Advanced User Interface for Augmented Information Display on Endoscopic Surgical Images

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INTRODUCTION

Robotic surgery has come to the forefront in the last decades mainly because this technology can provide enhanced dexterity and 3D perception of the surgical field. These advantages turn into a surgical approach that is easier for surgeons and, ultimately, into better surgical outcomes for patients [1]. The incorporation of real-time sensing technologies during complex medical procedures is an essential component for future surgical robotic platforms. Despite the specific type of advanced sensing technology, the introduction of novel sensing requires proper integration in the standard surgical interface to be used effectively [2].

In this work, we present an advanced user interface (AUI) able to provide the surgeon with additional information about the operational field of view. In particular, we retrieved information from the kinematics of a robotic tool and from an electric bio-impedance (EBI) measurement system for tissue classification. These data constitute the input for augmented reality (AR) visualization of the surgical scene.

MATERIALS AND METHODS

The AUI is based on the Unity3D cross platform game engine, which provides an easy way to create complex graphics in space. The integration with a ROS-based robotic device is achieved by creating a C++ native plugin. It provides a simple C interface exposed to C# scripts. The virtual world created in Unity (see Fig. 1) is close to the real surgical setup. In this world, the real stereo-endoscope is modeled by two juxtaposed cameras (${}^{V}C_L$ and ${}^{V}C_R$) that record a textured plane each. The two textures (I_L and I_R) are mutually visible by the virtual cameras and they are continuously updated with the images recorded during the medical procedure. The virtual environment preserves the depth perception of the surgical scene and allows the projection of additional information (e.g. user interfaces, 3D models or point-clouds). The graphical user interface (GUI) is placed close to the virtual cameras, such that it can be seen in both their fields of views without being occluded by other objects.

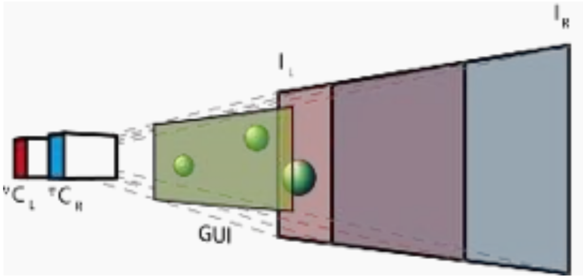

Figure 1. The AUI virtual environment: two virtual cameras (${}^{V}C_L$ and ${}^{V}C_R$) record a textured plane each, where the textures (I_L and I_R) are the images obtained with the real endoscope. The GUI is placed close to the cameras, while 3D objects are positioned between the textured planes and the GUI.

Registration is fundamental to correctly overlap spatial-related information to the endoscopic images. We achieve this goal by measuring a set of fiducial points on a ChArUco board (i.e. a checkerboard augmented with fiducial visual markers). These points have known coordinates in the *world frame* (the one of the board). Then we place the tip of the robotic tool on each fiducial point of the ChArUco board and we record the corresponding coordinates in the robotic frame. Quaternion matching method [3] is applied to estimate the transformation between the tool and the world reference frame. In addition, the camera coordinate frame is registered to that of the *world frame* through online extrinsic calibration of the camera. Finally, the transformation between the camera and the tool is obtained by combining the previously estimated transformations. Expressing the tool coordinates in the camera reference frame, the AUI can provide position-related information to the surgeon.

In this study, the AUI is used to assist the surgeon to understand the tissue type in contact with the surgical tip. To identify the type of tissue, we use the EBI sensing technology. Then, a dot is marked in a predefined color on the AUI to represent the corresponding tissue type.

As shown in Figure 2(A), the EBI measurement system integrates a single chip with the proximal end of

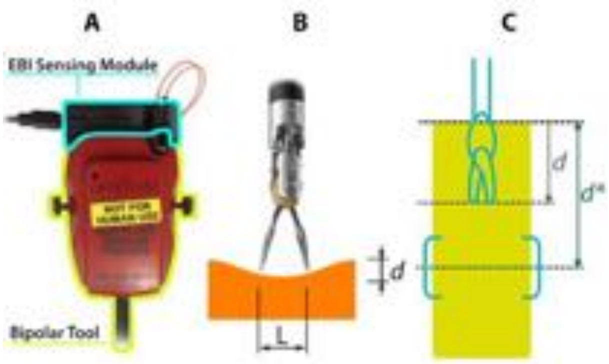

Figure 2. (A) The EBI measurement system integrated with the Maryland Bipolar Forceps. (B) The factors influencing the electrical impedance. (C) Visual feedback on the insertion depth as it appears in the final AUI.

a bipolar tool. For instance, we used the standard Maryland bipolar forceps (Ref. 400172) available for the da Vinci Research Kit (Intuitive Surg.Inc.). The EBI measurement depends on several variables including the jaw opening distance (L) and the insertion depth (d) (see Fig. 2.B) [4]. In fact, different jaw opening angles of the forceps are related to different current densities applied to the tissue, and thus result in different EBI values. This opening angle is accessible from the robot joint encoders and it is taken into account while performing the tissue classification. In addition, pressing the tissue can change both the intracellular and extracellular tissues' impedances. Here, an optimal insertion depth (d^*) was defined to obtain reliable tissue classification [5]. Therefore, the correct position of the surgical tool with respect to the tissue surface is essential: this information can be provided to the surgeon by means of a visual feedback on the AUI.

RESULTS

The final AUI allows to (i) communicate the result of the classification in text form, (ii) provide a visual feedback on the insertion depth (Fig. 2.C) and (iii) create a tridimensional point on the touching site of the tooltip to mark the classified tissue type.

A preliminary experiment was designed to verify the proposed system (Fig. 3). Four types of porcine tissues (i.e. muscle, fat, liver and lung) were used to construct a realistic surgical scene. The designed AUI was found very helpful since on-site tissue type can be detected in real time. Also, visual feedback on the tool insertion depth assures a more accurate tissue identification. In terms of classification marks positioning, the calibration method allowed to obtain an accuracy (reprojection error) of the order of millimeters.

CONCLUSION AND DISCUSSION

In this preliminary work we presented a novel AUI to improve the surgeon understanding of EBI sensing data. The AUI provides integrated AR data visualization and

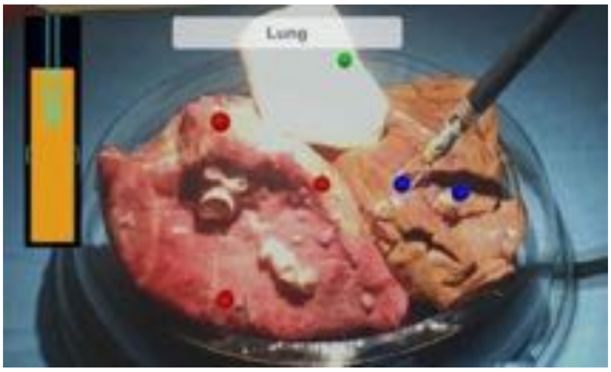

Figure 3. The AUI visualization components: the lateral bar provides a visual feedback of the insertion depth and it turns green when the optimal distance is reached; the upper central box contains the classification outcome in text form.

indications of the surgical tool positioning to obtain consistent measurements. It allows to map the surgical scene with information of the tissues touched by the tooltip. The map might be particularly useful if the visual feedback provided by the endoscope fails (e.g. in case of bleeding, blurred camera or smoke in the field of view). Most importantly, the map could help in tumors resections because EBI sensing has been demonstrated to discriminate between healthy and cancerous tissues [6], which is difficult to be achieved by the only visual inspection.

This study is a part of the EL.I.S.A. project which aims to apply EBI sensing for various surgical applications and future work will focus on improving hardware and software components with the objective of testing the proposed approach with in-vivo experiments. A relevant improvement would be the implementation of tracking algorithms to adjust the position of the classification dots in case of tissue displacement.

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