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A Low Cost Linear Force Feedback Control System for a Two-Fingered Parallel Configuration Gripper

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Abstract

This paper presents a simple linear control based force feedback for the gripper of a SCORBOT ER-4u robotic arm. The SCORBOT ER-4u is a 5 degree of freedom (DOF) dexterous robotic arm with a rigid 2-fingered parallel configuration gripper. A Flexi-Force Force Sensitive Resistor (FSR) is attached to one of the claws of the gripper and interfaced to a notebook computer using Arduino Uno microcontroller. The force sensor aids the robotic arm in three different ways: one, senses if an object has been successfully grasped, second determine the coefficient of friction of the object, and third prevent damage when the object will be grasped. The gripper along with the force sensor is calibrated prior to grasping objects. During calibration, samples of the object to be manipulated are used to establish the extents of the gripper on the basis of its grasping force. By following calibration pattern, the gripper is able to grasp objects with approximately the same coefficient of friction. Most importantly, it ensures that the object to be grasped is not damaged by applying sufficient amount of force based on the object's weight. The experimental analyses of the proposed work have shown interesting results to control both the SCORBOT ER-4u robotic arm and the force sensor for grasping masses, strictly conforming to the safety margin of the object.

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Keywords Mechatronics; Force; Friction; Calibration; Robotic Arm.

1. Introduction

For robotic arms, the end–effector is an indispensable component which physically interacts with the environment. The end effectors are commonly used for painting, welding, drilling and also for pick and place tasks. In addition to this, they are used for medical applications as well [1, 2]. In many cases handling of the target object is critical. To some extent, the design of the end of the arm tooling (which is the tool attached to the end effector), are task oriented which is quite expensive and time consuming. According to Kumar and Chand [3], many efforts have been made specifically to eliminate the human operator for three major reasons: First is to save labor costs, second is that a human can be bad for the product (when it comes to handling of products or the semiconductor devices) and third is that the product can be bad for human (handling of radioactive or corrosive components). Upon interaction with the target object, it is inevitable that some amount of force is exerted onto the object. This force must be controlled to finish the task successfully without damaging the product.

Controlling force exerted on an object upon grasping is very well implemented by the human hand. Its capability to apply just the right amount of force is likely to be unmatched in comparison with artificial prosthetic hands. However, researchers have strived to come closer in developing technologies which would mimic a human arm. To understand the concept of grasping, enthusiasts have studied the human arm which is said to have a total of 22 degrees of freedom [4].

An approach is taken by Rahman, Choudhury [5] to mathematically model the thumb and a finger of human subjects to generate a position profile with varying speed of the movements of the fingers. In this study, a force sensor was used to measure the bending angle of the human finger while performing a gripping like action. In [6], a Willow Garage PR2 robot was used to perform object grasping task using a tactile sensing based controller. It behaves by acquiring the hand mounted accelerometer data in real time

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and generates tactile signals to resort to one or the combined set of their proposed states to prevent slippage of the object. Moreover, Wettels, Parnandi [7] presented on Bayesian inference and biologically inspired algorithms for the control of the tangential forces for an anthropomorphic mechatronic prosthetic hand. In accordance with the biomimetic tactile sensor, the Kalman filter is used to remove noise from the acquired data for the calculation of the tangential force. Similarly, Takaki and Omata [8] focuses on strengthening a light–weight anthropomorphic robot hand to make it capable of exerting a large grasping force. Additionally, in [9], the anthropomorphic robotic arm is used to manipulate remote objects through teleoperation. The user manipulates the object through the linkage with a control rig. The force incurred in the robotic arm (which is used to interact with the object remotely) is fed back to the user.

Lin, Ren [10] uses a force imaging approach to tackle the problem of grasping and manipulation through demonstration. Deploying an image sensor (camera), a Fanuc robot is taught by a human how to grasp, pick and place an object. The Fanuc robot exactly mimicked what the human teacher demonstrated to it. In addition to this, Payeur, Pasca [11] presents a 16×16 FSR to recognize small sized 3D objects with the use of machine learning techniques. Though a reliable and a cheap solution for a rough visualization of 3D objects, this method does not work well with objects which are hollow or not easily seen or sensed.

Biologically inspired configurations of the human arm mostly use 2-fingered [12] or 3-fingered [13] grippers to facilitate the same task [2, 6-11] . As explained in Becedas, Payo [12], a 2-fingered flexible gripper attached with a force sensor using a proportional integral control method is used to grasp objects. The control scheme is simple for this system, however, it's modelling is highly complicated for manipulation of rigid and flexible objects.

From the surveyed literature, it can be said that an FSR is a versatile transducer to use for applications or components that require force analysis. The FSR is more reliable and accurate than the other transducers and can also depict force sensing characteristics. One of the primary objectives of robotics research is to develop systems than can operate autonomously. For a pick and place robotic arm, in the context of gripping, the major factor which should be looked at is the application of the right amount of force to grasp and lift an object without crushing it. This paper deals with Tekscan's Flexi–Force [14] FSR to measure the gripping force using a rigid 2-fingered parallel configuration gripper of the SCORBOT ER-4u [15].

2. System Overview

At the high level control, incorporated in this robotic arm platform is an intelligent vision system for object detection and recognition [16], and also a multi-layered feed-forward artificial neural network based kinematics algorithm [3]. The force feedback system is added to the existing setup for object grasping. This would be advantageous to the system for object manipulation as the risk of dropping or crushing the object will be reduced with the help of FSR. Currently, in the SCORBOT ER-4u, there is no sensor for providing force data when the gripper of the robot grasps any object. In this work, an approach has been made by using a low cost sensory design for a force feedback system in order to determine just the right amount of gripping force required by the gripper of SCORBOT ER-4u to grasp a uniform object. The force feedback system is developed using SIMULINK model for the parameters of the gripper of the SCORBOT ER-4u. Experimental study is discussed based on the behavior of Tekscan's FSR, the relationships with respect to the load, normal and frictional forces.

3. The Gripper and Force Sensor Specifications

The gripper is located at the end effector of the robot which is attached to the wrist of SCORBOT ER-4u. The gearing mechanisms enable it to open and close depending on the user's requirements. This gripper mimics the human thumb and index finger capable of holding, tightening and releasing an object. It has a maximum payload of 2kg and is driven by a 12V DC servo motor whose feedback is given by incremental optical encoders. The gripper can open up to 75mm (without rubber pads) and 65mm (with rubber pads). Both the fingers/claws of the gripper moves simultaneously (2-Finger Parallel configuration) to grasp objects.

The force sensor used for feedback in this research is a Flexi-Force FSR manufactured by Tekscan [14]. It is a 191mm long flexible force resistive sensor which is 0.203mm thick. The measuring range for this force resistive sensor is from 0N to 445N. However, to measure forces out of the stated range, an amplification technique can be used. In this application, the sensing range will not exceed 445N.

4. Communicating with the Gripper and the Force Sensor

The gripper is controlled through MATLAB using a USB connection. From the MATLAB command prompt, motor commands are sent to the MATLAB Toolbox for Intellitek SCORBOT's (MTIS) intermediary Dynamic Link Library (DLL) to the Intellitek's Name mangled DLL and then to the control box for actuation through the USB cable. The motor along with the gear mechanisms operate to give desired gripper positioning. The gripping range is from 0mm to 65mm (with rubber pads), hence, each gripper claw moves 32.5mm in order to fully close the gripper claws.

5. Force Sensor Calibration and Force Measurement

As stated in [14], the Flexi-Force FSR offers a repeatability of less than 2.5% along with a response time of less than 5μs. The whole sensing area of the FSR is subjected to different masses for calibration purposes. Since the FSR has a circular sensing area