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Design and Fabrication of a Programmable Stiffness-Sensitive Gripper for Object Handling

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***Abstract*—**Stiffness sensing is an important issue in medical diagnostic, robotics surgery, safe handling, and safe grasping of objects in production lines. Detecting and obtaining the characteristics in dwelling lumps embedded in a soft tissue and safe removing and handling of detected lumps is needed in surgery. Also in industry, grasping and handling an object without damaging in a place where it is not possible to access a human operator is very important. In this paper, a method for object handling is presented. It is based on the use of an intelligent gripper to detect the object stiffness and then setting a programmable force for grasping the object to move it. The main components of this system includes sensors (sensors for measuring force and displacement), electrical (electrical and electronic circuits, tactile data processing and force control system), mechanical (gripper mechanism and driving system for the gripper) and the display unit. The system uses a rotary potentiometer for measuring gripper displacement. A microcontroller using the feedback received by the load cell, mounted on the finger of the gripper, calculates the amount of stiffness, and then commands the gripper motor to apply a certain force on the object. Results of Experiments on some samples with different stiffness show that the gripper works successfully. The gripper can be used in haptic interfaces or robotic systems used for object handling.

***Keywords*—**Gripper, haptic, stiffness, robotic.

I. INTRODUCTION

STIFFNESS of an object is one of important characteristic which must be considered in physical contact with other objects. The stiffness of an object can also be indicative of the physical characteristics of the object. For example, in clinical practice, doctors routinely palpate the patient's body with the fingers and palm to detect tumors, indwelling lumps and smaller nodules. Moreover, in telesurgery, doctors take out, pick up and move the tissue or organ of the body. Thus, there is a need for sensors that can sense stiffness of tissue for safe handling and safe grasping of tissues. Also, in industries, there are many cases for demand of safe gripping and manipulating delicate and sensitive objects. In some of such cases, it is needed to know the stiffness of objects. In all these cases, there is a need for a tool that acts as an artificial tactile sensor give feedback to the operator.

The concept of artificial tactile sensing based on force and torque measurements and geometric calculations was first proposed by Salisbury [1]. He showed that from the measurement of a six-axis force/torque sensor, and by knowing the geometry of the finger surface, most of the necessary information for the large majority of manipulating tasks including magnitude of contact force, finger touching point and the direction of applied force can be obtained in a simple and fast way. Intrinsic type of this contact sensor which can be placed far from the surface where contact occurs, and is often located inside the fingertip, was designed by Bicchi et al. [2]. This intrinsic tactile sensor was used to prevent and control object slippage [3]. In addition, tactile sensor is usable not only in the case of point contact with friction, or hard finger surfaces, but also can be extended to the case of robotic legs, and used to improve the control of legged locomotion on unknown terrain [4].

Major recent advances in artificial tactile sensing technology have been obtained in surgical assistant robots. This technology has been used in Minimal Access Surgery [5]. Using this method, tactile sensing is reproduced to surgeons by using actuators such as piezoelectric actuators. This technology is known as haptic. In addition, force sensitive tactile sensor was used for minimal access surgery [6]. Artificial tactile sensing technology was also used in minimally invasive surgery [7]. A medical tactile sensing instrument for detecting embedded objects, with specific application for breast examination was designed and fabricated in [8]. In this study, the functionality of this tactile sensor for detecting the existence of an embedded object inside a tissue was simulated and analyzed with the help of finite element contact analysis. In this research, by using force and displacement sensors, the variation of breast stiffness was measured and exact location of embedded tumors was obtained.

In this paper, using the idea of artificial tactile sensing for detecting hard tissues in medical applications and laparoscopic surgery, a new programmable gripper for moving objects, with the ability to detect the object stiffness, is designed and fabricated. Although the force sensor has been used in gripper robot fingers, but the feedback was limited to force; and objects softness detection was done using only the force feedback not calculating body stiffness. By calculating the stiffness of moving objects, it is possible to exert gripping force with certain predetermined criteria. In this study, in addition to force measuring sensor, a displacement measurement sensor is added to a gripper for calculating body stiffness of moving objects. After measuring the stiffness of the body, according to a predefined conditional control strategy based on the measured stiffness and determined by

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user, the gripping force is applied on the moving objects. Finally, the performance of the gripper is evaluated using some samples with specific stiffness.

II. Design and Modeling of the Stiffness Sensitive Gripper

A. Governing Equations

The stiffness of a body is a measure of the resistance offered by an elastic body to deformation. For an elastic body with a single degree of freedom, the stiffness is defined as

$$k = \frac{F}{\delta} \tag{1}$$

where F is the force applied on the body, and δ is the displacement produced by the force along the same degree of freedom. As the objects have different structure and do not follow special model, the governing equations for calculating displacement of two bodies in contact with each other are on the basis of elastic module.

In this paper, stiffness measurement is performed in the direction of applied gripping force. Also, a simple spring is considered as mechanical model for objects. So, for measuring object stiffness, it is nodded to measure applied gripping force and object deformation in same direction of applied force.

B. Mechanical Design of the Gripper

Grippers were designed to increase the power of human hand to grab and pick up objects. By advancing science, the duty of lifting and moving objects on production lines was transferred to the robot and manipulator. This entails designing advanced gripper for the robot end effectors, haptic devices and manipulators. In design and fabrication of stiffness sensitive gripper, the physical contact between gripper fingers and object is so important, and hence, some contact parameters are selected for actuating the gripper fingers. These parameters are gripping force and object deformation in the direction of applied force. So, in addition to the conventional gripping and moving mechanism, designed gripper must be capable of measuring force and displacement in the direction of gripping forces and consequently, this requires the use of sensors for measuring force and displacement inside the gripper body. According to conventional grippers in robots and manipulators, the opening and closing gripper mostly is done using electrical motors and interface mechanisms. For measuring gripping force, it is necessary to place force measurement sensor (load cell) in gripper fingertip where to be in contact with body. It is possible to measure gripper fingertip displacement in various ways. The best method is using displacement sensor inside gripper fingertip; but due to high cost of such sensors, it is possible to use rotary encoders or potentiometer and turn the rotary displacement of motor to linear displacement of gripper fingertip. A processor (microcontroller or PC) is required to measure the object stiffness by interpreting data obtained from sensors and apply force on the object based on its measured stiffness and predefined conditions. In this study, according to the load cell and potentiometers available on the market, a gripper, which can be installed on a robot arm, was designed. Fig. 1 shows the simple model and related parameters, and Fig. 2 shows the gripper model and dimensions. Gripper and load cell sizes have been chosen to be close to the size of an adult human hand and finger length is proportional to the length of the selected load cell. Fig. 1 is used for calculating gripper fingertip applied force and displacement in terms of rotational angle θ and torque M of the electrical motor that used for actuating the gripper.

$$d_i = b \cos \alpha_i + (a - \frac{e}{\sin \theta_i}) \cos \theta_i \tag{2}$$

where α_i is

$$\alpha_i = \sin^{-1} \frac{a \sin \theta_i - e}{b} \tag{3}$$

On the other hand,

$$\gamma_i = \sin^{-1} \frac{f + \Delta d}{c} \tag{4}$$

In this equation, *f* is at maximum aperture opening angle of gripper. By rotation of motor from primary angle θ_1 (maximum opening of the gripper) to θ_2, the amount of $\Delta d = d_1 - d_2$ is added to *f*. Finally, the linear displacement of gripper fingertip due to object deformation is obtained from:

$$\Delta L = \frac{j}{k} \Delta g \tag{5}$$

where

$$\Delta g = 2c(\cos \gamma_1 - \cos \gamma_2) \tag{6}$$

The gripping force F at the gripper fingertip is obtained from

$$F = \frac{Mk \sin \theta \cot \gamma}{aj} \tag{7}$$

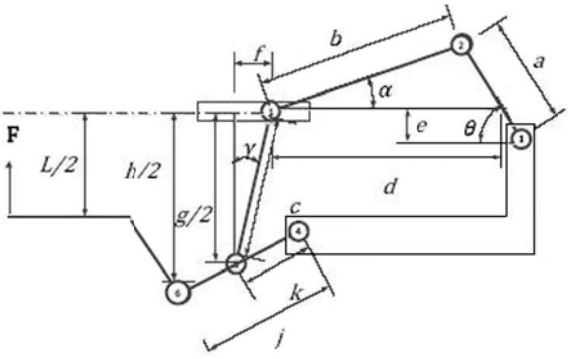

Fig. 1 The simplified model and its parameters of designed gripper

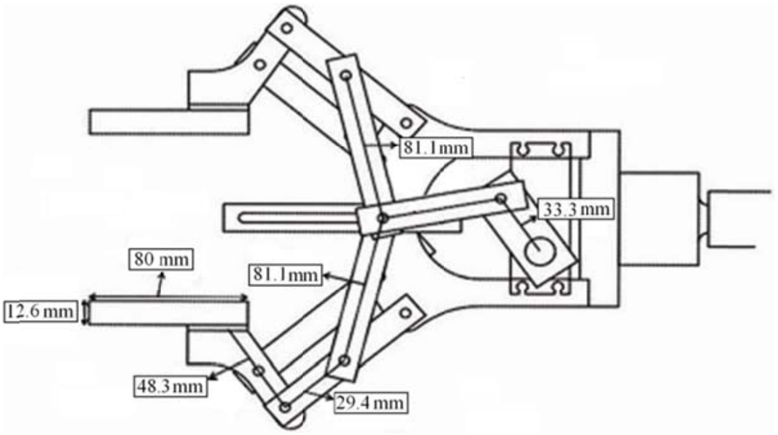

Fig. 2 Gripper model and its dimensions

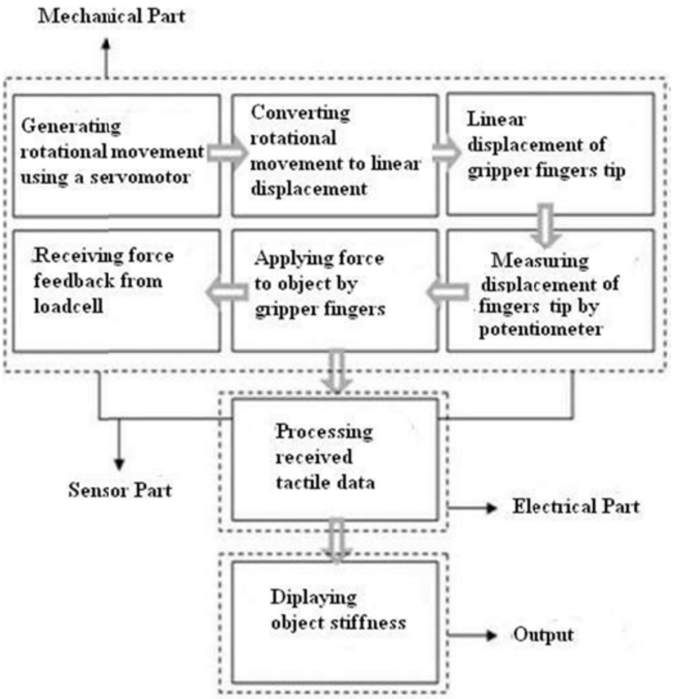

Fig. 3 Block diagram of the performance of stiffness-sensitive gripper for handling objects

For implementing experiments, a handle and base was designed, so that the gripper can pick up objects on a laboratory scale.

C. Control Strategy

Fig. 3 shows the functional block diagram of the stiffness sensitive gripper for handling objects. As is shown in this figure, the main components of the stiffness sensitive gripper are sensors (including force and displacement measuring sensors), mechanical parts (including hardware of tactile sensor system, gripper, handle and base), electrical components (including electronic circuits and data processing systems) and output display. By sending a command from the operator to the gripper, gripper motor operates and the gripper fingers are closed. As the gripper finger touches the object, both measured gripping force by loadcell and the gripper fingertip displacement by the rotary potentiometer, is sent to the processor at the same time. Considering (1), because of greater elastic modulus of loadcell in comparison to selected spring, the amount of measured displacement can be considered only for spring. Data processing system calculates the object stiffness based on the measured gripping force and gripper fingertip displacement and then, according to a predefined control strategy, controls gripping force. Gripping force depends on object stiffness and gripper application. Table I shows the control strategy which was used in this project. The applied force on the object in this research has been chosen based on the selected loadcell. It is clear that for applications that require greater gripping force, it is necessary to use appropriate load cell and electrical motor.

III. FABRICATION OF THE STIFFNESS-SENSITIVE GRIPPER

Fig. 4 shows the fabricated and assembled gripper. The selected loadcell for this gripper is a single base type and was assembled on the gripper jaws. The load capacity is 5 kg. Selected electric motor to open and close the gripper fingers is a DC motor model 9805MG with torque of 25 kg.cm and working voltage of 6 V. A rotary potentiometer (model B5K) was installed on the axis of gripper for measuring motor rotation and converting it to linear displacement of the gripper finger tips. Electrical part of the system consists of a processor for processing haptic information received from force and displacement measurement sensors. The processor sends these data to gripper motor and display unit after processing. The system processor is a AVR microcontroller (ATmega 128A). Force Control Strategy for gripping has been written in C programming software and was sent to the microcontroller using a programmer. To monitor, control and adjusting the gripper parameters, a control program was written in C software. The program is designed so that when the computer is connected to the gripper controller electrical board by using a USB cable; it is known and connected to. In program displays, the graph of potentiometer output values versus time, gripper fingers displacement versus time, measured force versus time is shown and finally stiffness is calculated for each object. The program allows user to reset the system. Fig. 5 shows the experimental set-up.

TABLE I
FORCE CONTROL STRATEGY

Stiffness of object (N/mm)	Object category	Applied force to object (N)
$0.1 < k \le 0.2$	Very soft	2-3
$0.2 < k \le 0.4$	Soft	3-5
$0.4 < k \le 0.6$	Middle	5-6
$0.6 < k \le 0.8$	Hard	6-7
$0.8 < k$	Very hard	7-8

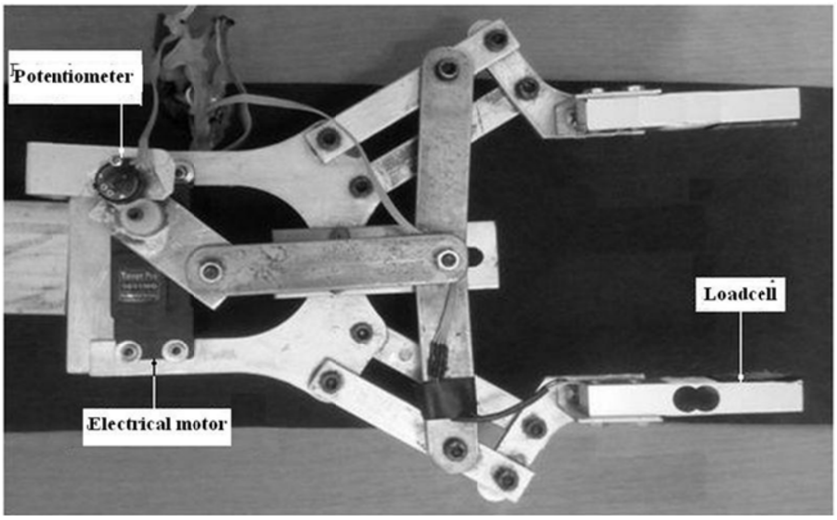

Fig. 4 Fabricated stiffness-sensitive gripper

IV. PERFORMANCE EVALUATION OF THE FABRICATED STIFFNESS-SENSITIVE GRIPPER

For evaluating the performance of the fabricated stiffness sensitive gripper, three springs with different stiffness were selected. The stiffness of these springs was shown in Table II. To evaluate the performance of the gripper, the stiffness of each spring was measured three times (to demonstrate repeatability of the gripper clamping action) by the gripper. Results of experiments are shown in Figs. 6-8. The vertical axis in Figs. 6-8 represents the force of the gripper fingers to the spring and the horizontal axis represents the length of the spring at any moment. To eliminate the effect of noises in measurements, the amount of compression force of springs was considered from 0.3 N and the stiffness was calculated after this point. The force control is based on the measured stiffness.

As can be seen in Table III, the values of measured Stiffness in springs 2 and 3 are close to the true value and in spring 1 is further so that the gripper controller detected it as a soft spring. The main reason for this difference between the measured and actual values of stiffness is the clearance between the gripper connections. By using displacement sensor at gripper fingertip, it is possible to reduce this error. Another reason for this error is spring buckling.

TABLE II
THE SPRINGS STIFFNESS USED FOR EVALUATING THE PERFORMANCE OF THE GRIPPER

	Spring-1	Spring-2	Spring-3
Stiffness(N/mm)	0.48	0.53	0.4

V. CONCLUSIONS

In this paper, a stiffness sensitive gripper for moving objects in robotic and Haptic systems was introduced. The gripper having force and displacement sensors was able to calculate the stiffness of objects and based on a programmable control strategy applied gripping force on objects.

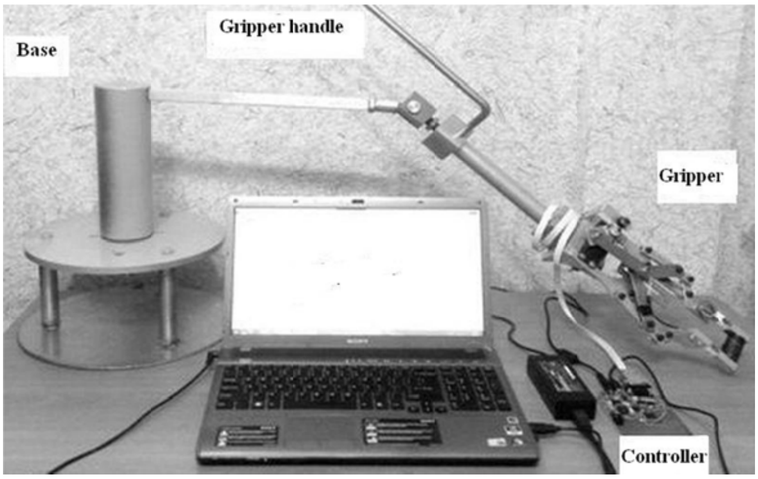

Fig. 5 Fabricated set-up for experiments

The performance of the fabricated stiffness sensitive gripper was evaluated using some spring with different stiffness. The results of experiments show repeatable measured stiffness by the fabricated gripper. Also, the measured stiffness was close to actual values and errors resulting from the clearance between the gripper connections and buckling springs were observed during measurement. This gripper can be used in robotic systems and manipulators for handling delicate objects. Other application of this gripper is in surgical assistant robots for gripping and picking up the sensitive tissues of the human body.

TABLE III
TYPICAL SPRINGS STIFFNESS MEASURED BY GRIPPER

	Run-1	Run -2	Run -3
Stiffness of spring-1(N/mm)	0.40	0.33	0.40
Stiffness of spring-2(N/mm)	0.52	0.52	0.47
Stiffness of spring-3(N/mm)	0.38	0.38	0.35

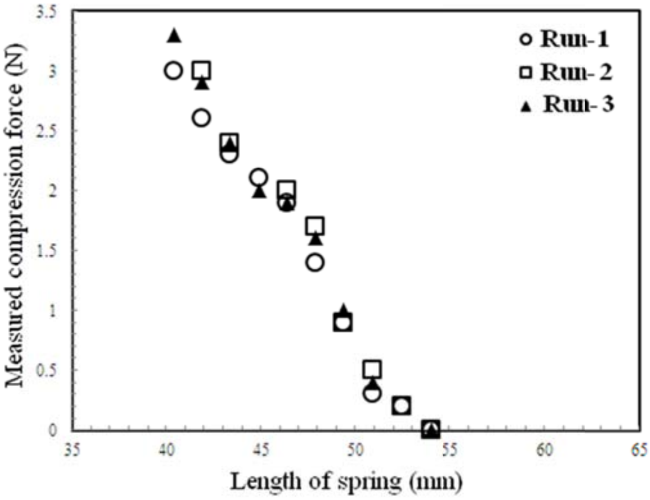

Fig. 6 Measured stiffness by fabricated stiffness-sensitive gripper for spring-1

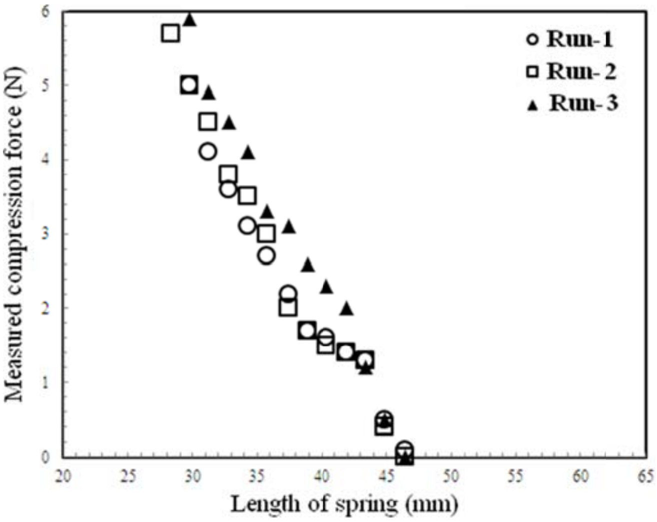

Fig. 7 Measured stiffness by fabricated stiffness-sensitive gripper for spring-2

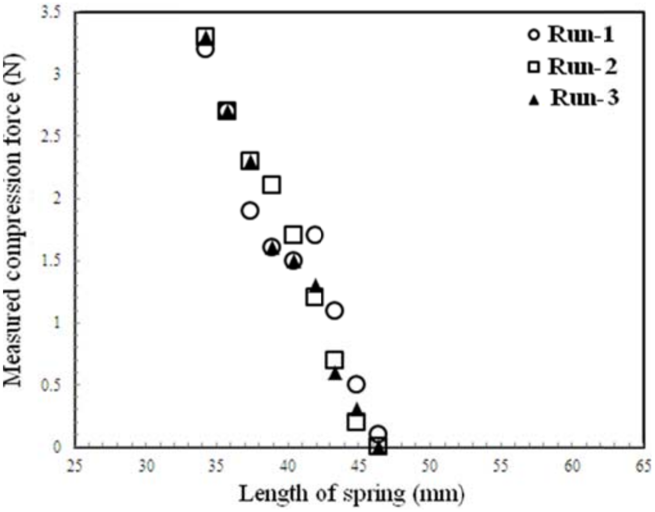

Fig. 8 Measured stiffness by fabricated stiffness-sensitive gripper for spring-3

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