

Contactless Operating Table Control based on 3D Image Processing

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Abstract—Interaction with mobile consumer devices leads to a higher acceptance and affinity of persons to natural user interfaces and perceptual interaction possibilities. New interaction modalities become accessible and are capable to improve human machine interaction even in complex and high risk environments, like the operation room. Here, manifold medical disciplines cause a great variety of procedures and thus staff and equipment. One universal challenge is to meet the sterility requirements, for which common contact-afflicted remote interfaces always pose a potential risk causing a hazard for the process. The proposed operating table control system overcomes this process risk and thus improves the system usability significantly. The 3D sensor system, the Microsoft Kinect, captures the motion of the user, allowing a touchless manipulation of an operating table. Three gestures enable the user to select, activate and manipulate all segments of the motorised system in a safe and intuitive way. The gesture dynamics are synchronised with the table movement. In a usability study, 15 participants evaluated the system with a system usability score by Broke of 79. This states a high potential for implementation and acceptance in interventional environments. In the near future, even processes with higher risks could be controlled with the proposed interface, while interfaces become safer and more direct.

I. INTRODUCTION

Operating rooms(OR) are high technology working environments used for advanced therapeutic and diagnostic applications. New equipment is introduced to support surgical techniques providing better patient care. This increases the variety and complexity of surgical procedures as well as of human machine interfaces. The interaction between the staff and the technical equipment becomes more and more relevant, due to an increasing quantity of critical functions, which are carried out by the equipment. It appears that people are forced to learn and train on a variety of interfaces, which can be challenging and threatening in terms of the cognitive burden. This tends to be a negative influence on the workload and ergonomics [1], [2]. One elementary component of an equipped OR is the operating table(OR table), on which this paper focuses on. OR tables are complex modular systems, which are capable of an individual positioning of patients. The position must suite the



Fig. 1. OR- Scene example: OKM Markgroeningen¹

patient, the surgery and the employees. This not only ensures a safe and efficient operation, but also better workplace ergonomics for the surgeons. To utilize the OR table in the best way, an intuitive and natural control is desirable. For the most sophisticated technology currently available, OR table interfaces consist of a wireless remote control with pressure sensitive buttons. Each motion function of a table segment is accessible by a associated button on a remote control, described by pictograms. Besides the interpretation of the pictograms, the user is forced to get access to the remote control and to touch the surface, which may lead to problems in terms of sterility. To overcome those problems in daily routines, surgical nurses and anesthesiologists are often trained and responsible to interact with the system. Hence the interaction for the surgeon with the OR table system is better described as a human - human(surgeon - anesthesiologist) interaction, rather than a human - machine interaction. The human - human interaction process is by nature prone to misinterpretation and ineffectiveness. This should be avoided especially in complex and high risk environments like the OR. Our approach is to create a discrete interaction space, in which the user, e.g. the surgeon, is given a cognition based, intelligent, human - machine interface. The approach is generic to common electrically driven OR tables. Design goals for the interface are efficiency, effectiveness and a natural interaction.

II. RELATED WORK

Direct and natural user interfaces include e.g. touch screens, brain machines and gesture- or voice control interfaces [3]. A direct interface e.g. is a voice control interface,

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by only saying commands without using a keyboard or any other helping device to communicate. It is also natural, as the vocabulary set learned and trained in human - human interaction is utilized. These interfaces are easy to learn and to handle. Gesture based natural interfaces are grouped in touchscreen- and free-form interaction [4]. These interactions are realized by detecting body poses and movements [3].

Natural user interfaces based on touch interfaces receive greater significance, as they are often implemented in a conjunction with graphical interfaces (GUI), which allow requesting and navigating through patient information during the surgery. In most applications [5] the sterility of the user can only be guaranteed by applying foil drapes to cover the touch screens. Hence, the visual impression of a GUI suffers. Free form interaction becomes more suitable by evaluating OR scenes in RGB-Depth sensor data. Most favoured is the RGBD-sensor Microsoft Kinect [6]. Applications range from navigating through images [5] to object interaction [7].

"A movement of a part of the body [...] to express an idea or meaning"² is a broad definition of a gesture and includes different influences as personal execution [8], [9] and cultural habits [10], which can transform a gesture in terms of meaning and design. In the development of a natural user interface, gestures can be categorized by context, function, usability, conjunction with speech or intention [10], [11]. The usability is strongly dependent on either the gesture is known or has to be learned. A more technical approach to group gestures is to describe the temporal appearance as static and dynamic [4]. The dynamic gesture is a set of sequenced static gestures.

The usability of interfaces is described by different standards [12], which focus on efficiency, effectiveness and user satisfaction. These aspects are taken into specific account according to the context and processes to support. Standards for the usability evaluation of medical products and development processes focus especially on system integrity and safety [13], [14].

III. SYSTEM OVERVIEW

A. Sensor

For a touchless interaction with an OR table an appropriate sensor for motion capturing is needed. In this application the Microsoft Kinect is chosen. The Microsoft Kinect is a 3D sensing camera released by the Microsoft Cooperation. It was developed for the gaming industry but found broad usage in other applications. The sensor system includes a microphone array a RGB-camera and a depth sensor, consisting of an infrared (IR) laser projector and an IR camera. The range of the depth camera³ is between 400 mm - 4000 mm. The depth information is gained by the principle of structured light. Compared to other depth sensors, it provides sufficient depth and image resolution for the shown approach.

²Oxford Dictionaries <http://oxforddictionaries.com/definition/english/gesture>

³Microsoft Corporation <http://msdn.microsoft.com/en-us/library>

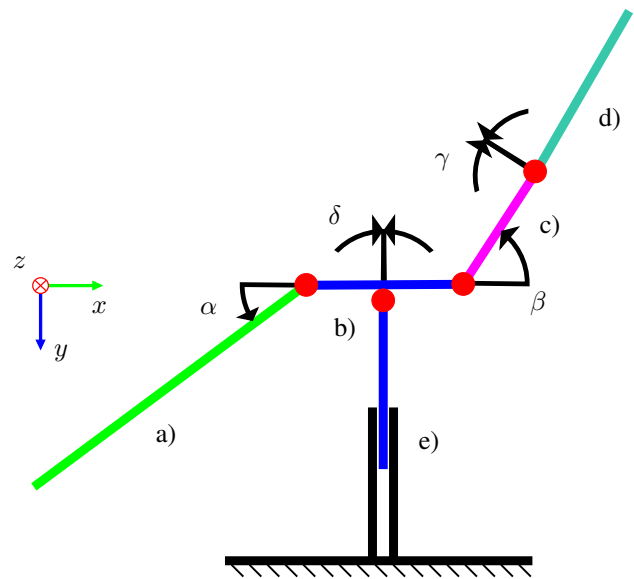


Fig. 2. Kinematic model of the OR table: a) leg-, b) hip-, c) back-, d) head- segment, e) column

B. Operating table

As visible in figure 1, the OR table is a central element within the operating room. The field of work and activity during a surgery consists of the patient and the staff around the table.

At present, common OR tables are controlled by a remote control with pressure sensitive buttons. It has the significant disadvantage that it can not be used readily by the sterile employees in the operating room, because it is not an sterile working equipment. It has to be covered with a sterile foil in beforehand, which increases the setup time. In practice the foil can smear during surgery and therefore worsens the functionality, impairing the haptic and visual feedback.

The OR table, TruSystem 7500 of the manufacturer TRUMPF Medizin Systeme GmbH, is described by a kinematic model, consisting of the pillar-, leg-, hip-, back- and head- segment. These segments are stiff and differ in dimension and degrees of freedom. As shown in figure 2 the pillar is the base segment and the first segment in the kinematic chain. The mechanic chain is characterized by electromotive joints. The pillar has one degree of freedom (DOF), a translation in y-axis, and is connected to the hip segment in a rotational joint (δ) around the z- axis. The following joints connecting leg, hip and back segment, are all rotational joints (α, β, γ) around the z- axis. To reduce the complexity of the real system, one electromotive joint at the head segment is not implemented. Also complex movements within the pillar and hip- segment joint, partial due to a electromotive tripod, are reduced to one DOF, the rotation around the z- axis.

IV. GESTURE INTERFACE

The OR table is controlled while standing directly in front of it facing the column. It is manipulated according to the

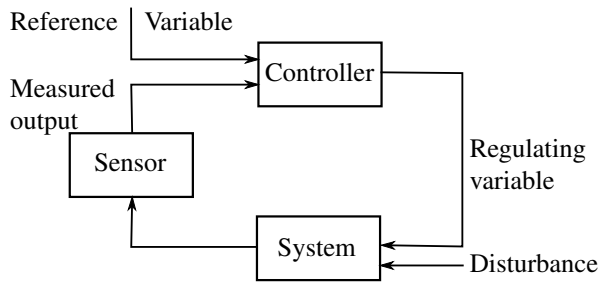


Fig. 3. Reference control circuit of the OR table interface

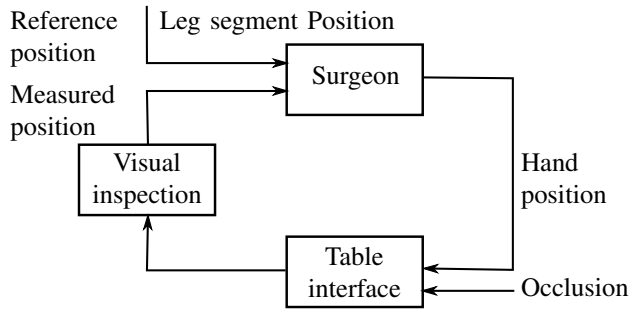


Fig. 4. Control circuit of the OR table interface: Manipulation of the OR table by hand gesture

user's hand movements. The control interface consists of the table movement functions and adequate gestures. For a better usage of the interface the user is provided with graphical feedback.

A. Control

The manipulation process of the OR table can be described in a control circuit, see figure 3 and 4. Assuming a surgeon's intention to set a new leg segment position, the actual hand position within a gesture would be the regulating variable for the OR table system and the interface. The interface includes the actuator and the sensor system as well as the motion tracking system (RGBD-sensor) and the graphical user interface. Negative effects on the motion tracking system are scene occlusions and bright ambient light conditions in the interaction space, which cause inaccurate or invalid depth information. Visual inspection of the new OR table position enables the surgeon to compare the target position with the actual position. In human machine interaction, the description of the controlled system dynamics is an important task. Often the user assumes a system response behavior, which is significantly different from the real system dynamics. The motorized OR table shown here is limited in the system dynamics due to actuator speeds and delay in the communication interfaces. Therefore, the user is forced to adapt to the system. One approach of an adaptive control design is to overcome the gap between the gesture- and system dynamics. The first two system response modes can be selected. One for precise point to point motions, in which the gestures start and end position are relative to the OR table. In the second response mode, direction and value of the relative velocity gradient between the gesture and the

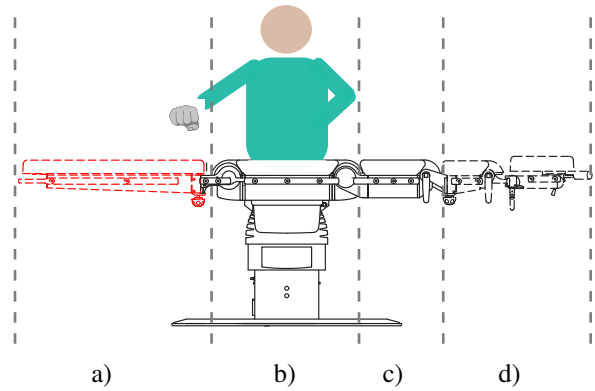


Fig. 5. Controlling of the OR table within the single segment mode. Selecting and moving a table segment. Interaction space for selection: a) leg-, b) hip-, c) back-, d) head- segment

OR table is evaluated. By measuring the gesture velocity a conversion factor adapts the system response. The adaption is not only suitable to achieve a better system usability, but also the specific application is taken into account, if precise movement or fast positioning is needed.

Functions: To navigate through the system, a variety of movement functions with several gestures is implemented. First of all the user is supposed to register to the system. The following two interaction modes are selectable: One for movement functions associated with one OR table segment and the other one for complex movement functions dependent on more than one segment. The single segment mode groups eight movement functions. For each segment two manipulation directions (see figure 5) are accessible with one hand. The multi segment mode groups six movement function. In the medical field well known functions within these are Trendelenburg- and Flex- movement. All functions are accessible with two hands. Over all, the following functions are needed: sign on and sign off, select segment mode, select and manipulate a motion unit.

B. Gesture setup

The usage of gestures is an intuitive way to interact with the environment. Intuitive, because the user is familiar to communicate with other people by means of gestures. Hence, in order to interpret and perform a gesture, the cognitive requirements are low. To imitate this communication, gestures have been chosen to give a natural impression while interacting with a system. It also helps the user to overcome the initial fear to interact and to learn new interaction possibilities. The choice of the right gesture set is a highly important task. The capability of the interface is strong related to the imitation of human to human communication.

1) *Register (Wave, figure 6):* A problem with gesture control is the so called "live mic" problem, this means the system is always watching the user and it is hard to separate gestures meant for the system and those which are not [3]. This tends to be one of the most addressed safety concerns related to gesture interfaces. Therefore, a distinct

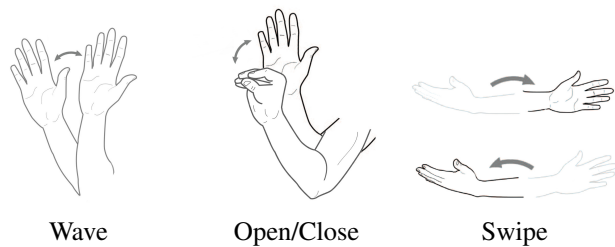


Fig. 6. Gestures⁴for the control interface

and uncommon gesture in the operating room is needed to activate the control. To activate and inactivate the system the waving gesture was chosen. Waving is a natural way for saying hello or goodbye and it is well distinguishable in the operating room. According to Saffer, it is a gesture typically applied for the use of activating a system [4]. Besides a registration gesture other interface modalities should be taken into consideration e.g. audio, increasing the interaction safety.

2) *Select and move (Grip)*: To manipulate a segment of the OR table the related motion function needs to be selected. Assuming the user is interacting within the single segment mode intending to manipulate the leg segment, gripping the segment and manipulate it by muscle power, would be most intuitive. Gripping is a way in which people pick up things or move them. Saffer describes the clenching of one's fist as a gesture to pick up digital objects in gesture based applications [4]. Moving the OR table units by the use of the interface is realized in the same way except that the user does not touch the object directly. The user grips in interaction space with a small offset above the segment, see figure 5. The interaction space size is fixed to the OR table size and does not change during the interaction. Once an object or unit is selected, it follows the movement of the hand. By leaving the interaction space the unit is deselected and stopped. After 10 seconds without selecting a segment, the user is also unregistered and no interaction is possible. As described above, the implemented interaction spaces support the interaction safety.

3) *Switch mode (Swipe)*: For switching between one-handed and two-handed gesture control mode, the user swipes horizontal, see figure 6. The activated mode is illustrated on the graphical user interface, see figure 7 e), f).

C. User feedback

The user is given feedback by a GUI, see figure 7. The laboratory scene is exemplary, however the system would have no restriction against an OR environment with e.g. complex backgrounds. The dialogue text and visual feedback helps navigating through the system, especially when it comes to the one and two handed mode, which are either way highlighted appropriately. Furthermore, the user is given feedback about the status of the user registration, each hand and each function activated. This way the user has all knowledge about his actions and can follow the events.

⁴CoVii <http://wiki.viim.pt>

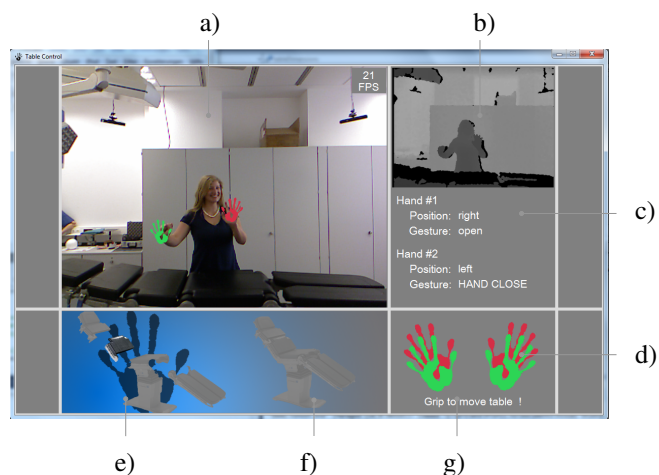


Fig. 7. Graphical User Interface: a) RGB-image, b) Depth-image, c) Text information, d) System state, e) One handed mode, f) Two handed mode, g) Interaction request.

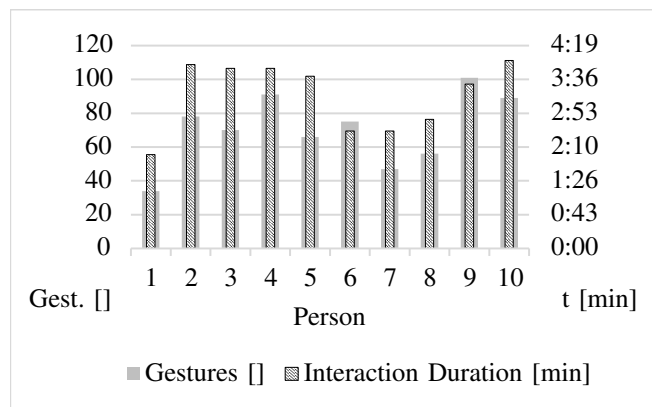


Fig. 8. The interaction test of the usability study shows the efficiency in the positioning process indicated by the total count of hand open - close gesture and the required time

V. EXPERIMENTS

The implementation of a touchless OR table control interface by 3D image processing was shown in this paper. To evaluate the system in daily routines of patient positioning, a usability study with 10 persons provides results to describe the interface in effectiveness, efficiency and user satisfaction. In a test case, the participants have to manipulate the OR table from a start position, see figure 5 to a given end position, see figure 2 with approximately $\alpha = 30^\circ$, $\beta = 45^\circ$, $\gamma = 30^\circ$, $\delta = 10^\circ$.

In terms of efficiency of the positioning process, the error-prone hand open - close gesture recognition hindered the user while manipulating the OR table. The total count of gestures necessary to position the OR table varies from 32 to 100. The required time to complete the positioning process correlates, see figure 8. It needs to be rated against the interaction time for current interfaces.

The effectiveness should be influenced by changes in the gesture detection error rate and be related to the system usability score (SUS) by Brooke [15]. Contrary to the

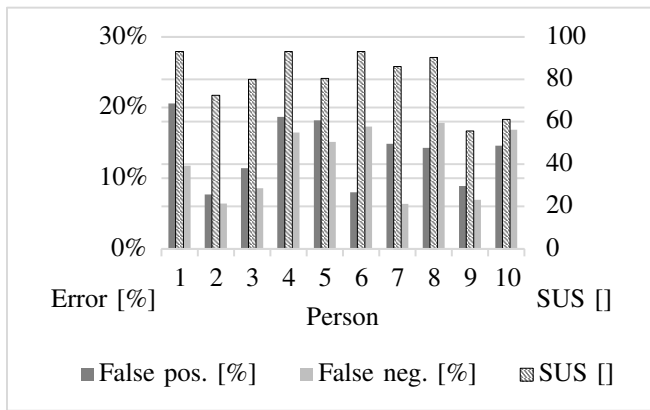


Fig. 9. The interaction test of the usability study shows the user satisfaction indicated by SUS and the effectiveness indicated by error rate



Fig. 10. Multiple people positioned between user and sensor system. Sensor viewpoint of the occluded user.

assumption that the interacting person has a strong interest to work with an effective interface in comparison to the common remote control interface, a correlation between this two values can not be shown, see figure 9. This indicates that within the SUS more user experience related aspects are weighted and displayed. The SUS is determined by a survey with 18 questions per person. The average detection percentage of false negatives and false positives is approximately 12 % each. Most of them are caused by the error-prone recognition of the hand open and close gesture. Even though the process was interrupted by the partially wrong gestures recognition, the system gained an average SUS of 79. According to Brooke this is equivalent to grade B interfaces and an above-average rating [16]. This are promising results for integrating this interface in real OR setups, overcoming interactions hazards caused by changing habits and modalities.

Tests with multiple people disturbing the interaction zone showed that the usage of the system is negatively effected. Problems occurred due to an error-prone gesture recognition and obstruction by other people in the interaction zone, see

figure 10. When people are positioned on the other side of the OR table, between the camera and the user, both the user's view on the GUI and the camera's view on the scenario is blocked. A further evaluation revealed that wearing operating room clothes while using the system does not influence the handling of the system. The wearing of typical clothes, like a tunic or a surgical gown with surgical gloves and pants, was tested.

VI. CONCLUSIONS AND FUTURE WORK

The OR table control system developed in this work, allows the user to manipulate all motion units in a touchless fashion. In first tests the system achieved promising results. The interaction safety was addressed by implementing an authorisation gesture and interaction zones. However, problems occurred due to an error-prone gesture recognition and obstruction by other people in the interaction zone. A more robust and more precise gesture recognition would be possible with the usage of sensors with a higher resolution. Furthermore, the setup of a camera-array would overcome problems with the obstruction by other people. At this stage of development, the system does not seem to be integrable in an OR environment.

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