EasyChair Preprint

№ 8171

A Soft Palpation Sensor for Early Detection of Biological Tissue Abnormalities Based on Electrical Impedance Tomography

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June 1, 2022

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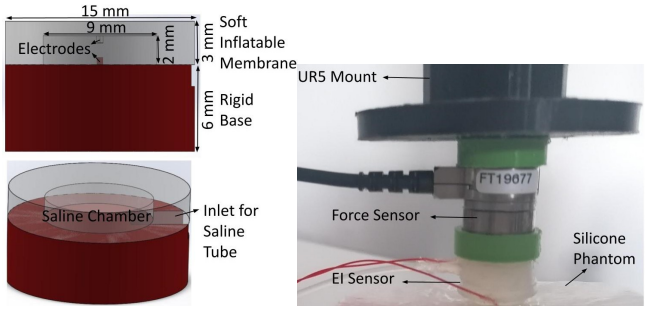
INTRODUCTION

We propose a soft inflatable sensor to detect tissue anomalies for internal examination of organs, especially in cases which are difficult to visualise, and where external palpation by physicians is not possible or informative. Rectal cancer is one of the most common cancers in the world, with over one third of cases diagnosed at a late stage. Assessment of elastic properties of colorectal tissue has been shown to offer potential improvements to tumour diagnostic accuracy, and early detection of precancerous tumours that are not visible through endoscopic imaging [1]. The proposed sensor provides a novel approach for sensing small lesions that are not easily detected by the current visualisation methodologies. The sensor includes an inflatable unit which is used to distend the tissue analogous to a palpation task. Any variation in tissue stiffness will cause a change in the shape of the soft inflatable unit, which is detected using the principles of Electrical Impedance Tomography [2]. A prototype has been designed and tested against a silicone phantom simulating a tissue with abnormalities.

MATERIALS AND METHODS

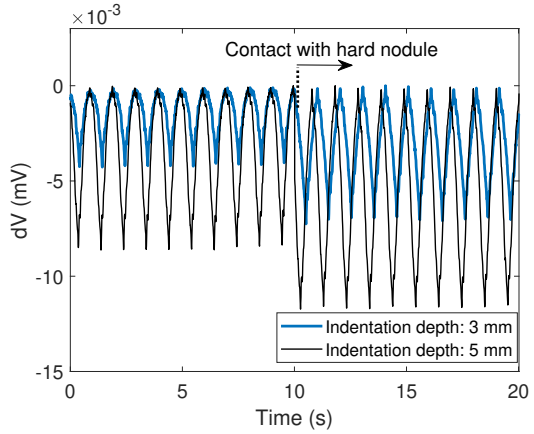
Fig. 1(a) proposes a soft inflatable cylindrical sensor, with a diameter of 15 mm and height of 9 mm, whose shape changes when it is pressed against tissues of different stiffness. The idea of Electrical Impedance Tomography (EIT) [2], [3] is to apply currents to different electrodes and measure the voltages across them to infer any non-uniform conductivity inside the body [4]. The sensor's design and working principle are inspired by EIT. In abstract, the shape changes are inferred via changes in the voltages across electrodes. Regions with higher stiffness values cause greater deformation in the shape of the sensor and hence, higher change in voltage signals are expected. The sensor is comprised of a thin membrane (1 mm) which is supported by a thicker silicone layer (Ecoflex 00-30) referred to as rigid base in Fig. 1(a). The membrane was inflated using 0.5% saline solution via an inlet tube of 5 mm outer diameter. Two electrodes (copper wires of 0.4 mm diameter) were integrated within the saline chamber. One electrode is fixed in the centre point of the rigid base. The second electrode is embedded within the soft membrane allowing it to move closer or further away from the first electrode as it is pressed against tissues of different stiffness values. As such, any change observed in the voltage values corresponds to the change in distance between the two electrodes. 0.5 ml of 0.9% saline solution is injected causing the membrane to inflate to a dome shape. A current of 2 mA at a frequency of 5 kHz is applied using a Howland current source. The voltage across the electrodes is measured using a National Instruments Corp USB-6363 DAQ at a rate of 50 kHz.



(a) (b)

Fig. 1 (a) Sensor Design and (b) attachment to UR5 arm for palpation task.

The sensor was tested against a 110x70x25 mm tissue simulating phantom of Ecoflex 00-20. Seven spherical nodules (hard beads), with diameters $d = [4, 6, 8, 10, 12, 14, 16]$ mm, were integrated at a depth of 3 mm during the silicone curing process to simulate tissue abnormalities. The chosen nodule sizes and depth were representative of cancerous tumours in colon tissue [1]. A Universal Robot UR5 arm is used to perform the palpation task. The sensor was mounted on UR5 arm as shown in Fig. 1(b). In addition, a force-torque sensor Nano 17 (ATI Industrial Automation) was placed between the UR5 mounting plate and the proposed soft sensor to measure applied forces. Initially, the sensor is placed just in contact with the silicone phantom - the initial contact point is determined by the force sensor readings. The sensor then indents the tissue vertically with a frequency of 1 Hz. The experiment is repeated with an indentation depth of 3 mm and 5 mm. The palpation task is performed at the location of each hard nodule and on the soft silicone in the neighbourhood of each nodule. The average demodulated amplitude of 10 voltage sine waves was measured.



(a)

Fig. 2 Change in voltage during palpation upon contact with soft region of silicone phantom and 4 mm hard nodule. Experiment was repeated for indentation depths of 3 mm (blue line) and 5 mm (black line).

RESULTS

Fig. 2 shows the changes in voltage values dV as the sensor is in contact with the soft tissue and the 4 mm hard nodule. The hard nodule is detected for an indentation depth of 3 mm (equal to the nodule depth) and also in the case of deeper indentation (5 mm).

Fig. 3 compares the performance of the sensor to that of the commercially available ATI Nano 17 force torque sensor. The sensor is able to identify nodules both smaller and larger than the sensing area of 9 mm. A heatmap of the change in voltage values in Fig. 4, demonstrates that the sensor can successfully detect the presence of hard nodules in all seven locations. The locations are identified as a change in amplitude of voltages detected between palpating a nodule and a neighbouring soft section on the phantom. As such, the heatmap does not represent the size of nodules detected. Comparison of nodule size and more accurate localization is the subject of a future study.

DISCUSSIONS

This work proposed a new palpation sensor design, inspired by ideas in EIT. The sensor successfully detects small (4 mm) nodules in the model silicone phantom, which would not be visible during existing imaging techniques such as endoscopy. In addition, the sensor has a soft structure as opposed to the commercially available Nano 17 sensor and has a considerably lower cost. The soft nature of the sensor, along with its material choice (silicone, low currents, and non- ferromagnetic) make it safe for use in internal examination and minimally invasive surgery, and MR compatible. Moreover, the small size (15 mm in diameter) and soft structure of the sensor allows it to be attached to a conventional endoscope in the future and navigated inside the colon during endoscopy. However, a soft actuation platform is needed for implementation of the sensor to palpate movable soft tissue (e.g. the colon) and is the subject of further studies.

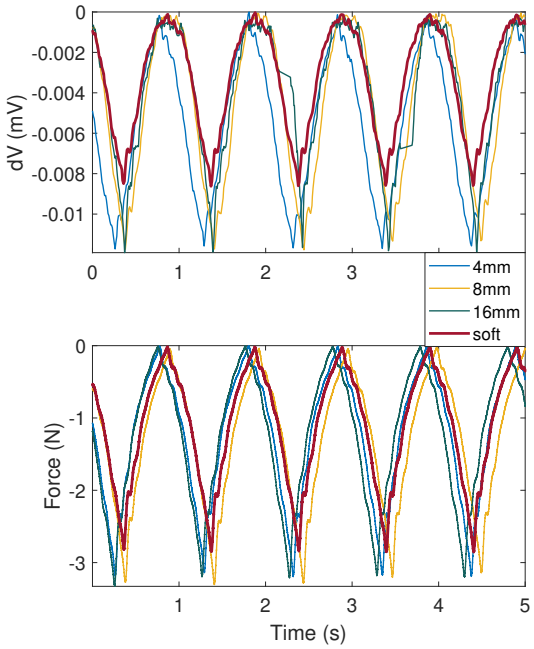


Fig. 3 Comparison of the proposed palpation sensor's performance (top) against an ATI Nano 17 Force sensor (bottom). The red signal corresponds to the sensor's output upon contacting the soft tissue. The experiment was repeated for 3 nodule sizes of $d = \{4, 8, 16\}$ mm.

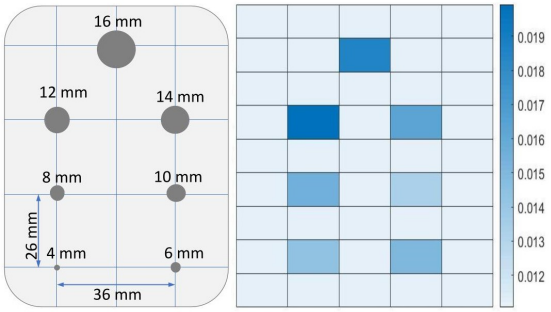


Fig. 4 Sketch of silione phantom model and hard nodule placements (left) and a heatmap of phantom obtained by the palpation sensor (right).

ACKNOWLEDGEMENTS

The work was supported by CRUK award C57560/A30036.

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