Concept for a navigated microsurgical assistant system for middle ear surgery

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Abstract. In this paper a concept for a navigated microsurgical assistant system for middle ear surgery will be described. The aim of this system is to support a surgeon during the milling and placing of prosthesis. For these applications an accuracy of 100 μm is required. With extended focus on the used tracking system MicronTracker (Claron Technology, Toronto, Canada) the setup of the system will be analyzed. The accuracy analysis of the MikronTracker was one of the first steps, because actually the tracking system is still in evaluation status.

1 Introduction

The introduction is divided into two parts. In the first part the medical problem and periphery of micro surgery is shown. In the second part the concept of the complete system is specified.

1.1 Problem

In the field of microsurgery, e.g. middle ear surgery, the surgeon is very often confronted with very small and sensitive structures. In this context there are some general problems:

- The size of these structures that should be manipulated is hard at the edge of the human manipulating skill of approximately 0.5 mm (figure 1a).
- While getting access to the operation field the surgeon has to mill with extensive force, whereas shortly after he has to do precise and tremble free positioning of the surgical instrument.
- In many cases the surgeon decides to use a microscope for the surgery (figure 1b). Thereby the coordination of the optical sensed scene and the handling of the haptic sensed surgical instrument is very difficult to combine to a precise work.

These problems could lead into complications (injury of sensitive structures like nerves or vessels) or cost-intensive following surgeries. To achieve lower complication rates and a better quality a combination of navigation and robotic assistant system is conceived for supporting the work of a surgeon and eliminating the described problems.

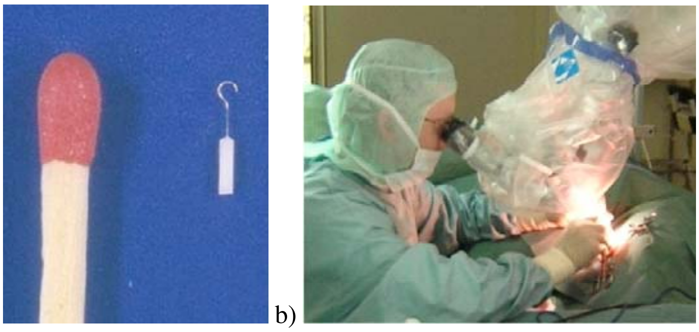


Fig. 1. a) Stirrup prosthesis [1] and b) ENT surgery scene for insertion of stirrup prosthesis with usage of a microscope

1.2 Concept of System

During the first realization step the navigation system was implemented (figure 2a). It consists of a tracking system MicronTracker (Claron Technology, Toronto, Canada), localizers for instrument and patient, a micro robot for positioning tasks, and a visualization computer with a touch screen monitor. The tracking system is fixed at an operation room lamp to assure that the tracking system points to the operation field. For the visualization of the 3D-scene CT-Data taken before the surgery are integrated. Due to the fact that the accuracy of a pure freehanded navigation is insufficient to achieve the demanded accuracy of 100 μm, a 2 d.o.f. manipulator is developed parallel to the first realization step (figure 2b).

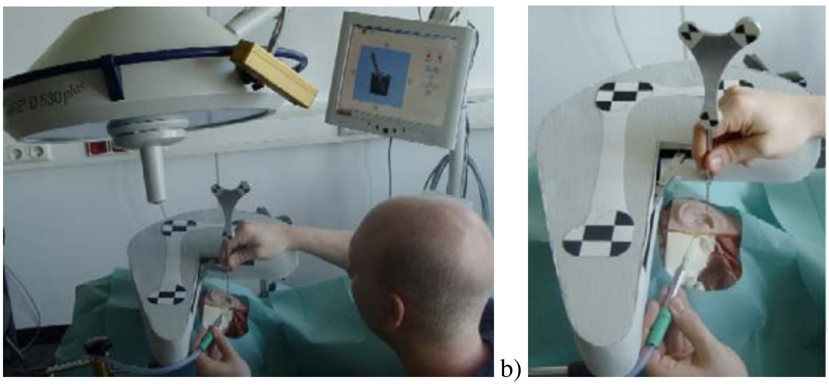


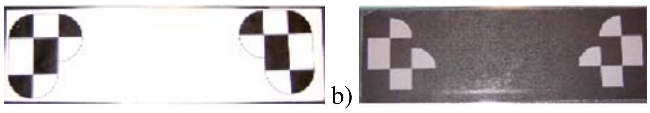
Fig. 2. Complete system with navigation system, MicronTracker system and manipulator [2]

2 Material and Methods

2.1 Material

The used tracking system is compact in size (157x39x42 mm^3) and based on a new principle of black-white pattern recognition. This system is currently only available for evaluation. Therefore the evaluation of the tracking system's accuracy under real conditions is an important step for the complete evaluation of the system. Especially the influence of intense light, which is given in surgeries, is interesting in this context. The experiments are designed in a way that an interface application requests the tracking system to track the 3D position of two markers (marker-objects). The two markers are fixed on thick-flat plastic material and are at a fixed distance from each other. This distance d_f is exactly measured using a caliper.

The standard marker-object that is available with the MicronTracker system consists of two black-white contrast patterns placed on a white background (figure 3a). For the evaluation of intense light an alternative marker-object is designed. To reduce reflections the background is painted black and for less over lighting the pattern is changed to black-grey contrast (figure 3b). Both marker-objects are the same size.



a) b)

Fig. 3. Different marker-objects for verifying the influence of colored patterns: a) white background - Marker A and b) grey background und black-grey contrast - Marker B

2.2 Methods

The following accuracy measurements have been carried out to show the usability of the system in surgery. Experiment 1: Error distribution over the work area of the camera. Experiment 2: Influence of intense surgery-light (80,000 to 150,000 Lux) on the error. Both measurements where taken for the noise of one measurement point as well as for the distance between two measurement points. The 3D positions of the two markers belonging to a marker-object are processed for obtaining the distance between these two markers.

Experiment 1: For each measurement sample more than 100 values (d_i) are taken. The values are recorded with the interface application and saved in a text file for further processing. The text file is imported to Microsoft Excel and the distance between the two markers is calculated. For the measurement sample the mean $\bar{d}$ of all calculated distances d_i is taken.

The difference of calculated distance $\bar{d}$ (taken by tracking system) and the measured fixed distance d_f is obtained and called error ε for this experiment (figure 4).

$$\varepsilon = \bar{d} - d_f \tag{1}$$

with $\bar{d}$: mean value of measured values
d_f : fixed distance

The standard deviation of one marker can be seen as the noise of the tracking system. The noise is separated for rotation and translation. For obtaining the translation noise the noise values along the x, y and z-axis is squared, added and afterwards the root is extracted.

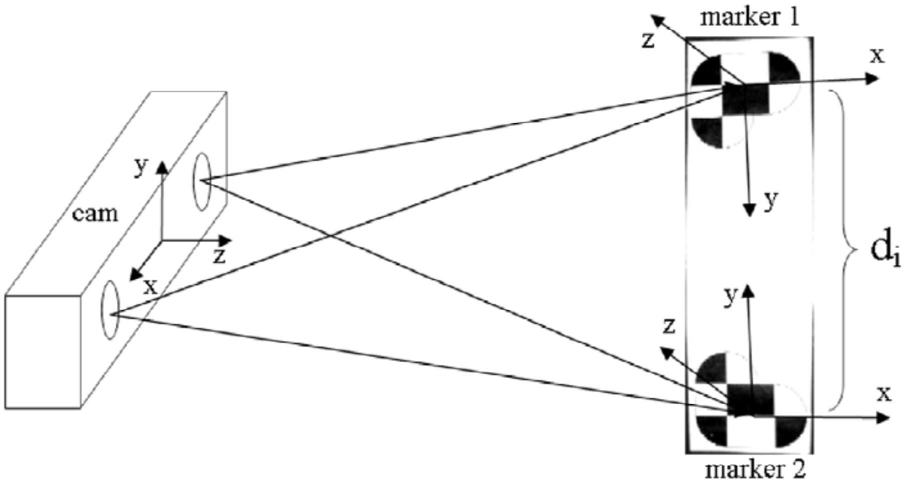


Fig. 4. Scheme of the experimental setup

Experiment 2: Taking the measurement data is based on the same approach as experiment 1. In first attempts the tracking system was not able to measure the positions of markers within the field of intense light (figure 5). Only after optimizing the shutter settings of the camera from MicronTracker system values were given.

a) b)

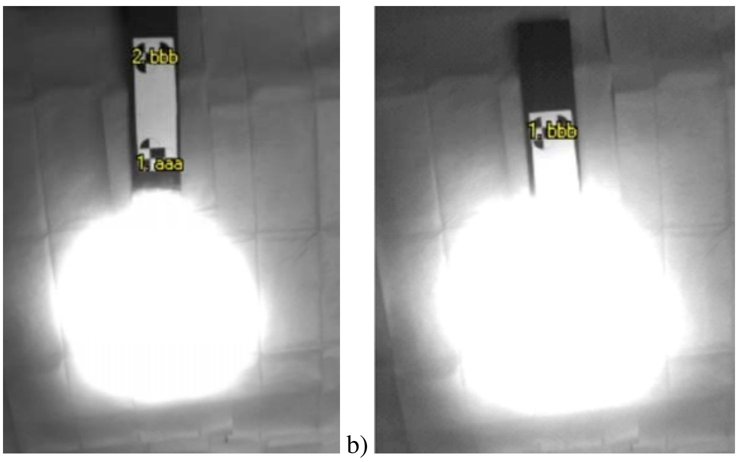


Fig. 5. Influence of intense light without optimized shutter settings. a) Both marks are recognized and b) the mark on the bottom cannot be recognized in the spot light.

3 Results and Discussion

The experiments have shown that the error between two measurement points rise by increasing camera distance (figure 6).

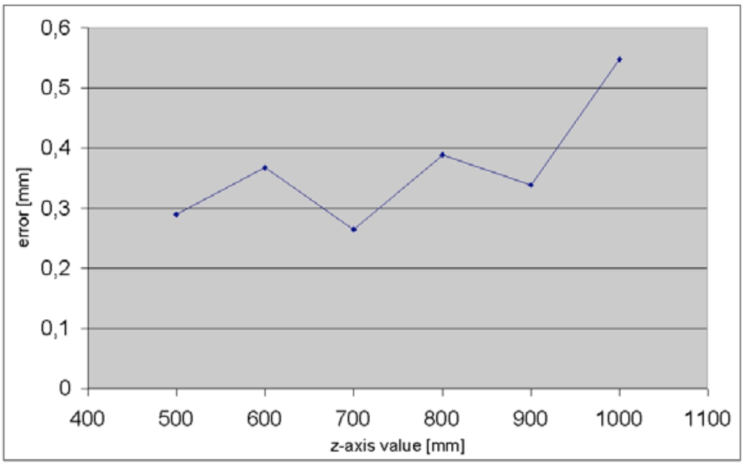


Fig. 6. Error over z-axis distance from tracking system to object

The work area along the camera to object axis (z-axis) is between 300 and 1500 mm. The mean error in the essential work area between 500 and 1000 mm is 0.36 mm with a standard deviation of 0.09 mm. Under influence of surgery light the mean error falls to 0.27 mm with a standard deviation of 0.13 mm. The better value given by intense light is to be studied further. One reason for this could be the shutter setting, which is optimized for the usage under intense light. With a new design of the localizer pattern the mean error under lamplight is reduced to 0.17 mm with a standard deviation of 0.08 mm.

This shows that the new design of the marker-object resulted in better error values. The noise of rotations around the three axes of all three experiments is nearly constant. Notable is the low noise around the z-axis. All results are summarized in the following table:

Table 1. Summarized results of measurements

	Error ε / σ (500-1000 mm) [mm]	Noise for:			
		Position [mm]	Rotation [Degree]		
			x-axis	y-axis	z-axis
Marker A no light	0.36 / 0.09	0.06	0.52	0.36	0.04
Marker A with light	0.27 / 0.13	0.07	0.31	0.36	0.04
Marker B with light	0.17 / 0.08	0.09	0.39	0.44	0.03

The maximum error is higher than the demanded error of 100 μm therefore it is absolute necessary to combine the tracking system with an accurate manipulator.

4 Acknowledgement

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