Development of an Autonomous Friction Gripper for Industrial Robots

Majid Tolouei-Rad and Peter Kalivitis

Abstract—Industrial robots become useless without end-effectors that for many instances are in the form of friction grippers. Commonly friction grippers apply frictional forces to different objects on the basis of programmers' experiences. This puts a limitation on the effectiveness of gripping force that may result in damaging the object. This paper describes various stages of design and development of a low cost sensor-based robotic gripper that would facilitate the task of applying right gripping forces to different objects. The gripper is also equipped with range sensors in order to avoid collisions of the gripper with objects. It is a fully functional automated pick and place gripper which can be used in many industrial applications. Yet it can also be altered or further developed in order to suit a larger number of industrial activities. The current design of gripper could lead to designing completely automated robot grippers able to improve the efficiency and productivity of industrial robots.

Keywords—Control system, end-effector, robot, sensor

I. INTRODUCTION

INDUSTRIAL robots play an increasingly important role in material handling and pick and place operations. This activity requires use of various types of end-effectors or grippers for properly grasping and relocating objects with different shapes, geometries, and considerations. Most grippers are a simpler model of the human hand which is considered as an impactive method of prehension where they use a clamping jaw-like system to grasp objects. Impactive grippers typically possess fingers which usually move synchronously. These aspects allow for an automatic method of object centering which is vital for ensuring correct object positioning and orientation. When considering industrial applications, automatic object positioning and orientation is an invaluable resource as gripping systems do not need to halt manually for manual alignment of workpieces. Another important characteristic of impactive grippers is the contact region that refers to the contact points of the gripper with workpiece. Generally impactive grippers use two methods for object retention, non-penetrating and penetrating contacts. Often non-penetrating contact is preferred as it simply relies on the frictional force between the gripping surface and the workpiece surface in order to retain the object. Most of common grippers used in industrial robots are not equipped with range and force sensors in order to avoid collisions with

objects in the workspace, and also to apply sufficient gripping force to different objects. Consequently sometimes robots hit the object or apply excessive gripping forces that could result in deformations or exerting damages to objects or to the robotic systems. Researchers [1] believe that a safer and collision free working environment is vital as in industrial and domestic applications unifying the workspace of humans and robots are foreseeable in the near future. This would require safe and dependable robot designs and control systems.

II. LITERATURE REVIEW

In recent years various aspects of robotics technology has attracted many researchers. These include robot kinematics [2], [3], control systems [4], [5], vision system [6], task planning [7], [8], and off-line programming [9]. Shimoga [10] presented a survey of computational algorithms for achieving four important properties in autonomous multifingered robotic hands. The four properties are dexterity, equilibrium, stability, and dynamic behavior. According to him the multifingered robotic hands must be controlled so as to possess these properties and hence be able to autonomously perform complex tasks in a way similar to human hands. Cutkosky [11] carried out a study on the choice, model and design of grasp and developed an expert system to resolve grasping issues. Osyczka [12] proposed a multi-objective optimization based robot gripper design and solved the gripping problem with different configurations. Ceccarelli *et al.* [13] and Cuadrado *et.al* [14] performed dimensional synthesis of gripper mechanisms using Cartesian coordinates. The formulation was based on practical design requirements and the aim was to derive an analytical formulation using an index of performance to describe both kinematic and static characteristics. *Cabrera et al.* [15] developed a strategy using evolutionary algorithm for optimal synthesis of a two-hand multi-objective constrained planar mechanism. They validated the results by evaluating the mechanism with some points on the Pareto-optimal front and showed satisfactory results. Another study [16] proposed an optimum design of two-finger robot gripper mechanism using multi-objective formulation, considering the efficiency, dimension, acceleration and velocity of the grasping mechanisms and reported a case study by using 8R2P linkage. Datta and Deb [17] proposed determination of optimum forces to be extracted on robot grippers on the surface of a grasped rigid object a matter to guarantee the stability of the grip without causing defect or damage to the grasped object. They proposed solving a multi-criteria optimization of robot gripper design problem with two different configurations involving two conflicting objectives and a number of constraints. The objectives involved

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minimization of the difference between maximum and minimum gripping forces and simultaneous minimization of the transmission ratio between the applied gripper actuator force and the force experienced at the gripping ends. In another work Zhang and Nelson [18] proposed kinematic design of serial manipulators. This method provides uniform manipulability over the workspace and genetic algorithms are used to solve the resulting linear problem.

From the above discussion it can be concluded that despite great improvements made in robotics technology and friction gripper designs, still the issue of applying proper gripping forces is a matter of research. Current frictional grippers do not necessarily apply sufficient gripping forces to different objects. On the other hand, customized friction grippers are designed for specific applications and incorporate high costs not affordable for many industries. The objective of this research is to design and evaluate the functionality of a low cost friction grip end-effector equipped with appropriate force and range sensors for general pick and place applications.

III. PROJECT DEVELOPMENT

In this project first a prototype version of the sensor-based friction gripper has been made and subjected to various tests for evaluation of performance and reliability. Then, on the basis of results improvements were made and eventually the finalized gripper has been designed and manufactured. This involved developing all mechanical and electronic parts of the prototype and the final gripper.

In the initial stages of the project many possible gripping mechanisms and configurations were considered and analyzed. In doing so many factors were taken into consideration that included simple design, low cost, and availability of manufacturing resources. During the entire design process a large number of friction gripper designs were designed, 3D modelled and analysed, and some were prototyped. Fig. 1 illustrates an prototype that was first modelled with SolidWorks 3D modelling CAD package, and then prototyped into a completely working mechanism. The prototype has been subjected to many tests. Although this mechanism responded to some of the expectations, however, a number of issues were identified that needed improvement. These included some aesthetic, functional, and manufacturing issues. Since extensive improvements were proposed, later it has been decided to develop another design instead of improving the initial design. The new design heavily focused

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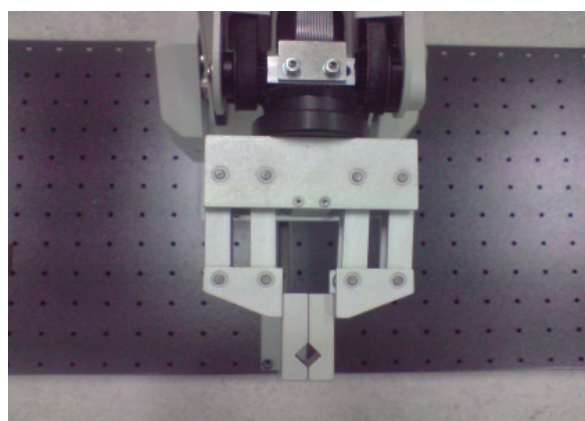
(b)

Fig. 1 (a) Prototype of initial design for sensor-based friction gripper, and (b) gripper in action

on addressing the three main issues encountered in the initial prototype. These included ease of manufacturing, improving precision and material strength. Again at this stage a number of new designs were considered, modelled and subjected to analysis in order to find the one that responds to all requirements. Eventually the one shown in Fig. 2 has been designed and manufactured using 3D printing that is a rapid manufacturing technique. 3D prototype printing is a material addition method of manufacturing whereby, ABS prototyping plastic and soluble building material is heated to $200^{\circ}C$ and then printed upon a prototyping pad. 3D prototype printing proved to be a simple, quick, precise, and inexpensive method compared to other alternative methods such as using conventional and CNC machines. The 3D printing design developed takes into consideration factors such as material consumption, material strength, ergonomics, and aesthetics. This allowed developing a strong, precise, low cost, light-weight and aesthetically pleasing gripper. Due to the limited rigidity of ABS plastic the forces applied to the working system had to be limited to the strength of the material. As a consequence a force channelling design approach was adopted whereby the structure distributes the expected forces evenly.
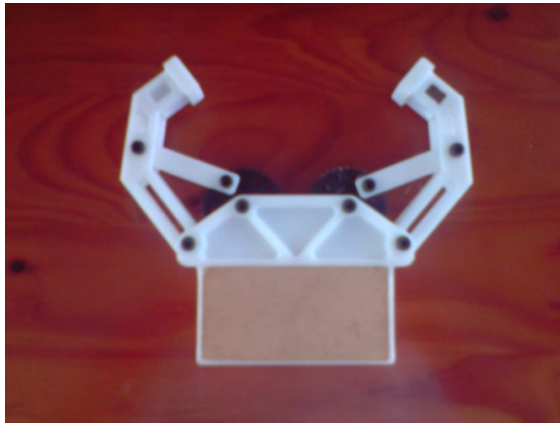
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Fig. 2 The final gripper that has been design with SolidWorks and rapidly manufactured by using 3D printing method

IV. THE CONTROL SYSTEM

A. Prototype Circuitry Development

The prototype circuit was designed on the LTSPICE IV circuit design and analysis software package. LTSPICE allowed to design all aspects of the control system as well as prevented potential component damage. The initial prototype circuit contained a total of five main components including Pololu 6ch Mini Maestro Servo Controller , WS S35 STD continuous servo motor, BlueSMIRF Gold Bluetooth modem, SharpIR analogue range sensor, and standard force sensing resistor (FSR).

The Pololu Mini Maestro 6 channel servo controller is responsible for interoperating and processing the incoming data from the BlueSMIRF Bluetooth modem (serial port link), and the sensors were attached to two of the six servo channels. It was also used to supply the current and control pulse to the gripper's 6V continuous servo motor which defines its direction and speed. The servo controller has been setup to receive data from any computer system which is Bluetooth or USB enabled.

The GWS S35 STD continuous servo motor has been selected as the main source of actuation. When controlled via a servo controller the supplied pulse signals define the rotational speed and direction. It is responsible for the opening and closing the gripper.

The BlueSmirf Bluetooth modem simply allows for serial (Tx/Rx) wireless communication between the servo controller and PC controller.

The Sharp IR range sensor has been employed to detect objects within prehension range. This sensing system detects objects by use of reflected inferred light waves which determine the distance between the object and sensor itself.

The FSR detects pressure applied to the sensors face. It provides an output in the form of resistance which is converted to a voltage differential with the use of a 10kΩ pull down resistor across the ground and signal connections. The FSR has been placed on the contact region of the gripper

fingers. This results in relevant readings to be obtained from the sensor which are related to the applied force.The finalized prototype LTSPICE circuit sketch involving all the above mentioned components is shown in Fig.3. The entire system was powered by a 6 volt, voltage rail system.
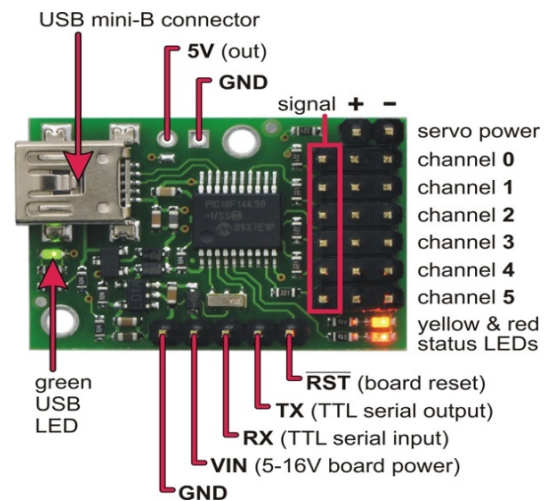

Fig. 3 Pololu Maestro 6CH servo controller with pin lables [19]

B. Programming the Control System

In order to make use of the BlueSMIRF Bluetooth modem it was necessary to develop a program which could communicate through gripper's Bluetooth capability, and also allow for integration of all aspects of the prototype gripper into one control panel (connection settings, sensor monitoring and servo control). The finished prototype gripper controller program shown in Figure 4 was developed in the C++. The executable can be run on any PC based system with Microsoft .NET Framework 2.0 which is a requirement of any application developed with the Microsoft Visual Studio.

It should also be noted that this initial program does not include an automated mode whereby the system would use its available sensory data to act appropriately at the point of completion. Instead it provides sensory data for user's perusal. This is due to the discovery of a communication issue. Upon implementing the entire control system to the gripper, some issues were identified that affected its performance. The main issue involved the Bluetooth modem and servo controller communication, which found to be slow and sometimes unresponsive. This problem was not initially noticeable but after adding additional sensors to the system it became increasingly apparent that there were small incompatibilities between the two devices and the controller PC system. Therefore it was concluded that a new control system design be developed. Development of final control system focused on enabling the gripper to operate autonomously. This would be done by assigning incoming sensory data with required

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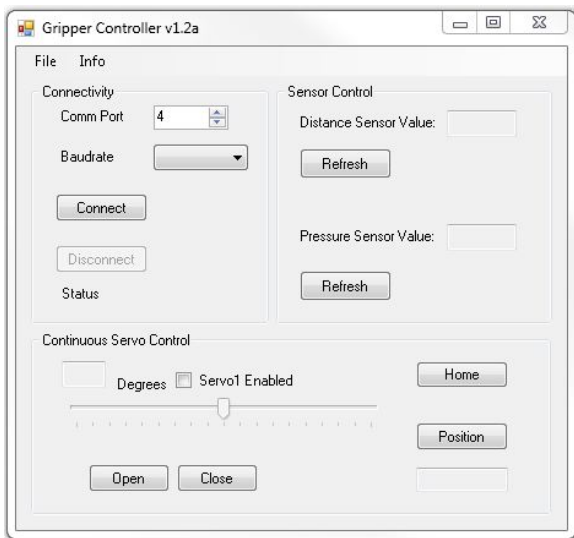Vol:5, No:10, 2011

Fig. 4 Gripper's control application developed in C++

actions, i.e. the system would consult with the implemented sensors in order to decide upon which operation to perform. A step by step operational guide has been developed in order to enable the gripper to function autonomously. This guide would help determine how the final control system would function once completely implemented. It also assisted in deciding upon the position of the various sensors.

In the course of developing the control system some communication issues were noticed that needed to be resolved. It was then decided to remove the Bluetooth modem from the control system. Initially the BlueSMIRF Bluetooth modem was implemented in order to assist in allowing the gripper to be completely automated. A programming has been done with the use of the supplied scripting based Pololu Control Centre software in order to allow the gripper to work autonomously. With this method of programming any written code could be restored locally within the servo controller. This allows the use of the servo controllers "run program on start-up" feature which enables the system to be self contained and completely automated. By enabling the "run program on start-up" feature the communication issues were effectively resolved and programming has been contained on the board of servo controller's random access memory (RAM). This allowed the system to function responsively and effectively without the need of Bluetooth capability. After resolving the communication issues a new circuit design was developed on LTSPICE which included some additional components in order to improve control system's ability to act autonomously. The additional components included an added SharpIR range sensor, a whisker/bumper switch, and a housing for the entire control system. The added inferred range sensor was implemented to detect the drop-off/release position on the robot workplace. Once triggered the gripper be would open completely releasing any objects within the drop-off zone.

This SharpIR range sensor is identical to the gripper mounted range sensor but has a more effective range of 100 mm.

The whisker/bumper switch has been employed as both a necessary component and a safety precaution. Its primary function is to inform the controller when the gripper is in its widest position, which is an automation operational requirement. It has also been used as a safety precaution due to the fact that if the controller is not informed when to cease the closing command, the gripper continues opening until damage is exerted on the servo motor or one of the mechanical components will fail.

Even with the help of the operational guide developed the mounting of the sensory components to the gripper was not an easy task. Many trial and error tests were conducted in order to locate suitable positions, whereby the mounted sensors would perform as intended. The final locations of the mounted gripper sensors are shown in Figs. 5 and 6.
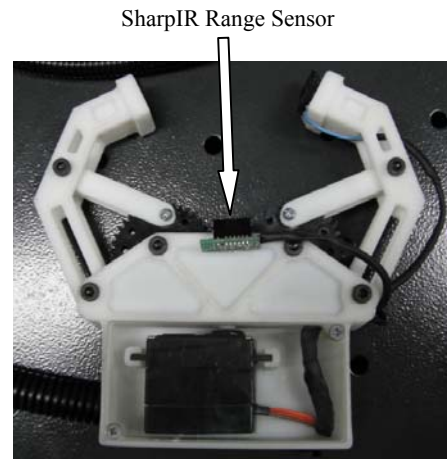

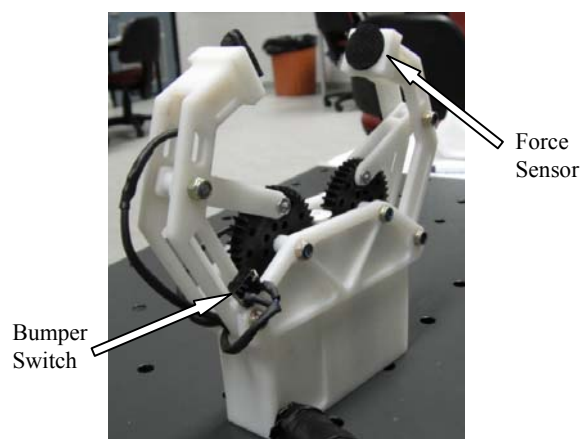Fig. 5 Placement of range sensor and FSR on the gripper

Fig. 6 Placement of bumper switch on the gripper

Programming was completed on both the Maestro Servo controller and the LabVolt RoboCIM 5150 software in order to explore the potential of the gripper design within a working environment. Both systems were programmed to work

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together effectively. The gripper programming has been completed with the use of the Pololu Maestro Control Centre package which utilizes the Maestro script language. The Maestro language is based on utilization of commands which can set servo targets, speeds, and accelerations, retrieve input values, and perform mathematical computations. The final code developed for the Maestro Servo Controller utilized resulted in a fully functional automated gripper which picks and places various objects automatically.

C. Programming the Robotic Arm

Fig. 7 illustrates the developed gripper when mounted on an elbow robotic arm. A gravity feeder is positioned in front of the robotic arm that supplies incoming parts. As mentioned the robotic arm was programmed using the LabVolt RoboCIM 5150 software package. Programming has been completed in the text mode as it allows the use of various control commands. The program developed involved detecting cylindrical parts located in the gravity feeder, approaching the gravity feeder until the designed gripper detects and grasps one of the available film canisters, and finally approaching the drop-off zone where the part should be released. This process has been preformed successfully and was repeated until all available parts were transported from the gravity feeder to the drop-off zone.

Fig. 7 Lab Volt 5150 robot with mounted gripper setup

V. GRIPPING FORCE

The gripping force has been determined experimentally through the use the FSR (force sensing resistor) which was calibrated in order to supply a realistic force related value. Calculations regarding the gripping force for the gripper has been achieved through the equation presented below:

$$F_g = \frac{m(g+a)}{2\mu} \tag{1}$$

where,

F_g = Gripping force
m = Mass
g = Gravitational acceleration
a = Gripper acceleration
μ = Frictional coefficient

For the designed gripper,
m = 1kg, as the weight gripped
g = 9.81m/s^2
a = 0.0025m/s^2, this value was experimentally determined
μ = 0.15, as a slightly oiled gripping surface

$$F_g = \frac{m(g+a)}{2\mu} = \frac{1(9.81+0.0025)}{2(0.15)} = 32.71N \tag{2}$$

Therefore the average gripping force applied by the gripper is 32.71N which corresponds to approximately 3.33kg of applied gripping weight. The maximum gripping force achieved using this method is 28.75N which corresponds to approximately 2.93kg of applied gripping weight.

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Peter Kalivitis received a Bachelors degree in mechatronic engineering in 2010 from Edith Cowan University in Perth, Western Australia. He worked on a challenging task as his final year engineering project that resulted in manufacturing the prototype of a friction-grip end-effector equipped with various sensors for an elbow robot.