

Robotically assisted electrical bio-impedance measurements for soft tissue characterization: a feasibility study

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INTRODUCTION

The incorporation of advanced sensing technologies (STs) for tissue discrimination during complex procedures is an essential component of future surgical robot systems (SRS). Real-time STs are required to further improve the surgeons' performance in tissue discrimination and manipulation [1]. In the future, these novel STs will also enable an autonomous SRS to recognize contact with different tissue types in different conditions [2]. This information could be of enormous importance in the correct autonomous execution of complex procedures when other sensory data are not providing enough information for estimating the actual surgical conditions.

This work presents the application of a compact electric bio-impedance (EBI) measurement device that can be integrated into standard surgical instruments [3]. EBI measurements have been demonstrated to be a valuable supporting ST in a range of clinical applications, for instance in the localization of pathological areas in breast [4], or for detecting venous entry of catheters [5]. It is a challenging task, however, to obtain stable and robust measurements with a standard bipolar surgical instrument.

In [6], Cheng et al. identify the two main parameters that impact EBI measurements: the distance L between forceps jaws and tissue compression depth d . A graphical user interface was integrated into the standard endoscopic view to support the human operator in correctly controlling these critical acquisition parameters. Even with this interface, stable EBI acquisition between different measurements, i.e. almost constant L and d values, was difficult for a human operator to achieve.

To overcome this problem, we propose a robotically assisted EBI acquisition system (REAS), able to obtain stable EBI measurement over a regular sampling grid in a user-defined region of interest (ROI), with very limited a priori knowledge of the region properties (e.g. no knowledge about geometrical, anatomical and tissue properties). We demonstrate the feasibility of the REAS in an ex-vivo experiment based on the da Vinci Research Kit (dVRK) [7]. The results confirm the capabilities of the proposed method of performing robust EBI data acquisition. This could be a step toward improving the sensing capabilities of future autonomous SRS.

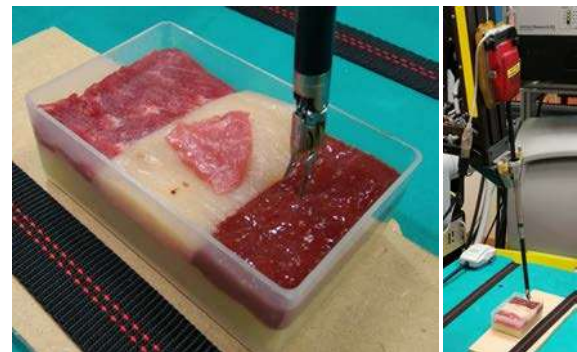


Fig. 1 Left: The phantom made of 3 different ex-vivo animal tissue samples, pork muscle (left), chicken breast (centre) and beef liver (right). We added a triangular piece of pork muscle on top of centre chicken section to increase the complexity of the acquisition. The rough phantom dimensions are $88 \times 55 \times 25$ mm. Right: The bipolar forceps with integrated EBI sensor.

MATERIALS AND METHODS

The EBI sensor used in this work is an embedded device based on an AD5933 (Analog Devices, Inc.) impedance converter IC. Please refer to [6] for a more detailed description of the sensor and its calibration. The sensor is mounted on the housing of an EndoWrist Maryland Bipolar Forceps (Intuitive Surgical, Inc.) and the bipolar leads of the instrument are used to connect the sensor circuit to the forceps grasper jaws. The jaws are placed in contact with the tissue sample under test (see Fig. 1) and the EBI sensor samples the complex impedance $|Z|\angle\theta$ with an excitation frequency of 100 kHz, jaw opening $L = 6$ mm and tissue pressing depth $d = 2$ mm. Impedance measurements are obtained at a rate of 50 Hz.

We propose a measurement planning algorithm that requires only minimum input information. The algorithm is initialized with an orientation (vector \mathbf{n}) and a bounding box representing the ROI to be analysed. The algorithm then generates a regular grid in a plane with normal \mathbf{n} , above the tissue surface. The forceps is moved between each point in the grid, and at each point toward the surface, keeping the wrist aligned with \mathbf{n} . Surface contact is detected when the measured impedance magnitude $|Z|$ crosses a given threshold level. Once surface contact is detected the instrument is pushed against the surface along direction \mathbf{n} to obtain the desired pressing depth d . Finally, the instrument is held steady for 0.4 s to

collect 20 impedance measurements at that point.

An ex-vivo experiment was conducted with the dVRK platform to evaluate whether the sensor is indeed capable of autonomously detecting tissue surface and map impedance measurements to contact points. Fig. 1 shows the experimental setup in which a phantom made of three different animal tissues (beef liver and pork muscle and chicken breast) is used to test the proposed system. The measurement planning algorithm was initialized with acquisition orientation roughly aligned with the surface normal and a bounding box of 76×40 mm centred with respect to the phantom. A grid of 21×12 evenly spaced measurements across the ROI is acquired. The threshold level for contact detection was set to 2000Ω .

RESULTS

Fig. 2 shows the surface map generated using the impedance measurements collected at the contact points. Specifically, the axes show the Cartesian positions (relative to the robot kinematic frame) where instrument-tissue contact was detected. Surface triangle (x, y) coordinates are determined from the Delaunay triangulation between contact points and the z coordinates are found by linear interpolation. The surface colour is mapped to the mean of the magnitude of the impedance measurements $|\bar{Z}|$ taken at that point. The black lines represent ground-truth boundaries. The map shows a clear separation of impedance values between tissue types. The triangle piece of porcine muscle in the middle is clearly visible in the map. However, its impedance values are not significantly different from the surrounding tissues except at three points.

DISCUSSION

The fact that tissue-instrument contact detection was successful at every sample point demonstrate that contact detection is robust and reliable. Since we use a bipolar instrument, contact detection is limited to when both grasper jaws are open and in contact with the tissue.

A qualitative assessment of the resulting surface map confirms that we are able to distinguish between different tissue types. Autonomously measurements using a robot lets us accurately control sample positions, pressing depth d and grasper jaw opening L . However, other factors such as blood on the tissue surface can greatly reduce the trustworthiness of measurements. Although we can distinguish between different tissue types, further studies are required to evaluate how the method will perform in distinguishing pathological tissues from healthy ones.

In this work, we demonstrated the feasibility of an autonomous REAS and experimentally evaluated its performance in ex-vivo conditions. The preliminary results are encouraging but also affected by many limitations. The results motivate future research to improve the actual acquisition performance and push the system closer to clinical applicability.

Future work will improve the scanning pattern by substituting the evenly-spaced grid with an adaptive grid to sample more densely in regions with significant EBI measurement difference, which could correspond to

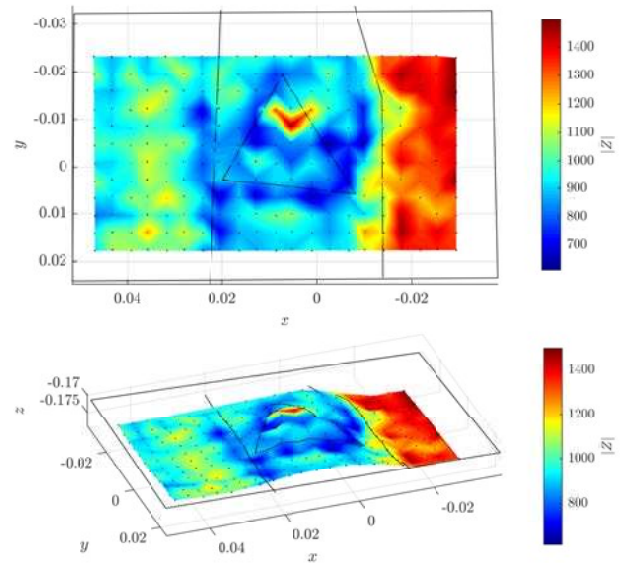


Fig. 2 Surface map (seen from different viewing angles) showing the result of the phantom acquisition. Surface points are extracted from robot kinematics and the surface colour is mapped to the mean of the corresponding impedance magnitude values $|\bar{Z}|$, measured in Ω . Black lines represent boundaries between different tissue types and the outer edge.

pathological regions. Another improvement will be related to multi-modal data fusion, in particular, the integration with stereo endoscopic images to obtain information about surface properties in the ROI thus optimize acquisition parameters, e.g. by adapting instrument tip orientation to surface normal estimation. Finally, we aim to test the proposed system in more realistic conditions, such as in-vivo animal trials and to discriminate between healthy and pathological areas of the same organ.

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