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Method, accuracy and limitation of computer interaction in the operating room by a navigated surgical instrument

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***Abstract* — This article describes a new interaction device for surgical navigation systems – the so-called navigation mouse system. The idea is to use a tracked instrument of a surgical navigation system like a pointer to control the software. The new interaction system extends existing navigation systems with a microcontroller-unit. The microcontroller-unit uses the existing communication line to extract the needed 3D-information of an instrument to calculate positions analogous to the PC mouse cursor and click events. These positions and events are used to manipulate the navigation system. In an experimental setup the reachable accuracy with the new mouse system is shown.**

I. Introduction

In modern operating rooms navigation systems have been used for more than 20 years to assist the surgeon to orient in the interior of the patient even under difficult or non-existent visibility conditions [1]. If the surgeon operates inside the body using surgical instruments, he needs information about the precise position and orientation of the instruments. The standard tools to see where the instruments are located within the body are microscopes and endoscopes. A navigation system can be used to visualize the relative position of the instruments according to preoperative image data such as CT/DVT or MRI data. Surgical navigation systems are computer-based assistance systems, consisting of a computer with monitor, a stereo camera and instruments with attached measurement markers [2]. Preoperative image data (usually CT data) are loaded into the navigation system. The measurement system, the stereo camera, is able to analyze the position of the measuring markers on the instruments. After a registration process, the position and orientation of the instruments can be displayed relatively to the image data. Thus, the distances can be measured or the surgeon can be warned if he comes too close to a risk structure.

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To work with a computer-based system like the navigation system the user has to interact with the graphical user interface of the software. Subsequent interactions need to be handled:

1) Loading of patient image data sets
2) Setting and shifting of landmarks (registration points) in the image data
3) Select menu items in the navigation software
4) Confirm commands
5) Measure anatomic structures in the patient data

The typical interaction concepts with today's navigation systems of the market leaders (Medtronic, BrainLAB, B. Braun Melsungen, Aesculap, GE Healthcare, KARL STORZ Endoskope, RoboDent) are:

Indirect interaction: The systems are manipulated by instructing the interactions to non-sterile surgical staff [3].

Keyboard and mouse: For a long time, navigation systems have been controlled by a keyboard covered with a sterile bag and a mouse cleaned by a disinfectant wipe. The keyboard is most appropriate for writing strings. The mouse is one of the most established and best input devices for the two-dimensional interaction with software interfaces.

Touchscreen: Many of the current systems use touchscreens. These are covered with a sterile bag. Thus, the surgeon can work with the system in the range of his arms. One example is the *Navigation Panel Unit (NPU)* of the company KARL STORZ [4].

FESS-Frame: This product sold by Medtronic uses a navigated board which allows the interaction of medical navigation systems. This approach was demonstrated in 1997 in [5]. Here, a control board with various control icons is used. The board itself, which is extended with measurement markers, is tracked by the navigation camera. By this means, the position of the board and thus the position of the icon on the board are known in space. If the control board is affected by a navigated instrument on the surface, the pre-defined action according to the touched icon which is labeled on the board is executed.

Voicecontrol: Another approach is the interaction by voice control as described in [6]. A headset is used for this interaction. The speaker navigates with pre-defined voice commands through the menus of the software. The possible voice commands are visualized by the software on a monitor to provide a visual feedback on the selection. A commercially available product is *VOICE1*® by KARL STORZ. It translates the voice commands and puts them on

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a bus, the so-called *SCB* (StorzCommunicationBus).

Gesture recognition: A gesture recognition system for the OR interprets gestures [7-9]. These gestures can control the user interface of the software.

WiiMote: In current research projects, systems are known as described in [10] and [11]. In one project, a *WiiMote* is used for interaction purposes with the *IPA* (*Intraoperative Planning Assistant*). The *WiiMote* is a wireless bluetooth pointing device intended for controlling the *Wii*, the gaming console by Nintendo. The *WiiMote* uses an optical sensor as well as an acceleration sensor for motion analysis. This *WiiMote* is read directly into the *IPA* system without using the Wii console itself. The *IPA*-system interprets the motion information of the *WiiMote*. So the *WiiMote* can be used for interaction with the system as a pointing device.

These approaches are still facing some problems. In case of interaction with a computer mouse and keyboard it is a problem to find a suitable underlay within the range of the surgeon.

The use of the touch screen is complicated by the sterile cover [7]. The image quality of the screen is affected due to the lesser transparency of the bag. To interact with a touch screen it must be located within the range of the surgeons. This is not always possible due to shortage of space in the operating room.

When using the FESS-frame, the board is required as an additional tracked instrument. Moreover, the board has to be sterilized.

An indirect interaction by instructing the OR-team can be afflicted with errors and delays [3].

According to the gesture recognition approach [7-9] the currently used instrument must be set aside and the arm must be lifted to achieve the desired action. This system also requires an installation of another camera for gesture recognition in the operating room.

In case of using the *WiiMote* according to [10] and [11] the target monitor must be upgraded with a sensorbar, an array of infrared LEDs. Thus, the visualization and interaction is linked to this monitor. Moreover, additional software must be installed on the target system.

This article describes an accuracy study with a new interaction system for surgical navigation systems which uses an already existing instrument for interaction. This instrument is often used during the surgery. The interaction with the navigation system can directly be carried out by the surgeon himself without any additional instruments. The system is an external, small (about 8 cm × 5 cm × 4 cm) controller based stand-alone module. One advantage is that the original software running on the navigation system does not have to be changed. Another advantage is that this instrument is a purchased part of the navigation system. Thus, the sterilizability of the instruments is assured by the manufacturer. To ensure the usability it should be possible to click buttons on the screen. Therefore, the new interaction system is experimentally compared with a touch screen.

II. Material And Methods

A new interaction device (*NMS – navigated mouse system*) for navigation systems and accuracy study are presented in the subsequent sections.

A. The navigation system upgraded with the new interaction system

The new system uses a commercially available navigation system as described by [4]. Fig. 1 shows the typical schematic structure of a navigation system. This navigation system uses a PC as a navigation computer. The graphical user interface is displayed on a monitor. This navigation computer is connected to the navigation camera by a communication cable. There are several tracked instruments available for the navigation system. The position and orientation of these instruments can be tracked via the attached measurement markers. The information of position and orientation is transferred to the navigation computer via a communication cable. An input device is connected to the navigation computer. Mice or touchscreens are typical input devices for navigation systems.

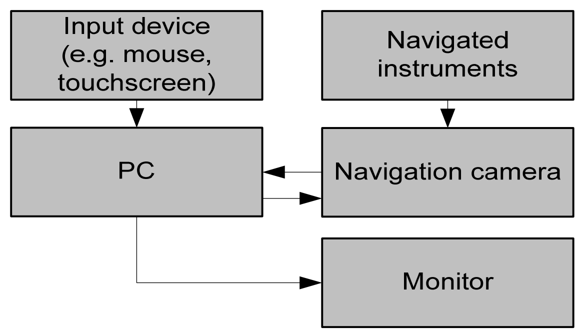

Fig. 1: Schematic structure of a surgical navigation system

The new input device is integrated into the navigation system as a module instead of or in addition to the normal input device (Fig. 2). Therefore, a further processing unit, a processor, is connected to the communication line between the navigation computer and navigation camera. This processing unit can listen to the communication of the navigation camera and the navigation system. However, the processing unit is also able to write data to the camera. Thus, the camera can be initialized by the controller-unit, and the camera can be used for interaction before the navigation is started on the navigation computer. The unit features, alongside the interfaces for the communication line to the camera and to the navigation computer, an additional interface for transmitting mouse data to the navigation computer. This additional interface is a HID-conform USB-connection. An advantage of the USB-HID is that this is a standardized plug'n'play interface, which does not need any software changes. For this work the *NMS* is connected to the navigation system for interaction. However, the USB-interface could also be connected to any other computer-based system for interaction. For the new interaction method a tracked instrument is used. This tracked instrument is an elongated pointing instrument, the probe, with three attached measurement markers in a predefined geometry. The probe is an already existing instrument which is always used for a navigated surgery. Its usual use is to match the anatomic surface of the patient with the CT-data and to check intraoperative the progress of preoperative planed surgery.

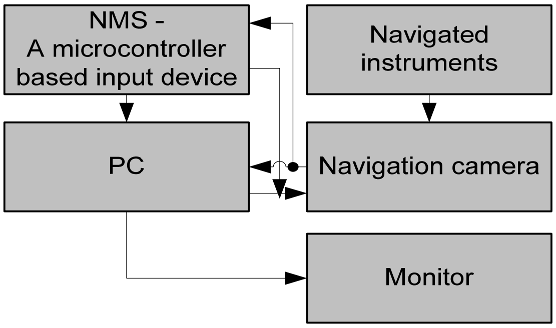

Fig. 2: Schematic structure of the navigated mouse system integrated in the navigation system

The graphical user interface of the navigation system is visualized on a monitor. In navigation mode the instruments which are located in the field of view of the camera can be tracked. The navigation camera recognizes the pre-defined geometry of the measurement markers of the probe and calculates the 3D-position and orientation of the instrument. The 3D-information is transferred in form of a quaternion and a translation vector to the navigation computer. This quaternion and the translation vector are also available for the processor unit which is listening on the communication line. This quaternion and the translation vector are transformed into homogeneous coordinates. If certain markers can not be associated with any instrument geometry, these are transmitted as pure translation vectors in the camera coordinate system, the so-called *stray markers*. For example, if one of the markers of an instrument is hidden (Fig. 3) the geometry cannot be detected. So the remaining markers are transferred as *stray markers*.

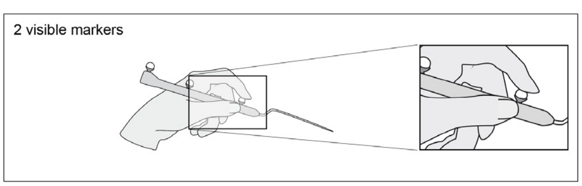

Fig. 3: Two visible measure markers, one hidden measure marker

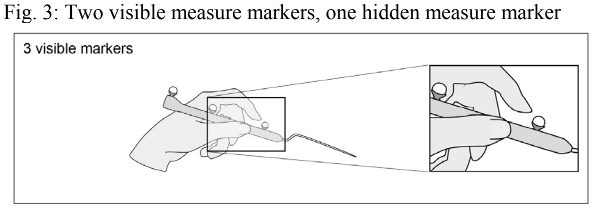

Fig. 4: Three visible measure markers

This feature uses the *NMS* to control the cursor on the navigation computer with a tracked instrument. In detail, the *NMS* uses the two stray vectors of the probe for calculating cursor information. If the distance of the two remaining markers is 58 mm ± 1 mm the *NMS* identifies that the first measure marker is hidden by the surgeon and works in mouse mode. In the mouse mode the cursor can be controlled by pointing with the probe in direction to the camera (Fig. 6). The two markers span a line which subtends a vertical virtual pointing plane through the navigation camera. The cursor information and click events are transferred via the additional interface to the navigation computer. To trigger a click event by the *NMS* the hidden measurement marker must be visible (Fig. 4) for a short time (Fig. 5). Then the marker must be hidden within a defined time interval Δt. Conditions for Δt to trigger a click:

$\Delta t < 0.2$ s : the *NMS* remains in mouse mode
1.0s > Δt > 0.,2 s : a click is triggered
$\Delta t > 1.0$ s : the probe is used in navigation mode

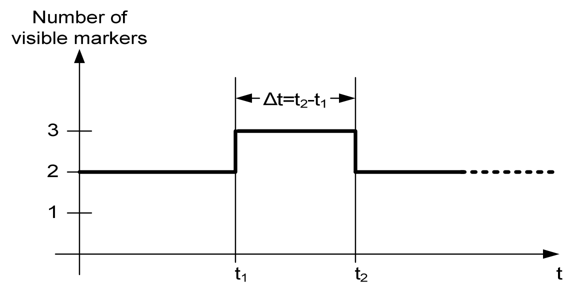

Fig. 5: Triggering a click event

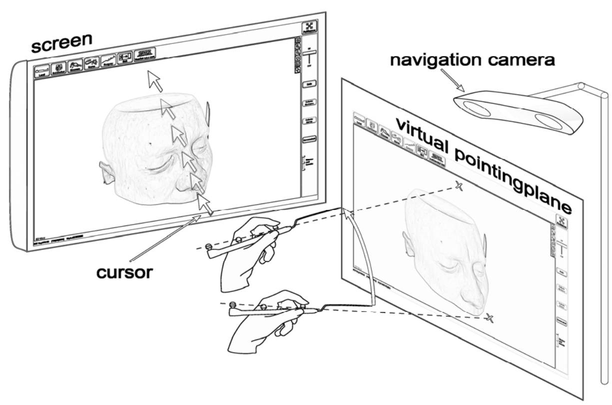

Fig. 6: Coupling of probe motion with cursor motion

B. Description of the measurement method

To ensure the usability of the *NMS* test persons have to click 20 buttons using the new input device. The button size is 3% of the horizontal/vertical screen resolution. The buttons appear in a defined order, so that every test person encounters the same conditions. In order to have the possibility to compare the results the measurements are also executed with a touch screen (screen size: 12.1'', resolution: XGA).

III. Results

The results of seven test persons (N=7) who accomplished the experiment are presented in the subsequent section.

The mean fail clicks generated with the touch screen:

$\bar{k}_{fail/touch} = 2.43$

The standard deviation of the fail clicks generated with the touch screen:

$s_{k_{fail/touch}} = 2.51$

The mean fail clicks generated with *NMS*:

$\bar{k}_{fail/NMS} = 2.00$

The standard deviation of fail clicks generated with *NMS*:

$s_{k_{fail/touch}} = 0.58$

Mean time for clicking 20 buttons with the touch screen:

$\bar{t}_{touch} = 26.40\,\text{sec}$

The standard deviation of the time using a touch screen:

$s_{t_{touch}} = 4.61\,\text{sec}$

Mean time for clicking 20 buttons with *NMS*:

$\bar{t}_{NMS} = 75.31\,\text{sec}$

The standard deviation of the time using *NMS*:

$s_{t_{NMS}} = 15.99\,\text{sec}$.

According to these results the failure rate of clicking a button using *NMS* is:

$$rate_{fail,NMS} = \frac{k_{fail,NMS}}{n_{button}} = \frac{2}{20} = 10\%$$

The time it takes to click one button is:

$$\Delta t_{button,NMS} = \frac{\bar{t}_{NMS}}{n_{button}} = \frac{75{,}31\,\text{sec}}{20} = 3.7\,\text{sec}$$

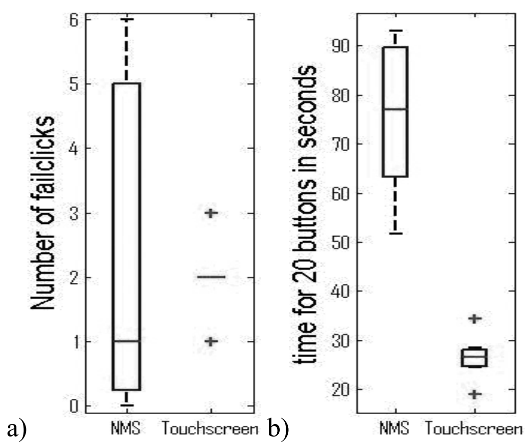

Fig. 7: Results of N=7 test persons in boxplots: a) Number of fail clicks over the 20 Buttons, b) time elapsed to click all 20 buttons

The results of the experiment, carried out with seven test persons, are illustrated Fig. 7 in form of boxplot-diagrams. Fig. 7a) shows the number of fail clicks the test persons produced when trying to click 20 buttons. The median of the failclicks with the *NMS* is even lower than the median of touchscreen. But the range of upper quartile of the *NMS* interaction is higher. This means 50% of the attempts to click a button succeeded with the first try. The other 50% took up to 6 tries. This can be traced back to line-of-sight-problems (LOS). The user hides with his hand the second marker, when the probe is in an acute angel to the pointing plane. Fail clicks are accidentally triggered when trying to align the probe in an appropriate angle. Fig. 7b) shows the time it takes to click all 20 buttons. The interaction with the *NMS* takes longer than with the touch screen. The bigger spread of the interaction time of the *NMS* can also be traced back to the LOS problem.

IV. Discussion

With the *NMS* it is possible to interact with a navigation system with the already existing instruments and without any software changes in the navigation computer. The usability of the new interaction system is shown in an experiment. All seven test persons together clicked 140 buttons on the whole. With the *NMS* even less failure is carried out than with a touch screen. A clinical evaluation can give information on how the *NMS* can be integrated in the surgical workflow and on how the workflow is optimized by the *NMS*.

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References

[1] R. Mösges and G. Schlöndorff, “A new imaging method for intraoperative therapy control in skull-base surgery,” *Neurosur*g. Rev. 11 (1988), pp.245-247, 1988

[2] G. Strauss, E. Limpert, M. Strauss, M. Hofer, E. Dittrich, S. Nowatschin, T. Lüth, “Evaluation of a dailyused navigation system for FESS,” Laryngorhinootologie. 2009, 88(12):776-81, 2009

[3] C. Christian, M. Gustafson, E. Roth, T. Sheridan, T. Gandhi, K. Dwyer, M. Zinner, M. Dierks, “A prospective study of patient safety in the operating room,” *Surgery*: Vol. 139, Issue 2, pp. 159-173, February 2006

[4] M. Strauss, S. Stopp, K. Koulechov, T. Lueth, “A novel miniaturized system for ENT surgery and its first clinical application,” Journal of Computer Assisted Radiology and Surgery, *Int J CARS* 1: 487-515, p: 503, 2006

[5] H. Visarius, J. Gong, C. Scheer, S. Haralamb, LP. Nolte. “Man&Machine Interfaces in Computer Assisted Surgery,” *Computer Aided Surgery*, Vol. 2, Issue 2, pp. 102-107, 1997

[6] A. Schafmayer, D. Lehmann-Beckow, M. Holzner, „Process-optimized operating room. Implementation of an integrated OR system into clinical routine,” *Electromedica*, Vol. 68, Issue 2, pp. 83-87, 2000

[7] P. Chojecki and U. Leiner, “Touchless Gesture-Interaction in the Operating Room,” *i-com*: *Mensch-Computer-Interaktion im Operationssaal,* 05/2009 Vol. 8, Issue 1, pp. 13-18, 2009

[8] J. Penne, S. Soutschek, M. Stürmer, C. Schaller, S. Placht, J. Kornhuber, J. Hornegger, “Touchscreen without Touch – Touchless 3D Gesture Interaction for the Operation Room,” *i-com*: *Mensch-Computer-Interaktion im Operationssaal,* 05/2009 Vol. 8, Issue 1, pp. 19-23, 2009

[9] C. Grätzel, T. Fong, S. Grange, C. Baur, “A non-contact mouse for surgeon-computerinteraction,” *Technol Health Care*, 12(3), pp. 245-257, 2004

[10] C. Hansen, A. Köhn, S. Schlichting, F. Weiler, S. Zidowitz, M. Kleemann, H.-O. Peitgen, “Intraoperative Modification of Resection Plans for Liver Surgery,” *Int J CARS* 3, pp. 291-297, 2008

[11] F. Ritter, C. Hansen, K. Wilkens, A. Koehn, H.-O. Peitgen, “User Interfaces for Direct Interaction with 3D Planning Data in the Operating Room,” *i-com*: *Mensch-Computer-Interaktion im Operationssaal,* 05/2009 Vol. 8, Issue 1, pp. 24-31, 2009