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Research paper

Tactile Sensor for Manipulation of Deformable Object

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Abstract

The variable physical property of deformable objects, which are very flexible, soft and viscoelastic, causes the design of reliable automated handling system relatively difficult. In fact, most of these objects tend to be handled manually during the handling process. Therefore, a new optical tactile sensor for an intelligent handling of the non-rigid materials is presented in this paper. Mathematical modelling and control algorithm are developed and the tactile sensor is calibrated in this research. Based on the results that have been recorded, the surface characterization with the respect to normal force applied to the object is attained. A gripper handling system is used to accommodate variable physical properties of the deformable materials, which are very flexible, soft and viscoelastic. In addition to that, the gripper needs to handle the materials with the minimum deformation so that less distortion, and higher accuracy of manipulation can be achieved. Efficient and accurate modelling of deformations is crucial for grasping analysis.

Keywords: *Deformable object, Material handling, Normal force, Tactile sensor*

1. Introduction

The surge of demand in using robot in everyday life that replicate human arms and hands brings us to the study of control system for manipulation of deformable objects. Robots are formerly developed to give support or replace humans in doing dull, repetitive, dirty and dangerous tasks [1]. However, there are only a few studies on the manipulation of deformable objects as they are challenging area of study. This area of study is important in order to realise the prospect of digitalization of services by means of robotic manufacturing and engineering [2]. With the new Industry 4.0 technology, intelligent handling of non rigid materials is essential to revolutionize manufacturing industry by decreasing the number of labour needed, growing the market range to customer and also creating new competitors.

The applications of robotics in our daily lives are broad. This highlights the importance of reviewing the many recent developments that are occurring in research and discuss the future directions of designs and applications. This paper provides an insight on the manipulation of deformable objects. It will focus on applications of grippers embedded with tactile sensor for deformable objects. There are four classes of gripper that exist.

Every type of gripper belongs to one of four classes [3]:

- Astrictive — systems using suction (like vacuum cups), as well as magnetism and electro adhesion
- Impactive — mechanical, fingerlike grippers that either wrap around the object or rely on friction to hold it in place
- Ingressive — penetration of the object for lifting purposes using pins or needlelike tooling.
- Contigutive — uses adhesive, surface tension or freezing to bond to the object

There are many general applications of the intelligent servo control system for manipulation of deformable object which is used in wide area of industry such as in medical industry, agriculture industry, textiles industry and many more. The outcome of this project, researchers and industry can grasp a new mechanism for manipulation of deformable object and advancement in the technology of robotics as this a challenging area of study. At the end of this paper, we conclude by discussing the challenges and future directions in this field.

2. Robotics for Material Handling System

The inventions of robot have converted the handling system from conventional material handling system to a more convenient automated material handling system. The study, design and use of robot system in manufacturing are defined as robotics. In manufacturing industry, robots are used to avoid human contact with unsafe, hazardous, highly repetitive and unpleasant tasks. Some of the popular robotics used in the manufacturing industry processes are arc welding, resistance welding, assembly, painting, spraying, and machine tool load and unload function, material handling and etc. Robot is a reprogrammable multifunctional manipulator, designed to move specialized devices through a variable programmed motion [4]. The used of robot for automated handling of non-rigid material is still not very establish and required further research. There are different types of robots for every different material handling application of non-rigid materials. Figure 1 shows the example of usage of robotic arm in manipulation of object in the manufacturing industry.

Fig. 1: Robotic arm that used for manipulation of objects in the manufacturing industry [5]

2.1. Robotics for Handling Deformable Material

In recent times, major progresses that have been made in the design of applied robot hands that can execute tasks required in various industrial fields. However, the industrial robots that exist are only designed to perform to a specific movement according to the input of the object to be manipulated such as mass and sizes of the object. In order for the robot to be able to grasp the object without slipping, it is vital for the robot to exert force not larger than necessary force as the load force of grasped are varies for different object [6]. Nevertheless, when excessive grasping force is applied to an object that is delicate and easily broken, the force given may damage the object. Human beings are the best example to perform agile manipulations even though the object being handled is fragile. This is being said that the ability of manipulation of agile object is based on precision handling with minimal force by which the object can be held (Johansson & Westling, 1984; Kim Shiire, & Inooka, 1993; Nakazawa, Ikeura, & Inooka 1996) [7,8,9]. In Figure 2, shows example of the robotic arm trying to grasp a deformable object (plastic cup) using different controller.

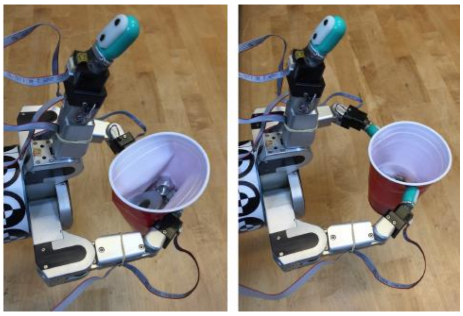

Fig. 2: Robotic arm grasping a deformable object using a standard position controller (left) and the proposed force grip controller (right). [5].

2.1.1 Application in Manufacturing Industry

The application of material handling or gripper for handling fabrics in textiles industry is still one of the ongoing challenges as the material are soft and flexible. The properties of the material make the application of handling material using robot hard. For the time being, researchers have designed penetrating grippers (ingressive grippers) to handle fabrics in textile industry [1]. Ingressive grippers are use as alternative to hold fabrics since suction cup are not able to hold the fabric due to the porous property of the material. By using ingressive gripper, the fabric can be penetrated with a minimal underlying damage to the woven structure [1].

Spiked wheels are one of the earliest designs that used in material handling of fabrics. The spiked wheels separate different textiles from each other [10] and it has been improved by using different type of gripper that has also been used in removing the backing sheet from fibers [11] [12].

Then a suction cup gripper is introduced and developed for fabric [13]. However, there are some limitations as the fabrics cannot be deformed during the cutting process [1]. There is also another method of handling deformable material (fabrics) and it is called as contigutive grippers. Contigutive grippers used adhesion such as glue and sticky adhesives to hold the fabrics. However, there are some setbacks for this method. The limitation of this method is that it will reduce the ability to stick to textiles as the microfiber will adhere to the surface over time [14].

2.1.2 Application in Medical Industry

In the medical application mostly robotics gripper is used in surgery. However, there are some issues with the lack of force feedback and damaging the biological tissues. As the medical fields are limited and intrinsic safety feature that needed safe interaction with biological tissues, a soft bodied gripper is more suitable.

Example of robotic in the medical industry which is used in sewing soft tissues is shown in Figure 3. For minimally invasive surgery, researcher has developed a soft gripper that is used for delicate and safe interaction. The design that has been developed could enforce maximum of 1 N by using elastomeric material and the design are easily scalable [15].

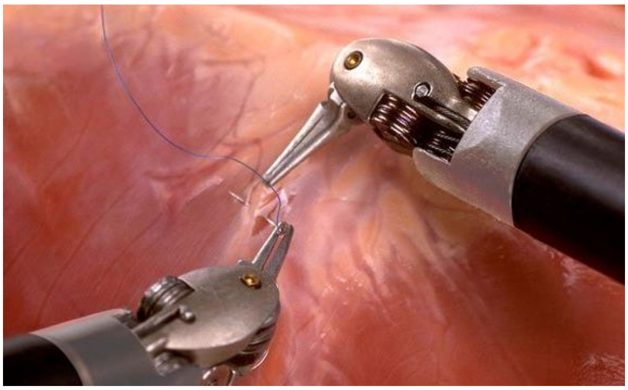

Fig. 3: Robotic gripper that used to sew soft tissue.

Technique such as suction is also used in medical applications [16]. It is design to bowel that has the characteristic of large, delicate, flexible and slippery part of the body. This suction method was found to be capable of firmly gripping bowel sections: however, it is not known whether a manual pump or vacuum pump would be more optimal.

Recent development in medical grippers made them more trustworthy to be used in applications such as robotic surgery, minimally invasive surgery and medical grippers. The recent progresses are designing novel mechanisms, developing and employing high tech actuators. Although many works have addressed force control problem in medical application, the challenge of force control still persist.

3. Methodology

There are three phases that involve in this research project. In phase one, we design and model the system. During this phase, we identified the control system parameter and come out with a new computer algorithm system and mathematical modelling for the tactile sensor system.

The second phase for this project is developing a test-rig. The purpose of developing test-rig is for assembling the optical tactile sensor with the robotic end-effector with the computer algorithm that has been developed in phase one. After the test-rig has been develop, the system hardware and software undergo testing before being calibrated. In this phase also, a series of system calibration are being made to determine and establish the test-rig of the system. Errors within operating range of tactile sensor are corrected by troubleshooting and modification to the system.

For hardware system, we used the CataLyst-5 robot which consists of 5 degree of freedom (DoF) arm with a linear track, C500C robot controller, 6 DoF Force-Torque sensor and a teach pendant. Five DC motors are used to power the 5 DoF revolute joint arm and another DC motor to run the prismatic joint of linear track. A 6 DoF force-torque sensor used for the robot system to detect forces and torques during contact with workpiece is mounted at the end-effector of the arm robot. The tech-pendant is used to move the robot, teach location and to run the robot program. Tech-pendant is an optional hand-held device. Fig 4 shows the component used in this project.

The end-effector flange is mounted to the force torque sensor where it is directly mounted on the robot tool flange . then, the silicone tactile sensor is attached at the end–effector as shown in Fig. 5. When the tactile sensor is in contact with the workpiece, a pressure-sensitive device in side the force sensor measured the applied force and sent the information to the controller.

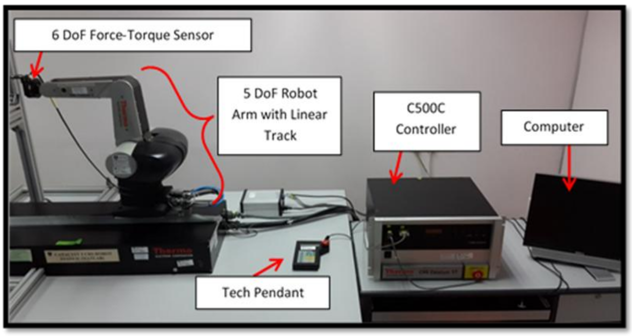

Fig. 4: Basic component of CRS CataLyst-5 robot.

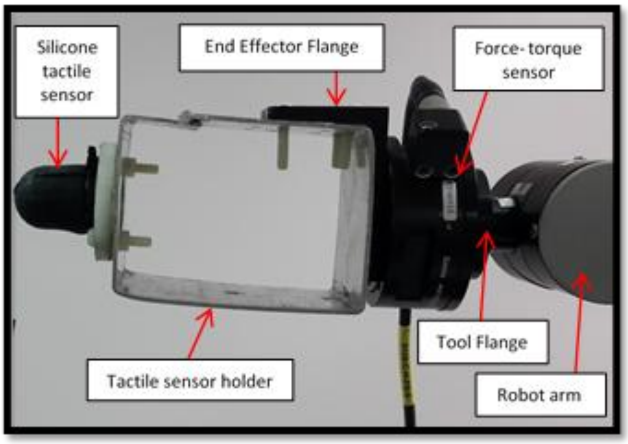

Fig 5: Force-torque sensor arrangement.

3.1. Normal Force Set Up

The calibration of force-torque sensor is done by applying force to the silicone tactile sensor that has been mounted on the end-effector of the robot. For soft and deformable workpiece, a soft sponge workpiece is used in this set up. The normal force data is obtained when the silicone tactile sensor is in contact with the workpiece. From Figure 6 shows the calibration system arrangement and the motion involved for the normal force calibration set up.

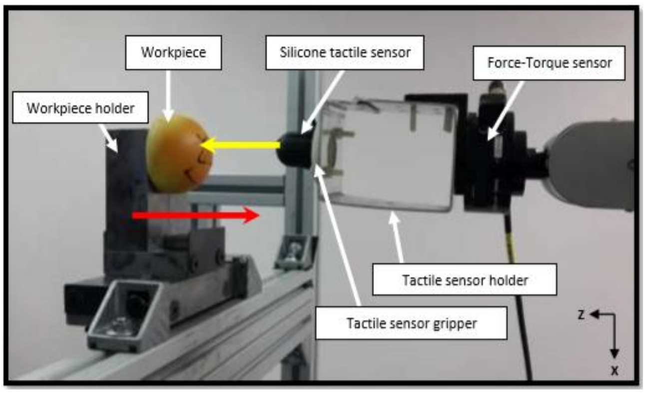

Fig. 6: Force torque sensor axis.

The yellow arrow shows in Figure 6 indicates the movement of robot towards the workpiece, while the red arrow indicates the direction of workpiece moving towards the robot. The robot movement towards and return from the workpiece (yellow arrow) are done automatically using a computerized system, while the movement of workpiece towards and return from the robot (red arrow) is done manually.

Data is taken directly from robot’s force-torque sensor. When the applied force is given to the workpiece by moving the robot towards and returns from the workpiece, the tactile sensor will deform due to the force that exerted. The measured normal forces generated directly form the sensor and can be viewed in MATLAB. Each set of data collected from the distance of 0 mm to 15 mm of tactile displacement with 3 mm increment.

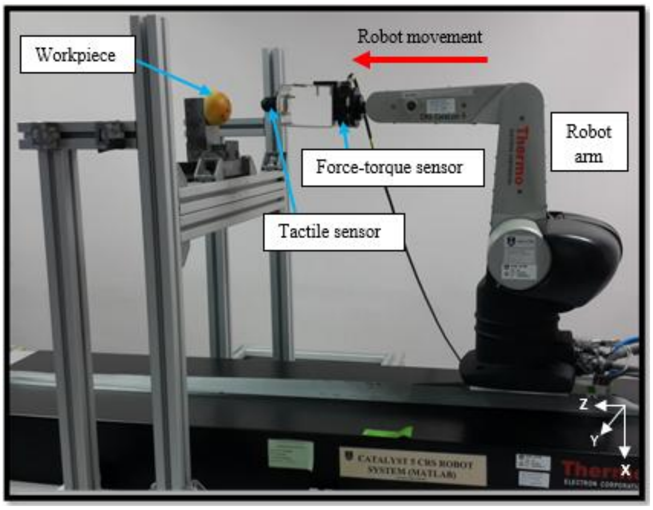

Fig. 7: Actual figure of part arrangement in the research.

Free body diagram is shown in Figure 8 to show all forces acting on the workpiece. Lastly, data are collected and evaluation on the performance of the system is made. The control system is being tested and evaluates to provide results and discussion. Data are analysed and documented. Tables and graph such as are produced using the data collected.

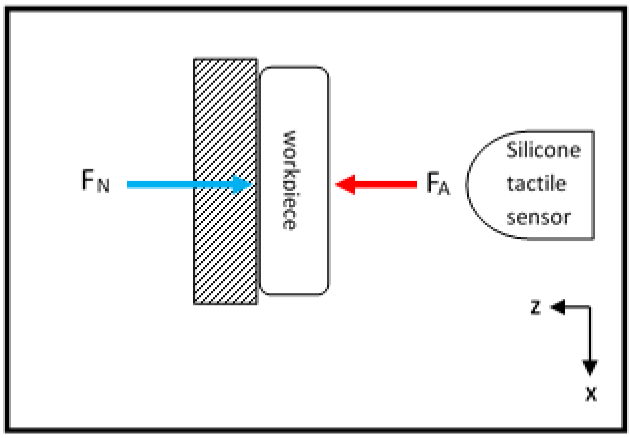

Fig. 8: Free-body diagram of force exerted on the workpiece.

4. Result and Discussion

Data that had been collected from the experiment were compared with the graph pattern. Theoretically the return graph should contrary of the forward graph pattern because there is no applied force on it. The workpiece or robot is moved in Z direction range from 0mm, 3mm, 6mm, 9mm and 12 to obtain the normal force data. The information that is obtained from the tactile sensor (force-torque sensor) is displayed in the form of graph of force versus time which in this case it is run in real time condition. Data are then tabulated in Microsoft Excel and graph is plotted. Only the Z axis data are considered from the 3 axes (X, Y and Z) from the force-torque sensor as it is a normal force to the tactile sensor.

4.1. Workpiece Movement.

The data collected are tabulated as shown in Figure below. The graph (Figure 9) below shows the data obtained from robot force-torque sensor when the workpiece are moving towards the robot while Figure 10 shows the graph force-torque sensor when workpiece return from robot.

From Figure 9 and Figure 10, displacement increase as the normal force value increases. The negative value that shows in the graph representing the force-torque sensor is compressing the workpiece.

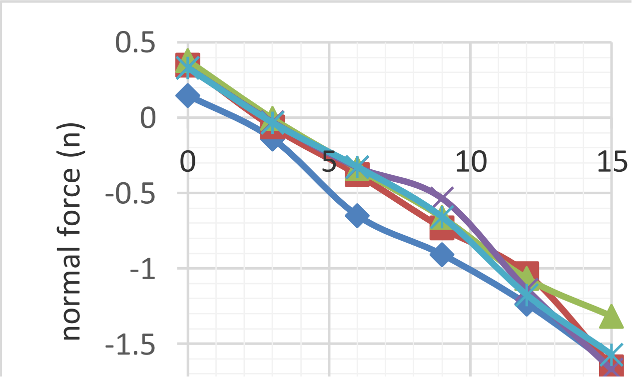

Fig. 9: Normal force graph for soft workpiece (workpiece moving towards robot**)**

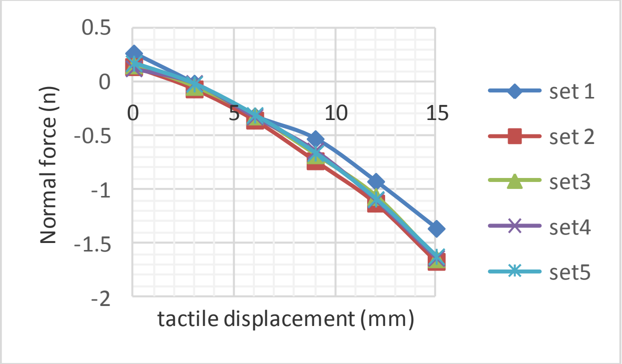

Fig. 10: Normal force graph for soft workpiece (workpieces return from robot).

4.2. Robot Movement.

Figure below shows the data that have been collected when robot move towards and from the workpiece. In this step, workpiece are put in a static condition while only the robot moves and applied forces on the workpiece.

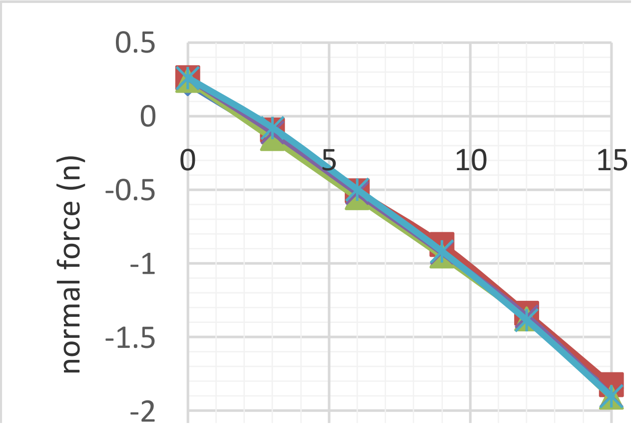

Fig. 11: Normal force graph for soft workpiece (robot moving towards the workpiece).

In Figure 11 and Figure 12 shows the pattern of normal force movement towards and from the workpiece. By increasing the displacement, we can understand that displacement will increase if the normal force values are increased.

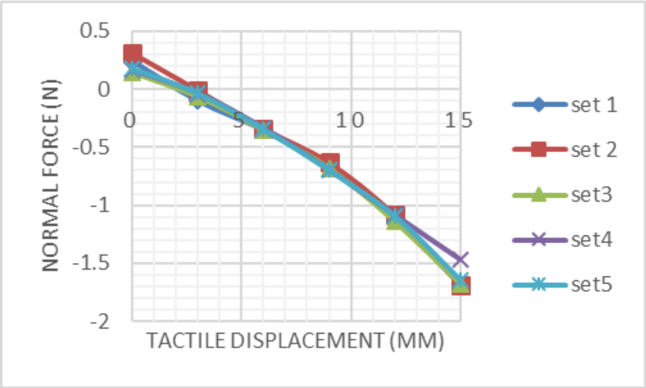

Fig. 12: Normal force graph for soft workpiece (robot returns from workpiece).

4.3. Calibration Analysis

By using the robot's force-torque sensor for two (2) type of movement (robot towards and return from workpiece and workpiece towards and return from robot), the differences in normal force values are obtained. The normal force yield by the silicone tactile sensor is low for 15mm tactile displacement and the tactile deformation are less than 2 Newton (N) for each of the movement when in contact with the soft workpiece (sponge toy).

Figure 9, 10, 11 and 12 shows the graph pattern obtained when the result of different movement is compared. The pattern of movement for both type of movements (i.e. robot movement and workpiece movement) are not accurately similar as different approach have been used in the experiment. For robot movement method, computerized method has been used to move the robot towards and from the workpiece. However, for movement of workpiece towards and from the robot, the movement are manually done by human.

Referring to Figure 13, it has been proven that the normal force and tactile displacement or tactile deformation has a linear relationship. As the silicone tactile sensor is deformed or displace either by the robot movement or workpiece movement, the normal force value also increased. The return graph also shows that it is inversely proportional to the forward graph.

The area boundaries between the graphs show that hysteresis error phenomenon. Hysteresis error is the main source of uncertainty in the sensor devices and is related to loading and unloading condition. This is caused by the viscoelastic behavior. Viscoelasticity is a type of deformation exhibiting the mechanical characteristics of viscous flow and elastic deformation.

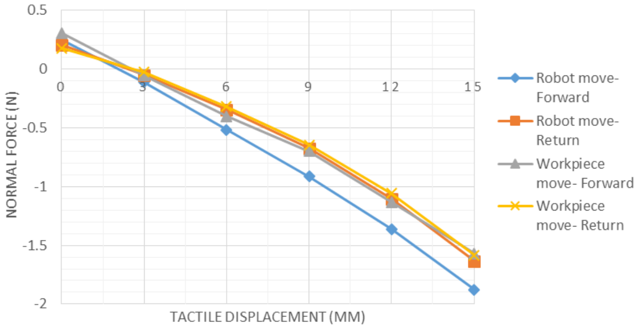

Fig. 13: Normal force graph pattern for both type of movement

5. Conclusion

This paper introduces the usage of tactile sensor when dealing with the manipulation of deformable object. The usage of robotic in everyday life can give a significance impact to society, environment, industry and economy. The challenges today are to recognize and overcome the barriers that are currently preventing robots from being more widely used. The overall objective of this project is to implement the used of tactile sensor approach in manipulation of deformable object. Besides, the silicone tactile sensor was determined and measured experimentally on the relationship between the normal force and the tactile displacement or deformation.

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