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Demonstration of a Prototype for Robot Assisted Endoscopic Sinus Surgery

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***Abstract*— In this video we show our current prototype for robot assisted endoscopy. The system requires only few and simple instructions from the surgeon, in order to guide the endoscope in an intelligent, autonomous, and safe way: The surgeon tells what to do and the robot decides how to carry out the task by choosing the best manipulation primitive in every control cycle. Several sensors are integrated into the decision process: The endoscope camera, a stereo camera system, a force/torque sensor, a biomechanical model based on CT data and statistical knowledge, a position and velocity sensor for the manipulator, and interface devices like a foot switch. The executed manipulation primitive is handled by a hybrid controller allowing to switch the control mode (e.g. trajectory following or force control) for each degree of freedom of the task frame individually.**

I. INTRODUCTION

In recent years, *Functional Endoscopic Sinus Surgery* (FESS) has been established as one of the most important standard techniques in the field of ear, nose, and throat medicine. However, the major disadvantage of this technique is that the surgeon has to hold the endoscope himself. This results in unsteady endoscopic images during long surgeries caused by tiredness of the surgeon or in frequent instrument changes, e.g. between a knife to cut away tissue and a sucker to remove this tissue and blood. Since this is also true for other endoscopic surgeries like laparoscopy, robotic systems are in development able to guide the endoscope during an endoscopic surgery (some of these developments are listed in [1], [2], [3]). Our ultimate aim in *Robot Assisted FESS* (RAFESS) is that the robot guides the endoscope during a surgery as autonomous as possible. One of the main challenges is the close proximity of critical regions like brain, eyes, and carotid artery to the workspace of the robot, which, of course, is not allowed to collide with these structures. Therefore, the motions of the robot should be restricted as much as possible without loosing the flexibility needed to satisfy the demands of the surgeon. Part of these requirements are that (1) the tip of the surgical instrument is always in the center of the endoscopic view, (2) the surgeon has enough free space to operate his instruments, (3) the motions of the robot harmonize with the motions of the surgeon, (4) the robot can automatically clean the camera lens, and (5) the surgeon can direct the robot to specified locations (e.g. on the basis of CT data).

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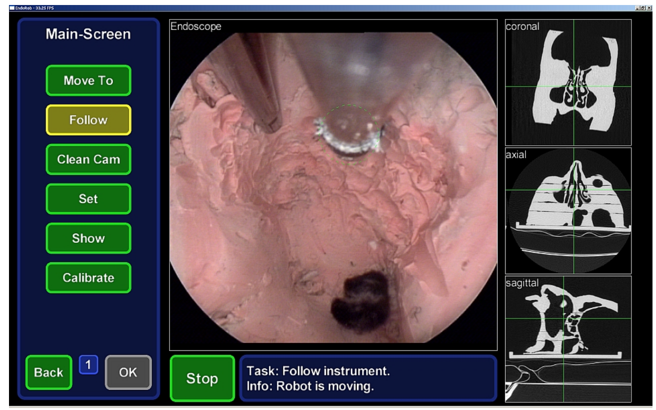

Fig. 1. Graphical user interface: Available commands are listed in the left panel. The center panel shows the current endoscope image and the status of the robot. The right panel displays three orthogonal slices into the CT data. These slices intersect at the position of the endoscope's tip or any other selectable position. We use a ring marker at the tip of an instrument, in order to estimate its 3d position.

In this video we show a prototype already fulfilling most of these requirements in our experimental setup. Details about our concepts, implementation and future work are given in the following chapters.

II. OVERVIEW OF THE PROTOTYPE

A. ARCHITECTURE

Our system architecture is shown in Fig. 2. In order to achieve a modular and distributed system design, we use the middleware MiRPA (Middleware for Robotic and Process Control Applications) [4]. MiRPA supports several communication models; the client/server model is one of them. Based on this model, each component provides some services available to the other components. The main control of the system is located in the component *application*. It decides what task is to be executed next based on the user inputs, which are processed by the components *touchscreen*, *speech recognition*, and *foot switch*. Furthermore, it displays status information via the component *view* (see also Fig. 1). Depending on the sensor values and status of the system, the component *task execution* selects the next manipulation primitive. See [5] for more information on the *manipulation primitive execution*. The component *joint control* gets new position and velocity setpoints at every control cycle ($250Hz$ rate) and delivers them to the Low Level Interface (LLI) of the Staeubli TX40 manipulator. Forces and torques are provided by an ATI Nano43 sensor. Information about the other components are given in the following sections.

B. TRACKING SYSTEM

The *tracking system* component tracks the poses of all relevant objects within the workspace of the manipulator using the sensor data of a stereo camera system placed above the workspace, the endoscope camera, and the pose of the manipulator given by its kinematics. Also integrated is the registration (see [6], [7] for details) between the patient's head lying on the operating table and the CT data.

C. BIOMECHANICAL MODEL

Due to the limited space within the nasal cavities, soft tissue is deformed by the endoscope. The amount of deformation has to be limited depending on the affected structure (e.g. entry of the nose or middle turbinate) and on the pose of the endoscope. Therefore, we are using a simplified biomechanical model for online computations. Its parameters (e.g. strain values) are initialized offline with the help of a more accurate finite element model. Our current implementation is based on potential fields as described in [8].

D. NAVIGATION

Since CT data is available many hours before the actual surgery starts, we can precompute roadmaps for the global (coarse) navigation of the endoscope. Local (fine) navigation is done online, so that we can react to sensor events in a flexible way. Destination poses are either directly chosen by the user or computed in the "instrument following mode" by balancing view direction, available space for the instruments, and soft tissue deformations (see also Fig.1).

III. CONCLUSION AND FUTURE WORK

Although our prototype is still work in progress, it already shows very promising results in our (artificial) experimental setup. The major challenge is to harmonize the motions between the endoscope and the instruments while minimizing the risk of injuring the patient. Therefore, we need further optimizations of our algorithms especially in the context of cooperative handling and soft tissue simulation. We are also planning full length surgeries on anatomical preparations.

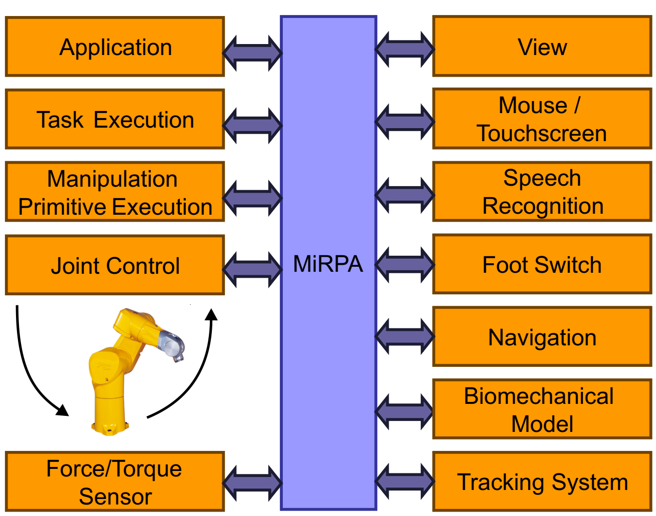

Fig. 2. Components (orange) of the system communicate over the middleware MiRPA (blue). Communication is always in both directions, since services reply to requests.

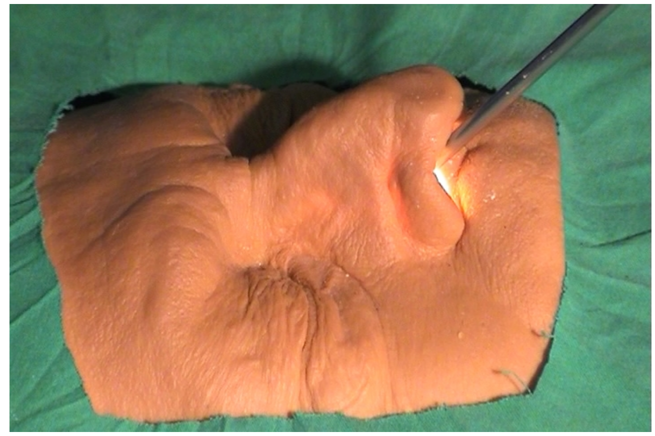

Fig. 3. CT data based silicone model of a patient's head used in our experiments. Compared to soft tissue of a human nose, the silicone of our model was too stiff resulting in a reduced workspace. Thus, we had to remove some parts of the internal structures.

IV. ACKNOWLEDGMENTS

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