

Exploration of 3D Medical Image Data for Interventional Radiology using Myoelectric Gesture Control

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Abstract

Human-computer interaction with medical images in a sterile environment is a challenging task. It is often delegated to an assistant or performed directly by the physician with an interaction device wrapped in a sterile plastic sheath. This process is time-consuming and inefficient. To address this challenge, we introduce a gesture-based interface for a medical image viewer that is completely touchlessly controlled by the Myo Gesture Control Armband (Thalmic Labs). Based on a clinical requirement analysis, we propose a minimal gesture set to support basic interaction tasks with radiological images and 3D models. We conducted two user studies and a clinical test to evaluate the interaction device and our new gesture control interface. The evaluation results prove the applicability of our approach and provide an important foundation for future research in physician-machine interaction.

1. Introduction

Interventional radiology is based on the review and assessment of pre- and intraoperative images to guide instruments, identify and document findings, and provide treatment [TCZ*13]. However, interaction with 3D medical images in a sterile environment such as an operating room (OR) challenges physicians. During interventions, available interaction devices for medical image exploration, i.e., joysticks, buttons, and touch screens, are wrapped in a transparent plastic sheath which makes the interaction cumbersome.

Direct control with a keyboard or mouse is not an option due to contamination with bacteria [RWGW06]. Therefore, many functions are usually triggered and controlled indirectly by radiology technicians in a (non-sterile) control room. The technicians interpret voice commands and hand gestures of the radiologists and operate the interventional software using conventional interaction devices. However, indirect interaction is time-consuming and error-prone [OGS*14] and requires additional specialized personnel which can result in higher treatment costs.

With the introduction of new input devices and interaction paradigms, modern human-computer interaction offers a lot of opportunities, e.g., natural 3D user interfaces and gesture interaction [WW11, BKLP04, PD15]. Touchless gesture interfaces have the potential to improve interaction with medi-

cal images and devices in sterile environments. Accordingly, underlying interaction concepts need to be carefully adapted to interventional scenarios and workflows.

In this work, we present a new method to control a medical image viewer completely touchless using the Myo Gesture Control Armband (Thalmic Labs Inc., Kitchener, Canada) as an input device. In contrast to camera-based systems, this device does not introduce line-of-sight or positioning problems in the OR. Furthermore, the sterility is preserved, because the device is worn under the physician's clothes and does not provide an additional hazard. We introduce a gesture-controlled interface using a minimal gesture set to interact with radiologic images and 3D planning models.

To evaluate the Myo Gesture Control Armband, its clinical applicability, and the proposed gesture set, we conducted two quantitative user studies and a clinical test during neuroradiological interventions. The first quantitative user study focuses on the functionality, including device wearability and assessing the gesture recognition rate of all hand gestures supported by the software development kit (SDK). The second quantitative user study investigates interaction with a medical image viewer using the minimal gesture set proposed in this work.

2. Related Work

Commercial interaction devices have been used in the sterile area of operating rooms for years. In many cases, touch screens are used. A disadvantage of touch screens is that they need to be wrapped in a sterile plastic sheath. According to observations by the authors, the plastic sheath considerably reduces the image quality and could cause interaction errors. In addition, touch screen interaction is only possible if the physician's hand can reach the display. During an intervention, this is often hard to achieve because of limited space around the examination table.

Nowatschin et al. [NMWL07] proposed to install a 3D mouse close to the surgeon to allow interaction with medical image data and 3D planning models visualized by a surgical navigation system. 3D mice are appropriate to rotate 3D models precisely. However, they are inappropriate for simple (but essential) interaction tasks such as object selection. Several groups [HKS*08, GPM08] propose using a 3D pointing device based on optical tracking and inertial sensing, i.e., the Nintendo Wiimote, to interact intraoperatively with medical images and 3D models. Interaction with medical image data using inertial sensors was also proposed by Schwarz et al. [SBN11]. They introduced a system that learns defined user gestures that are most suitable for a given task. Hence, the user can integrate their preferences and does not depend on a predefined gesture set. Another system using inertial sensors for snapshot-guided nephrostomy was proposed by Kotwicz et al. [HLUF14]. A three-axis compass, a three-axis gyroscope, and a three-axis accelerometer are affixed on the user's hand under a sterile glove to execute, via small hand gestures, interaction functions like scroll, select, and reset.

Many systems attempt to detect finger positions using stereo cameras [CL09] or TOF cameras [PSS*09] to control a mouse cursor. Ritter et al. [RHW*09] track the movements of hands to enable simple interaction tasks such as rotating geometric planning models or triggering of events via buttons. Gallo et al. [GPC11] present an interactive system for medical image exploration using the Kinect depth camera (Microsoft, Redmond, WA, USA) as a proof of concept. The user interacts with static or dynamic hand and arm gestures in front of the camera to execute exploration functions like pointing, zooming, translating or windowing on radiological images. Ebert et al. [EHA*12] translate the data delivered by the Kinect camera and a voice recognition software into keyboard and mouse commands, and evaluate response times and usability when navigating through radiological images. Hoker et al. [HPMD13] propose a basic set of six voice and six gesture commands for direct touchless interaction in a real OR environment using the Kinect. Although gesture recognition rates were high and remained stable under different lighting conditions, their study showed that the rate of accidental triggering due to unintended commands is too high for clinical use and should be reduced. Tan et al. [TCZ*13] evaluated a Kinect-controlled image viewer

system with 29 radiologists with different levels of experience during a routine abdominal computed tomographic study. 69% of their subjects found the system useful and 7% did not. Cited issues included hand tracking, inconsistent responsiveness, the required use of two hands, and the need for ample space to operate. Mewes et al. [MSR*15] presented a natural gesture set to explore radiological images (projected onto a radiation shield) using the Leap Motion Controller (Leap Motion, Inc, San Francisco, USA). The results of their user study show that sterile and direct interaction with the Leap Motion Controller has the potential to replace conventional interaction devices in the OR. However, the optimal placement of the depth sensor close to the operator, the limited robustness of gesture recognition, and missing feedback are reported as problems. In summary, optical-based gesture recognition systems are widely used in experimental clinical settings. However, they show considerable drawbacks when applied in the OR, e.g., responsiveness, robustness, limited interaction volume, and line of sight.

Human-computer interaction based on myoelectric signals (MES) is investigated only by a few groups worldwide. The majority of applications in the field of myoelectric control focuses on prosthetics, signal analysis, robot control and rehabilitation. A substantial survey about the use of myoelectric signals was introduced by Oskoei and Hu [OH07]. They reviewed various research in pattern recognition- and non-pattern recognition-based myoelectric control, state-of-the-art achievements and potential applications. Based on the discussed achievements, their paper has led to a development of new approaches for the improvement of myoelectric control. In another work, Oskoei and Hu [OH09] examined time-related variabilities in myoelectric signals that occur through fatigue while playing video games. They proposed an adaptive scheme that models fatigue-based changes and modifies the classification criteria to provide a stable performance in long-term operations.

With respect to the analysis of myoelectric signals, several different methods are used to detect hand and finger gestures, improve diagnostic applications and build the foundation for myoelectric gesture control. Chen et al. [CZZ*07] used a linear Bayesian classifier, Naik et al. [NKA10] presented a method using Independent Component Analysis in combination with blind source separation. Samadani and Kulic [SK14] used Hidden Markov Models to analyze the myoelectric signals.

An early work concerning myoelectric gesture control was presented by Wheeler [Whe03]. He used two neuro-electronic interfaces for virtual device control. Both interface configurations are based on sampled data which were collected from the user's forearm with an electromyogram. In the first study, a sleeve with dry electrodes (fixed arrangement of the electrodes) is utilized to emulate a virtual joystick of a flight simulator with the directions up, down, left and right. In the second study, wet electrodes are placed on

the participant's forearm (free and variable arrangement of the electrodes) to simulate a virtual keyboard with the keys 0 to 9 and Enter. The results illustrate the potential of myoelectric gesture control using a non-invasive setup. However, to the knowledge of the authors, myoelectric gesture control to support human-computer interaction during surgical procedures or radiological interventions has not been described so far.

3. Material and Methods

The focus of this work is the evaluation of touchless interaction with radiological images and 3D planning models using the Myo Gesture Control Armband as input device. Therefore, we introduce a minimal gesture set for a medical image viewer. Technical and clinical requirements for our approach were determined by analyzing the workflow of neuroradiological interventions.

3.1. Requirement Analysis

In previous work [HHB*14], we analyzed video data from more than 25 different neuroradiological procedures. We classified single interaction steps during each procedure, such as scrolling through acquired digital subtraction angiography (DSA) images, rotation of 3D vascular models, or zooming to analyze details in the images. Second, we participated in various radiological interventions where a modern angiography CT imaging system (Artis zeego, Siemens) was utilized to support instrument guidance. As a result, we can confirm the following disturbances in the clinical workflow:

- *Delegation of tasks*: Verbal comments or hand gestures are used to delegate human-computer interaction tasks to an assistant in the OR or in a non-sterile control room (indirect interaction).
- *Leaving the OR or operating table*: Physicians have to change their position to use the provided interaction devices (joystick, buttons, and touch screens). In complex cases, they have to leave the sterile OR to use a workstation in the control room to interact with the patient data.
- *Leaning over the operating table*: To interact with touch screens, physicians have to lean over the operating table and the patient.

Third, our requirement analysis covered the research of literature related to *gesture-based* and *touchless interaction*. With these information, we specified seven functions listed in Table 1.

Based on discussions with our clinical partner, we decided to provide only two degrees of freedom for the rotation of 3D models in order to reduce the complexity. In this work, we decided to focus on the interaction tasks that we observed most frequently during interventions. Further observed interactions, such as changing window-level settings or distance measuring, are also important but not considered here.

Table 1: Specified explicit 2D and 3D interaction functions based on our requirement analysis.

2D	3D
Scrolling in z-direction	
Panning in x-direction	Rotation around the x-axis
Panning in y-direction	Rotation around the y-axis
Zooming	Zooming

3.2. Myo Armband and Gesture Set

The Myo Gesture Control Armband is worn on the user's forearm and measures the electrical signals which arise from biochemical processes through muscle contractions. These contractions are caused through the movement of the hand. The armband holds eight surface electromyographic sensors (Medical Grade Stainless Steel EMG sensors) that measure those signals. The hand movements include the following five gestures (see Fig. 1) which are supported by the armband:

- *Double Tap*: Tapping the thumb and middle finger twice together.
- *Fist*: Forming a fist with the hand.
- *Spread Finger*: Open hand with struttred fingers.
- *Wave In*: Wave motion with the hand to the body (palmar flexion).
- *Wave Out*: Wave motion with the hand off the body (dorsiflexion).

For haptic feedback, the armband provides an opportunity to access various lengths of vibrations. The connection and data transmission is based on Bluetooth technology, which is certified for use in the OR and does not interfere with any other devices [WW04].

Due to the small number of recognized gestures by the device, we propose a minimal gesture set. We assign a gesture to more than one function rather than assigning a specific gesture for each tool or function. This results in a concept that offers the possibility to expand the system and integrate new functions without the need of learning new gestures. Furthermore, the cognitive effort of memorizing the gesture and corresponding function is minimal. To realize a minimal gesture set, we first reduced the seven specified *explicit functions* (see Table 1) to four *basic functions*. For that, we mapped the available gestures on each function individually. Subsequently, we merged the functions to simple and general interaction tasks if it seemed consistent. The results of this merger are the four basic functions consisting of a *lock*, a *select*, a *parameterize* and an *interaction function*, which are in turn mapped on the five available gestures and then used to control the software and to interact with the visualization.

The locking status of the medical image viewer is switched using a *Double Tap* (Fig. 1a) gesture. If the system is locked, no interaction is possible and the physician

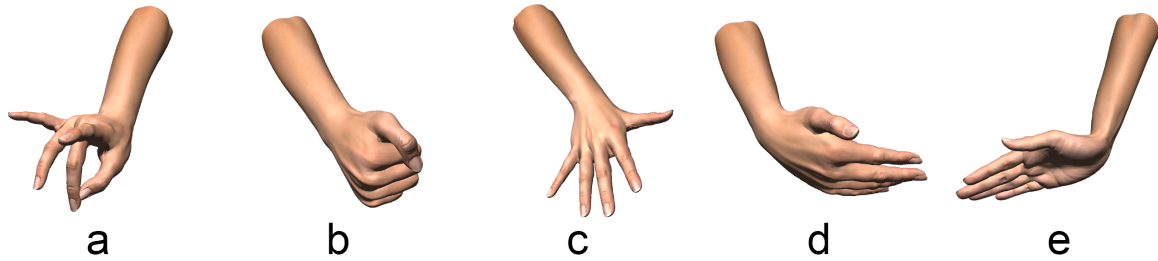


Figure 1: Hand postures of the five gestures: (a) Double Tap (b) Fist (c) Spread Fingers (d) Wave In (e) Wave Out

can work without any disturbances. To switch between functions or change a function parameter (e.g., slicing speed) the gestures *Fist* (Fig. 1b) and *Spread Fingers* (Fig. 1c) are used to activate the selection. Finally, the two opposing gestures *Wave In* (Fig. 1d) and *Wave Out* (Fig. 1e) are used to select and parameterize a function. In addition, these gestures are used to control functions, e.g., incrementing or decrementing the current slice position in the 2D image viewer.

3.3. Medical Image Viewer

We implemented a medical image viewer that serves primarily as a tool to evaluate the interaction with the Myo armband. The Qt application framework was used in version 5.4 to build the Graphical User Interface (GUI) and the Visualization Toolkit (VTK) in version 6.1 to visualize the medical dataset. For the Myo armband, we utilized the manufacturer’s C++ SDK in *version 0.81* and the firmware in *version 1.1.755*.

This viewer also offers the possibility to integrate different devices for comparison studies between device-specific interaction styles. To acquire quantitative measurements, a data logger is implemented as well. The complete control of the viewer is performed using the Myo armband. The viewer has two viewports to display 2D and 3D images, as shown in Figure 2. Furthermore, a visual as well as a haptic feedback was implemented to provide additional information about the selected function, its parameterization and occurring events.

3.4. Evaluation

We conducted two quantitative user studies and a clinical test in the OR to evaluate the Myo armband, the proposed minimal gesture set, and its clinical applicability.

Experimental setup: The two quantitative user studies were performed under controlled lab conditions in an OR-like setup that aims to simulate the conditions in an intervention room (see Fig. 3). We displayed our medical image viewer on a 24” touch screen monitor belonging to the CAS-ONE IR navigation system (CAScination AG, Bern, Switzerland). Furthermore, we placed an operating table

with a medical phantom on the table in front of the user to simulate the real distance between monitor and the physician’s position in the OR. For our user studies, we used a liver CT data set (84 slices) with a primary liver tumor. The corresponding 3D planning models including segmented liver vessels (portal vein and hepatic vein) and the tumor were generated using the medical image processing platform MeVisLab [RBH*11].

Evaluation Criteria: Based on the requirements, we defined criteria which we evaluated in our studies. The most important clinical requirement is preserving the *sterility* of the device and inherent hardware. Another aspect is the training *time* and the time needed to interact with the gesture-based interface to fulfill a given task. Furthermore, the *acceptance* of the proposed concept by the physician as the end user is important. Finally, the conducted user studies investigate the *robustness* of the gesture recognition and the associated impact on usability and applicability in the OR.

A *functionality study* was performed to evaluate the Myo armband as interaction device with regard to accuracy and robustness. During the study, we ensured that the position of

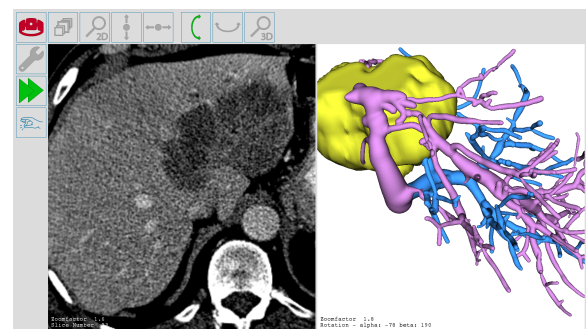


Figure 2: Graphical user interface of our medical image viewer with a viewport to explore radiological images (left), and a second viewport to visualize 3D models (right). Left and above the two viewports, interactive icons provide visual feedback about function, parameterization, locking status and the currently recognized gesture.

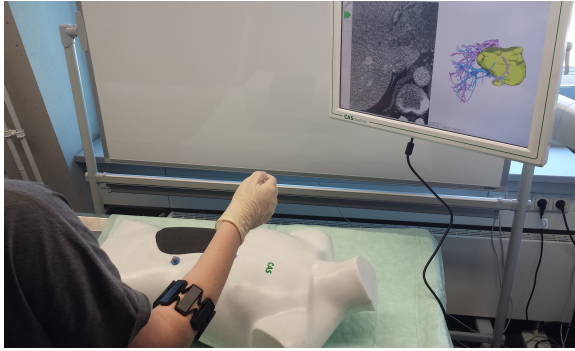


Figure 3: Experimental setup showing the operating table, a medical phantom, and the CAS-ONE IR navigation system (CAScination AG, Bern, Switzerland). The subject wears the armband on the right arm and interacts with the visualization.

the armband was equal for all subjects by placing a marked sensor module of the armband on the *musculus palmaris longus* (lower surface of the forearm). The experiment consisted of the following two parts, which were performed for each arm individually (dominant arm first) to see if there are any differences in handedness:

1. *Training:* Each subject was introduced to the functionality of the armband by explaining each gesture. Afterwards, the subjects had unlimited time to familiarize with the device. This means, each subject knows how to move the wrist and hand so that the system recognizes the gesture.
2. *Verification:* Each subject had to explicitly perform a given gesture ten times to verify accuracy and robustness. This was repeated for all five gestures.

The quantitative measurements comprised the training time, the correct and the incorrect recognized gestures. Overall, 2150 gestures were recorded and analyzed. Furthermore, we acquired physical data about the subjects' arms to gather information about possible causes of unpleasant sensation or a change in the recognition rates, due to a too tight or loose fit of the armband. At the same time, we instructed the subjects to use the think-aloud protocol [FKG93] to gather individual and qualitative information about the Myo armband as input device. After the test, we asked in a questionnaire about the wearing comfort of the armband, the motion of each gesture to determine problems in the early stages of our development, and if there were any differences between the dominant versus non-dominant arm.

The *interaction study* focused on the interaction with the medical image viewer using the proposed concept of a minimal gesture set. Analogous to the first study, the second study started with an introduction and a training. The handling of the medical image viewer with the minimal gesture set was part of this training phase. Therefore, we explained

the user interface including the visual and haptic feedback system and the gesture control using the armband. Each subject received an unlimited amount of time to understand the handling of the medical image viewer. The test supervisor answered no questions after the training phase in order to evaluate the developed feedback systems regarding problem handling and interaction flow. In the test phase, each subject had to perform the following four tasks:

1. Localizing the liver tumor in the 2D data set and determining start and end slice (9 to 38).
2. Selecting a specific slice, zooming the image to a predefined value and positioning it in the viewer's center (complex task).
3. Rotating the 3D planning model to a given orientation.
4. Zooming in the 3D view to a predefined zoom value.

All experiments were recorded using a video camera in order to log verbal comments of the participants. Quantitative measurements included the time a subject needed to perform each task. In addition, we asked the participants to fill in an adapted ISONORM 9421/110 questionnaire [Prü97] in order to evaluate our interaction approach regarding usability, naturalness of the execution, weariness, memorability and understanding of each gesture.

The *clinical test* focused on the evaluation of the armband during two neuroradiological interventions. This pilot study helped us to identify problems with the gesture recognition in a real clinical setting and moreover to get feedback from the physicians after using the Myo armband. Therefore, we used the data logger to record the recognized gestures and the time steps at which the gesture was recognized. During each intervention we also recorded the single workflow steps (including time stamps) to evaluate the recognized gesture and the individual hand movement. This way, we could identify, if and under which conditions any of the gestures of the set were accidentally performed or recognized.

The first intervention was a periradicular therapy and was performed by a resident physician who wore the armband for about 45 minutes during the preparation and intervention. In the second intervention, an assistant medical director wore the armband during an embolization of a cerebral arteriovenous malformation for about two hours.

4. Results

The results of the *functionality study* are shown in Figure 4. 20 subjects (average age = 27.2 years, 14 female and 6 male) with different levels of experience in gesture control and varying constitutions of their forearm (circumference and hairiness) participated in this study. Two participants were left-handed and 18 right-handed.

Differences in handedness were noticed by nine of the subjects after the second run of this study, regarding the easier understanding of the hand movement (hand gesture),

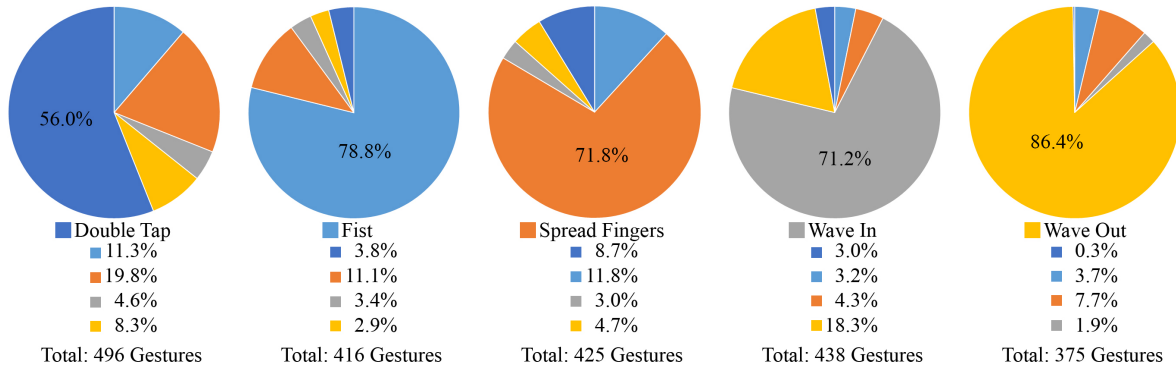


Figure 4: Recognition rates for each hand gesture within our functionality study. The pie charts visualize correctly and falsely negative detected gestures (Double Tap = dark blue, Fist = light blue, Spread Fingers = orange, Wave In = grey, Wave Out = yellow).

and some users had difficulties using the armband on the non-dominant arm. The *Double Tap* gesture had the lowest correct recognition rate (56.04%), whereupon a double lock system was applied to prevent unintentional interaction. This means that an interaction is only possible if the viewer is unlocked and a function selected and parametrized. It should be noted that this gesture was the most time-consuming for understanding in the training phase. Both *Wave* gestures achieved a good recognition rate (71.23% and 86.40%). Also, the *Fist* (78.84%) and *Spread Fingers* (71.76%) had a similar good recognition rate. It should be mentioned that both gestures (*Fist* and *Spread Fingers*) have a mutual recognition rate of about 11% due to the contractions of neighboring muscles. According to our data, the recognition rate depends on the training time and can be improved by a longer practicing period for the users to familiarize with the device.

The average training time to familiarize with each gesture was 111 s with a standard deviation of $\sigma = 60$ s for the dominant arm, and an average of 98 s with $\sigma = 58$ s for the non-dominant arm. We assume that the differences occurred because the hand movements were known after the first test. The collected data about the subjects' arms including circumference (with a mean value of 25.75 cm and $\sigma = 1.72$ cm) or hairiness did not influence the results in our experiments and therefore provide no additional value. For thinner arms, we provided a better fit of the armband through applying clips to it to make it tighter and thus establish a better skin contact. Comments collected from the questionnaires and the think-aloud protocol included issues about the wearing comfort of the Myo armband depending on the period of time the armband is worn and related pain or unpleasant sensations in the arm. Minor problems were reported regarding the form of individual gestures and a resulting unpleasant hand posture. Six subjects experienced a constricting sensation and two mentioned that the *Fist* and *Spread Fingers* gesture are exhausting through strong exertion executing the

gesture. The *Wave Out* gesture was easier to execute than the *Wave In* gesture for most subjects in this study. Moreover, a tenosynovitis can make the hand movement painful through hyperextension of the wrist.

Our subject pool for the *interaction study* consisted of 10 medical domain experts, i.e., medical students and assistant physicians (average age = 23.8 years, 6 female and 4 male). None of these subjects participated in our first study. The training time for the understanding of each gestures was similar to our functionality study. However, the training time for the interaction differed from subject to subject. The mean time for the training was 4:51 minutes with $\sigma = 1:59$ min. This is sufficient for our non-security-sensitive purposes. The times for each interaction task of the study are shown in Table 2. Subjects needed the most time (2:14 min) to rotate the 3D model to the given orientation. This might be explained by the fact that the rotation had to be performed on two axes and not via the trackball metaphor as usual. The interaction with the 2D slices, however, succeeded in most cases without any problems.

Table 2: Measured times for each interaction task (time in minutes) during the interaction study.

Task	Mean Time	Standard Deviation σ
Training	4:51	1:59
1	1:06	0:29
2	2:03	1:20
3	2:14	1:10
4	0:53	0:36

We used a Likert scale from 1 to 5 for *simplicity*, *naturalness*, *memorability* and *understanding* of each gesture as well as the *weariness* using a gesture. The results are presented in Table 3. The findings of the interaction study are in line with the results of the functionality study. This can

Table 3: Questionnaire results for each gesture (interaction study). Rating is based on a 5-point Likert scale from 1 = strongly disagree to 5 = strongly agree.

	Double Tap	Fist	Spread Fingers	Wave In	Wave Out	Mean ± SD
Simplicity	3.9	4.9	4.1	4.4	4.5	4.36 ± 0.385
Naturalness	3.9	4.8	4.2	4.2	4.4	4.30 ± 0.332
Memorability	4.7	4.9	4.7	4.6	4.6	4.70 ± 0.122
Understanding	3.8	4.4	4.0	4.2	4.2	4.12 ± 0.228
Weariness (not tiring)	3.8	4.6	4.1	4.0	4.1	4.12 ± 0.295

be seen, e.g., in the values for the *Double Tap* gesture, which had the worst recognition rate of the five gestures. This leads to an obstruction in the workflow while solving the four given tasks due to unintentionally executed gestures, which triggered unwanted behavior.

The results from the *clinical test*, particularly the analysis of the logging data, shed light on the relation between intra-operative workflow steps and recognized gestures (see Table 4). A major problem is the *Unknown* gesture, which informed about a connection loss between the armband and the host computer. In case of a radiological intervention, several physicians and assistants with radiation protection vests can obscure the Bluetooth signal. Also, a too large distance between the receiving host PC and the physician wearing the armband can lead to a connection loss (Bluetooth range). The *Double Tap* gesture was recognized most often (first intervention), because movements such as knocking a syringe or tapping devices like a touch screen are similar to the gesture's muscle contractions and performed often during this kind of intervention. The two gestures *Fist* and *Spread Fingers* do have a chance of mutual recognition. Both gestures are recognized in similar procedure steps consistently, e.g., when inserting a catheter or using a syringe to administer a contrast agent for vessel imaging (full tension of the forearm). It can be assumed that those two gestures are recognized most frequently during minimal invasive interventions if no additional intervention system is used. The *Wave* gestures are recognized when using the angiography system, e.g., when positioning the table with a joystick or interacting with the image data. In some cases, those gestures are also recognized by pointing on the monitors or gesticulating.

For a qualitative analysis, the operating physicians answered questions about the wearing comfort and a possible future use of the Myo armband as interaction device. Depending on the circumference of the forearm (tight fit), wearing the Myo armband during a whole intervention could be constricting, but did not affect any procedure step.

5. Discussion

The results of the functionality study showed that there are only minor problems concerning the wearing comfort of the armband. However, this was not confirmed by the feedback

Table 4: Log analysis of two neuroradiological interventions. The table shows the quantity of recognized gestures during the procedure.

Gesture	Intervention 1	Intervention 2
Unknown	8	2
Double Tap	132	203
Fist	62	131
Spread Fingers	108	440
Wave In	28	152
Wave Out	26	89
Overall	364	1017

we received from the physicians after the interventions during the clinical test. The physicians reported no problems with the Myo armband as device and no interference of the clinical workflow was observed. The haptic feedback was not actively noticed by the physicians during the operation, accordingly an adaption of the vibration feedback is necessary.

The interaction study showed that the proposed concept of a minimal gesture set is a notable option compared to individual gestures for each task. One benefit of this concept is the expandability regarding new functionalities, as far as it is logically practicable, e.g., the modification of the window level. The individual gestures of the used set were consistently rated as a good match for the functions, easy to execute and remember, and overall a good option to interact with the visualization through simple hand gestures. Only the *Double Tap* gesture was rated inferior because of the insufficient recognition rate and the resulting disturbances in the workflow. Although the *Double Tap* gesture performed badly in the functionality study, the authors decided to use it as unlock gesture, because the other available gestures were already used as logically connected controls for the software functions. Delineation and unambiguity of the gestures should be preserved. Minor drawbacks were sometimes an unpleasant hand posture and problems with the precise execution of a function. Our defined requirements were fulfilled, except for the robustness of the system, which is one of the most crucial aspects. Formal feedback from the physicians after the clinical tests indicate that the proposed concept has the potential to improve the workflow in an OR. If physicians

could navigate directly without delegating interaction tasks, assistants could prepare upcoming procedure steps instead. Therefore, this might lead to a shortening of the intervention time and a reduction of intervention costs. Compared to interaction devices with a fixed position and varying distance to the user (such as a control panel placed on the operating table), or camera-based systems with a limited field of view, the proposed system enables a very flexible and mobile interaction in the OR.

6. Conclusion and Future Work

Direct interaction with medical images in a sterile environment is a challenging task. We presented and evaluated a concept for myoelectrically controlled touchless interaction with medical image data. Our results prove its applicability and may inspire future research.

Future improvements concerning the robustness of the Myo Armband are necessary to ensure a trouble-free workflow, without misinterpreted gestures or accidentally-executed functions. For example, a connection loss is not acceptable for security-sensitive purposes. However, robustness and recognition rate may increase for future versions of the device and SDK.

Concepts for multimodal user interfaces (or the use of the remaining inertial measurement unit sensors in the armband) should be considered to further improve this system. Furthermore, a transfer of the proposed gesture set to other input devices would enable a systematic comparison of different interaction devices.

The willingness of the physicians to use the armband during radiological interventions showed its potential for a real clinical trial. This would allow us to acquire more quantitative data and to evaluate the benefit of using a myoelectrical device for direct interaction compared to task delegation.

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