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Contactless Surgery Light Control based on 3D Gesture Recognition

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Abstract

Surgery lighting systems (SLS) aim to provide optimal lighting conditions for the surgeon in an operating room. To visually differentiate between only marginally different looking tissues, SLS offer settings for the level of illumination, color temperature and size of the illuminated field. By today's standards, SLS are controlled with control panels that are situated at the lamp housings. The operation of the control panel is handled in an ergonomically unfavorable position with the hands above the operator's head. On top, the region above the operator's shoulder is considered as not sterile and causes a potential safety risk. To secure asepsis, it is required to extensively sterilize all equipment that the operator comes in contact with.

In this paper, a contactless gesture control for a SLS is developed with the intention to offer the surgeon a sterile and ergonomically comfortable operation. A Microsoft Kinect 3D-sensor is used. The gesture control offers control of the level of illumination, the color temperature and functions of a camera for documentation requirements like zooming, rotating and taking a picture. A sophisticated procedure to logon and logoff the system prevents unintentional operation.

The gesture control system and the conventional control panel were tested and compared in a usability study. The participating subjects rated the usability of the gesture control to be *good* to *very good* according to the System Usability Scale by Broke. 94% of the subjects perceived the gesture control to be ergonomically more comfortable. After simultaneous operation of the surgery light and execution of a cognitive task, 82% stated that the gesture control is less likely to distract them from that task. This data indicates that the concept of a gesture control with a 3D-sensor for a SLS is feasible and that it has a potential to receive a high degree of acceptance.

1 Introduction

With a growing number of technical equipment in operating rooms, the complexity to control these devices increases. Surveys amongst nurses and surgeons indicate that current operating rooms are not designed in an optimal way and improvements, especially regarding the usability are sought-after [1–3].

Knulst et al. [1] evaluated the SLS use during 46 hours of surgery in 13 hospitals, and surveyed 98 OR-staff persons. There has been an interaction every 7.5 minutes, on average, with the SLS, although all interactions have been solely repositions of the SLS. Settings like the illumination level and color temperature have never been changed. However, 88% of the surveyed surgeons mentioned to have experienced problematic lighting during surgery. Besides the repositioning of the SLS, the most severe problems were the illumination of deep wounds, the reduction of shadows, and the optimal level of illumination. To the largest extend, it has been the surgeon himself who operated the SLS. This can be explained as the surgeon itself can evaluate the required lighting situation at best. In 97% of the situations when the surgeon is operating the SLS, he is engaged with the surgery during the same time. Knulst et al. [1] note that any distraction from the surgery by the operation of the SLS is not desirable. Especially, since the operation of the SLS is handled in an ergonomically unfavorable position with the hands above the surgeon's head (see Figure 1).

Figure 1: Typical scene in an operating room: The OP-staff personal has to reach up to a control panel to adjust the SLS.*

U. Matern et al. [3] surveyed 425 surgeons and 190 nurses on their working conditions in an operating room. Their results show that 70% of the surgeons and 49% of the nurses have difficulties operating medical devices in a surgery room. 59% of the surgeons and 40% of the nurses indicated, that they do not feel sufficiently trained for using these devices. Ergonomic shortcomings emerge mostly at the use of SLS, but also with other devices such as surgery room tables. U. Matern et al. [3] state, that over 90% of the devices in a surgery room are stand-alone devices and directly controlled at their housings.

In summary, there are two major desires for the operation of SLS. Firstly, the surgeons operate the SLS themselves and thus need sterile interaction possibilities. The possibility to adjust the SLS should be solved in an ergonomic manner that the distraction from the surgery is kept to a minimum. Secondly, the operation of SLS should be *simple* and *intuitive*, to keep the education and training needs minimal and to increase interaction safety. Desirable is a "homogeneous operating philosophy in the sense of a system-surgery-room" [3] for all devices.

* Source: TRUMPF Medizin Systeme GmbH + Co. KG

Natural User Interfaces, such as speech or gesture control [4], promise to offer intuitive human-machine interactions. We introduce a gesture control system, which aims to overcome many of the current shortcomings of conventional SLS controls. First, we describe the system setup consisting of the SLS and a 3D-sensor for gesture recognition. Second, the human-machine interface is introduced, describing the process to logon and logoff, the possible gestures to control the SLS, as well as different possibilities for giving feedback to the operator. In section 4, we describe how the system is evaluated in a usability study. Finally, the results are presented in section 5.

2 System Setup

The light control system consists of a TRUMPF Medical iLED5 SLS and a Microsoft Kinect for Windows version 1 depth sensor. The sensor is mounted on the housing of the SLS (see Figure 2). This ensures a free line of sight with no obstacles in between the sensor and the gesture performing hands of the operator, as it has been the problem with a sensor positioned at a wall or ceiling [5,6].

Figure 2: A 3D sensor is mounted on the lamp's housing, offering a free line of sight in between the sensor and the gesture performing hands. The yellow area indicates the operating range of the gesture control panel to adjust the SLS.†

2.1 Surgery Lighting System

The SLS provides the possibility to adjust the lighting situation to the needs of the operator. To offer the highest contrast for various tissues, the illuminance level and color temperature can be adjusted. A RGB-camera can be zoomed and rotated to take videos and pictures for documentation purposes. All controls are handled by turning and pressing a knob on a control panel that is part of the lights' housing (Figure 1). Reaching and looking up to the control panel requires the operator to interrupt his current task. Additionally, the adjustment takes place in an unfavorable ergonomic posture with the hand above the head. To operate the SLS within the sterile zone of an operating room, the knob can be taken off and sterilized in advance.

† Source: Modified from TRUMPF Medizin Systeme GmbH + Co. KG

2.2 3D Image Processing

The Microsoft Kinect for Windows‡ sensor is used to acquire depth information of the operator's hands. The sensor uses an active infrared illumination which caters for consistent depth acquisition independent of environmental illumination changes such as by the SLS. The hands are tracked with the help of 3Gear System's Nimble SDK§ (v0.9.36 beta), which provides information about the hands' position, orientation and the probability that one out of four predefined hand poses are performed. While the Kinect is specified to provide depth values for a range of 400 mm to 4000 mm in a 43° vertical by 57° horizontal field of view, our experiments show that the Nimble SDK recognizes hand poses best within a range of 650 mm to 1650 mm. The disability to recognize hand poses further away than 1650 mm is due to the decrease in spatial resolution with increasing distance to the sensor.

3 Human – Machine Interface

Gesture controls offer advantages over conventional controls with hardware buttons like a contactless and thus sterile control. There has therefore been research to implement gesture controls in several medical devices, especially for medical image visualization (e.g. [7,8]), but also for the positioning of operating room tables [6]. However, the use of gesture controls also introduces new difficulties. One difficulty is, that there is no haptic feedback, which has to be compensated by other sources of feedback in order to inform the operator about the current state of the system [9]. Another difficulty is the *live mic* problem [9]. As a 3D sensor is always active and receiving data, there is no differentiation of the hardware between intended and unintended interaction of a user with the system. It is thus necessary to employ a logon and logoff process software wise.

3.1 Gesture Control

To logon to the system, we chose a *spread* pose (Figure 3a), which is easy to perform, but differentiates enough from the usual tasks of the hands during a surgery. All poses can be performed at any position or orientation within the field of view of the 3D sensor, as well as with either the left or the right hand. To further differentiate the logon pose from any unintentional *spread* poses (false positives), but also to include potentially not recognized *spread* poses (false negatives), it is required that the system successfully recognizes the *spread* pose for a total time of 0.5 seconds during a time span of 1 second. Therefore, the duration of the logon is between 0.5 and 1 seconds.

(a) system logon (b) illumination level (c) color temperature (d) camera control

Figure 3: The SLS can be controlled by four gestures. A *spread* pose (a), a *pointing* gesture (b), an *L* gesture (c), and an *OK* gesture (d).

‡ Microsoft Corporation (www.microsoft.com)
§ Formerly 3Gear System, now Nimble VR as part of Oculus (www.nimblevr.com)

When logged on to the system, there are three distinctive hand poses to control the illumination level (*pointing* pose), color temperature (*L* pose), and camera functions (*OK* pose) (Figure 3b-d). To lower the illumination level, the color temperature, or the zoom level of the camera, the corresponding pose has to be moved in a downward direction, and upwards for the opposite effect. Rotating the *OK* pose rotates the image of the camera in the corresponding direction. Additionally, moving out the hand of the field of view of the 3D sensor, while holding the *OK* pose, takes a picture with the camera. As the 3D sensor and the camera are both located in the SLS' housing, they are having a similar field of view. By moving the hand out of that field of view, any occlusion of the photographic subject by the hands is prevented.

Logoff occurs automatically when none of the four poses has been recognized for two seconds.

3.2 Feedback to the User

The operator can perceive whether a setting has been changed directly through the change of light in illumination or color temperature, or on a monitor for the camera. It is thus possible to control the SLS without turning the attention away from the center of interest. Acoustic feedback notifies the operator weather he is logged on or off to the system. Additionally, all current settings, including the logon status, are displayed on the control panel through LEDs.

A graphical user interface (GUI) assists users, who are not familiar with the gesture control system. It is purely intended for training purposes and returns feedback whether the hands are within the field of view of the 3D sensor, whether a gesture is recognized and the actual settings of the SLS. The GUI also displays which hand poses are available for each setting and how the gestures have to be performed to adjust these settings.

4 User Evaluation

A study with 17 subjects is performed to evaluate the usability of the gesture control system for the SLS in comparison with the control panel. 15 of the subjects are students of various backgrounds with no previous experience in using SLS. Two of the subjects have had experience with SLS, a medical assistant and a veterinarian. At first, each subject is introduced to the project and can get accustomed with each system until the subject feels comfortable and secure interacting with the systems (for six minutes each at most). Then, the subjects perform two usability tests; first they control the SLS with the control panel and second with the gesture control system. Subsequently, a survey is conducted to acquire a *System Usability Scale* after Brooks [10].

The intention of the first usability test is to examine the hypotheses that using the gesture control system causes less distraction from the surgery and that it offers an ergonomic operation. An Ishihara color plate no. 13[**] with 30mm diameter, usually intended to test for red-green color deficiencies, is placed inside the open abdomen of a manikin to simulate two visually difficult distinguishable tissues. The subject is asked to adjust the illumination level and color temperature to the subjective best settings to recognize the number of the color plate. Afterwards, the camera shall be rotated and zoomed, that the number is upright and fully displayed on a monitor and a picture must be taken. Finally, three questions of Table 1 are posed to evaluate the posed hypotheses.

[**] https://en.wikipedia.org/wiki/Ishihara_test

Using the control panel facilitates concentrating on the color plate in comparison to the gesture control.
I perceive the gesture control system to be more ergonomic than the control panel.
I could imagine adjusting the settings of the SLS more often during a surgery to achieve a better illumination using the gesture control system instead of the control panel.

Table 1: Questions of usability test one to be answered with: *I disagree, I rather disagree, neither, I rather agree* or *I agree.*

A second usability test further examines the hypotheses that the gesture control system causes less distraction from the surgery. To simulate a situation, where a surgeon is operating on a patient and the SLS simultaneously, the subjects have to play a cognitive challenging game[††] on a tablet PC - which is located on top of an operating table - while receiving commands to change the settings of the SLS. The goal of the game is to tap on 36 randomly arranged numbers in the correct ascending order. One correct number is one game point. Five seconds after starting the game, the subject has to change a certain setting of the SLS. When the setting is successfully changed, another instruction to change a setting is given after six seconds. In case the subject is not able to change a setting within five seconds, the subject is allowed to skip that instruction. When the last instruction is successfully completed, the required total time and the achieved game points are noted. There are eight instructions to control the illumination level or the color temperature and two instructions to control the camera. Additionally, all actions are recorded on video to analyze any occurring errors. Finally, two questions of Table 2 are posed.

The operation of the SLS with the gesture control system is less distracting from my main task (the game) than with the control panel.
I feel more relaxed during the operation with the control panel than with the gesture control system.

Table 2: Questions of usability test two to be answered with: *I disagree, I rather disagree, neither, I rather agree* or *I agree*.

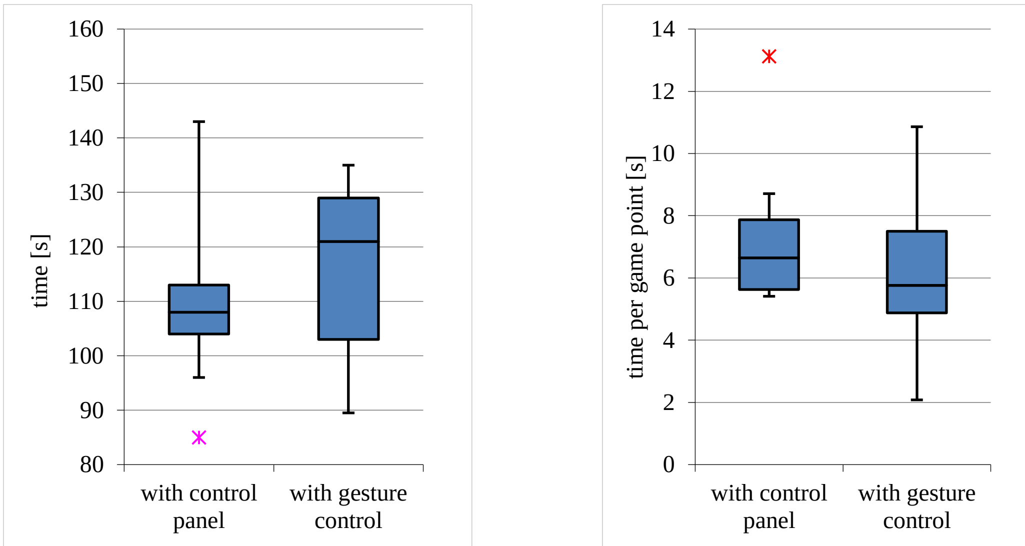
5 Results

The results of the user tests validate the posed hypotheses. All results compare the gesture control system with the control panel. In experiment one, 82% of the subjects agree or rather agree that the gesture control system allows them to better concentrate on the lit object. 94% agree or rather agree that the gesture control system is more ergonomic to use. The medical assistant remarks that the hand movements of the gesture control system in a free-to-choose height are very pleasant, especially for surgeons who often have to remain in a stiff posture for several hours. 87% agree or rather agree, that they could imagine using the implemented functions of the surgery light (e.g. color control) more often with a gesture control system.

When handling a cognitive task simultaneously in experiment two, 82% of the subjects agree or rather agree that the gesture control system causes less distraction of their primary task. In that context, 76% agree or rather agree that the gesture control system of the SLS feels also more relaxed. Several subjects remark positively, that the concentration on the cognitive task is not interrupted when using the gesture control system. When using the control panel, they had to interrupt their current task to look up to the control panel to change a setting, which caused them to lose orientation in the cognitive task. This better concentration on the cognitive task is also supported by the taken measurements. **Figure 4**a shows the required time to execute all instructions to control the SLS while

[††] ForzaVerita: Attention Test. Version 1.3. (https://play.google.com/store/apps/details?id=org.forzadroid.attentiontest)

performing the cognitive task. The subjects require on average 9% more time when using the gesture control system in place of the control panel. However, **Figure 4**b shows, that the subjects were able to acquire more game points during that time using the gesture control. The gesture control system is 11% more effective to complete a cognitive task simultaneously.



(a) (b)

Figure 4: The required time to finish the cognitive task (a). The required time per game point (b). Both measures were taken three times: First the cognitive task alone, then by additionally controlling the SLS with either the control panel or the gesture control system.

The effectiveness is decreased by a high error rate while operating the SLS, both for the control panel and for the gesture control system (**Figure 5**). However, the types of errors differ between the two systems. Operating errors (12.3%) are the only errors for the control panel. An error is considered an operating error, when the SLS reacts correctly to the input of the subject, but the intention of the subject is not achieved. This was for example the case, when a button on the control panel was assigned with more than one function, and the subject did not know which function was active at the moment of pressing that button. The operating errors for the gesture control system are low in comparison (0.9%), which indicates an intuitive interface. The main errors for the gesture control system are *false positive* (4.1%) and *false negative* (8.8%) errors.

The *System Usability Scale* for the gesture control system is 80 - which indicates a *good* to *very good* usability, whereas the control panel scored below average with 63.

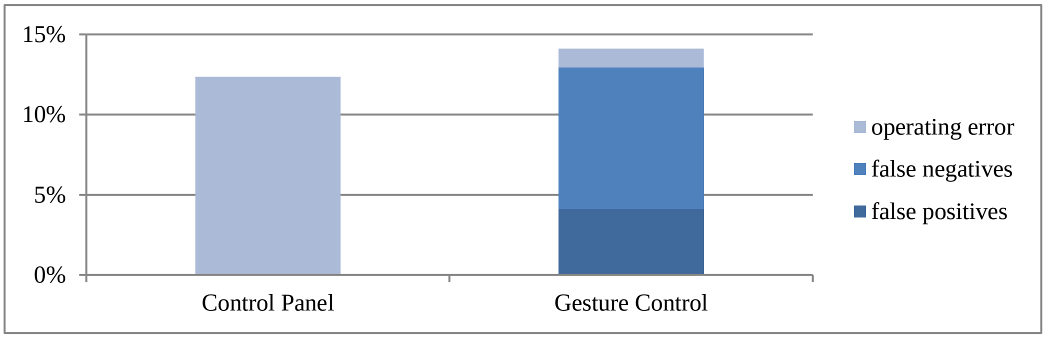


Figure 5: Occurring errors during operation of the SLS with either the control panel or the gesture control system.

6 Discussion

The results indicate that the concept of a gesture control with a 3D-sensor for a SLS is feasible and that it has a potential to receive a high degree of acceptance. Disadvantages of a gesture control such as the risk of unintended operation of the SLS and missing direct feedback to the user can be overcome by taking measures such as a logon and logoff process, as well as by the integration of other means of feedback (e.g. audio). High *false positive* and *false negative* errors cause a problem for the current integration in an operating room. However, these problems are likely to be solved by improved sensor technology and improved gesture recognition software. The low operating error rate of the gesture control system compared to the control panel indicates a high usability, which is supported by the good results of the *System Usability Scale*.

As a gesture control system has also been successfully tested to interact with an operating room table [6], the next step is to create an interaction concept that allows to control several medical devices with one unified human-machine interface, in the sense of a *system-surgery-room*. That control system must be able differentiate which device is intended for control by an operator, as well as to differentiate between the operator and other persons in the surgery room. This could be achieved by a room observation system, consisting of several 3D-sensors that survey the whole surgery room.

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