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CALIBRATION OF OPTICAL SILICONE TACTILE SENSOR

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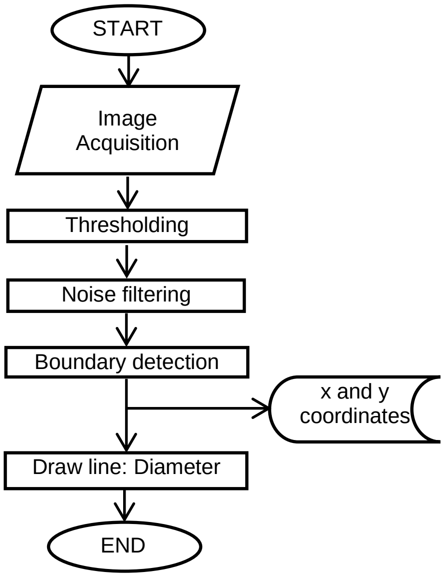
Graphical abstract



Abstract

This paper presents the calibration and development of a computer algorithm to analyze the deformation behavior of the changes in the diameter of a silicone tactile sensor using an image processing technique. In addition, the scope of the work also aims to evaluate the sensor's sensitivity. Unfortunately, the current design and the system of tactile sensor is not suitable for soft tissue characterization because the sensor system uses multiple optical waveguide transduction technique which is relatively large in diameter size, not flexible and less accurate which is lack of 'sense of touch'. Hence, an image processing algorithm has been developed using image processing software. The results indicate significant increase in the change in the diameter images. The overall image analysis technique involves the following main stages: image acquisition (capturing of images) and image processing (thresholding, noise filtering, component labeling, and geometric properties). The use of fiber scope and as well as an effective image analysis computer algorithm will facilitate and automate the process for sensing information. This study results in finding the mathematical model of a new technique to establish the sensitivity value of the silicon tactile sensor where a higher sensitivity indicates a more sensitive sensor. The outcomes of this research shows that the functionality of the developed new image analysis computer algorithm technique is suitable to establish the sensing information on the 'sense of touch' such as hardness, roughness and other physical characteristics of the surfaces.

Keywords: Optical tactile sensor, image processing, calibration, computer algorithm

1.0 INTRODUCTION

Real-world objects exhibit rich physical interaction behaviours on touch. These behaviours depend on how heavy or hard the object is when held, how its surface feels when touched, how it deforms when in contact and how it moves when pushed, etc. Unfortunately, many traditional tactile sensing technologies do not fit the requirements of robot manipulation in human environment due to lack of sensitivity, dynamic range and material strength. Previous study has developed and investigated an artificial tactile sensing where the technology can obtain useful information of tactile data and display information to the surgeon [1, 2].

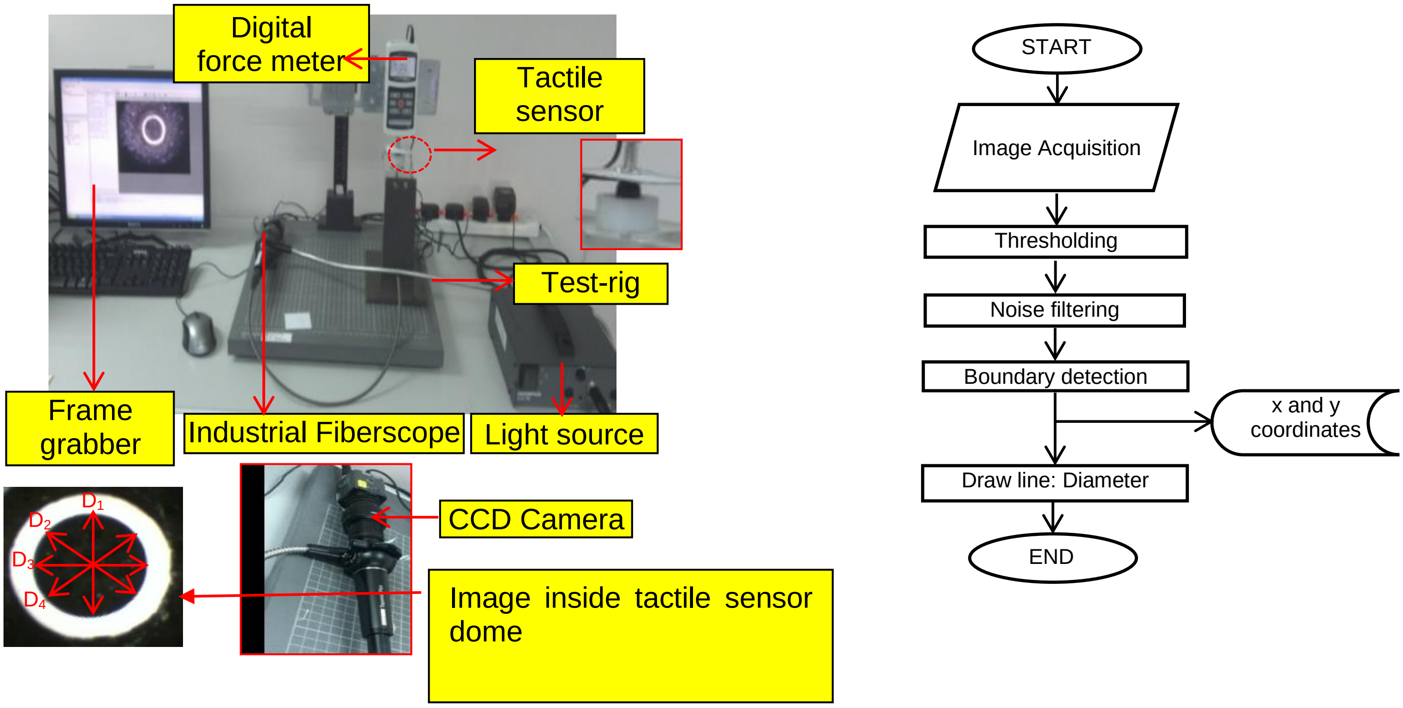
Minimally Invasive Surgery (MIS) is usually used as the preferred choice for many operations [3, 4, 5]. Unfortunately, during MIS procedures, the surgeon sensory might lead undesirable results lacking sense of touch on the surface characteristics information. Indeed, tactile sensors for object detection that are capable of detecting the surface characteristics of objects are in demand [6]. Most of the researches work done on the development of tactile sensors did not address the constraint due to its ability to classify between hardness and softness while touching, flexible and real-time capability that can be used in biomedical applications. Thus, the necessity to sense surface characteristics is important in medical applications.

Therefore, the use of silicon tactile sensor for surface characterization is a new approach in robotics. Previous study has shown the normal force calibrated by analyzing the sensing information [7, 8, 11]. Unfortunately, these optical sensors that had been developed are relatively large in size and have nonlinear characteristics that result in less accurate measurement. In addition, safety issues such as the type of material, softness and sensitivity of the tactile sensor are important in biomedical applications [6]. Hence, the outcome of this study is expected to produce a new technique of tactile sensor and computer algorithm that can measure the deformation and the sensitivity with high accuracy as in biomedical application.

2.0 EXPERIMENTAL TEST RIG

A series of calibration tests will be conducted on the silicon tactile sensor. A test-rig was developed locally to suit the experiment needs and designed to test on a silicone tactile sensor having a diameter of 30mm. The test-rig has both hardware and software components. The processes are explained as follows [9]:

i. The Mark-10 digital force meter (0-50N) at 0.01N resolution is installed to test-rig. Mark-10 digital force meter gives reading when contact pressure is applied to the tip of the tactile sensor.
ii. The Charge Coupled Devices camera (CCD camera) captures an image inside the tactile sensor.
iii. The image data retrieved by the CCD camera are delivered to the PC via PCI bus of the image processing software Sapera CamExpert. The image analysis module uploads the image data and performs an image analysis technique using special software. The complete experimental set-up is shown in Figure 1(a).
iv. Image processing algorithm: Utilized image analysis WiT 8.2 software from Dalsa Technologies to analyze and measure the image data. During the measurement process, the dividing procedure, digital filtering, boundary detection, arithmetic and logical, and integrated gray-scale value are controlled. A summary of the algorithm flowchart is shown in Figure 1(b). The experimental process was repeated 5 times to get the average data.



(a) Test rig and acquired image (b) Computer algorithm flowchart

Figure 1 Schematic diagram of silicone tactile sensor system

3.0 MATHEMATICAL MODELLING

This project is to determine the sensing characteristics by calculating the applied force distribution and deformation through experimental calibration. The calibration is static and performed by increasing the applied force up to 10 mm deflection. The tactile sensor will change its shape when the applied force acts on its surface. To correlate to the applied force, the change in the diameter ΔD was measured. The amount of deformation values is calculated simultaneously based on the data image using the diameter values for each point, p at ith deflection Dpi as in the image processing software.

By using Pythagoras' theorem as in Equation 1, the distance between the points are calculated

$$D_{P_i} = \sqrt{((x_2 - x_1)^2 + (y_2 - y_1)^2} \qquad \text{(Eq. 1)}$$

Where, D_{Pi}: Diameter of point p at ith deflection, $1 \leq p \leq 4$ and $1 \leq i \leq 11$, i: Reading number

The measurement of deformation, which is the change of diameter, ΔD_{pi} is defined in Equation 2, where ΔD_{p0} is a deformation reference value at 0 mm displacement.

$$\Delta D_{P_i} = D_{P_i}.D_{P_o} \qquad \text{(Eq. 2)}$$

Where, ΔD_{Pi}: Change of diameter for point p at ith deflection

D_{P0} : Change of diameter for point at 0mm deflection at ith deflection

Hence, when Equation 1 is applied to Equation 2, the average point of deformation ΔD_i, will be defined in Equation 3. The objective to find the average point of deformation, ΔD_i is to get accurate data from the whole point, p.

$$D_i = \sum(D_p / 4) \qquad \text{(Eq. 3)}$$

Where, ΔD_i: Change of diameter for average point at ith deflection

According to Equation 3, the deformation of tactile sensor ΔD_i is proportional with contact force, F, as shown in Equation 4:

$$\Delta D_i = kF \qquad \text{(Eq. 4)}$$

Where, F: Applied Force and k: Sensitivity

$$k = (\Delta Y)/(\Delta X) \qquad \text{(Unit: pixels/Newton)} \qquad \text{(Eq. 5)}$$

Therefore, the measurement of sensitivity, k is defined by Equation 5, where Δx,y is the change in 'x' and 'y' point in Linear Curve Fitting graph (Figure 2). Sensitivity, k is defined as the change in the y coordinate divided by the corresponding change in the x coordinate, between two distinct points on the line. The readings were taken for five experiments, (n) and the average readings were recorded.

4.0 RESULTS AND DISCUSSION

This section presents the analysis of data for the overall performance of the machine vision for the silicone tactile sensor. The performance of the machine vision will be based on the analysis of results from the image processing techniques, the analysis of the source of image noise and the analysis of deformation behaviour.

Five series of the same experiment were done in order to ensure the reliability and accuracy of the results. The results from Experiment 1 to Experiment 5 were tabulated in Table. 1. Figure 3 shows the changes of diameter, ΔD_avg value with respect to applied force, F. As seen, when force is applied to the tip of tactile sensor, all data show significant increase in diameter change, which relates that there is almost a linear relationship between force and deformation. However, the plotted graph was unable to determine the sensitivity of the silicon tactile sensor. Hence, a Linear Curve Fitting was plotted to derive the sensitivity value. The graph demonstrates that the value of sensitivity, k is 15.98 pixels/N which influences the sensitivity of the tactile sensor. A higher sensitivity, k value indicates a steep incline, which also signifies that the tactile sensor is sensitive even when a small force is exerted onto the tactile sensor.

The limitation in this finding is the range of deflection and force which is between deflection, δ=0 to 10mm and F = 0N to 8N. Deflection and Force higher within this range are not effective on this particular type of silicone tactile sensor because the system cannot analyze the deformation image completely. For medical applications, it is considered satisfactory if the force sensitivity is within the range of 0.1N-11N [10].

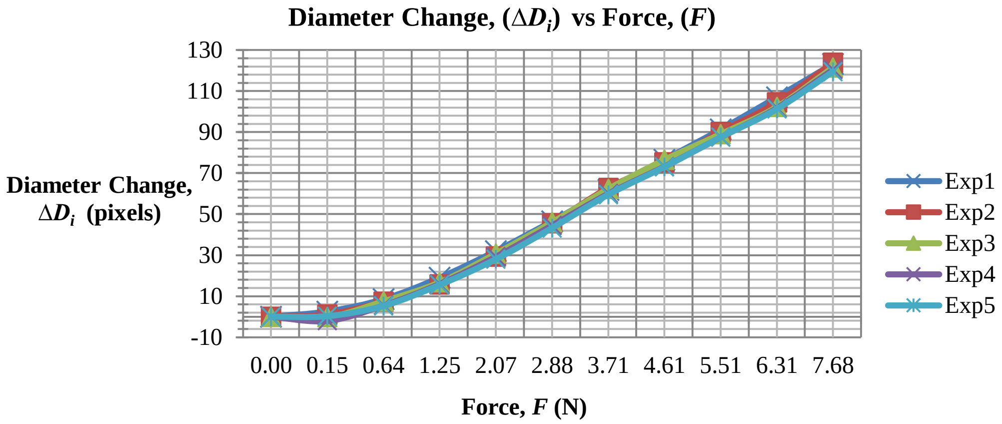


Figure 2 Sensor responses to the calibration

Table 1 Change in diameter for a given displacement

No	δ	*Exp 1*		*Exp 2*		*Exp 3*		*Exp 4*		*Exp 5*	
i	(mm)	Force (N)	ΔD$_i$ (pixels)	Force (N)	ΔD$_i$ (pixels)	Force (N)	ΔD$_i$ (pixels)	Force (N)	ΔD$_i$ (pixels)	Force (N)	ΔD$_i$ (pixels)
1	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
2	1	0.20	2.5	0.13	1	0.13	-0.25	0.68	-2	0.15	0.25
3	2	0.65	8.5	0.63	7.25	0.71	7.5	0.68	5.5	0.55	5.25
4	3	1.28	19	1.18	15.75	1.29	16.75	1.32	16	1.19	15.5
5	4	2.10	32	2.01	29.25	2.13	30.75	2.15	29.25	1.96	28
6	5	2.82	46.5	2.90	45.5	2.97	46	2.94	44.25	2.79	43.25
7	6	3.67	61.75	3.75	62.75	3.78	62.25	3.74	60	3.59	59.5
8	7	4.57	76.5	4.62	75.25	4.72	76.5	4.63	73.25	4.50	73
9	8	5.45	91.25	5.53	90	5.52	89	5.55	87.5	5.48	87.5
10	9	6.30	107	6.42	104.5	6.21	102.25	6.41	101.5	6.20	101.25
11	10	7.35	123.25	7.88	123.75	7.72	121.5	7.82	120.5	7.61	119.5

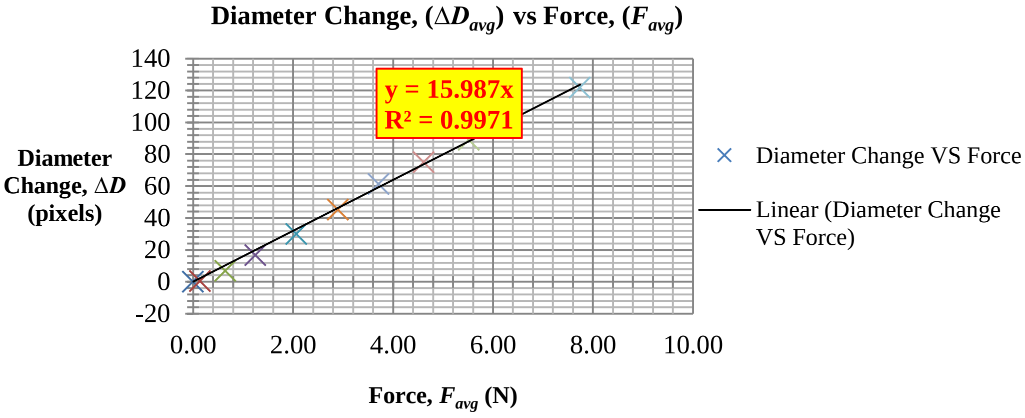


Figure 3 Relationship between applied force and diameter change

5.0 CONCLUSION

This research establishes on the fundamental principles of tactile sensations using fiber scope and image analysis algorithm to facilitate and automate the process of tactile sensor behavior. In this paper, a silicone tactile sensor was designed for robotic finger applications using silicone rubber as the based material. The most important feature of this silicone tactile sensor is that it exhibits features whose diameter changes with the force applied. As the applied force increases, the changes in the diameter will also increase. With these experiments, it can be concluded that image processing analysis is very important for biomedical applications. This is because the use of fiber scope and effective image analysis algorithm will facilitate and automate the process of surface characterization by correlating to the applied force. Currently, there are further works being carried out to focus on calibration of shear force and its correlation with the changes in diameter. A series of experiments will be conducted by using different test-rig and analyzed by *WiT 8.2* image processing software. Hence, the outcome of these further works is expected to generate comprehensive and detail technical information on the hardness, roughness and other physical characteristics of the surfaces to be studied.

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