Grasping Analysis for a 3-Finger Adaptive Robot Gripper

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Abstract—A 3-Finger Adaptive Robot Gripper is an advanced robotic research that provides a robotic hand-like capabilities due to its flexibility and versatility. However, the grasping performance has to be analyzed and monitored based on the motor encoder, motor current, and force feedback so that the finger position and grasping force can be effectively controlled. This paper provides an open-loop grasping analysis for a 3-Finger Adaptive Robot Gripper. A series of grasping tests has been conducted to demonstrate the robot capabilities and functionalities. Different stiffness levels of the grasped objects have been chosen to demonstrate the grasping ability. In the experiment, a Modbus RTU protocol and Matlab/Simulink are used as communication and control platform. A specially modified interlink FSR sensor is proposed where a special plastic cover has been developed to enhance the sensor sensitivity. The Arduino IO Package is employed to interface the sensor and Matlab/Simulink. The results show that the significant relationships between finger position, motor current, and force sensor are found and the results can be used for a proper grasping performance.

Keywords—3-finger adaptive robot gripper; motor current; FSR force sensor; encoder position; open-loop;

I. INTRODUCTION

Underactuated robot hands have been extensively studied over the last few years. The mechanism provides simplistic designs and opportunities to explore new ideas for robotic fingers. It also enables robust and adaptive power grasping which improves the precision grasping for object manipulation. In modern robotic systems, grasping and manipulation skills are the core elements which are involved in unstructured environments (i.e. active and passive compliance). It is important to understand the performance of robotic hands during the grasping process before implementing it with a high complexity system or controller (i.e. closed loop environment). Thus, an open loop grasping analysis is essential to identify robot performance characteristics. The same approach was used in [1], [2] and [3] and it is found that the open loop grasping analysis is simple but yet effective way to understand the behaviors of the robotic hand during multiple grasping operations.

Many robotic hands have been developed mainly for mimicking the capabilities and functionalities of human hand [4]-[5]. However, none of these robots so far able to fully copy due to the complexity of human hand structure. Recently, a ROBOTIQ company has introduced an underactuated robot hand called a 3-finger adaptive robot gripper. Although the size is bigger than the human hand, the robot gripper was still useful for the application in advanced manufacturing and robotic research. In brief, the robot encompasses of four (4) actuators and adaptive joint mechanisms. Its flexibility and versatility allows the gripper to pick up any object of any shape safely. This feature certainly provides the flexibility to the researchers for enhancing and simplifying their control design [6]. The robot can be conveniently communicated with robot controller such as Ethernet/IP, TCP/IP and Modbus RTU. In addition, the Matlab/Simulink can also be used to develop the control algorithm. The 3-finger adaptive robot gripper is shown in Fig. 1.

II. ROBOT FEATURES AND GRASPING MODE

This paper provides an open-loop grasping analysis for the 3-Finger Adaptive Robot Gripper. The feedback information from motor encoder, motor current and force sensor are important aspects to be analyzed for monitoring the grasping performance. A series of grasping test has been conducted based on different object stiffness such as a sponge and a rubber ball. The external force sensor is introduced by incorporating the low cost interlink FSR sensors. A modified plastic cover has been proposed to enhance the sensor sensitivity. Providing such information is the steps for implementing active compliant control on a 3-Finger Adaptive Robot Gripper in the future.

![Fig. 1] A 3-Finger Adaptive Robot Gripper by ROBOTIQ

The 3-Finger Adaptive Robot Gripper by ROBOTIQ was developed in 2014. The robot supports a variety of communication protocols including Ethernet/IP, TCP/IP, DeviceNet, CANopen, EtherCAT, Modbus RTU. Each finger design consists of three (3) links (l1, l2, and l3) where the active joint is driven by a DC motor (with encoders) and the passive
joint is driven by the underactuated mechanism (elastic tendons) as shown in Fig. 2 [7]. These encoders provide useful information, particularly for positioning and motion control of each Robotiq finger.

![Diagram of Active and Passive Joint for 3-Finger Adaptive Robot Gripper](image)

Moreover, the grasping force and speed can be pre-set where the robot has the capability to produce grasping force up to 60N. There are four (4) different grasping modes can be used to test the grasping performance. First, basic mode for objects that have one dimension longer than the other two. Second, wide mode is optimal for gripping round or large objects; third, pinch mode is used for small objects that have to be picked precisely and fourth, scissor mode is used primarily for tiny objects. This mode is less powerful than the other three modes, but is precise. In scissor mode, it is not possible to surround an object (see Fig. 3 and [8] for details). In this study, only basic mode, wide mode and pinch mode are considered.

![Images of Robot Grasping Modes](image)

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III. EXPERIMENTAL SETUP

A. Hardware Setup

Fig. 4 shows the general hardware setup for the experiment. The setup is simple and straight forward and did not require any “third party” hardware. The robot was controlled using Modbus RTU communication protocol via Matlab/Simulink Instrument Control Toolbox. It was then connected to a computer (laptop) via USB cable. The setup also consists of Arduino UNO which acts as a DAQ device. The analog input from the sensors are connected to Arduino ADC (Analog to Digital) pin and the data were then acquired using the Simulink Arduino IO Package. The robot and Arduino UNO were executed in the same Simulink program (with 2 different USB COM ports).

![Diagram of Hardware Setup](image)

B. FSR Force Sensor Setup

A low cost FSR sensors are used in the experiment for external force detection. Previous studies have shown that the low cost FSR sensors are sufficient and reliable for detecting force [9]. In general, the FSR sensors which produce the voltage (V) can be converted to Force (N) by using the linear model equation presented in [10]. A suitable voltage divider circuit can also be used to convert the resistance (kΩ) to voltage (V). The fact that the low FSR sensors used in this experiment are insensitive to the contacted object, a modified contact surface
is essential. The general specifications show that the detection force is ranged between 1N to 100N [11]. However, capturing higher force (more than 35N) can be troublesome. For this, the researcher has developed a 3D printed plastic cover as shown in Fig. 6. This plastic cover is designed mainly to enhance the force distribution during grasping. The FSR sensor and the plastic cover are mounted together by using double sided tape. The sensors are then placed on each robotic finger tip as shown in Fig. 7.

A preliminary test was carried out to observe the performance of the FSR sensors with and without (i.e. a standard FSR sensor) the plastic cover. A low stiffness spongy ball is used for the test object. The maximum speed and force (approximately 60N on the finger tip) are set and the results can be seen in Fig. 8. It is found that the standard FSR sensors are not capable of detecting a grasping force higher than 35N. The thinness of FSR sensors makes it harder to detect the pressure from a soft object (i.e. a low stiffness ball). In contrast, the FSR sensor with plastic cover improved significantly the reading where the captured data are approaching 60N. The results clearly show that the FSR sensors with 3D plastic covers are useful for detecting a wider range of forces. This technique is certainly very helpful when the low cost sensors are used on robotic hands, particularly on a 3 Finger Adaptive Robot Gripper.

C. The Open Loop System

An open loop control system has been set up for a 3 Finger Adaptive Robot Gripper to perform a grasping analysis as illustrated in Fig. 9. The desired position (joint angle) of each finger is manually controlled by using Matlab/Simulink. The desired position is based on the size and shape of the grasped object. The feedback data, such as an encoder, motor current, and force value are also required for real time analysis.

IV. GRASPING ANALYSIS AND DISCUSSION

A. Grasping Variations

There are two (2) different scenarios can be expected when executing the grasping test. First, when grasping a soft object, the same level of force is produced by each fingertip. This allows each finger (finger A, finger B and finger C) stops at the same desired position. Second, when grasping a hard object, different force level is produced by each finger. Refer Fig. 10 for a better insight of grasping variations. In order to demonstrate this scenario, two (2) different objects which have similar size but different stiffness are selected (see Fig. 11). In the case of the 3-finger adaptive robot gripper, the grasping is driven by the elastic tendons that are controlled by the actuators. This actuator is mounted to the first finger link, $l_1$ (see Fig. 5).

In general, the test is carried out based on the pinch grasping mode where a precise grasping is required. To begin with, the desired position is set to 100 degrees as shown in Fig. 12. It can be observed that all fingers have reached the desired position satisfactorily for the low stiffness ball (see Fig. 12(a).
This implies that the object has produced a low force level and consequently driven all fingers to the desired position easily. On the other hand, in the case of grasping for the high stiffness ball, only finger A is able reaching to the desired position as compared to finger B and finger C (see Fig. 12 (b)). This scenario obviously represents the case as depicted in Fig. 10 (b). According to [5], this grasping variation occurred (at a different desired position) was due to the summation of force from two fingers (in this case finger B and finger C).

The additional grasping test has been carried out by employing the wide grasping mode (usually used for power grasping). A hard rubber ball which has a 13 cm diameter is used for the test object. The desired position is set to 85 degrees. The results show that only finger B and finger C follow the set point satisfactorily while finger A only achieves a set point of 78 degrees. However, the grasped object is still in stable condition and the performance is shown in Fig. 13.

**B. Force Analysis**

This section provides the grasping analysis with respect to the external force. The analysis will be based on the pinch grasping mode and two (2) different balls are considered (a soft and a hard ball). The desired position is set to 80 degrees and only performance of finger B is observed for simplicity. Fig. 14 demonstrates the performance of the FSR sensor when grasping a soft ball (a low stiffness ball). It is found that the grasping position of finger B follows a set point satisfactorily when an external force is applied. However, the force level is maintained at 40N. The results are different when grasping a hard ball where the grasping position of finger B is below a set point (reaching approximately 79 degrees). Meanwhile, the force level is maintained at 49N.
Moreover, Fig. 17 shows the correlation between force and motor current. Their characteristics are summarised in Table I. Additionally, the relationship between motor current and force sensor is also recorded. The results are depicted in Fig. 18. The robot finger and object are in contact starting from point “c”. As the finger continues to grasp, the contact force and the motor current increase proportionally. Once the finger reaches the desired grasping position, the motor current drastically drops to 0 mA at point “c”. Then the finger stops at period 6.5 seconds.

C. Motor Current Analysis

This section provides the grasping analysis with respect to the actuator’s motor current. The motor current is recorded based on the “no load” grasping condition. The desired position is set to 90 degrees. Interestingly, the current dropped to 0 mA when the desired position is achieved (spans of 3.2 s to 5.8 s). Meanwhile, the average motor current is 0.75 mA during grasping (X) and ungrasping (Y). Fig. 16 shows the detail grasping analysis and current level. The difference of current level produced during grasping and ungrasping has been addressed in [13].

It can also be observed that the motor current has a different amplitude for different grasping objects. The test on three (3) different objects, namely a sponge, a plastic bottle and a pen will verify this scenario (see Fig. 18). Obviously, the stiffer object (i.e. a pen) produced the highest current amplitude, followed by the plastic bottle and the sponge. In addition, Fig. 19 summarizes the relationship between $\Delta$ Pos and $\Delta$ Current for finger A, finger B and finger C based on six (6) different objects.
The study also discussed the grasping variations with respect to the joint angle, $\theta$. It was found that the power grasping has significantly produced various grasping performance, particularly for each finger. Essentially, the information from the grasping variation analysis, force analysis, and current analysis can be very useful for future study. This is in particular for the implementation of active compliant control where the grasping, force and current usually taken into considerations.

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**REFERENCES**


