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A High Resolution Bladder Wall Map: Feasibility Study

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***Abstract*— The aim of this work is to provide the surgeon-urologist with a system for automatic 2D and 3D-reconstruction of the bladder wall to help him within the treatment of bladder cancer as well as planning and documentation of the interventions. Within this small pilot-framework a fast feasibility study was made to clear if it is generally possible to build a bladder wall model using a special endoscope with an embedded laser-based distance measurement, an optical navigation system and modern image stitching techniques. Some experiments with a realistic bladder phantom have shown that this initial concept is generally acceptable and can be used with some extensions to build a system which can provide an automatic bladder wall reconstruction in real time to be used within a surgical intervention.**

I. Introduction

The management of the bladder cancer by endoscopic imaging with a simultaneous treatment via the endoscope is a conventional procedure which is very efficient. But there are some difficulties in this standard intervention which are caused by the insufficient visibility of the bladder wall through the endoscope and low ability of the surgeon to imagine the whole bladder wall surface basing on the single areas that he has seen during the inspection. The cystoscopic examination is rather subjective and dependent on the expertise of the examiner. There is no certainty that the entire bladder wall is inspected and there is no way to measure the exact tumor site during the operation, so it is estimated by the examiner only. The surgeon has no objective tool to compare tumor localization with previous tumor localizations and therefore cannot judge whether the tumor has developed newly or was eventually left behind. Today the surgeons have difficulties of planning an operation (special forms of anesthesia) based on a written cystoscopy report only. The proposed approach in this work is a generation of a high resolution map of the entire bladder wall and of an individual 3D model of the bladder. This could help the surgeon to solve the described problems.

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II. Related Works

There are many efforts to segment or reconstruct the human bladder described in the literature. Possible techniques are using CT and MRT segmentation, endoscopic image stitching, endoscopic image displacement, etc. A short review of these techniques has shown that they are not applicable for a real-time reconstruction or cannot provide any textural information of the bladder wall.

Daul *et al.* [1] have investigated a mosaicking algorithm which is able to create a 2D bladder map and also 3D surface reconstruction. The authors are using the overlapping parts of neighboring images and Parzen's windows to register them and build the 2D map. For the 3D reconstruction a method with a projection of eight laser spots on the bladder wall is proposed. Dependent on the distribution of the laser pattern the image surface is reconstructed and used to create the 3D model. The authors have measured the method's accuracy which lies by 0.8 mm, we found this result very good but in our opinion the used accuracy estimating method cannot reflect the real surface reconstruction error.

Ben-Hamadou *et al.* [2] have improved the method described in [1]. They have also reported about a computation time and it was 20 seconds for each image position. The authors suggest that the bladder map will be always built beyond the operation and therefore the computation time is not very important. But in our opinion the previously created bladder map has to be compared with an actual one and that must be created in a real time.

Costa *et al.* [3] as well as Niu *et al.* [4], Bay *et al.* [5] and Garnier *et al.* [6] presented the reconstruction methods of bladder based on the segmentation of CT or MRT datasets. However, such models cannot contain any textural information, so they cannot be used for a bladder map.

There are no systems on the market which could be a real assistance for the surgeon by providing him with a high resolution bladder wall map in real time.

III. Proposed Approach

As it was already mentioned the system is based on an optical navigation system, rigid endoscope with a laser distance measurement function and fast and efficient stitching techniques. Our suggestion is that the setup with different hardware systems for the position, distance measure and image processing allows building a robust and reliable system which would be able to generate a bladder map from the original high-resolution endoscopic images in real time. Some details about the system components are given below.

A. Navigation

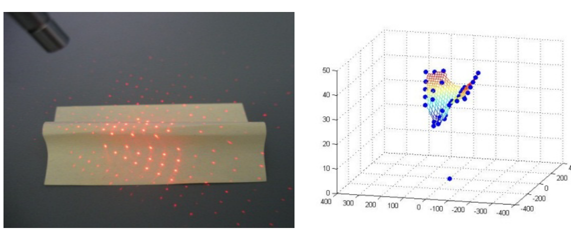
The medical navigation systems are generally divided into two types: optical and electromagnetic. Optical navigation systems are more precise but in principle they can help only measuring the positions of rigid instruments. Electromagnetic navigation systems can be applied also with flexible instruments with sensors being mounted at or in the instrument tip because the sensors are thin and flexible and the system works without a direct optical contact with them. The described navigation systems are shown in Fig. 1.

a) b)

Fig. 1. Navigation systems: a) optical (Polaris Vicra); b) electromagnetic (Ascension MedSafe).

B. Endoscope with triangulation pattern

For the surface reconstruction and distance measurement an experimental model of rigid endoscope is in use which has an optical fiber with a rectangle laser pattern consisting of 49 points. The distance between the points is depending on the distance to the object whose surface is measured as well as on the angle between the surface and endoscope axis. The opening angle of the laser beam is approximately 3.8 degrees; it means that the distance between the pattern points is 13.3 mm if the measured surface is plane, perpendicular to the laser beam and lies 20 cm away from the endoscope tip. Fig. 2 shows the endoscope with the laser pattern. The working



a) b)

Fig. 2. Distance measuring: a) endoscope tip and laser pattern; b) reconstructed surface in Matlab.

principle of the distance measuring with such an endoscope is not new: the pattern is distorted depending on the surface form and the distance to the surface. The normal form of a pattern and the standard distances between the points are known and the needed parameters can be calculated from the comparison of normal and distorted patterns. Such questions as occlusion problems and calibration were not concerned in this work; the system was already tuned and was just used as a ready instrument. In Fig. 2 one can see a simple example of distance measuring and surface reconstruction with the described principle: a distorted paper sheet can be a curved surface on which a straight laser pattern is correspondingly distorted (Fig. 2a); the information from the distorted laser pattern can be interpreted with a Matlab script and depicted in form of a graph (Fig. 2b), where the reconstructed pattern point positions are represented by the blue points as well as the position of the endoscope tip (the point on the bottom of the Fig. 2b). It is important to have a proper registration matrix between the endoscope image and the navigation system sensor. Therefore a calibration body is needed to obtain this registration matrix. In this feasibility study we have not used any calibration body because it was not critical to prove the concept's applicability.

C. Stitching and creation of map and 3D model

As the location and the form of the single images are measured by special systems, there are no complex algorithms needed to build the map and the 3D model. The image characteristics during the bladder examination can be unstable and the vascular pattern can change but it must have no effect on the image stitching. The main problem is a creation of the standard for the model concept and main key indicators for the model building for different patients. That is one of the main points of our further work. An example image stitching made within this feasibility study is given in Fig. 3. This image was made on the basis of some single cystoscopic images during a usual cystoscopic intervention. The optical flow algorithm [7] was used for the stitching.

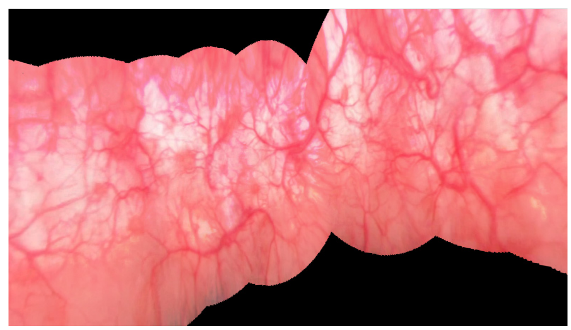


Fig. 3. Stitching.

IV. Experiment

We have made some experiments using an optical navigation system, rigid distance measuring endoscope, realistic rubber bladder phantom and a cinematic construction to hold, fix and move the endoscope (Fig. 4). To measure the coordinates of the instrument tip an optical tracker was mounted on its shaft. There was no connection between the navigation system and distance measuring system, so this experiment was made manually. Several sequences of snapshots were made where the transformation matrix from the navigation system was recorded simultaneously with the distance matrix from the endoscope system and the current endoscopic image. A sequence containing 42 datasets was chosen for the further evaluation of the concept feasibility. The data were evaluated using the Matlab environment. The combination of navigation and distance measurement data is shown in Fig. 5 where the blue points (on the bottom) represent the measured 49 distances for each endoscope position and the green points (on the top) represent the positions of the endoscope tip. One can see that the measured points are forming a spherical shape like the bladder

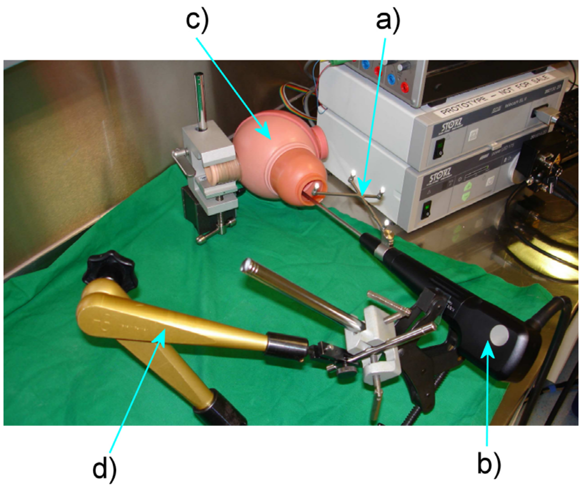


Fig. 4. Experimental setup: a) optical tracker; b) rigid distance measuring endoscope; c) rubber bladder phantom; d) cinematic construction to hold, fix and move the endoscope.

phantom. It shows that the phantom's surface can be reconstructed using a combination of distance measurement and navigation. Of course, the combination of a rigid endoscope and optical tracking cannot allow generating a model of the whole phantom. To generate a map of the whole phantom or bladder one would need a flexible endoscope in combination with an electromagnetic navigation system and this is also a part of our concept which should be implemented. Also some experiments for image stitching were made (see Fig. 3). Using the fast optical flow technique it was possible to mosaic the real images of a bladder wall in real time.

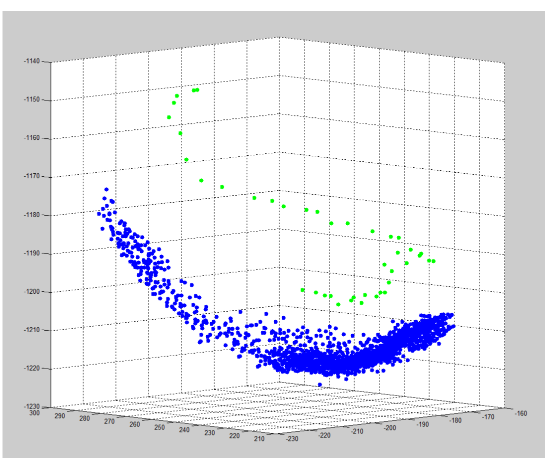


Fig. 5. Matlab plot of the endoscope tip positions (green) and the bladder phantom surface points (blue) reconstructed using the navigation and distance measurement.

V. Experimental Results

In order to find out the phantom's radius using the obtained data we have evaluated the coordinates of *1404* phantom surface points which have been measured with the navigation and distance measurement. At first we have measured the real phantom's dimensions with a ruler. The problem was that the phantom hasn't a correct spherical form, but was rather elliptic. The small radius (*"equatorial"*) was approximately *52* mm and the big (*"meridional"*) was approximately *68 mm*. The data evaluation method was quite simple and could make only possible to find one average radius: a point was found, from which the distance to all *1404* points has the smallest standard deviation. In principle the form of the measured point set was very wide-stretched and the set lay along the phantom's meridian, therefore we should obtain a radius value which would be more or less close to the bigger phantom's radius. We have calculated the distance standard deviations from different positions on various distances from the surface point set. At first we have found the center of the area containing all surface points. It was simply the point with the average *x, y* and *z* coordinates among all points, practically the point in the middle of the set. After that we have calculated the distance standard deviations of all points of a big rectangular area around this central point. This area was a parallelepiped with each side of *200 mm* and the step was *5 mm*. We have found an area where the deviation was the smallest and proceeded with smaller areas around the found point (up to *20x20x20 mm*) and smaller steps (up to *0.5 mm*). At the distance *66 mm* the smallest standard deviation (*1.8 mm)* was obtained. On the shorter and longer distances the standard deviation was always increasing. So the found point with the smallest standard deviation *1.8 mm* was a reconstructed center of the bladder phantom and the distance from this point to other points (*66 mm*) was the found phantom's big radius. The found radius *66*±*1.8 mm* is strongly correlated with that radius (*68 mm*) which we have measured with a ruler. Of course, the measurement precision with a ruler is not high, it is about *1-2 mm*, so the hand-measured radius should be written as *68*±*2 mm*, but this precision (as well as this simple experiment setup) is considered to be enough for a feasibility study. Probably if we had used a spherical bladder phantom we could achieve a much higher precision.

VI. Conclusions

The experiment has shown that our concept is feasible and that it can be used for the surgical assistance system development for the bladder map generation. We have not made the image acquisition and stitching in real time, but it is definitely possible because we do not need to find the image superposition using image information. We also do not need to calculate the real position of the endoscope tip which is also measured by the navigation system. As far as we are using the navigation system we must only stitch the images and this procedure might not be very complex, so it seems to be possible to make it in real time. Large overlapping areas between the images are also not necessary, that makes the bladder map generation faster and simpler for the surgeon. Our concept also allows using the manipulator robots which could move the endoscope precisely along that path that is minimally necessary to build a bladder wall map in a shortest time. Of course, our study is still quite preliminary and need further development and testing in aspects such as system construction, real performance assessment and clinical studies. The system accuracy obtained within the experiment is quite sufficient but not finally because of the experiment setup. The accuracy must be proven and specified.

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