Characteristics of Optical Silicone Tactile Sensor

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ABSTRACT

The main objective of this research work is to analyze the characteristics of a newly developed optical tactile sensor for sensing surface hardness. Many optical tactile sensors are bulky in size and lack of dexterity for biomedical applications. Therefore, this tactile sensor is design relative small in size and flexible for easier insertion in endoscopic surgery application. The characteristics of the tactile sensor are calibrated with respect to changes in the diameter, area and perimeter of a silicon tactile sensor subjected to normal forces applied at the point of interaction. A surface exploration computer algorithm to obtain the sensing information was developed to analyse the characteristic of the optical tactile sensor. The overall image analysis technique involves the following main stages: image acquisition (capturing of images), processing (thresholding, noise filtering and boundary detection) and evaluation (force measurement). The measured forces were then compared to the actual forces to determine the accuracy of the tactile sensor's characteristics. The results showed that the sensing characteristic with respect to changes in perimeter of the tactile sensor is more accurate compared to the other sensing characteristics. The outcomes of this research shows that the functionality of the developed new image analysis computer algorithm coupled with the silicone tactile sensor is suitable for biomedical applications such as in endoscopic surgery for measurement of tissue softness.

Keywords: Image Processing, Optical Tactile Sensor and WiT. Introduction

Minimal access surgery (MAS), are known as keyhole surgery is routinely used as the preferred choice for many operations. The scanning technology with the assistance of a video camera and several thin instrument give an useful displays visual information which is "medical imaging" to the surgeon[1]. "*Medical imaging*" is the technique of creating images of the interior of a body for medical analysis. Currently, surgeons also performed manually using naked eyes or scanning device to analyze characterization of soft tissue by captured the images [2]. Unfortunately, the main limitation this technique is the lack of sense of touch on the surface characteristic information such on the hardness of the soft tissue. Tactile sensation is important information for surface sensorization, manipulation and exploration. Because of that, many researcher concerning in this area.

During recent years, Minimally Invasive Robot-Assisted surgery, this has become the main choice for surgically reported in Science Daily. Because of that, this surgery manipulates the tactile feedback of organs and assesses the condition of tissue. In other words, the system allows greater precision and better visualization compared to MAS technique by the combination of the image processing with the sense of touch. However, it would be advantageous for the surgeon to have an idea about the characteristic of the surfaces which are in contact with the tools.

According to, researcher from Nagoya [3], they developed an optical three-axis tactile sensor capable to recognize the objects shape and surface condition either its hardness or smoothness by utilized image processing as their method to obtain the information of the sensor. Therefore, the use of optical based tactile sensor for surface characterization is a new approach in biomedical applications. This new approach provides more information regarding the surface condition directly by analyzing the sensing information. The consequence of this technique, several applications of a sensor is detecting various tumors in patient's body by through analyzing the softness of the tissues based on its sensing information such as the change in size, shape, texture, etc. [4] will be eased to achieved.

The material used in this project for the development of the miniature tactile sensor element is silicone rubber. Silicone rubber is a very stable material and has been widely used in many fields because of its ability to be fabricated by conventional techniques, its inherent silicone advantages, including excellent thermal stability, good water characteristics, weather and chemical resistance[5] and [6].

Several researchers have actively involved and engaged in developing a better tactile sensor[3], [4] and[7]. Unfortunately most of the developed tactile sensors are bulky in size and lack of flexibility for biomedical applications. Hence, there is a need to explore and develop new generation of tactile sensor that can perform various tasks in biomedical applications. The developed tactile sensor in this paper is focus on the application for endoscopic inspection where sensorization information is need.

In this research, the development of the vision based tactile sensor is using single wave optical image conduction method [7]. The tactile sensor which is made of a silicone based material has been used for measuring normal and shear forces. The finite element model and its initial behavior of the tactile sensor was explained in [8],[9] and [10]. In this paper, the characteristics of the tactile sensor will be further analyzed by using surface exploration computer algorithm developed in this research project.

Thus, the outcome of this study is to validate the functionality, reliability and characteristics of the optical silicone tactile sensor using the developed surface exploration computer algorithm that can measure the normal forces to a high accuracy in order to facilitate and automate the process of surface characterization.

1.0 EXPERIMENTAL TEST RIG

A test rig was developed to suit the experimental needs and designed to characterize the silicone tactile sensor which is having a diameter of 6mm and 90mm long optical fiber. The test rig has both hardware and software components as shown in Figure 1 and Figure 2. The description of the main experimental test rig [8]:

1. Initially, calibrated force F_c, was gradually applied and increased intermittently at the tip of the tactile sensor. The constant value of the tactile sensor *k* was obtained based on the graph of the "Calibrated Forces vs Deformations" [9]. Then an actual force F_a was applied to the tip of the tactile sensor. It was recommended the, F_a values were approximately equal to the Fc values so that the accurately and reliability of the calibration results could be easily observed. To measure the F_c and F_a, a digital force meter was used.
2. For image acquisition, a *CCD* camera was used to capture an image inside the tactile sensor. The image data was delivered to the frame grabber in the *PC* via 90mm long fiber scope that was connected to *PCI* bus of the computer. A computer image processing algorithm was developed to analysis the image data and performs an image calibration.
3. The image processing algorithm utilizes WiT 8.2 software to analyze and measure the image data. During the force measurement process, three main steps of computer algorithm were performed; image acquisition, image processing and image recognition. Details of the image analysis will be explained in the next section. For the measurements of the experimental forces F_e, three different sensing characteristics which were *changes in diameter, changes in area and changes in perimeter*. The whole process is repeated three times to show the repeatability of the measurement results and their average values were obtained[9].
4. Data obtained from both the *image processing algorithm* (F_e) and digital force meter were evaluated and compared for the three sensing characteristics. Then the average percentage of error was determined. The lowest average percentage error obtained would be the selected parameter of study.

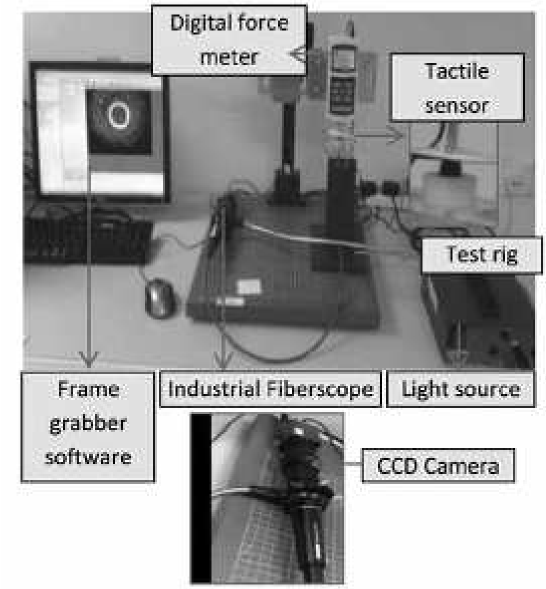

Figure 1: Experimental test-rig

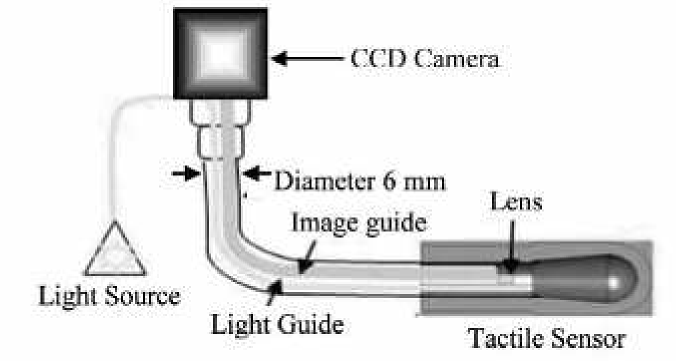

Figure 2: Schematic diagram for Industrial Fiberscope [8].

2.0 IMAGE PROCESSING ANALYSIS

To perform the image analysis, a surface exploration computer algorithm was developed to obtain three different sensing characteristics; *changes in diameter*, *changes in area and changes in perimeter* of the tactile sensor. Data obtained from the image analysis will relate to the normal force values. The scope to be highlighted here is the manner in which the machine vision system is exploited to calibrate the image of the tactile sensor. The in-process image analysis is the key important aspect of this test rig. The hardware components constitute of a PC computer, frame grabber (type of video card) and CCD camera. The optical fiber scope is connected to the CCD camera to acquire the image of the tactile sensor. The image is captured and stored for further processing.

A. Image processing algorithm

The image processing algorithm for the tactile sensing analysis was developed and programmed using Microsoft Visual C/C++ and WiT 8.2 Image Processing software [10]. The WiT8.2 image processing library consists of built-in operators which provides a great toolset for image processing [10]. Additional custom image analysis operators and control system operators were specially developed via Microsoft Visual C/C++, which created a dynamic link library so that the corresponding operators were available in WiT environment. These image operators were integrated in theWiT 8.2 Igraph of the image analyzed algorithm to measure the applied forces. A summary of the data communication process for the image processing algorithm is shown in Figure 3. The processes are explained as follows:

1. Image acquisition: The image acquisition was performed when the image data were captured by CCD camera and transferred to the computer via fiber scope.
2. Image processing: Image processing was performed to enhance the image by using thresholding and noise filtering approach: In tactile sensor image analysis, the region of interest was defined as the circle inside the tactile sensor. Using the threshing and blobing technique, the selected circle will be analyzed. Blobing is a technique to get the area of interest. In this research the area of interest is the white region (all pixels have a value of 255), as seen in Figure 4(a). All the relevant information such as height, width, pixel size, angle, coordinate, parameter, and centroid can be extracted from the blob.
3. Feature Recognition: Feature recognition was accomplished by boundary detection of the circle: The circle was detected by grouping the blobs and filtered until relevant blobs for the

circle were found. All the parameter values to filter the blobs were obtained and optimum values for all conditions were obtained. After getting a satisfactory hole detection result, the area, perimeter, diameter and centroid of the hole are computed using the following equation:-

1. Area:

$$A = \sum_{i=1}^{n} \sum_{j=1}^{m} B[i,j]. \quad (1)$$

2. Perimeter:

$$P = \sum_{i=2}^{n} \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}. \quad (2)$$

3. Diameter:

$$D = \frac{\sum_{i=1}^{n} 2[\sqrt{(\bar{x} - x_{i-1})^2 + (\bar{y} - y_{i-1})^2}]}{n} \quad (3)$$

4. Centroid: The location of X and Y coordinates were determined by calculating the centroid of the circle from the relevant blob data. Please refer to Figure 4(b). The accuracy of the centroid location depends on the technique, control variable and the noise analysis. By using equations (4) and (5), the centroid locations from the relevant blobs are calculated. All the measurements are in pixels unit.

$$\bar{x} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} jB[i,j]}{A} \quad (4)$$

$$\bar{y} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} iB[i,j]}{A} \quad (5)$$

Where:

A = Number of pixel in blob

P = Length of digital curve

D = Diameter

$\bar{x} = x_{centroid}$

$\bar{y} = y_{centroid}$

x, y = Coordinate for global

i, j = Coordinate for local

4. Calculation of measured force value: The force value has been calculated by using equation (6). Here, *k* a constant value of tactile sensor determined from the previous calibrated experiment. This k value depends on the sensing characteristics which are the *changes in diameter, area* and *perimeter*. It is important to define k in order to enhance the performance of the tactile sensor algorithm during real-time object manipulation. The user is required to key in the *k* value for each sensing characteristics. All the measurements are in pixels unit. The equation of the measured force value is as follows. This equation is according to calibration experiments.

$$F = \frac{Diameter/Area/Perimeter}{k} \quad (6)$$

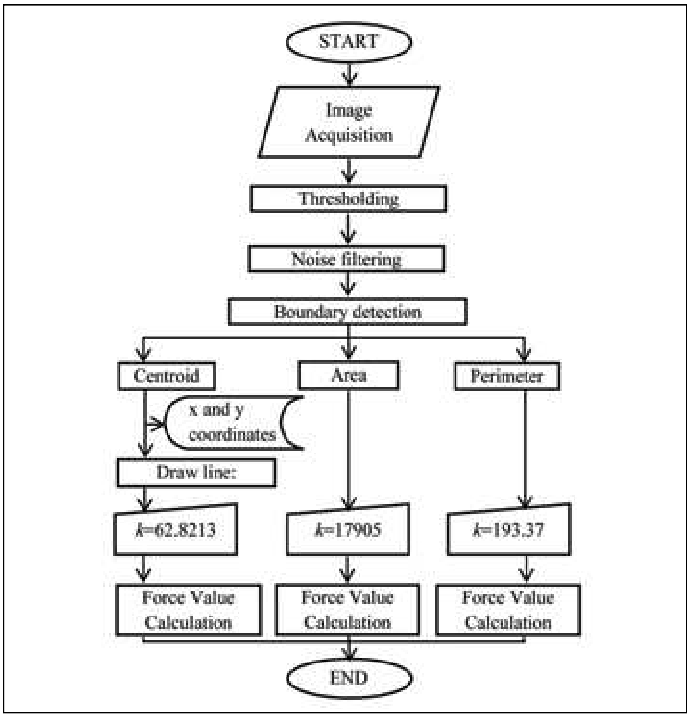

Figure 3: Surface exploration computer algorithm flow chart.

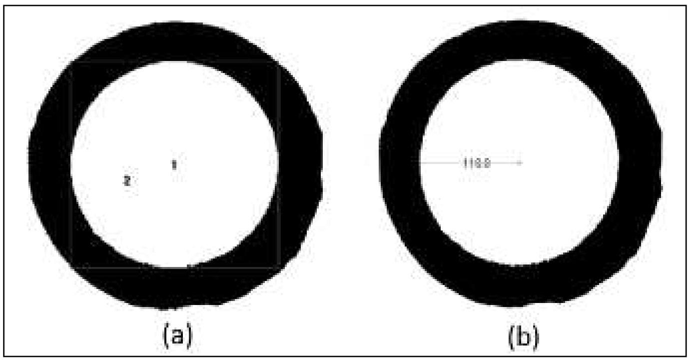

Figure 4: Image analysis output (a) boundary detection (b) draw line.

B. Data Acquisition System

The data acquisition system is realized by the design of Image Processing Algorithm of the optical silicone tactile sensor. To obtain the information of the sensor, the characteristic of the images are analyzed and correlated to the *Fa-*.

C. Conversion Factor

In order to determine the SI units, the *pixel* measurement has to be converted to *mm* (4). It is clear from the zoomed image shown in Figure 5 that the, *154 pixels* have an equivalent value to *2.051mm* in distance.

$$pixel = \frac{mm}{pixel}$$

$$\pm 154\, pixel = 2.051\, mm$$

$$1\, pixel = \frac{2.051\, mm}{154\, pixel}$$

$$1\, pixel = 0.0133mm$$

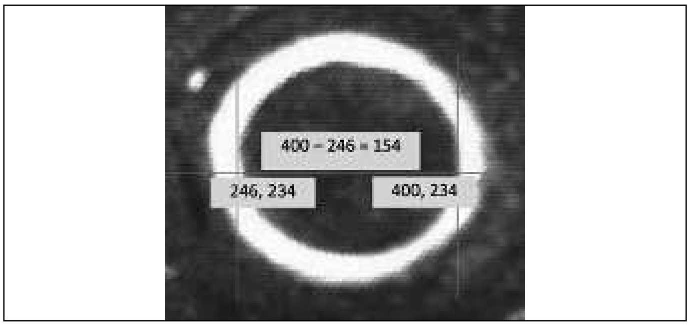

Figure 5: Zoomed image taken by CCD camera inside the silicone tactile sensor.

3. EXPERIMENTAL RESULTS

This chapter present the analysis of data for the overall performance of the machine vision for the optical 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.

Three series of the same experiments were done in order to ensure reliability and accuracy of the results. The results for the average forces of the changes in diameter, area and perimeter were presented in Figure 6, Figure 7 and Figure 8 respectively. The plotted graphs show the correlation between the calibrated force, F_c, actual force, F_a and experimental force, F_e for the three sensing characteristics. The graph demonstrates that the initial value of F_e, influences the accuracy of the results. As seen, when force is applied to the tip of the tactile sensor, all data show significant increase in experimental forces, which indicates that over prolonged time and increased applied force, the value of the experimental force become stable and reliable.

The limitation in this finding is the range of the F_a, which is between 0N to 1.5N. For medical applications, it is considered satisfactory if the force sensitivity is within the range of 0.1N-11N [4]. Forces higher than this range of values are not effective using this particular type of optical tactile sensor because the system cannot analyze the deformation image completely due to the limitation of the view range. This situation happens because the image for the next displacement is already out of view. Hence, the image processing is unable to define the data for these images. One of the reasons for this to happen is due to the small size of the tactile sensor used. Therefore, it is able to capture the full image up to certain amount of deflection. The optical tactile sensor in term concept in design and method are suitable for applications in the biomedical industries. Figure 9 shows an example of an image which is out of view and cannot be analyzed. Further works need to be carried out in this research study to use smaller silicone tactile sensor (suggest:*Ø=3mm*) that can influence the force sensitivity results so that in future, this sensor is suitable to be used for small internal parts of the human body such as arteries.

Another concern is that, the accuracy of the tactile sensor was not able to be determined directly from these plotted graphs. Hence, an average error value was calculated to derive the error value using equation (5) and (6). For the error analysis, the experimental force value, F_e which is the real time value, is compared to the actual force value, F_a which refers to the value indicated by the digital force meter. A lower average percentage error value indicates forces almost to the actual force line, which

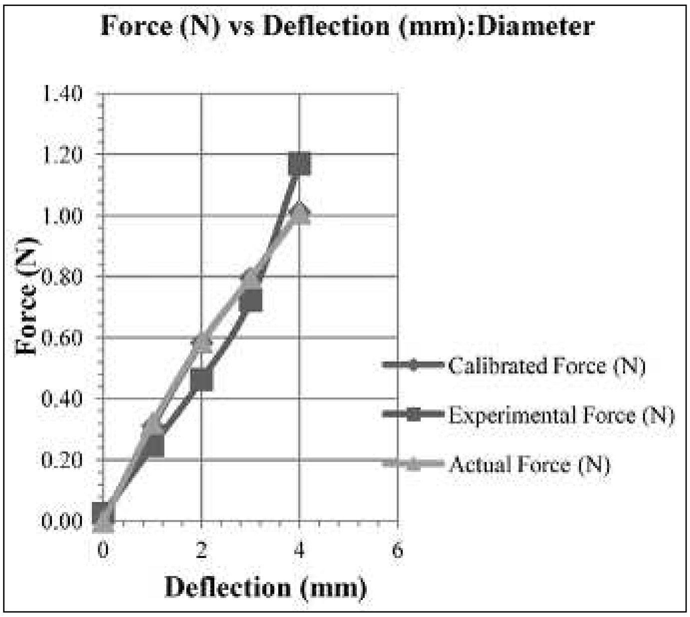

Figure 6: Average Forces for Changes in Diameter.

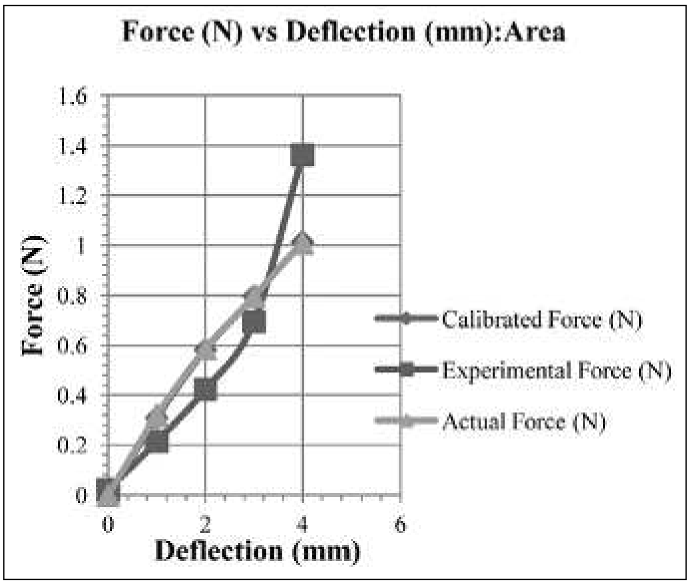

Figure 7: Average Forces for Changes in Area.

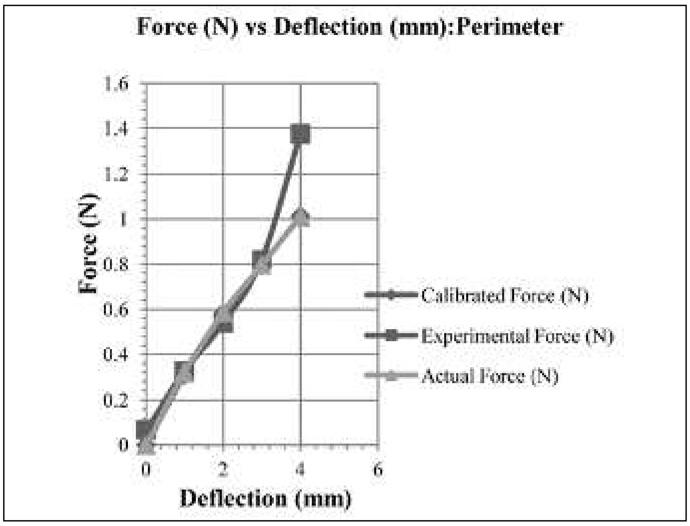

Figure 8: Average Forces for Changes in Perimeter.

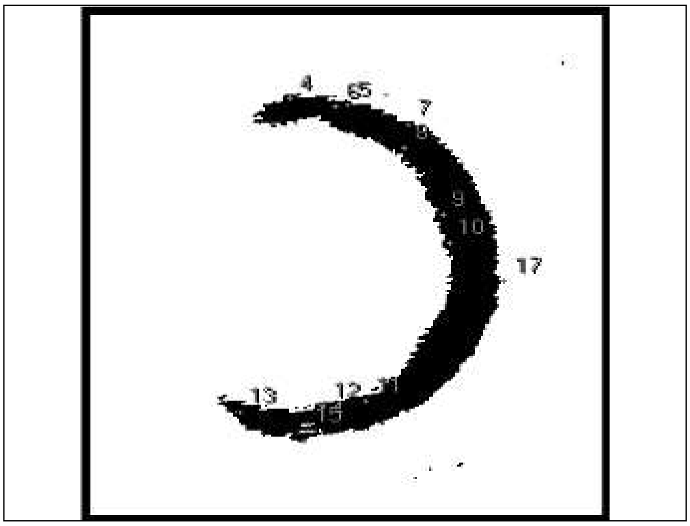

Figure 9: Out of view image.

also signifies the image processing algorithm reliability even when a small force is exerted onto the tactile sensor.

According to the others conference paper show that normal force calibration that only analysis one parameter for sensing characteristics there is area [9].Furthermore, it is difficult to obtain a good result to analyze with only one parameter are consider. In this finding, three parameters for the sensing characteristics of the silicone tactile sensor are analyzed in order to obtain the best parameter. Hence, the best sensing characteristic to select is the perimeter because its average error value is the lowest as compared to the other sensing characteristics as tabulated in Table 1.

Table 2: Concrete mix proportion

Percentage of Error, %		
Diameter	Area	Perimeter
13.865	21.726	10.113

$$\% \, Error = \frac{F_{exp} - F_{actual}}{F_{actual}} x \, 100\% \quad (5)$$

$$\Delta\% \, Error = \frac{\sum \% Error}{n} \quad (6)$$

Where,

n: Number of sample

4. CONCLUSION AND FUTURE WORK

This paper presents the development of an image analysis algorithm using WiT environment to facilitate and automate the process of a silicon tactile sensor behavior. Through series of experiments, it can be concluded that the image processing analysis is very important to help in getting detailed information on the hardness, roughness and other physical surface characteristics. The result shows that the perimeter (one of the sensing characteristics) is the best parameter since it has a low percentage error and able to detect small changes of force with better sensitivity. There are factors such as background lighting (contrasts color), camera light exposure (controls light) and camera focal distance (adjusts distance) which are not considered in the experimental set-up. These factors may possibly influence the current findings.

Hence, further work needs to be carried out to consider all these factors which can either be controlled or removed. Thus, a conclusion can be made that there is immense potential that this new optical tactile sensor coupled with surface exploration computer algorithm is able to assist in biomedical applications so as to replace the current manual characterization of soft tissues as well as for detecting various tumors based on its sensing characteristics information.

5.0 ACKNOWLEDGEMENT

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6.0 REFERENCES

[1] M. E. Eltaib and J. Hewit, "Tactile sensing technology for minimal access surgery—a review," Mechatronics, vol. 13, no. 10, pp. 1163–1177, Dec. 2003.

[2] C.-K. Chen, H.-T. Wu, H.-J. Chiou, C.-J. Wei, C.-H. Yen, C.-Y. Chang, and W.-M. Chen, "Differentiating Benign and Malignant Soft Tissue Masses by Magnetic Resonance Imaging: Role of Tissue Component Analysis," Journal of the Chinese Medical Association : JCMA, vol. 72, no. 4, pp. 194–201, Apr. 2009.

[3] S. C. Abdullah, J. Wada, M. Ohka, and H. Yussof, "Object Exploration Algorithm Based on Three-Axis Tactile Data," 2010 Fourth Asia International Conference on Mathematical/ Analytical Modelling and Computer Simulation, pp. 158–163, 2010.

[4] J. Dargahi, S. Najarian, and B. Liu, "Sensitivity Analysis of a Novel Tactile Probe for Measurement of Tissue Softness with Applications in Biomedical Robotics," Journal of Materials Processing Technology, vol. 183, no. 2–3, pp. 176–182, 2007.

[5] J. Liu and S. Wu, "The Research of Interaction Between the Silicone Rubber Sealant and Concrete," 2011 International Conference on Electrical and Control Engineering (ICECE) vol. 05, pp. 1839–1841, 2011.

[6] J. S. Liu, D. L. Li, J. Yu, and Z. W. Zhang, "Study on Durability of Silicone Rubber Sealant for Pavement Joint," Advanced Materials Research, vol. 496, pp. 30–33, Mar. 2012.

[7] B. Ali, Sukarnur, and M. Azmi, "Development of Experimental Test-Rig for a Vision-Based Tactile Sensor," Proceedings of International Conference on Advances in Mechanical Engineering (ICAME 2009), Faculty of Mechanical Engineering, UiTM Malaysia, 2009.

[8] Bakri Ali, R. Othman, R. Deraman, and M. A. Ayub, "A New Approach in Design and Operating Principle of Silicone Tactile Sensor," Journal of Computer Science, Science Publications, vol. 6, no. 8, pp. 940–945, 2010.

[9] A. Halim, B. Ali, and M. Azmi, "Normal Force Calibration for Optical Based Silicone Tactile Sensor," International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012), vol. 41, pp. 210–215, 2012.

[10] A. Halim, M. Azmi, and B. Ali, "Image Analysis For Deformation Behavior Of Optical Based Silicone Tactile Sensor," Proceedings of 2012 IEEE 8th International Colloqium on Signal Processing and its Application (CSPA), pp. 23–28, 2012.

PROFILES

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