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Gesture-controlled image system positioning for minimally invasive interventions

Abstract: This work examines how a touchless interaction concept contributes to an efficient, direct, and sterile interaction workflow during CT-guided interventions. Two hand gesture sets were designed specifically under consideration of the clinical workflow and the hardware capabilities. These were used to change the position of an X-Ray tube and detector of a CT scanner without breaking sterility and are compared regarding usability and performance in a user study with 10 users. The user study revealed that it is possible to change the angle of the gantry within 10 seconds average in an experimental setup. A straight hand gesture showed higher acceptance than a pistol motivated gesture. Furthermore, the sequences were not optimal and confused the users. It turned out that it feels more natural to activate and confirm the system with the same gesture.

Keywords: Computed tomography, C-arm CT, Radiography, Interventional, Gestures, Touchless interaction, Usability, Radiology, Workflow improvement

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1 Introduction

The number of percutaneous interventions is increasing due to the demographic change. Patients are older and more people get cancer. Especially older and multi-morbid patients often cannot be cured with invasive surgery, i.e. by resection of the lesion. With the help of imaging devices, such as CT scanners, the radiologist brings energy applicators into the tumour region with high precision percutaneously. However, most CT systems were developed as diagnostic devices and thus lack assistance and interaction concepts essential for the interventional workflow. Especially for flat panel CT's to acquire images to visualize the instrument and risk structure

locations, the radiologist must position the X-Ray tube and the detector to the dedicated angle for the radiography. Observations revealed that the current workflow is not optimal, due to sterility issues that arise with the use of haptic buttons or touchscreens covered with a sterile drape [1]. A lot of research effort has been done in interaction with visualization and controlling of medical image viewers or registration of images [2]. Wachs et al. [3] developed a vision-based hand gesture system to control medical image viewer. Shen et al. [4] developed a hand gesture interaction and visualization for CT volume dataset using a Leap Motion Controller (LMC, San Francisco, California, United States). However, during interventions, controlling imaging devices is a frequent task that still shows a need for application specific sterile interaction concepts.

In this work a gesture interaction concept that translates touchless hand gestures into commands for special-purpose radiography imaging and a graphical user interface (GUI) for visualization purposes is presented. With the help of this system, the interventionalist is capable to position X-Ray tube and detector to a dedicated angle without leaving the sterile area and without breaking sterility. This should improve the workflow of image-guided interventions and, consequently, save time and costs and improve the outcome of treated patients. The proposed interaction concepts were evaluated in a user study with 10 participants regarding error rate, task completion time, and usability.

2 Materials and Methods

To tackle the challenges of image-guided interventions listed above a hand gesture interaction concept was designed. Additionally, a GUI was developed to get live feedback of the current and the configured angle. The gestures were detected with a stereo infrared optical tracking system, the LMC.

2.1 Gesture Design

The proposed interaction concept consists of two gesture sets. Each set includes three phases: Activation, Continuation and

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Confirmation. Activating the gesture system prevents the user from performing unwanted commands. Especially during interventions, the system must not execute unintended commands. Therefore, the activation gesture unlocks the gantry control. The configured angle must be confirmed by performing the confirmation gesture visualized in Figure 1. Both interaction sets can be activated by performing a fist gesture, which is easy to detect and, at the same time, easy to distinguish from other occasional movements performed by the radiologist.

The first positioning gesture uses the straight hand that is also robust in detection. In order to position the X-Ray tube,

Figure 1: Procedure of the interventional touchless gesture interaction concept. From the Activation Gesture to the Confirmation Gesture two concepts are developed and evaluated.

the users have to roll the straight hand to the left or right along the extended arm axis. The confirmation gesture of the first gesture set is carried out by performing a quick straight downward movement similar to pushing a big button.

The second positioning gesture resembles a symbolic pistol. The rotation speed of the virtual X-Ray tube also depends on the roll angle of the performing hand. To confirm the angle with the pistol-based gesture set the tip of the thumb needs to hit the proximal interphalangeal joint of the index finger symbolically triggering the pistol (see Figure 1).

2.2 Graphical User Interface

The main purpose of the software is to control the position of the X-Ray tube. Especially when using gantry CT systems, it is not possible to see the real time angle of the X-Ray tube because of the CT housing. For this a prototypical GUI was developed to visualize the real time position and provide gesture interaction capabilities.

The software was created using the Qt application framework (Qt Group, Helsinki, Finland). Within the application (see Figure 2) the gantry and the real time position of the X-Ray tube are displayed. Commands for the study operator are placed on the right-hand side.

Figure 2: GUI start screen. The application visualizes the current gantry position (1, 5) by showing the position of the X-Ray tube (grey). The user can change the target position of the X-Ray tube by using gestures to move the X-Ray tube (dark blue). On the right-hand side the gesture can be selected (2). (3) shows four predefined angles. Gantry specific parameter (4) and control elements (6) can also be found in the GUI.

3 Evaluation

3.1.1 Participants

The study was carried out with $n = 10$ participants. The age of the participants was 22 to 52 ($M = 27.3, SD = 9.4$). Seven participants were male and three were female. All of these were right-handed. The participants were no professional physicians and had no special experience in medicine or with gesture interaction.

3.1.2 Study Design

The two interaction concepts Straight Hand Roll (SHR) Gesture and Pistol Hand Roll (PHR) Gesture were used to perform seven tasks described in section 3.1.3. The order of the beginning interaction modality was randomized to minimize training effects during the experiment.

3.1.3 Tasks

The tasks were designed to resemble the common interaction tasks of configuring different X-Ray orientations with respect to the patient during image-guided interventions. Each participant was asked to rotate the gantry displayed in the GUI application to a given angle with a tolerance of $\Delta\alpha = 2^\circ$ for both gesture interaction sets. The angles were: 90° , 270° , 135° , 45° , 225° , $0^\circ/360^\circ$, 122° .

3.1.4 Measures

As a measure of performance three criteria were recorded: error, correction, and task duration. An error was defined as the number of errors, when the systems erroneously detected gestures or the system did not detect the intended gesture. The time has been measured by the software itself. The timer started, when the activation gesture had been performed and the timer stopped, when the confirmation gesture had been triggered. The number of corrections was defined as the number of trials the user needed to configure the given angle. Whenever the user crossed the tolerance interval of $\Delta\alpha = 2^\circ$ a correction was counted.

Subjective usability was measured using the System Usability Scale (SUS) [5]. The SUS questionnaire assesses the subjective usability of a system with the use of ten questions that can be rated from “strongly agree” to “strongly disagree” on a 5-point Likert scale. Using the procedure described in [5], a score between 0 and 100 can be calculated where 100 indicates the highest subjective usability.

To evaluate the subjective workload of each gesture concept an additional questionnaire was developed. The study was performed without weighting of the subscales. For each thesis the scale rank ranged from 0 (“disagree vehemently”) to 4 (“agree completely”).

3.1.5 Procedure

Due to the COVID-19 pandemic the user study was not performed in the real clinical setting. The participants were sitting on a chair and the LMC was placed in front of the participant. The software was running on a laptop. The users had a free view on the GUI application on the laptop.

4 Results

All participants completed all tasks successfully. The mean (M) and the standard deviation (SD) were considered. The Straight Hand Roll Gesture was performed faster than the Pistol Hand Roll Gesture (*SHR*: $M = 10.99$ s, $SD = 4.3$ s vs. *PHR*: $M = 13.92$ s, $SD = 5.8$ s). The measured error rate was similar for both interaction concepts (*SHR*: $M = 0.53$, $SD = 0.94$ vs. *PHR*: $M = 0.56$, $SD = 1.04$). The number of corrections needed to justify the given angle was close to each other (*SHR*: $M = 0.98$, $SD = 0.87$ vs. *PHR*: $M = 1.1$, $SD = 0.98$). However, the values were not significantly different. Sometimes the participants held the hand palm 90° rotated, so that the trigger fingers were

not visible to the LMC. Time differences between the gesture sets were observed, when the system did not recognize the gesture correctly, which led to longer reaction time of the system. The SUS of the whole system, including the GUI was rated with a score of 86% ($SD = 9.6\%$). The results of the questionnaire are shown in Figure 3 and Figure 4.

Figure 3: Results of the questionnaire about the Rotation Gesture: Straight Hand. The range goes from disagree vehemently (orange) over neutral (gray) to agree completely (green).

4.1.1 Discussion

The determined data show the suitability of a touchless gesture interaction modality to position the imaging system in projection-based interventions. However, some potential of improvement was offered within this user study.

The gesture interaction sets show differences in performance. Longer reaction time of the system leads to frustration and therefore to less concentration of the radiologist, which is needed performing high precise

Figure 4: Results of the questionnaire about the Rotation Gesture: Pistol Roll. The range goes from disagree vehemently (orange) over neutral (gray) to agree completely (green).

interventions. However, most errors occurred when performing the confirmation gestures. The sequence was not optimal, because the participants were often confused and used the activation gesture again to confirm instead of the correct confirmation gesture. Furthermore, the effect of training needs to be considered in further evaluations. Trained users may show improvements of the results.

The results of the performance measurement are also reflected in the questionnaire. The determined data from the user study shows which rotation gesture was preferred by the users. The Pistol Roll Gesture seems to be uncomfortable and not natural for the users. This is also reflected in the recorded performance measurement.

Another factor, which may have influenced the study, is that the participants were sitting on a chair during the experiment. This makes it more difficult to hold the hand into the field of view of the LMC. The users were sitting close to the table and therefore had to lift their arm to stay in the interaction area of the LMC. This leads to more exertion in the shoulder muscle causing fatigue over time. However, the radiologists stand in front of the patient table and so may have a better position to the gesture detecting device.

In the user study the whole gesture-based gantry control system was rated with a SUS of 86%, which reflects an excellent usability [6]. However, the standard deviation was very high. Participants, which rated a lower SUS, mentioned that the layout and the colors were not well chosen. The contrast between X-Ray tube and gantry was too low to recognize at first glance. The most significant criticism was the position and the size of the visualization of the current angle. This made it difficult for the participants to solve the task successfully. The participants had to focus on the small label representing the current angle and the main visualization.

5 Conclusion

In this work a touchless, direct, and sterile gesture interaction control for the manipulation of the CT scanner rotation angle was developed and evaluated. With the usage of an LMC hand or finger movements were tracked and used to control the rotation angle of an X-Ray tube. Within this work a gesture set was designed to evaluate the suitability of gesture interaction in C-Arm CT or gantry CT applications to position the imaging system. Furthermore, to increase the usability of such a system, a simple GUI was developed to visualize the gantry movement in real time, but offered potential for improvements.

In a user study with 10 non-medical users the usability and the susceptibility to errors were evaluated. The study showed

that the first gesture interaction set performed by a straight hand is more acceptable than the symbolic pistol gesture set.

In the future, different interaction concepts need to be optimized and evaluated to be suited for other controllable devices in the intervention room, e.g. the patient table. A possible additional modality can be speech recognition. Applications for such systems could be to scroll through slices in diagnostic scans or to apply image processing tools, like e.g. windowing, contrast and brightness level during minimally-invasive image-guided interventions without delays in the workflow. To use the full range of human senses, ideally a combination of multimodal interactions concepts, as presented in [7] have to be further investigated.

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Author Statement

Conflict of interest: Authors state no conflict of interest.

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