Workflow Analysis for Interventional Neuroradiology using Frequent Pattern Mining

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Abstract:

Modern interventional imaging systems provide a wide range of functionalities and tools in order to perform complex radiological interventions. The aim of this work is to analyze and evaluate the workflow of such interventions with a focus on human-computer interaction. In our study, 25 neuroradiological CT interventions using the Siemens Artis Q imaging system were recorded on video. Based on the videos, the interaction between neuroradiologists, medical technicians and the interventional imaging system was analyzed. A frequent pattern analysis revealed that users concentrate on functionalities that are easy to reach and to understand. In addition, we observed several usability problems that were systematically collected, analyzed, and visualized using graphs and storyboards. The results of our study serve as a basis for further usability studies and workflow analyses, as well as for the design and development of future human-computer interfaces in interventional radiology.

Keywords: Human-Computer Interaction, Workflow Analysis, Interventional Radiology

1 Purpose

The interaction with complex interventional imaging systems within a sterile environment is a challenging task for radiologists. Interventional imaging devices, such as modern angiography systems, provide a wide range of functionalities and tools. The interaction interface of these systems usually consists of a control panel with buttons and joysticks, touch displays, and foot pedals. Using this technical setup, users of these systems perform different tasks such as controlling the position of a C-arm or the operating table, setting of acquisition parameters, or triggering of scans. The aim of this work is to analyze and evaluate the workflow of such interventions with a focus on issues in the field of human-computer interaction.

Our work is based on related work in the field of surgical workflow analysis: Dynamic Time Warping and Hidden Markov Models are used to analyze and process multidimensional data from surgical interventions [1-2]. Joosten et al. [3] propose petri nets for the description of surgical workflows, while Jannin et al. [4] and Neumuth et al. [5] propose to describe and analyze surgical procedures using UML class diagrams.

The quality of human-computer interaction influences the workflow of many interventions. While some groups propose systems that require a minimal amount of interaction [6], other groups propose interaction devices and user interfaces that are specially designed for intraoperative use [7]. In particular, interaction via gestures and voice represents a promising method for human-computer interaction within sterile environments [9].

2 Materials and Methods

In this work, we focus on the analysis and evaluation of workflows in interventional radiology. Thereby, we focus on neuroradiological interventions and diagnostic examination using a biplane angiography system (Artis Q, Siemens Healthcare).

2.1 Experimental Setup

For the observation in the intervention room two cameras were installed (Fig. 1a). A top view camera recorded the control panel (Fig. 1a-4) of the angiography system and was fixed on top above the operators (Fig. 1a-5). This camera was equipped with a microphone that recorded system sounds or discussions between users. A back view camera (Fig. 1a-6) recorded the operators in total view. In addition, radiologists also wear eye tracking glasses (SensoMotoric Instruments) during diagnostic treatments. The eye tracking camera was used as an additional video source in case the control panel was not visible in the other two cameras. The results of each experiment were video files from each camera that were synchronized in a post-processing step (Fig. 1b).

(a) (b)

Fig. 1: (a) Sketch of the experimental setup in the intervention room: (1) technician, (2) neuroradiologist with eye tracking glasses, (3) patient table, (4) control panel of the angiography system, (5) top view camera, and (6) total camera. (b) Picture-in-picture presentation of top view camera and back view camera.

2.2 Analysis

In sum, 25 treatments were recorded (20 diagnostic investigations, 5 interventions). Our subject pool consisted of 4 senior physicians, 2 specialist physicians, 1 assistant physician, and 4 technicians. The subjects were divided in two user groups: technicians and radiologists. For each user group it was recorded which control element was used at which time. In addition, verbal commands, interruptions of the intervention, and other important events were logged.

For each action during the treatment an entry in a log file was created that contains the time stamp of the video file, the subject and the action itself. In total, 99 different actions were distinguished (buttons, functions, verbal commands). The resulting log files were utilized to identify actions that are frequently used and to find sequences of actions that often occur. Therefore, the log files were represented as graphs. Each node represents one action that appeared during the treatment. An edge between two nodes is increased by value 1 if the user performed these actions successively. The edge weight increases with the frequency of this sequence. As a result, we received 50 adjacency matrices (25 for each user group). The adjacency matrices of the graphs (that contain the information how often which actions and which action sequences were performed) were analyzed with respect to frequent patterns. Therefore, the carpenter algorithm [10], a pattern mining approach was utilized. Figure 2 shows some of the patterns that could be found in the workflow of technicians and physicians.

In addition, a qualitative evaluation of the workflow was performed. Based on the videos, we identified situations where the workflow was interrupted or/and problems concerning the interaction with the angiography system occurred. The situations were visualized using storyboards. These storyboards were then presented to the radiologist and technicians in order to analyze and discuss these unfavorable situations in detail.

3 Results

The quantitative analysis using the carpenter algorithm [10] revealed that the most frequently used functionalities are related to table position control, C-arm position control and aperture control. According to user statements, these elements are easy to understand and to use. The most frequently used interaction elements on the touch display are visible on the start screen. On the one hand, this indicates that the arrangement of control panel items seems to fit to the needs of its users. On the other hand, functions which cannot be found quick enough, e.g. in critical situations, are not used during an intervention, even if they might be helpful.

The following problems were collected and discussed with three physicians and one technician by using storyboard charts:

- Users had to leave the sterile area in order to retrieve additional patient data (medical imaging data and diagnostic report) from a workstation outside of the sterile area
- The user tried to perform an interaction while the system was busy. In this case, the system only provided an acoustic signal and rejected the interaction request
- The user tried to interact with an interaction element that is out of reach or blocked by another user
- In many cases users had to move the wireless foot pedal (used for X-ray control) to a comfortable position

An informal discussion with the involved clinical users (without using storyboards) revealed that the clinical users already recognized the observed problems, but surprisingly they did not describe them as very distracting. Instead, they explained that they got used to these problems and consider them as a part of their daily work. However, a subsequent presentation of the developed storyboards to the clinical users generated a shared and accurate understanding of the existing usability problems. Based on subsequent discussions, concepts for the improvement of human-computer interfaces in sterile environments were developed.

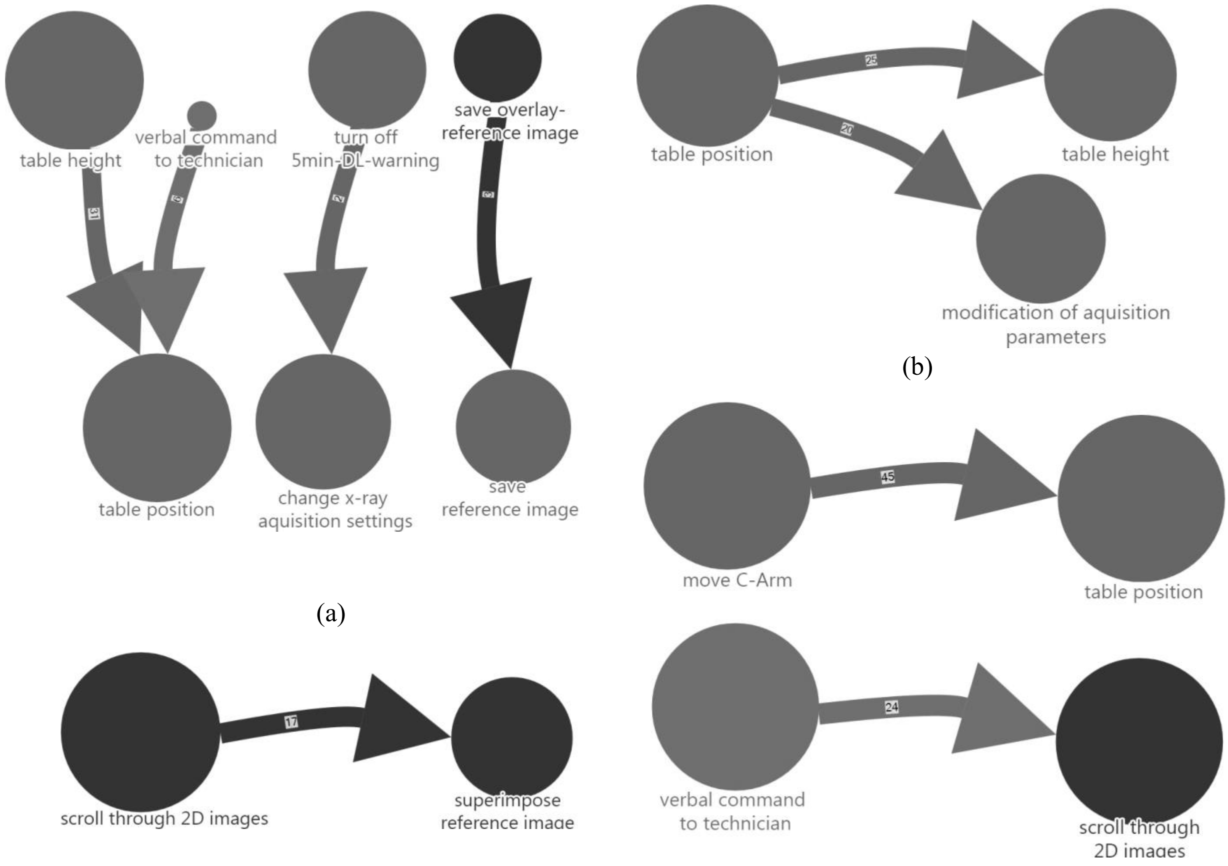

Fig. 2: Examples of frequent patterns that were found. Workflow patterns from medical technicians that occurred in (a) 12.5% and (b) 28% of cases, and from radiologists that occurred in (c) 27% and (d) 45% of cases.

4 Discussion

In this work, we analyzed and evaluated the workflow of neuroradiological CT interventions with a focus on human-computer interaction. The conduction and evaluation of our study was quite time-consuming. In particular, the post-experimental analysis of the videos took a lot of time and required a good understanding of the control panel. For a good video quality the use of a high-quality camera system is necessary. We used webcams which also did a good job because of their small size. Certainly, the resolution and lighting conditions caused that some actions could not be detected. However, we collected and analyzed sufficient data to shed light on an important usability problem in interventional neuroradiology.

Our work refers to a particular angiography system which differs from other interventional imaging systems. To receive meaningful results, the experiment should be continued in intervention suites with other systems. However, we expect that the general approach of analyzing international radiology tasks and of modeling corresponding workflows is similar. In this context, Frequent Pattern Mining has the potential to become an essential tool to derive surgical and interventional workflows in a bottom-up and data-driven manner.

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