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Smart Grasping using Laser and Tactile Array Sensors for UCF-MANUS- An Intelligent Assistive Robotic Manipulator

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SMART GRASPING USING LASER AND TACTILE ARRAY SENSORS FOR UCF-MANUS -AN INTELLIGENT ASSISTIVE ROBOTIC MANIPULATOR

by

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B.E. Visvesvaraya Technological University, 2012

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ABSTRACT

This thesis presents three improvements in the UCF MANUS Assistive Robotic Manipulator's grasping abilities. Firstly, the robot can now grasp objects that are deformable, heavy and have uneven contact surfaces without undergoing slippage during robotic operations, e.g. paper cup, filled water bottle. This is achieved by installing a high precision non-contacting Laser sensor$_1$ that runs with an algorithm that processes raw-input data from the sensor, registers smallest variation in the relative position of the object with respect to the gripper. Secondly, the robot can grasp objects that are as light and small as single cereal grain without deforming it. To achieve this a MEMS Barometer based tactile sensor array device that can measure force that are as small as 1 gram equivalent is embedded into the gripper to enhance pressure sensing capabilities. Thirdly, the robot gripper gloves are designed aesthetically and conveniently to accommodate existing and newly added sensors using a 3D printing technology that uses light weight ABS plastic as a fabrication material. The newly designed system was experimented and found that a high degree of adaptability for different kinds of objects can be attained with a better performance than the previous system.

ACKNOWLEDGMENT

I am grateful to my advisor Dr. Aman Behal, whose understanding, expertise, generous guidance and support made it possible for me to work on my thesis that was of great interest to me. I sincerely thank Dr. Michael Haralambous, Assistant Professor, Department of Electrical and Computer Engineering, UCF and Dr. Ladislau Boloni, Associate Professor, Department of Computer Science, UCF for mentoring me as my Thesis Advisory Committee members. I also thank my research colleagues: Nicholas Alexander Paperno and Amirhossein Jabalmeli for their sincere help and support throughout this thesis research works.

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CHAPTER 1: INTRODUCTION

UCF MANUS Robotic Manipulator System

When it comes to the designing of automation systems the advanced research focus has shifted from production and manufacturing field towards service segments. Particularly, Assistive Robotic Systems are one of the popular consideration in service sector. An assistive robot is a sensor based, mechatronic system that can be reprogrammed and can perform useful works to daily human tasks e.g. Pick and place of objects. Assistive robots may also include surgical robots, cleaning robots, rehabilitation robots, companion robots and workstation-based robotic arm systems.

This thesis deals with a special kind of assistive robot called MANUS Hok et al. [1], a wheelchair-mounted robotic arm(WMRA) designed by Exact Dynamics to meet the necessities of motion-impaired persons due to neuromuscular losses like spinal cord injury, multiple sclerosis, stroke that poses limitations to upper body extremities. The robotic arm is meant to be mounted to the side of a wheelchair Kim et al. [2]. With two-fingered end-effector it has six degrees of freedom (DOF) and can be directly controlled by the user using either a joystick, or a keypad controller. MANUS is upgraded to perform a set of pre-defined tasks automatically too with built in functions. Several interface options has been added apart from the initial robotic arm functions along with grabbing and retrieval of objects that were based on the general automated functions Kim et al. [2].

Further, UCF MANUS's performance was improved to work under complex environments and handle more challenging tasks like grabbing objects from cabinets/boxes on shelves or underneath a table with Fine Motion Control processes, Compensatory Gross Motion procedures and Particle Filter-Based Tracking algorithms to ease the grasping activities which could be performed by the robot itself in automatic mode or by the end user in the manual mode operations by Nicholas et al. [3] Kim et al. [2].

Problem Motivation

Although with these upgradation the system improved its design in terms of multimodal user interface suitable mainly for a range of user disabilities in performing activities of daily living (ADL) but did not involve any improvements in development of sensor components at the two fingered end-effector that could increase effectiveness of robot's autonomy. A human like grasping operations were limited by the present hardware configuration of the MANUS for instituting smart grasping set points to perform ADL on novel objects. Robotic grasping has been a principal focus in the field of robotics for decades in order for the robots to achieve the precision of human-like grasping abilities. Due to the large variation between the objects in the human surroundings, realizing an algorithm under such complex situations where the robot has no prior knowledge of shape of the object and with only known noisy and partial sensor data makes it necessary to build a system that can overcome these difficulties.

In the current system [2]-[3], grabbing of novel objects by the two-fingered end-effector relied on the visual characteristics and force profile of the target object to estimate the gripper's interacting force. The visual characteristics are analyzed using the eye-in-hand camera and force sensitive resistors placed on the robotic arm and the end-effector respectively. These methods poses a serious problem that might lead to situation where grasping operations would not be unique to the same object at different states. Lack of reliable data for certain objects may result in poor balance in forces that causes object to slip or be deformed e.g. a soda can, empty paper cup.

Objective

To develop a system that results in a high degree of adaptability and achieve better performance than the current system by enhancing the sensing capabilities of the robot at the end-effector for grasping operations that involves ADL for novel objects.

Thesis Organization

With respect to the above introduction and objectives the rest of the document is organized into six different chapters. Chapter 2 will extensively review related works in the present available sensor technology employed in a system congruent to UCF MANUS. Chapter 3 explains the pressure sensor device that detects the force applied between the end-effector grippers on deformable objects. Chapter 4 discusses the slip sensor device that is used for detecting the slip of grasping object. Chapter 5 documents the installation of the slip and pressure sensor on the 3D printed ABS plastic material and interfacing of these sensors on the UCF MANUS grippers. Chapter 6 discusses the idea behind the implementation of the proposed new smart grasping algorithm followed by analysis of the new configuration in chapter 7 experimental results for grasping operation on various test objects. Finally, chapter 8 discusses the important implications from the experimental results and provides necessary improvements and scope for future research works.

CHAPTER 2: LITERATURE REVIEW

Introduction

A report by Nation Spinal Cord Injury (SCI) Statistical Center [39] states that an annual incidence of SCI in US are 40 cases per million population as of 2014. At this incidence rate and with current population of 313 million people the total number of cases are estimated to be in the range 240,000- 337,000 persons at the rate of 12,500 new cases each year. Many of these persons are confined to wheelchairs, have moderate to minimal function in their upper extremities and need some amount of care and attention. On an average the expenses range from 230,000 USD to 780,000 USD in the initial year and may vary from 700,000 USD to 3 million USD for a 25 year old [40]. 2/3rd of assistive device users have difficulties with ADL e.g. pick and place of objects.

Smart grasping of objects in ADL for robotic manipulators has been active research area in recent period. Various force-control and slip detection methods have been published to achieve human-like dexterous grasping that are specific to a given hardware and control algorithms, and are limited to grasping particular category of objects only. Under such applications a versatile sensor attached to the end-effector of the robot plays a vital role in grasping. Issues associated with the shape and mass of the object would then become trivial, and thus can effectively overcome problem of slippage and deformation by applying right amount of force between the grippers.

Sensors

There exists two types of robotic sensing: contacting and non-contacting. A contacting or tactile sensor could be used in detecting the position, force, torque, etc. and on the other hand a non-contacting sensor could be used to perceive proximity, displacement, etc. Resistive, elastoresistive, piezo-resistive, tunnel effect, capacitive, optical, magnetic, piezo-electric, conductive rubber, are the different types of contacting and non-contacting sensors available and that could be used for a specific purpose of robotic applications. The main motivation for researchers on tactile sensing system is human skin. We often use tactile sensation for pressure detection and slippage sensation to control and manipulate grasping operations.

Pressure Sensing

Tactile sensors can measure force applied on the object directly on the point of contact of an object. These sensors find applications across wide range of robotic hand manipulators. Kiyoto et al. [4] implemented a control system on a prototyped robotic hand using a large number of tactile sensors that closes its fingers until the tactile pressure sensors located on the finger tips came in contact with the grasping object. Makoto et al. [5] developed a hierarchical multiprocessor controller algorithm that uses an optical-mechanical based tactile sensors on a three fingered robotic hand prototype. In [6], a flexible tactile sensor was fabricated for multi-fingered robotic hands that to detect shear deformation of the grasping object. In their work, the shear forces and contact position were measured using standing piezo resistive cantilever viscous embedded elastic sensor. Shimojo et al. [7] developed prototype of a mesh of tactile sensors that covers entire robot structure which used pressure-conductive rubber as a flexible sensing elements that can be mounted on arbitrary surfaces and can optimally distribute the applied load to a 2-D surfaces. A steady response characteristics were observed in their experiments regardless of the number, location and surface area of the sensor. Joseph et al. [8] presented a controller algorithm by placing pressure sensing arrays at the fingertips and real time hand-mounted accelerometer on Willow Garage PR2 robot’s two gripper parallel jaws. The designed mimicked several discrete grasping controller states with the help of tactile event cues and showed how tactile feedback could be used as primary source of sensing to achieve human like grasping.

Slip Sensing

Seiichi et al [9][10][11][12] in their extensive research on tactile sensors designed and developed a low-profile highly sensitive slip sensor using a pressure conductive rubber as the detection element and subsequently discussed the slip detection characteristics and the principle of the CoP Tactile Sensor. A combined optical-mechanical tactile sensing method with high sensitivity slip detection method has been developed by Makoto et al. [5] to enable the fine finger-force control needed for different grasping objects on a home use manipulation system. The finger-force adjustments method for slip sensing is studied and documented in [13]-[22] provides information on the minimum grasping force. In these conventional sensing methods the slip sensors are mounted on the contact surface of the hand and the slip is determined with respect to the deformation of the target object. Hamidreza et al. [23] introduces an optical-based LED motion detection sensor used to measure the actual displacement of the grasping objects that slips. Their system were less prone to external disturbances compared to sensors that rely on vibration or acoustics when compared to [24] [25], where researches placed an optical-acoustic sensor on the thumb of the prosthesis to manipulate the grasping force. The main drawbacks of these researches are that they are practically exposed to environmental noise and external disturbances that would sometimes lead to inaccurate grasping. Ravinder et al [26] discussed the various technology available that uses to improve capabilities of sense of touch for robots and, with more insight on the available trends and methodology to fabricate tactile array sensors.

Discussions

It is also important to keep in mind at the point of choosing suitable sensors, the structural complications such as embedding the detecting sensor on to the UCF-MANUS' two fingered robotic gripper and the wiring of those sensors should be minimal. Plenty of articles could be found on sensors that could be used for specific type of robotic hands that are not developed beyond the collaborations in which they were designed or fabricated. Numerous research suggests that there exist a gap between actual implementation and laboratory experimentation that are limits the progress of tactile sensors, and the software that controls them. The prototype pressure conductive sensor discussed in [9] has issues concerning the response time due to a difficulty imposed by the large voltage change at the point of slippage. Although research on optical sensor [22] sounds more promising than the others, but it still fails to detect grasping force for daily used objects such as those with transparent and reflecting surfaces. This study hence targets in developing a slip sensor for UCF-MANUS which is simple, fast, robust, cost-effective and, including and not limited to only prosthesis based applications rather could be used for researches that needs to detect slippage of the object without deforming during ADL grasping operations.

CHAPTER 3: PRESSURE SENSING USING TAKKSTRIP-2

Introduction

Although there are wide range of pressure sensing tactile sensors have been fabricated and experimented, most of them were restricted only to a particular prototype for research purposes. Very less number of tactile sensing technology have shown reliable and good performance and out of which only few are commercially made available. Use of miniaturized tactile pressure sensor [27] that was integrated using MEMS and CMOS in [4] demonstrated high accuracy, design flexibility for measuring various pressure range. Lael et al. in [28], used the low-cost commercially available MEMS Barometers tactile array sensors [29] and were successfully able to demonstrate stable adaptive grasps on i-HY Robotic Hand [28]. The MEMS Barometric sensor chips embedded called 'TakkStrip" fabricated by TakkTile Inc. [30] has distinguishable merits over various commercially available tactile sensors and has been experimented on range of robotic hands application as seen in iRobot-Harvard-Yale hand [29], Robotiq Gripper [31] and DoraTouch [32]. In this thesis TakkStrip-2: a version of tactile array sensors [30], were used as pressure sensors for tactile sensing.

MEMS Barometer Pressure Sensor Chips

Takkstrip-2 is nothing but an array of closely mounted MEMS Barometer Pressure sensors on a PCB chip. MEMS Barometer Pressure chips were mainly manufactured for applications like portable and desktop Barometry, Altimeters, Weather Stations, Air control systems, Hard-Disk Drives, etc. This miniature sensor chip is fabricated by Freescale Semiconductor, Houston, Texas as MPL115A2 [33] as an absolute pressure sensing device measuring 5.0 mm x 2.0 mm x 1.2 mm. The sensor chip consists of a MEMS diaphragm with a Wheatstone bridge, Differential amplifier, Temperature Sensor, ADC, MUX and an I2C interfacing for serial communication with an external microcontroller.

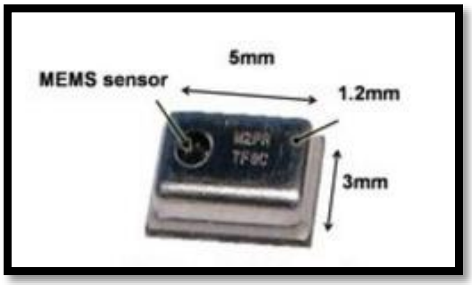


Figure 1: MEMS Barometer Chip MPL115A2

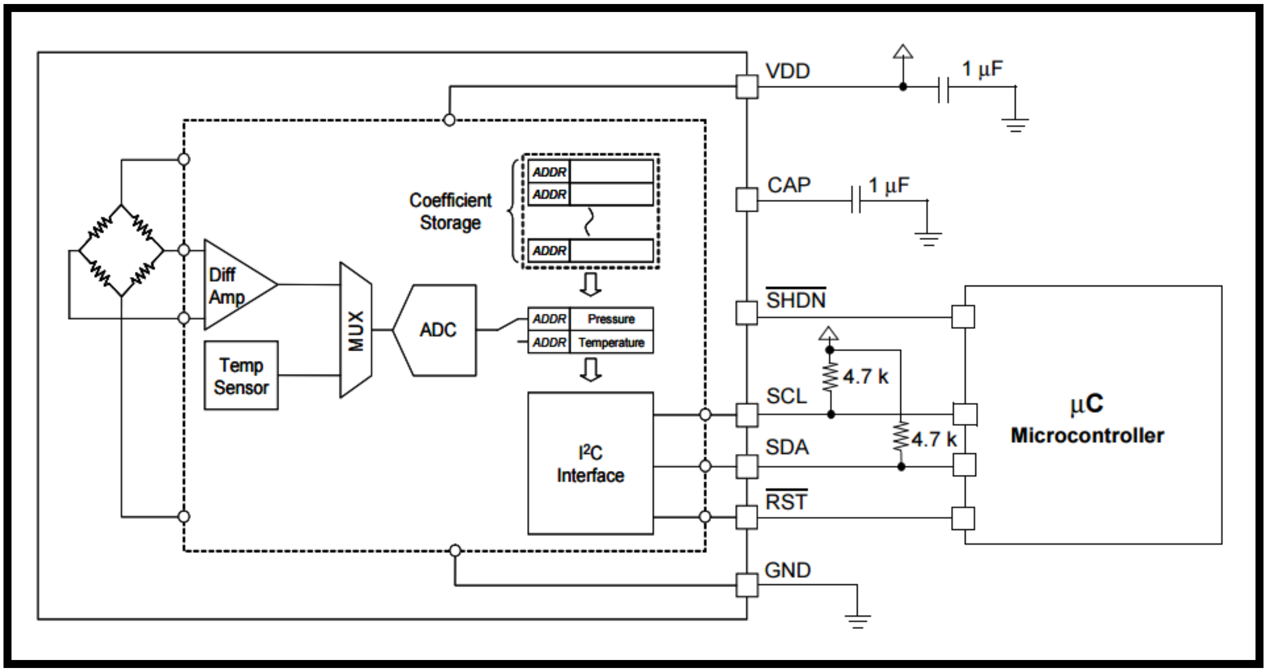


Figure 2: Block Diagram and Pin Connections of MPL115A2 [33]

TakkStrip-2

The TakkStrip-2 tactile sensor consists of 6 sensor arrays that are soldered in line with 8 mm optimally spaced to a hard PCB (Fig-4) and are then casted in a rubber (VytaFlex 20, Smooth Inc., USA) with overall thickness of 4.2 mm which easily fits inside robot's glove which shall be discussed in Chapter-5.

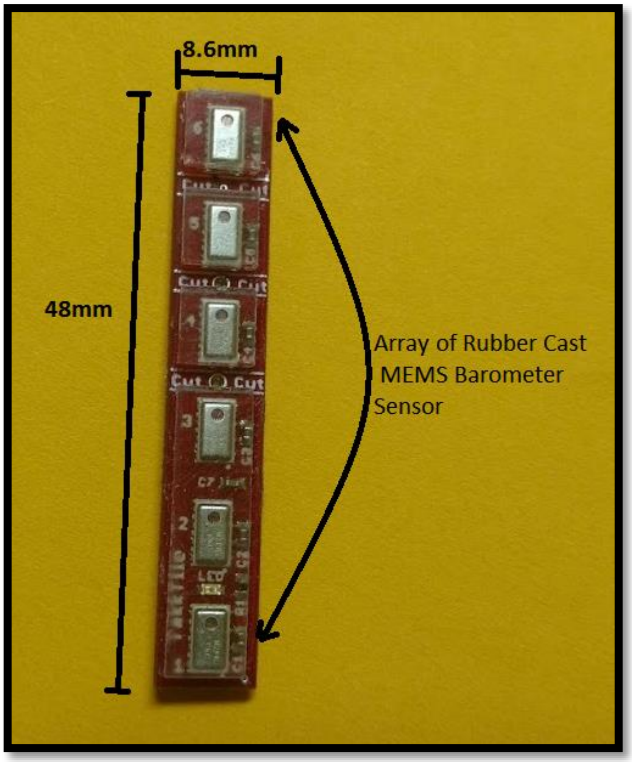


Figure 3: TakkStrip-2

The sensors communicate with the help of the USB-I2C bridge interface (manufactured by Cypress Semiconductor Corp., USA). The individual sensors when cut using Dremel tool can act as an individual taxels (individual sensor units termed by TakkTile Inc) and could be placed anywhere on the finger, as in [28] or up to 8 different TakkStrip-2 attached to the same I2C bridge by appropriately setting the address select jumpers at the base of the microcontroller as shown in (Fig-4).

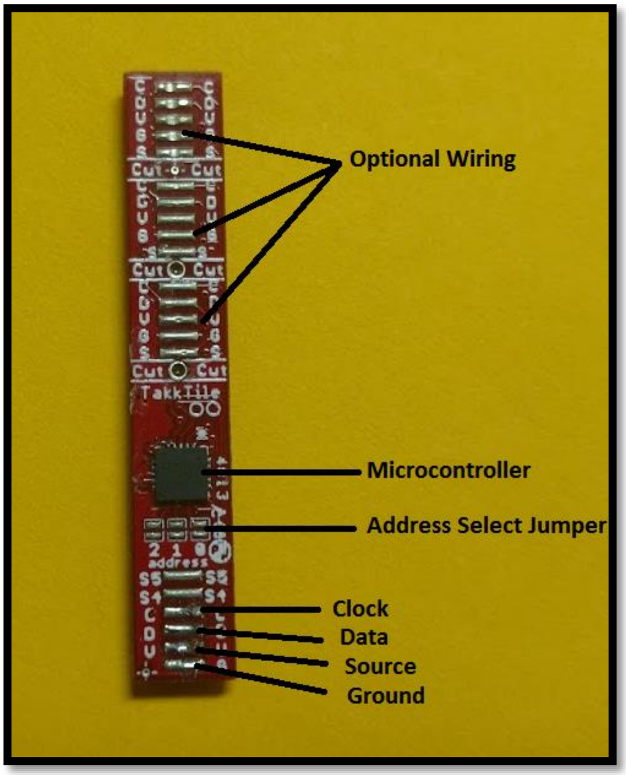


Figure 4: TakkStrip-2 Circuit Description

Salient Features

TakkStrip-2 makes it number one choice over any commercially available sensors in the current market for our application for the following salient features it offers:

- An individual sensor can be sensitive to as less as 1 gram- force (approximately 0.01 N) and measure force up to 11 kilograms (approximately 107 N)
- Highly linear behavior (linearity typically less than 1% and maximum deviation from linearity of 2.2%)

- Readily available in an array of sensors that could be integrated with Arduino Micro Microcontroller for interfacing with MANUS desktop workstation
- TakkStrip-2 dimension closely matches the present gripper-glove configuration hence could be easily mounted on both sides of the parallel grippers
- Robust rubber cast that makes it easy to grasp wide range of object with different mass, shape and surface properties.

CHAPTER 4: SLIP SENSING USING HIGH PRECISION LASER SENSOR

Introduction

There are several kinds of non-contacting sensors that are available in the current market for wide range of robotics application. Although only few kinds of non-contacting sensors are helpful in detecting in slippage for grasping of ADL objects. Our selection process for a non-contacting sensor was narrowed to ADNS-3530 LED and ADNS 9800 Laser Sensor from Avago Technologies, Inc. In Hamidreza et al. [23] clearly shows that the ADNS-3530 optical-based LED Sensor fails to detect grasping objects that are reflective and transparent. Hence, the high performance of the Laser Sensor makes it the number one choice in our research.

High Precision Laser Sensor

Further, we have used a high performing 8 bit RISC architecture microcontroller [34] HT46RB70 Holtek Semiconductors Inc that supports for serial communication with the MANUS Processing Unit. This particular device is widely used in SPI touch-panels, touch-pads, XBOX joysticks, Anker Inc Optical Mouse for PC. It comes with a HALT feature that is intended to reduce the overall power consumption with high Performance. The above specific ADNS-9800 Laser Slip Sensor interfaced with HT46RB70 microcontroller were found to be available in Anker CG100 8200 DPI High Precision Programmable Laser Mouse [35] for Personal Computers (PC).

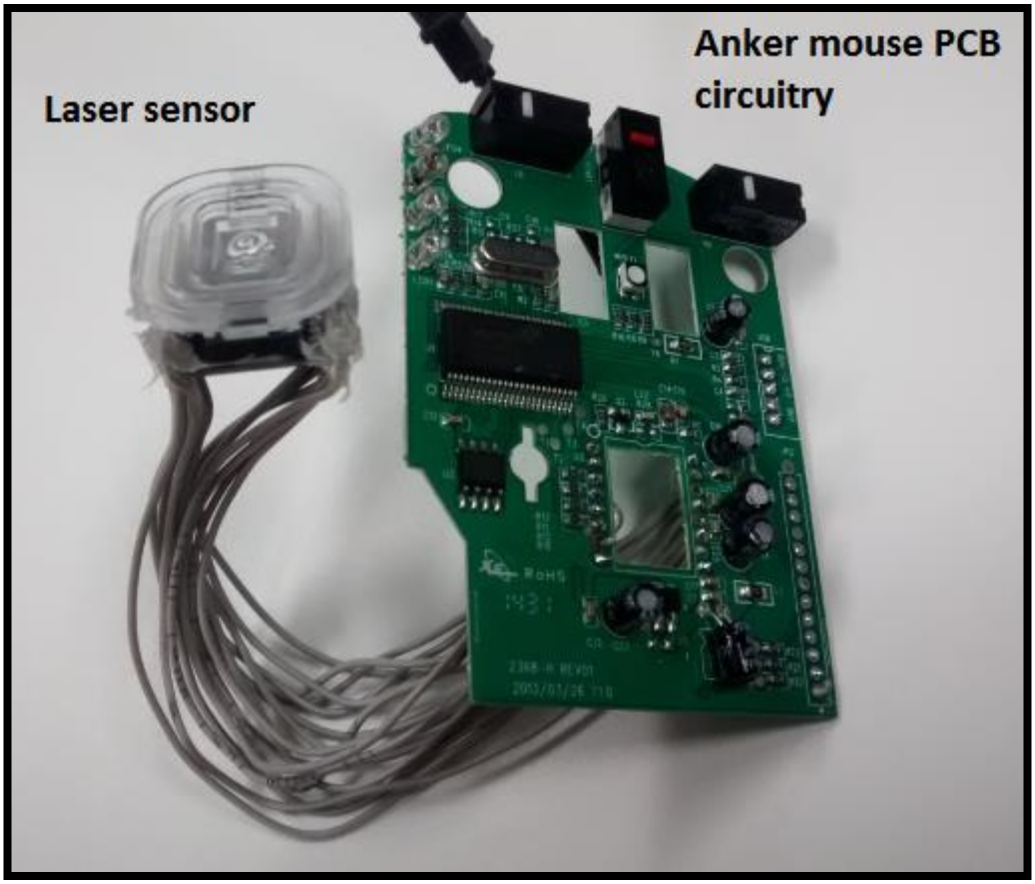


Figure 5: Rewired Laser Sensor Mouse Circuitry

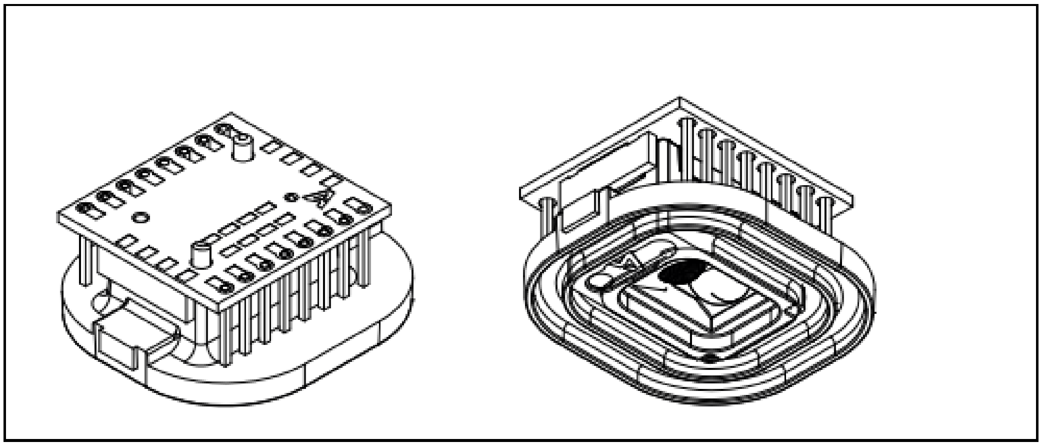


Figure 6: Isometric Drawing of ADNS-9800, PixArt Imaging Inc [36]

The LASER mouse uses an ADNS-6190-002 [36] polycarbonate round lens that delivers directed illumination and optical imaging required for precise sensing operations by the Slip Sensor. The dimension of the ADNS 9800 is 14.4mm x 31.5mm x 9.7mm and the assembly drawing with lens coupled to PCB and base plate is shown in (fig-6).

Salient Features

- User programmable frame rate (up to 12,000 frames per second)
- Configurable sleep and wake up time (in order to optimize power consumption)
- Dual power supply selections, 3 V or 5 V
- 16-bits motion data registers
- Compliance to IEC/EN 60825-1, eye safety limit 716 μW
- No Laser power calibration needed

CHAPTER 5: INSTALLATION

Introduction

This chapter discusses in detail on the design of the gripper glove and how the two types of sensors viz., TakkStrip-2 and Laser sensor are mounted on it. Further, the interfacing of both types of sensors with the MANUS Desktop workstation, the methodology of reading the sensor data and followed by the implementation of the new adaptive control algorithms against the existing force-gripper control algorithm is explained. The new adaptive control

Gripper Glove Design

The gripper-glove of UCF-MANUS presently designed to accommodate only the infrared (IR) gate sensors that can detect proximity of a grasping object and linear potentiometer to detect collision against hard surfaces on either side as shown in (fig-7). The proposed newly added sensors requires a new design that can accommodate more aesthetically and be able to grasp objects with much more accuracy than the present pair of gripper-gloves by placing the TakkStrip-2 and Laser Sensor as close to the gripper as possible. These sensors were experimented at two different phases. Considering these factors, two different models: Model-1 and Model-2, are designed in 3D printing technology that uses the light weight ABS Plastic fabricating material as shown in (fig-8 and fig-9).

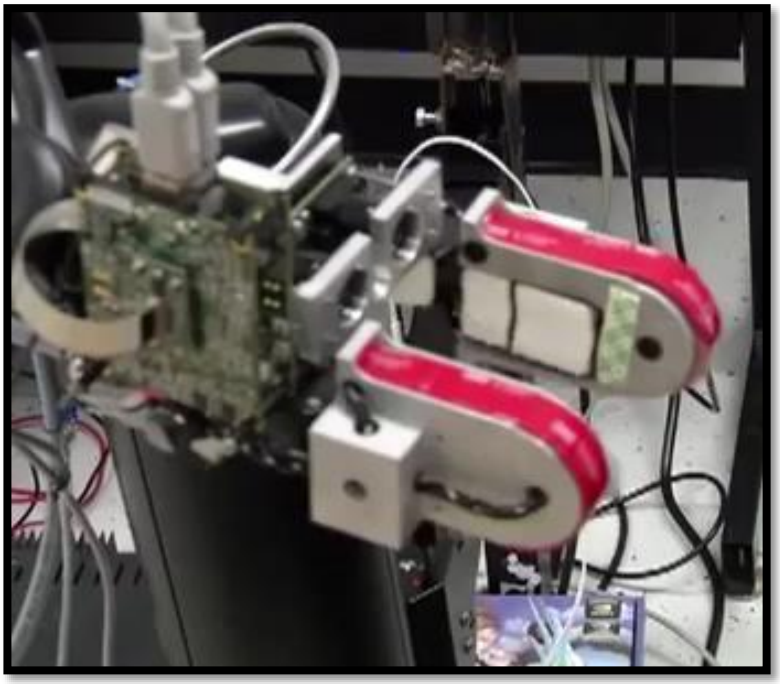


Figure 7: Old Gripper Glove Design

Newly Designed Models and their Implementation

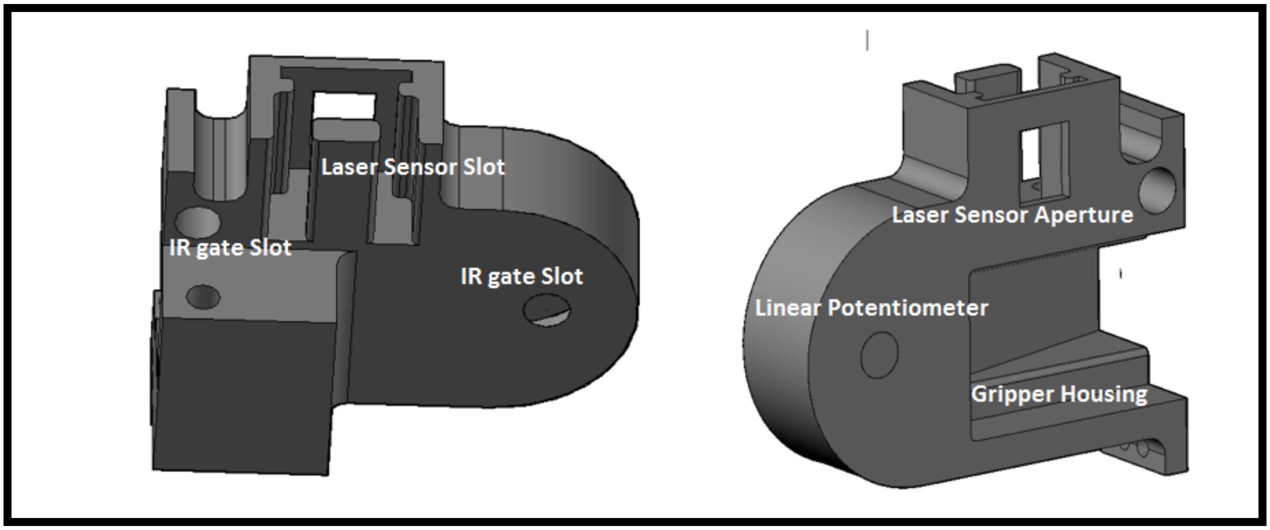


Figure 8: Proposed Model-1 for Laser Sensor-FSR Sensors (Phase-1 Experimentation)

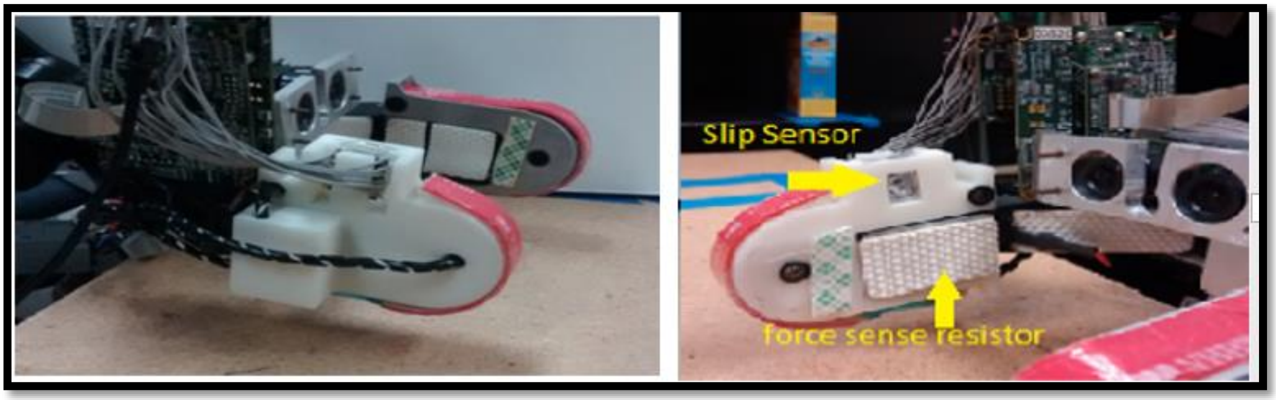


Figure 9: Implementation of Model-1

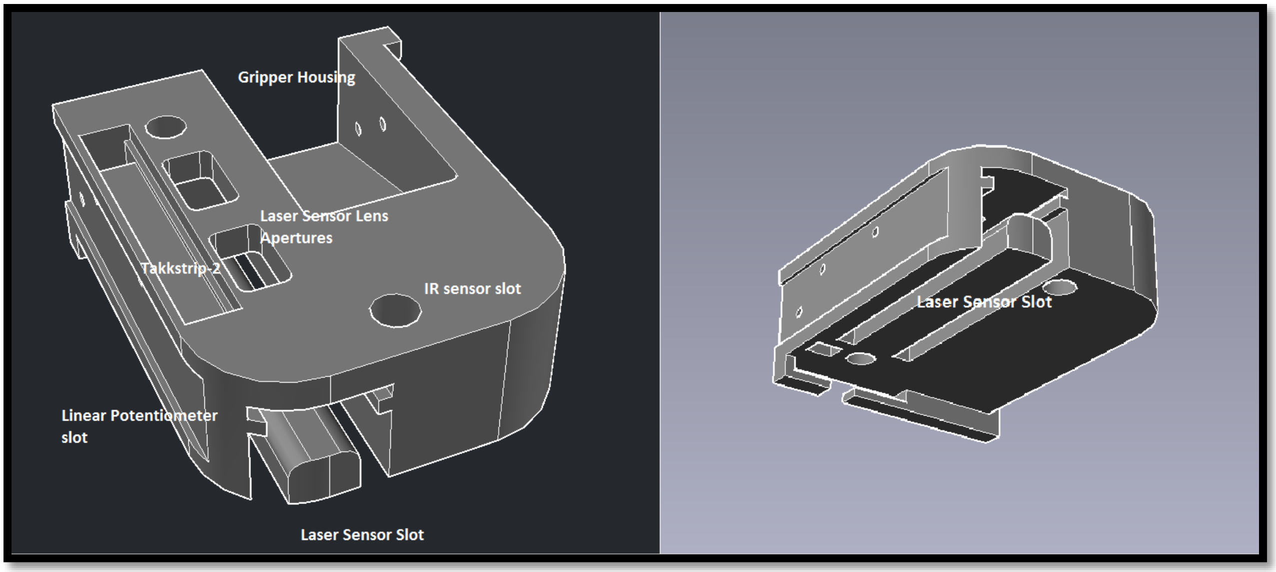


Figure 10: Proposed Model-2 for TakkStrip-2 (Phase-2 Experimentation)

Figure 11: Implementation of Model-2

Interfacing Sensors

Laser Sensor

Laser slip sensor detects the motion changes when the object surface is within 9.95 mm from sensor reference plane for accurate sensing as per the specification of the sensor. Hence, it is placed firmly well inside the slot with a distance of 5mm from the point of contact between the grasping object and the gripper. The readily available Laser Sensor is interfaced serially through any of the MANUS's available COM port. Since the PC of the Robotic Manipulator's operating system works on Microsoft WINDOWS OS data retrieval algorithm based on the standard windows desktop applications protocol available online at Microsoft Windows Dev Center [38] has been used. There are three different ways of reading the data from any Human Interfacing Device (HID) e.g. mouse:

- WM_MOUSEMOVE
- WM_INPUT
- DirectInput

The WM_MOUSEMOVE protocol reads the data based on the monitor screen resolution that means that the actual data read depends on the number of pixels the pointer has moved from its initial position. Thus it has a serious drawbacks as there is a pointer ballistics that accelerates those data based on how fast the grasping object moves in vicinity of the Slip Sensor. Whereas the WM_INPUT method read raw input data from the HID stack without any additional internal ballistics application that reflect high-definition results. By programming the Laser sensor to 8200 dpi with 1000Hz polling rate settings using the Anker Driver Programming Software it is possible to get a resolution of 0.0031 mm/pixel. The DirectInput on the other hand needs more thread to be handle to read the same WM_INPUT (also known as Raw Input Model) data and the algorithm gets cumbersome and has no significant advantages over the others. Also there are other advantages of using WM_INPUT Model for reading data:

- It is capable of distinguishing between similar type of devices e.g. when another similar sensor is used simultaneously
- A better data traffic management from group or a specific device types compared to other two models
- This model remains same for any number of updates that would be made to currently installed Windows Operating System on the UCF Manus work station

TakkStrip-2

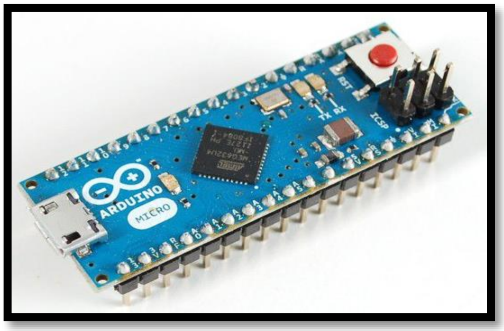


Figure 12: Arduino Uno Microcontroller for interfacing TakkStrip-2 to the MANUS PC

The individual sensors on the TakkStrip-2 are internally interfaced to the on board microcontroller through I2C bridge. The Arduino Micro controller (fig-12) allows to communicate serially using an I2C-USB that produces user readable data on an Arduino Integrated Development Environment (IDE). The external circuitry of the TakkStrip-2 that is connected to Arduino Micro allows the user to read data at the rate of 100 Hz per sensor element over a common communication bus. The flowchart in (fig-13) represents how the communication is established between the Arduino Micro via COM port of the

MANUS's Desktop PC.

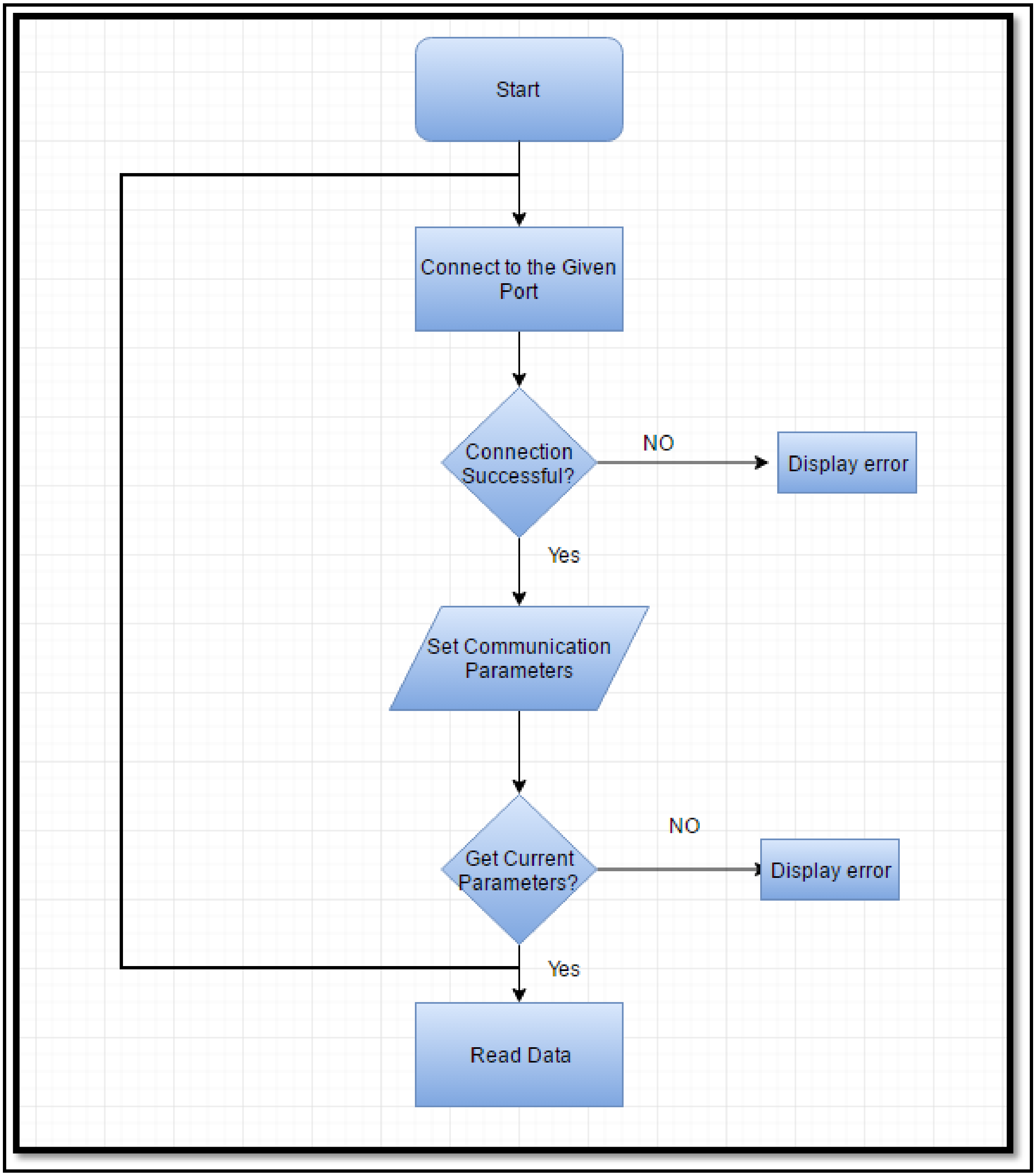


Figure 13: TakkStrip-2 Sensor Serial Communication Flow-Chart

CHAPTER 6: CONTROL ALGORITHM AND DESIGN

Introduction

It is at most important for a WMRAs to be able to grasp an object that are associated to the ADLs. If the robot grasps the object too tightly or with excess force it can accidentally crush a deformable or weak object. The robot would drop or lose the object from its grasp if the object is loosely grasped while retrieving it to the user. With respect to the algorithm [2] that is presently implemented using the FSR sensor in the UCF Manus the grasping mainly used the force profile of the object being grasped to determine when the gripper stops grabbing the object. This method works for objects like cereal boxes or any rigid structures that are used in ADLs. Issue arises when the gripper encounters less heavier, soft and deformable objects like Styrofoam cup, paper cup, empty water bottle, etc. Completely relying on the force sensor alone is not enough to successfully grab an object. Hence these issues are addressed in the newly proposed algorithms.

Smart Grasping using Laser Sensor and FSR

The new algorithm seeks to rectify the stated algorithm by not depending on the force profile for its determination on when to stop. This algorithm will utilize the already implemented force sensor in conjunction with a Laser position displacement sensor. The Laser sensor will be used to detect when the object is within the gripper and determine the force when to stop the grasping process. The reading from the force sensor will then be used as minimal force necessary to successfully grab an object. If for any reason the object was not grabbed with enough force, the Laser sensor will be utilized to detect any movement due to the object slipping and the force applied to the object by the grippers will be used as a control input to keep the object from falling.

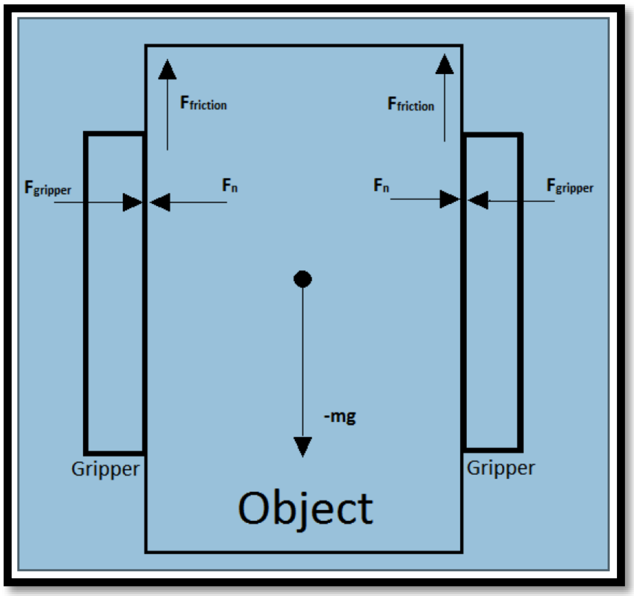


Figure 14: Force Model Schematic

Gripper Force Control

The slip detection method is composed of two parts. First is the determination of the force when initially grasping the object. The grasping motion for this process is controlled by the laser sensor as opposed to the pressure sensor given the sensitivity, or lack thereof, of pressure sensor. Laser sensors typically have a very high rate of input for its data. This leads to a lot of noise in the raw data from the sensor when gripping an object. This noise will be used to our advantage to tell when to stop the grasping procedure. It was experimentally determined that the threshold for determining if the object has been grabbed was roughly 120 data points in either the x or direction. This signals the robot to stop grasping and register the force that is recorded as the minimum force necessary to properly grip the object without crushing it. This registered force is then used as a starting point for determining whether or not the object is grasped appropriately.

Slip Detection

The second part of the method involves monitoring the velocity of the object as the robot moves. This part of the algorithm is also used to determine whether or not the object has been grasped successfully. This is due to the fact that both events will look identical to the sensor. Because of this we can utilize this detection method to also determine if the object was grasped too lightly to begin with. We can express the derivative of the velocity as,

$$m\dot{v} = W - \mu\, F_a \tag{1}$$

Where in (1), $W = mg$ is unknown. We can then define the applied force F_a as:

$$F_a = \hat{\mu}^{-1}(\widehat{W} + kv) \tag{2}$$

Where $\widehat{W}$ is the estimated gravitational force with $\widetilde{W} = W - \widehat{W}$ being error between the estimated and the actual, $\tilde{\mu} = \mu - \hat{\mu}$ the error in the frictional co-efficient and k is a constant. We then define the derivative of velocity as,

$$m\dot{v} = W - \mu\,\hat{\mu}^{-1}(\widehat{W} + kv) \tag{3}$$

$$m\dot{v} = W - (\tilde{\mu} + \hat{\mu})\ \hat{\mu}^{-1}(\widehat{W} + kv)$$

$$m\dot{v} = W - (1 + \tilde{\mu}\ \hat{\mu}^{-1})\big(\widehat{W} + kv\big)$$

$$m\dot{v} = \widetilde{W} - kv - \tilde{\mu}\ \hat{\mu}^{-1}\,(\widehat{W} + kv) \tag{4}$$

For some constant $\gamma_1 and\ \gamma_2$ a Lyapunov-based PI controller will be used to correct the error in applied force by controlling the velocity of the object. To do this we will first define a positive-definite Lyapunov function V as follows:

$$V = \tfrac{1}{2}mv^2 + \tfrac{1}{2}{\gamma_1}^{-1}\widetilde{W}^2 + \tfrac{1}{2}{\gamma_2}^{-1}\tilde{\mu}^2 \qquad (5)$$

Differentiating this equation yields the derivative as:

$$\dot{V} = \left(\widetilde{W} - kv - \tilde{\mu}\ \hat{\mu}^{-1}\left(\widehat{W} + kv\right)\right) v - {\gamma_1}^{-1}\widetilde{W}\dot{\widehat{W}} - {\gamma_2}^{-1}\tilde{\mu}\dot{\hat{\mu}} \qquad (6)$$

From this it can be seen that for any positive value of k the system will be globally asymptotically stable.

The newly designed controller is based on Barbalat's Lemma such that the new co-efficient of friction is positive.

$$\dot{\widehat{W}} = \gamma_1\, v \qquad (7)$$

$$\dot{\hat{\mu}} = \gamma_2\mu^{-1}\left(\widehat{W} + kv\right)v \qquad (8)$$

To ensure $\hat{\mu} > 0$, projection is used and hence,

$$\dot{V} = -kv^2 \leq 0 \qquad (9)$$

By Barbalat's Lemma, $\lim\limits_{t\to\infty} v(t) \to 0$. Signal chase to send boundedness of remaining signals or,

$$m\dot{v} = \widetilde{W} - \mu\mu^{-1}\left(\widehat{W} + kv\right) \qquad (10)$$

$$m\dot{v} = \widetilde{W} - \tilde{\mu}\,\mu^{-1}\left(\widehat{W}\right) - k\mu\mu^{-1}v \qquad (11)$$

Grasping using TakkStrip-2 Array Sensors

The drawbacks associated with the FSR with regards to limited sensation of force applied between the grippers is easily addressed by gram sensitive TakkStrip-2 array sensors that are mounted on either side of the robot’s gripper. The TakkStrip-2 array sensors runs with algorithm [12] and equation and uses the net force applied between the two TakkStrip-2 sensors (2). The grippers stops when the force profile reaches to a constant value. This part of the profile represents the resistance of the object that is at its initial state when the force is applied between the grippers. Followed shortly after this is the point where the object’s structure yields to the grasping force. The following condition should be satisfied when the profile reaches the constant or flattened section:

$$g(t) \triangleq \sup_{t \in [t-\Delta T, t]} \left| \frac{df(t)}{dt} \right| < \epsilon \qquad (12)$$

Where $f(t)$ is the net interacting force between the two TakkStrip-2 sensors, ΔT is the sliding time window width, and ϵ is a numerical tolerance constant.

CHAPTER 7: EXPERIMENTAL RESULTS

Introduction

The UCF-MANUS platform [3] was used as the main experimental setup for this thesis. The experiments were conducted in two different phases. In the Phase-1, grasping of objects that are heavy, deformable and uneven contact surfaces are carried out using the Model-1 gripper-glove design. Laser and FSR are the only two tactile sensors that are used and the gripper follows the adaptive control algorithm based on the positive definite Lyapunov Stability criteria described in the previous chapter. In Phase-2, grasping of small and light weight objects with different shape and size are experimented on the simple force control algorithm as mentioned earlier. Phase-2 experimentation shows successful grasping of objects that are as small and light as Cereal.

Phase-1 Experimental Set-up: Laser Sensor and FSR

Empty and full water bottles were used along with empty and full Styrofoam cups as test objects for the experiments. The full water bottle was filled with water and capped and the filled Styrofoam cups were filled with sand to prevent any water from affecting the sensors and other electronics. For all experiments the objects are initially grabbed using the either the proposed algorithm, the previous algorithm in [2], or using no algorithm. After the objects were grabbed, the gripper was moved upward to test whether or not the grab was successful. A force sensing resistor (FSR) will act as the force sensor for these experiments as it did for the previous algorithm.

Old Algorithm, Empty Styrofoam cup(left), Sand Filled Styrofoam cup(Right)

Present Algorithm, Empty Styrofoam Cup(left), Sand Filled Styrofoam Cup(right)

Proposed New Algorithm, Empty Styrofoam Cup(left), Sand Filled Styrofoam Cup(Right)

Figure 15: Pictures showing Grasping Operations on Styrofoam Cup

No Algorithm, Empty (Left) and Filled(right) Water Bottle

Present Algorithm, Empty (left) and Filled (right) Water Bottle

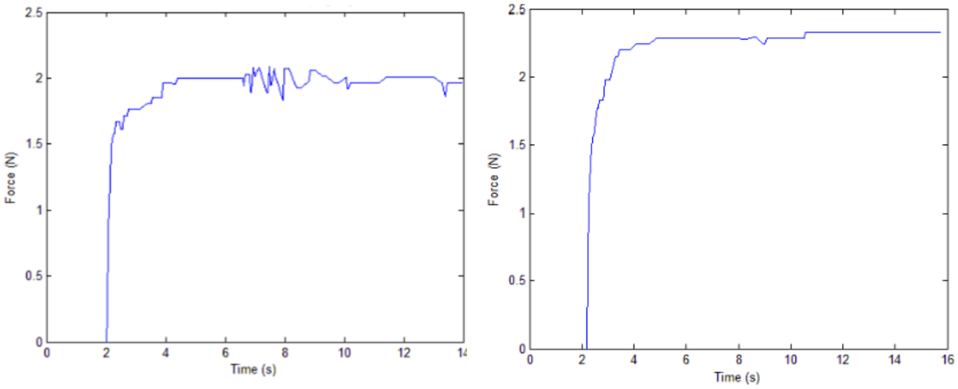
New proposed Algorithm, Empty (left) and Filled (right) Water Bottle

Figure 16: Pictures showing Grasping Operations on Water Bottle

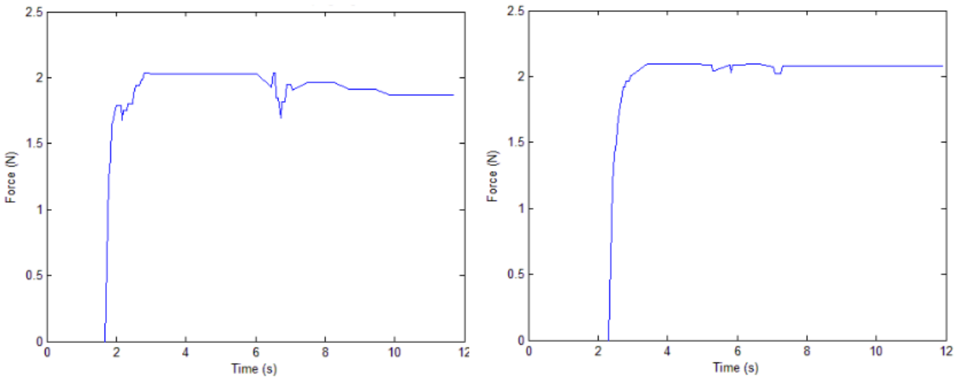
Grasping

The proposed algorithm succeeded in grasping the desired objects with little to no deformation and utilizing less force than previous algorithms to obtain its goal as seen in Fig. 17. When testing on the water bottles the proposed algorithm used 1.313 N of force to successfully grab the empty water bottle and 1.74 N to grab the full water bottle. Both of these are less than that of the old algorithm which used slightly less or just as much force as using no algorithm at all. The old algorithm used 2.03 N of force to grasp the empty water bottle and 2.09 N to grasp the full one. This roughly the same as using no algorithm to grasp the empty water bottle which used 2.07 N. This goes to show the deficits of using the previous algorithm to grasp pliable objects. The old algorithm did perform better when grasping the full water bottle using 0.246 N less force than when using no algorithm.

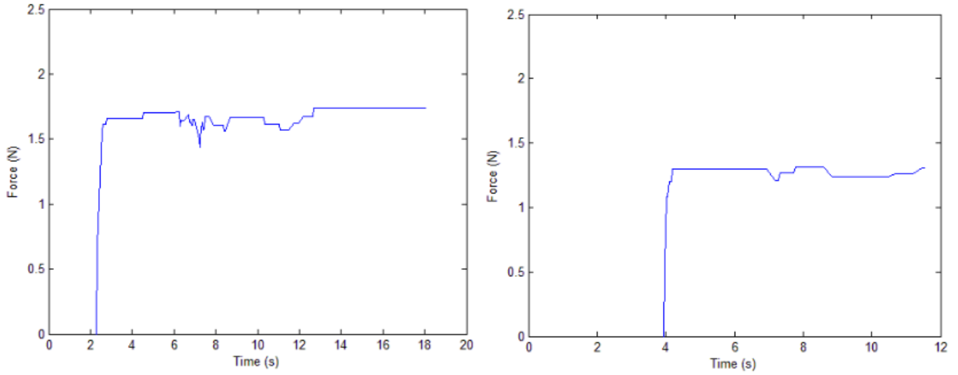
Pliable objects, such as the empty water bottle and cups, deformed significantly when grasped with the previous algorithm and using no algorithm. The deformation of the Styrofoam cups can be seen in (fig-15). The empty cup deforms slightly when using the proposed algorithm, but still retains most of its original shape. The previous algorithm and use of no algorithm completely deforms the cups when being grasped. The full cups fare better when being grasped. They suffered no deformation when grasped using the new algorithm and only a slight deformation when using the previous one. There is considerable deformation when using no algorithm on the full cups, but not as severe as with the empty cups. Other rigid objects had similar results as those shown for the full Styrofoam cup.



Old Algorithm, Empty Bottle(left), Filled Bottle (right)



Present Algorithm, Empty Bottle(left), Filled Bottle (right)



New Proposed Algorithm, Empty Bottle(left), Filled Bottle (right)

Figure 17: Force Plots using Pressure Sensor Data for Empty and Filled Water Bottles

Slip Detection

The full water bottle was also used to test the proposed algorithms slip detection. Two different experiments were run: one in where the bottle was not grabbed with enough force initially resulting in the gripper moving up without it and one where the bottle was grabbed correctly, but not tight enough to stop the force of gravity from causing the object to slip. Fig. 18 (left) shows the results from the unsuccessful initial grab and Fig. 18 (Right) shows the results from the slipping test. The results look very similar, but this is to be expected given that both are treated as an object slipping even if in one case it is the movement of the gripper that causes the velocity and displacement. The events are identical to the sensors, so they are treated as such. The difference lies in the velocity and position graphs. The slipping object has a significantly slower velocity and moves only a few millimeters compared to the object that is left on the table as the gripper moves upwards. In both cases though, the algorithm successfully re-grips both objects. As seen in the figures, when the object starts to move there is a distinct decrease in the force. Once this is detected, the robot starts to apply more force to the object causing its relative motion to stop.

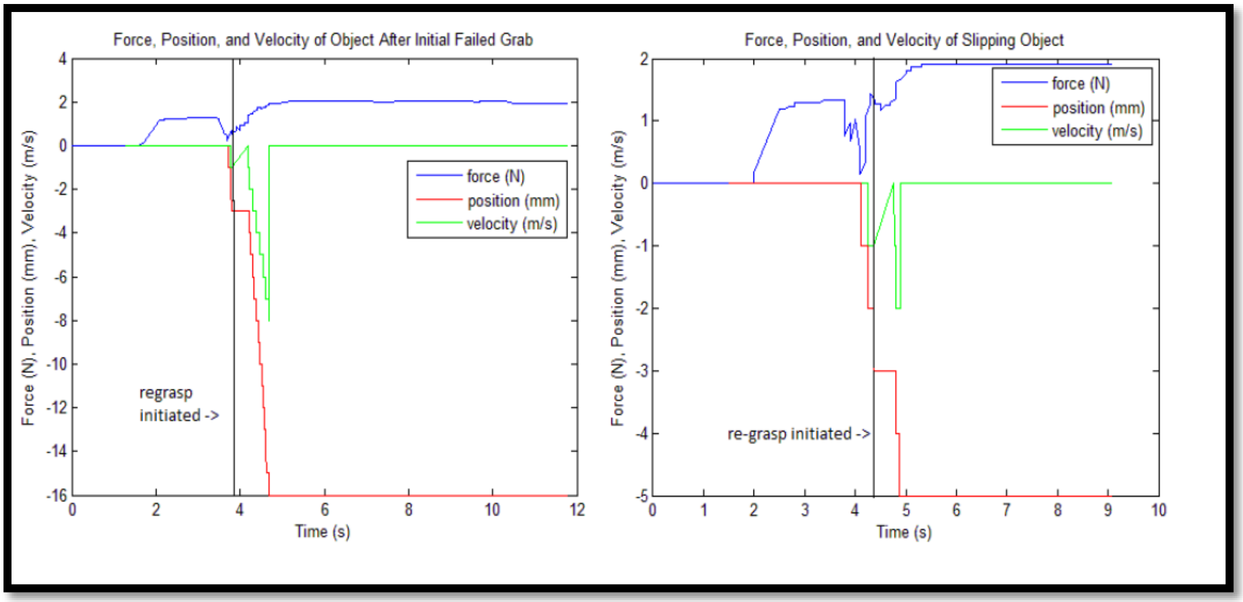
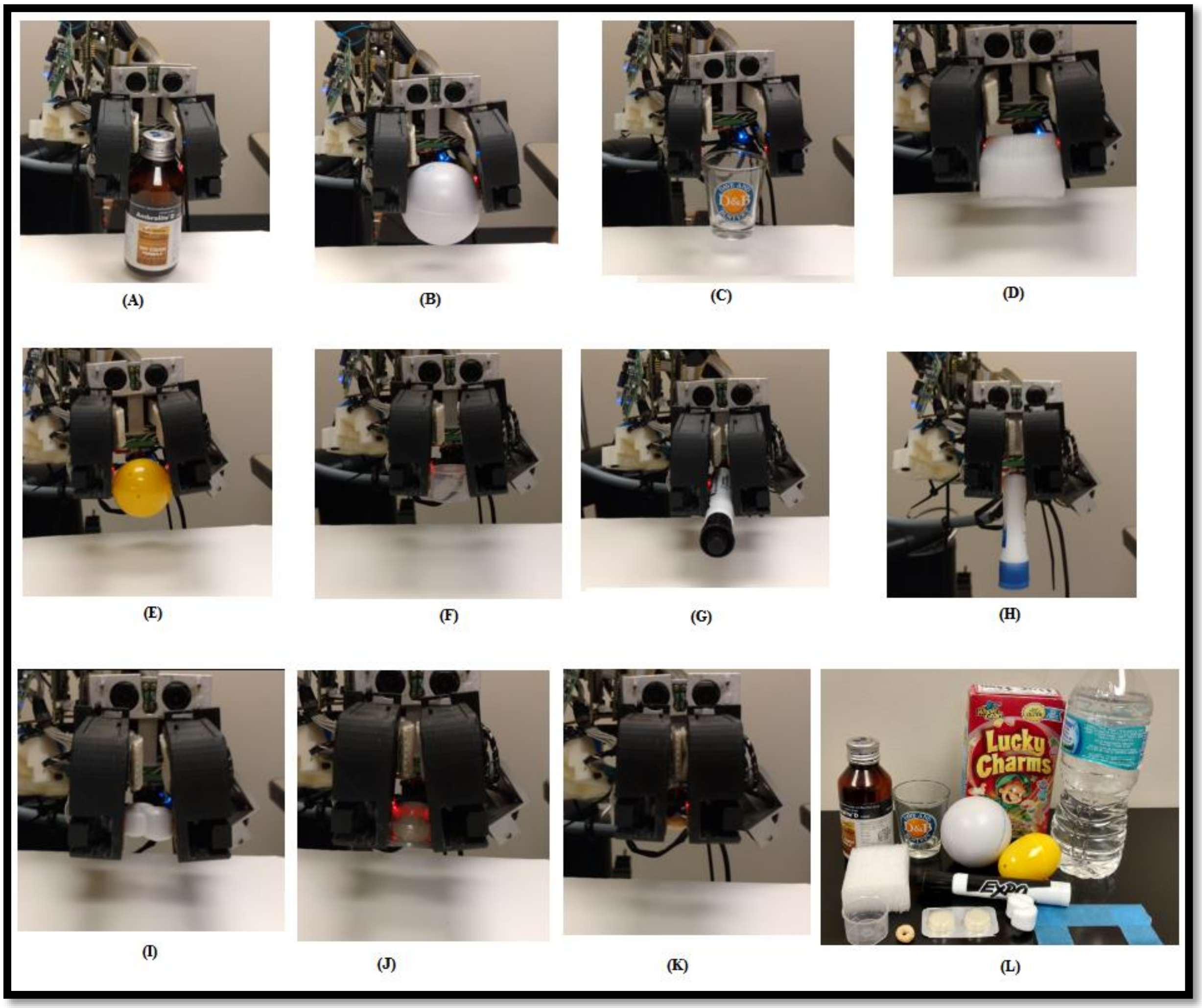


Figure 18: Force, Position and Velocity Grasps during Initial Grasp and Slip.

Phase-2 Experimental Set-up: TakkStrip-2

In a simple experiment of grasping of small objects a success rate of 100% were observed. The experiment involved use of only TakkStrip-2 for grasping. Figure-19 shows various objects : syrup bottle(A), foam ball(B), a shot glass(C), a foam block(D), plastic Easter egg(E), syrup measuring cap(F), whiteboard marker(G), moisturizer container(H), packing peanut(I), strip of pills(J), single cereal grain(K). And, the picture (L) all contains all of the objects used in both the Phase-1 and Phase-2 experiments. The grasping operations carried out in all the cases were a single click approach i.e. the user commands the robotic gripper to close on a required object and a mouse click is used to pick up the object based on the template that is available in the manual mode of operation. The user can control the position of the gripper but has no control on required grasping force for successful grasping of the object. The objects for experiments were chosen such a way that each of them have different size and shape, varying height, and width and different orientation on the table.


(A) (B) (C) (D)

(E) (F) (G) (H)

(I) (J) (K) (L)

Figure 19: Grasping of Small Objects using TakkStrip-2

The following table shows the summary of degree of deformation and successful rate of grasping objects that were used in both the Phase-1 and Phase-2 experiments.

Table 1: Degree of Deformation of Various Test Objects used in ADL

Sl. No	Objects	Old Algorithm	Present Algorithm	New Proposed Algorithm
1	Empty Water Bottle	Moderate	Moderate	NA
2	Full Water Bottle	Moderate	Slight	NA
3	Empty Styrofoam Cup	High	Moderate	NA
4	Full Styrofoam Cup	High	Moderate	NA
5	Empty Paper Cup	High	High	NA
6	Cereal Box	Slight	Slight	None
7	Syrup Bottle	Slight	Slight	None
8	Foam Ball	High	Moderate	Slight
9	Shot Glass	NA	NA	None
10	Packing Foam Block	High	Moderate	None
11	Plastic Easter Egg	High	Moderate	Slight
12	Plastic Measuring Cap	High	Moderate	None
13	Whiteboard Marker Pen	NA	NA	None
14	Moisturizer Container	Slight	NA	None
15	Packing Peanut	High	High	Moderate
16	Pills strip	NA	High	None
17	Single Cereal Grain	NA	High	None

CHAPTER 8: CONCLUSION AND SCOPE FOR FUTURE RESEARCH

In this thesis an intelligent grasping algorithm using a Laser sensor and a force sense resistor in Phase-1 and TakkStrip-2 in the Phase-2 of the experiment that improves upon the previous grasping algorithm that was being utilized by the UCF-MANUS system was demonstrated. There are significant improvement over the previous algorithm that was implemented that relied on force profiles to determine when an object was successfully grabbed. The results show that the proposed algorithm can accomplish the same task using significantly less force than the previous one. The slip detection and correction also succeeded in ensuring that the desired object remained grasped by the robot. This provides a cheap and easy way to implement an intelligent grasping algorithm to improve tactile sensing of UCF MANUS robotic grippers. Further research works may be done for replacing the force sensing resistor by TakkStrip-2 with a new gripper-glove model and perform grasping operations on more difficult-to-grasp objects.

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