learn robotic manipulators, forward and inverse kinematics, differential motion and robotic dynamics, mobile robots and control of robots. During the period of studying robotic kinematics, students will derive the angular values of joints and test their designs using the platform so that they can visually understand how a robotic manipulator works. In the junior-level course, Mechatronics I – Industrial Automation, students will see the demonstration of how a robotic manipulator is explored in the industrial manufacturing assembly line with the platform. Moreover, students are encouraged to integrate similar designs, i.e. a robotic arm with the universal jamming gripper, in their future course projects to demonstrate how a robotic manipulator works in the manufacturing industry.

In order to discuss the built educational kit in detail, we will describe our work in the following steps: In the next section, the size, structure and scope of the robotic arm are shown. Particularly, how we use the platform for students to verify the robotic design in forward and inverse kinematics will be discussed. Then, the working principle and implementation of a granular jamming gripper will be introduced. Following this section will be an example to demonstrate how the manipulator detects a metal or nonmetal object, grasps and puts it into the corresponding basket. Finally, the conclusion will be given in the last section.

The Structure of the Robotic Manipulator and Robotic Kinematics

The structure of the robotic manipulator under development is shown in Figure 1. The configuration of the manipulator is similar to the articulated robots which are most commonly used in industry. The robot has three degrees of freedom, i.e. the joint 1 (θ_1) is the base rotation, joint 2 (θ_2) is the shoulder rotation and joint 3 (θ_3) is the elbow rotation, where the joint 1 and joint 2 are perpendicular and joint 2 and joint 3 are parallel. Three angles are measured by three optical shaft encoders and controlled by four DC motors. The optical shaft encoders, provided by VEX® Robotics, Inc. have a channel with 90 ticks per revolution on each channel. The DC motors are also provided by VEX® Robotics, Inc. with the specification as follows: stall torque 0.97 Nm, free speed 100 RPM (revolutions per minute), stall current 2.6 Amps and free current 0.18 amps.

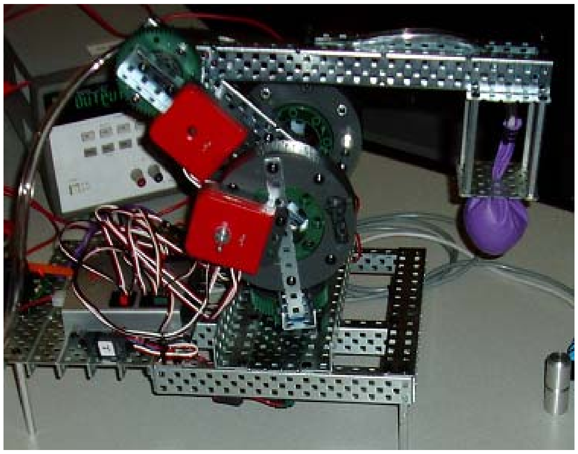


Figure 1 - Structure of Robotic Manipulator

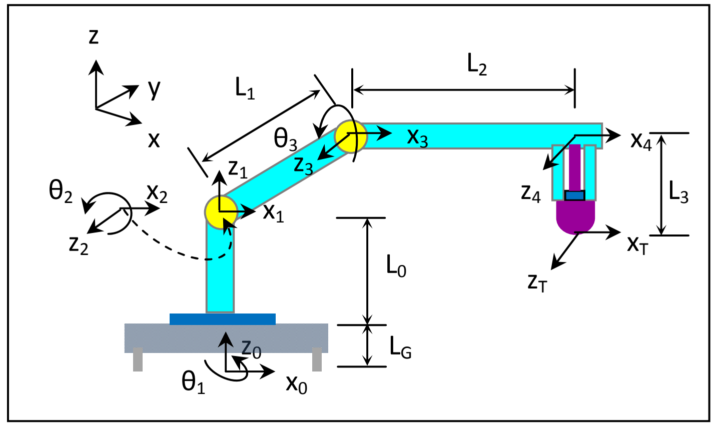


Figure 2 - Reference Frames for the Manipulator

Figure 2 shows the reference frames used for the robotic arm. The size of each link and the relationship between each link and each joint are listed and explained in the following table. For the safety in the experiment, three joint angles are limited to the following ranges: $-60° \leq \theta_1 \leq 60°$ around z_0 axis; $-45° \leq \theta_2 \leq 45°$ around z_2 axis and $-45° \leq \theta_3 \leq 45°$ around z_3 axis.

Table 1 The size of each link of the robotic manipulator

Symbolic names	Size (cm)	Explanation
L_G	7.5	From ground to the base joint.
L_0	11.5	From the base joint to the shoulder joint.
L_1	13	From the shoulder joint to the elbow joint.
L_2	26	From the elbow joint to the fixed joint of gripper
L_3	5.5	From the fixed joint of gripper to the bottom of the gripper

The robotic manipulator provides an experimental platform for students to verify their solutions for the forward and inverse kinematic problems since the relationship between the reference frame $F_{X_0Y_0Z_0}$ to the target frame $F_{X_TY_TZ_T}$ (or the hand frame) can be clearly derived through the following six steps:

(1) Transformation ${}^0T_1$: from the frame $F_{X_0Y_0Z_0}$ to $F_{X_1Y_1Z_1}$ is to rotate about z_0 an angle of θ_1 and then translate along z_0 a distance of L_G+L_0.

(2) Transformation ${}^1T_2$: from the frame $F_{X_1Y_1Z_1}$ to $F_{X_2Y_2Z_2}$ is to rotate about x_1 an angle of 90°.

(3) Transformation ${}^2T_3$: from the frame $F_{X_2Y_2Z_2}$ to $F_{X_3Y_3Z_3}$ is to rotate about z_2 an angle of θ_2 and then translate along x_2 a distance L_1.

(4) Transformation ${}^3T_4$: from the frame $F_{X_3Y_3Z_3}$ to $F_{X_4Y_4Z_4}$ is to rotate about z_3 an angle of θ_3 and then translate along x_3 a distance L_2.

(5) Transformation ${}^4T_T$: from the frame $F_{X_4Y_4Z_4}$ to $F_{X_TY_TZ_T}$ is to translate along x_4 a distance L_3.

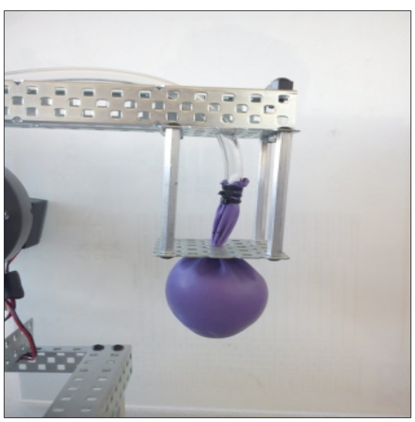
(6) The total transformation is ${}^{0}T_{T} = {}^{0}T_{1}\times{}^{1}T_{2}\times{}^{2}T_{3}\times{}^{3}T_{4}\times{}^{4}T_{T}$.

where ${}^{i}T_{i+1}$ is the transformation[6] from the frame i to the frame i+1 with i = 0, 1, 2, 3, 4 and T, respectively.

<u>To test the solution for the forward kinematic problem</u>: Since all link lengths and joint angles of the robot are known, the position and orientation of the jamming gripper using the above transformations can be calculated at every instant. Experimentally, the joint angles are programmed in the logic controller. The logic controller will turn on the DC motors to control each link to reach each desired angle. Students can see the actual vs. measured (from encoders) location and orientation of the robotic gripper and compare them with the calculated results.

<u>To test the solution for inverse kinematic problem</u>: Since the desired gripper location and orientation of the robotic arm and the length of links are known, the above transformations are used to solve the joint angles θ_1, θ_2 and θ_3, respectively. Experimentally, the solutions of the joint angles are used to place the robotic gripper to the desired position and orientation so that the object at the pre-specific location and orientation can be picked up.

The Granular Jamming Gripper



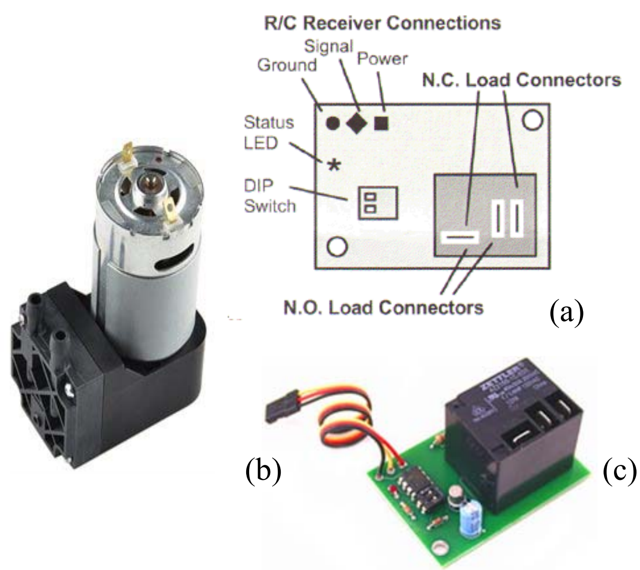


Figure 3 - Granular Jamming Gripper

Figure 4 - Vacuum Motor and Mechanical Relay

The main idea of the granular jamming gripper is to switch an elastic bag containing granular material between a deformable (with air) state and rigid (without air) state by applying a vacuum. With air, the granular material can flow around an object and conform to its shape. When the air is evacuated from the gripper, the granular material will jam and stabilize the grasp. Therefore, it virtually generates an infinite degree of freedom actuated by a single motor.

Figure 3 shows the components for the granular jamming gripper in the robotic kit under the development. It includes a vacuum pump, a mechanical relay and a latex membrane containing granular material. The D2028 pump used here (Figure 4(b)) is made by Sparkfun® Electronics with the vacuum range of 0-16" Hg, the pressure range of 0-32 PSI. It is driven by the DC voltage of 12 Volts with the power of 12 Watts. The mechanical relay switch RS210 (Figures 4(a) and 4(c)), made by Team Delta© Engineering, is used to turn on/off the pump. A PWM (pulse width modulation) signal with the duty cycle larger than 10% is used to turn on the power of the relay. In the experiment, a common party-balloon and coffee grains were chosen as the latex membrane and the granular material, respectively, due to their availability and affordable prices. Other acceptable granular materials can be beach sand and nano-spheres.

Figure 5 shows how the granular jamming gripper works. The gripper is connected to the vacuum pump via vinyl tubing. When the granular jamming gripper is in a relaxed state (i.e. neutral pressure), the gripper acts as a liquid capable of enwrapping an object. If the vacuum pump activates, the negative pressure (inside pressure minus outside pressure) turns the gripper solid providing a clamping action.

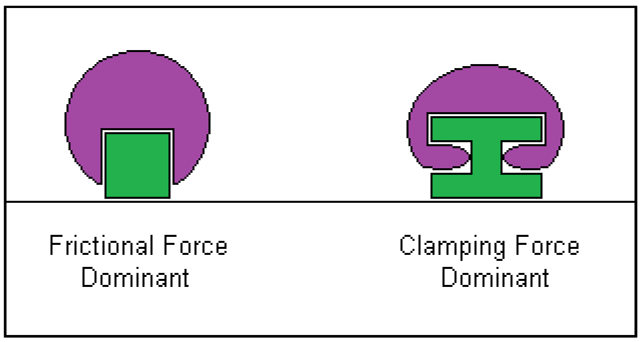


Figure 5 - Dominant Forces

While in the solid state, the irregular shape of each individual coffee grain is exposed through the latex membrane. The membrane will have a rough texture providing an additional frictional force when gripping an object. The frictional force is dominant when attempting to grasp an object where the clamping force is not practicable (i.e. a solid cube). The process of enwrapping the object, solidifying the granular jamming gripper, and returning to a relaxed state provides the necessary actions for object interaction.

When the robotic manipulator positions itself on top of the object, it thrusts down in a perpendicular manner making the object press against the latex membrane and providing enough contact area between the gripper and the object. The logic controller will then send a PWM signal with the duty cycle higher than 10% to activate the mechanical relay. Once the relay is closed, the vacuum will be turned on so that the air inside the gripper will be evacuated, and the negative pressure will be created. The object is now properly gripped by the granular jamming gripper and can be moved around by the robotic manipulator. When the desired location is reached, the logic controller will then send a PWM signal with the duty cycle less than 10%. This will open the relay and turn off the vacuum pump so that the jamming gripper can return to its relaxed state and release the object.

Demonstration of the Manipulator to Detect and Move Objects

Now, an example is taken to demonstrate how the robotic manipulator works. The logic controller will regulate the robotic gripper to a desired location and orientation according to inverse kinematics. It will detect the object at the specified location using sensors and then determine where to send the object. Finally, the robotic manipulator will use the granular jamming gripper to pick up the object and send it to the desired location.

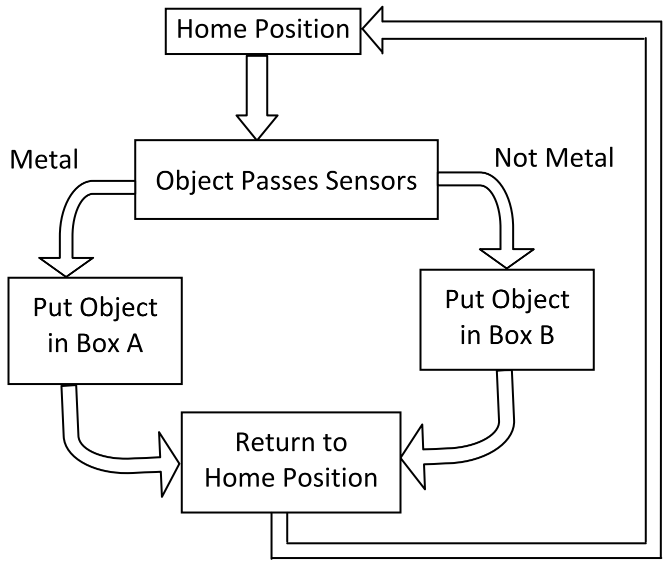


Figure 6 - Working Flowchart of Robotic System

Here, in addition to the robotic arm and the granular gripper discussed in previous sections, the programmable logic controller made by VEX® Robotics, Inc. is programmed in EasyC language and two sensors, the inductive and conductive sensors, are added into the robotic system. The inductive proximity sensors are used to detect both ferrous metals (containing iron) and nonferrous metals (such as copper, aluminum, and brass). Inductive proximity sensors operate under the electrical principle of inductance, where a fluctuating current induces an electromotive force (EMF) in an object. Capacitive proximity sensors are similar to inductive proximity sensors. The main differences between the two types of sensors are capacitive proximity sensors produce an electrostatic field instead of an electromagnetic field and are actuated by both conductive and nonconductive materials.

The robotic manipulator along with the granular jamming gripper can be implemented in an assembly line scenario with a working flowchart shown in Figure 6. The manipulator will be stationed in front of an assembly belt line. As the objects progress in increments of the assembly line, they will pass a station containing two sensors: an inductive-type proximity sensor and a capacitive proximity sensor. These sensors will signal the logic controller of three possibilities: metal, nonmetal, and nonexistent. When the inductive sensor and the capacitive sensor are actuated, the object is deemed metal. If only the capacitive sensor is actuated, the object is deemed nonmetal. In the case of an object falling off the assembly line or a factory worker manually removes an object, none of the sensors are actuated causing the logic controller to increment past the nonexistent object until the next available object.

When an object passes through the sensors, it will be processed step-by-step into a 'pick-up' station of the assembly line, a specified location where the robotic manipulator can grab the object and place it in its designated box. Through the calculated joint angles for each of the reference frames via inverse kinematics, the logic controller will position the gripper. If the object is metal, the robotic manipulator will take it to a designated box which only contains metal objects. Likewise, if it is nonmetal, it will proceed into a box only for nonmetal objects. After placing the object into the appropriate box, the robotic manipulator will return to its initial position waiting for the next available object.

Conclusion

In this paper, we have presented a method to develop a robotic kit in the education of undergraduate students in the Mechatronic Engineering program. In the robotic kit, the VEX® robotic parts has been used to build a testing platform for students to verify the correctness of the forward and inverse kinematic solutions. In addition, a granular jamming gripper has been implemented for students to practice object interaction of robotic systems. The well-worked robotic manipulator and universal granular gripper help students to understand robotics and be more creatively involved in robotic engineering. Furthermore, due to the high flexibility using the VEX® construction parts, students can easily transform the current setup to their needs by adding additional sensors and/or motors.

From the development of the project, we think educators could split the robotic course into position manipulation and object interaction using the provided robotic tool. Before students come to Robotics course, they should have fundamental knowledge of sensors and actuators. Then, they can learn robotic positioning, and finally they will attempt the topic like gripping an object. The application of universal jamming gripper can effectively bridge the two topics and make it ideal for education.

Acknowledge

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