naralap: augmented reality system for navigation in laparoscopic surgery

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1. PURPOSE

Laparoscopic surgery is a surgical technique in which the surgeon makes little incisions in the patient's abdomen and introduces a special instrumental called trocar [1]. In one of the trocars a camera is inserted which turns into the vision of the surgeon during the intervention, whereas in the others trocars, the rest of the instrumental that surgeon needs is introduced. Laparoscopic surgery offers a great deal of advantages over traditional methods which are related to the fact of making little incisions, as for instance: lower probability of infection or no necessity of consecutive interventions. These advantages provide the benefits of a shorter hospital stay and a quicker recovery period. However, the drawbacks of this technique are the lack of direct vision since there is a need of eye-hand coordination, and the lack of tactile perception.

Augmented Reality (AR) is a technology that registers and merges real and virtual images in real time. These tools have been employed in this type of surgery [2, 3] to help and guide the surgeon during the intervention. The main disadvantage is the necessity of one or several marks visible by a camera to carry out the registration and the fusion. Furthermore, the great majority of the augmented reality applications take into account rigid virtual models but in the particular case of abdominal organs, these suffer deformations due to the patient's breathing or the pneumoperitoneum technique [4].

The main goal of this paper is to present a tool, Naralap, that consists of several modules which will be different components of a future laparoscopic navigator. In particular, this work presents an AR system and a biomechanical model of the liver.

2. METHOD

Naralap consists of two main modules: the AR system whose objective is to register and merge real images and virtual models and a biomechanical model of the liver that simulates the behaviour of this organ in a typical procedure of a laparoscopic intervention.

2.1 Augmented reality system

The AR system input are the 3D images of a patient's abdomen obtained by CT or MRI. With these images, a segmentation to remove those organs not important for this work is performed. Once the model is segmented the registration process starts. For this purpose, a generic point has to be select. In this system, a mark is centred on the navel because the navel is visible in both, the real image and in the medical images (CT or MRI). A change in the coordinate origin is performed and a registration is applied to the model to merge the two environments. Fig 1 shows the procedure. First, a change in the coordinate system of the images and the model is performed to become the navel into the centre containing the system. A mark is placed on the navel of the patient and the registration is performed with AR algorithms [5]. Finally a fusion of the real images from the camera, and the virtual model extracted from previous images (CT or MRI) is visualized.

Fig 1. Left to right. Origin Coordinate change. Mark centred in the navel for registration. Fusion of virtual model and camera image.

2.2 Biomechanical model

The main purpose of the biomechanical model of the liver is to simulate its deformation during the laparoscopic intervention, and the first deformation to which it can be subjected is due to pneumoperitoneum.

At the beginning of the laparoscopic surgery, CO_2 is insufflated in the abdomen through a trocar in order to create enough space to make possible the intervention. This technique is referred to as pneumoperitoneum [4]. To study if the liver is deformed for this technique an experimental simulation was carried out which can be found in [6].

Two circular samples were obtained from four lamb livers, one of 100 mm of diameter and another smaller, of 80mm of diameter. The samples were introduced in a glass receptacle which was hermetically sealed but connected to a tube through which the CO_2 was insufflated (Figure 2, left). The device used to insufflate the CO_2 was Wolf IP20 (Figure 2, center). The pressure was kept constant during all the procedure. Two different ranges of pressure values were tested: 10-14 mmHg (the most common used in abdominal interventions) was applied to 4 samples and 16-19 mmHg was applied to the other 4 samples.

The receptacle was introduced in the multi-detector spiral CT *GE LightSpeed VCT–5124069* (Figure 2, right) of the *Hospital Clínica Benidorm* (HCB), and CT images were acquired from each sample before applying CO_2 and when the CO_2 was applied. The axial slices interval was of 0.625 mm. The CT images were processed using the software *ScanIP v4.0* from *Simpleware* (http://www.simpleware.com/) in order to obtain the volume of each sample.

Figure 2. Material used for the experiment: Liver sample inside the hermetical glass receptacle (left), insufflating device Wolf IP20 (center) and Multi-detector spiral CT GE LightSpeed VCT-5124069.

3. RESULTS

The AR system presents a precision of 2.91 mm. For this measurement an object was scanned in the same conditions that the liver: a CT *GE LightSpeed VCT-5124069* with a resolution of 0.625 mm in the axial slice. The segmentation of this object was carried out. The mark was placed in the middle of the object simulating the navel, and the same point was selected in the images and in the model. Different experiments with different parameters like the angle camera were made obtaining a mean precision of 2.91 mm. [5].

Regarding the biomechanical model of the liver, the experimental simulation of the pneumoperitoneum showed small differences between the volume of the samples when CO_2 is applied and when it was not [6]. As a result of this work, it was concluded that the liver is lightly compressed under these pressures when a laparoscopy surgery is carried out. According to Shi et al. [7], when the liver is subjected to small strains, its behaviour can be assumed linear elastic. Therefore, a linear elastic behaviour will be used for simulating this deformation.

4. CONCLUSION AND FUTURE WORK

The AR system has a good resolution and currently is used for the placement of the trocars. Possible improvements will be performed to make the system independent of the camera position or to use natural marks. The biomechanical model and the AR algorithms will be combined with a tracker, for tracking the surgical instruments, in order to implement a valid system for liver biopsies. It will take into account the deformation due to the pneumoperitoneum and due to the breath of the patient.

To develop the navigator that will guide the laparoscopic interventions, both AR system and biomechanical model will be combined with the laparoscopic camera in order to make an easier environment with only one vision in a 2D monitor.

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