

# Development and Evaluation of an Interface for Pre-Operative Planning of Cryoablation of a Kidney Tumor

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**Abstract**—Surgical interfaces are used for the interpretation and quantification of the patient information, and for the presentation of an integrated workflow where all available data are combined to enable optimal treatments. Human factors research provides a systematic approach to design user interfaces with safety, accuracy, satisfaction and comfort. One of the human factors research called user-centered design approach is used to develop a surgical interface for pre-operative planning of cryoablation of a kidney tumor. Two experiments of a simulated cryoablation of a tumor task have been performed with surgeons to evaluate the proposed surgical interface using subjective (questionnaires) and objective (eye tracking) methods to obtain the best surgical interface configuration.

**Keywords**—surgical interface; human factor analysis; user-centered approach; eye tracking; mental workload; situation awareness

## I. INTRODUCTION

Minimally invasive surgical procedures have been evolved for reducing hospitalization time and surgical complexities. In a conventional minimally invasive surgery however, a surgeon operates on deeply located lesions without actually seeing or touching. Thus, an easy to use surgical interface (SI), which benefits maximally from the surgeons' skills while providing all necessary information that can be perceived and processed by the surgeon during the intervention in the operation theatre, is needed. Surgical interfaces are designed to improve surgical treatments in all the stages of a clinical workflow, which ranges from preoperative diagnosis and planning of the surgical interventions up to postoperative evaluation. In this work, SI is used for the interpretation and quantification of the patient information, and for the presentation of an integrated workflow where all available data are combined to enable optimal treatments. Recently, several SIs that consist of functions for identification of liver segments and planning of liver surgery have been developed.

CAScination is a well-known commercial system that integrates stereotactic technology in complex liver interventions and surgery [1]. A preoperative surgical simulator has been designed to allow surgeons to plan the

surgical interventions for liver surgery in PATient Specific Simulation and PreOperative Realistic Training (PASSPORT) project [2]. LiverAnalyzer™ (MeVis Medical Solutions AG, Germany) and Synapse Vincent™ (FUJIFILM Co., Japan) surgical interfaces have functions that can segment the liver, vessels, biliary system, and tumors, volumetry of the remnant and/or graft, evaluate vascular territories, and plan the surgery. Note that not only inclusion of functions for liver surgery, but also incorporating these functions systematically into interface design by considering the surgeon's requirements is an essential issue. Thus, recently, a user-centered virtual liver surgery planning system for liver surgery called Dr. Liver, has been developed, that considers human factors research, usability and time efficiency issues [3].

Human factors research describes how much and what kind of information a person can use effectively, and how information should be organized and presented to make it usable [4]. Human factors research has previously been used to provide design solutions for the disciplines of medicine, psychology and ergonomics in which human-machine interactions affect performance and usability [5]. The human factors research focus on the physical and sensory characteristics through displayed symbols, audibility and perceptual and cognitive abilities (human perception, sustained attention) through arrangement of displays, alarms, information presentation, information processing during the design of interfaces. Therefore, the human factors activities should be incorporated into surgical interface during the design process from an early stage. Various traditional, sociotechnological systems, user-centered design, computer-supported design and ecological interface design approaches in human factors research have been developed to design interfaces [5]. In this work, we use user-centered design (UCD) approach to develop a surgical interface for pre-operative planning of cryoablation of a kidney tumor.

SI has been developed considering the four phases of user-centered design approach, which are analysis, design, implementation and deployment. Possible configurations of the SI, which comprise various combinations of menu-based command controls, visual display of multi-modal medical

images, 2D and 3D models of the surgical environment, graphical or tabulated information, visual alerts, etc., has been developed. We conduct two experiments of a simulated cryoablation of a tumor task with surgeons to evaluate the proposed SI. Surgeons are asked to find the tumor on the left kidney (target point) that is displayed on SI, and to determine a suitable entry point to start the ablation. Subjective (questionnaires) and objective (eye tracking) methods have been used to obtain the best surgical interface configuration.

## II. MATERIALS AND METHODS

In this section, initially development of SI considering the UCD approach has been given. Then experimental set-up, procedure, participants, and data collection and analysis details are provided.

### A. Development of SI Using User-Centered Design (UCD) Approach

UCD approach consists of four main phases, i) analysis - determine SI modules and define the important usability and functionality factors, ii) design – begin to develop SI prototypes, iii) implementation – construct a heuristic evaluation, whereby usability experts work together with the SI developers and surgeons to analyze the various dimensions of the prototype SIs, and previously-used products with similar functionality of SI, and iv) deployment – use surveys or other evaluation techniques to get surgeons’ feedback about SI for modifications (Fig. 1).

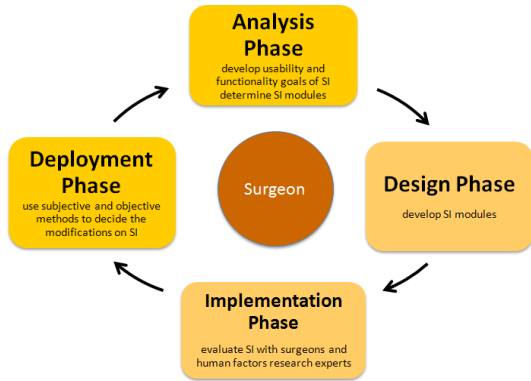


Fig. 1. User-Centered Approach during Design of SI

SI modules that satisfy the surgeons’ need and important usability and functionality factors to design SI modules have been determined in the analysis phase of the UCD approach. SI consists of Medical Image Module, 3D View Module, Phantom Model Module, Robot CAD Model Module, Visualization Module, Entry-Target Selection Module, Run-Time (Real-Time) Module, and Needle Force Tracking Module. The response time, ease of use, and efficiency have found to be the most important factors among the usability and functionality factors [6]. Thus SI modules are designed considering these usability and functionality factors.

Medical Image Module, 3D View Module, Phantom Model Module, Robot CAD Model Module, Visualization Module, Entry-Target Selection Module, Run-Time (Real-

Time) Module, and Needle Force Tracking Module have been developed in the design phase of UCD approach (Fig. 2).

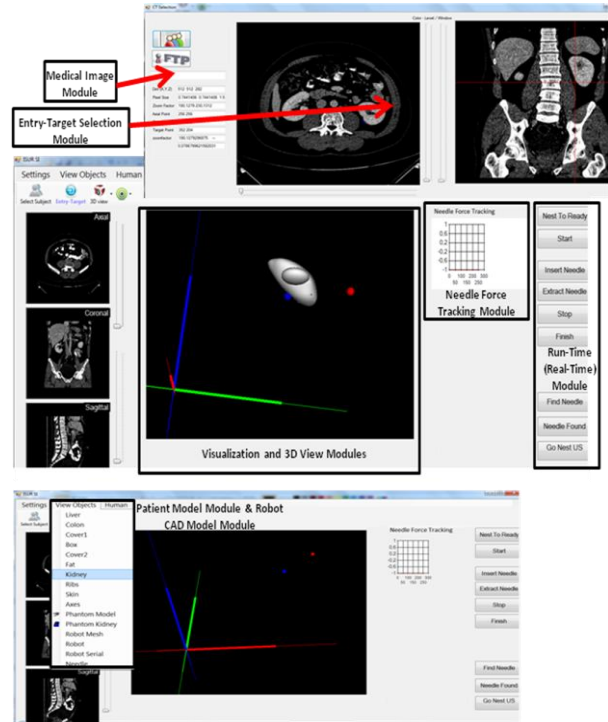


Fig. 2. Surgical Interface Modules

SI modules, menu and screen layout are reviewed with the surgeons, and experts in the implementation phase of the UCD approach. The button size, color, font size and information that are displayed on SI, which form the infrastructure of SI modules, have been decided considering the response time, ease of use, and efficiency factors. SI has been developed using Microsoft Visual Studio 2010 Development Environment to improve response time and efficiency. The visualization toolkit (VTK), which is an open source and freely available software, is used for 3D image processing and visualization to increase ease of use and efficiency.

Subjective and objective methods are used to evaluate the developed SI in deployment phase of UCD approach. An eye tracking system, which provides quantitative data, can help to understand visual and display-based information processing, and the factors that may impact upon the usability of interfaces. It could be possible to trace the surgeons’ attention and automate assessments for example, based on “how much certain areas of an interface have been watched by the surgeons”, with an eye tracking system. It is possible to learn where surgeons target on SI using eye tracking system, which will help us to remove the unnecessary information on SI, and obtain the optimum SI configuration.

### B. Experimental Set-Up

Participants are seated on a non-adjustable chair while viewing a 22” LCD monitor set at 1680 x 1050 resolution from a distance of 70 cm (Fig. 3). Thus, the screen covered approximately 37.5° of the visual field horizontally. Participants are seated in front of a remote eye tracker and the

computer screen with their head resting on the chin-rest to ensure the accuracy of the data recording. The remote eye tracker Sensomotoric Instruments (SMI) 500 have been used to sample the participants' eye gaze at 500 Hz. SMI's control and analysis software BeGaze has been used to extract the fixation counts and fixation time.



Fig. 3. Surgeon Performing Experiments on SMI 500 Eye Tracking System

### C. Procedure

Participants are asked to find the tumor on the left kidney (target point), that has been displayed on SI, and to determine a suitable entry point to start the ablation. The eye position and pupil size of the participants have been saved to a log file with the eye tracker device during the task execution. Two experiments have been conducted. In the first experiment, the aim is to evaluate the SI to determine the necessary modifications on it. Participants are required to perform the cryoablation task with the developed SI. In the second experiment, the SI has been modified in terms of visual display, button size, color etc considering the first experiment results. Participants are required to perform the cryoablation task with the modified SI. The visual information acquisition and time to complete the task have been used to evaluate the configuration of SI in two experiments.

### D. Participants

3 surgeons (all male) (Participant A (PA), Participant B (PB) and Participant C (PC)) from Urology Department of Faculty of Medicine, Istanbul University have attended the first experiment. 3 radiologists (two female and one male) (Participant D (PD), Participant E (PE) and Participant F (PF)) from Radiology Department of Faculty of Medicine, Istanbul University have attended the second experiment. All the participants are right-handed, and have normal vision. All urologists have experience with laparoscopic surgery, and radiologists have experience in kidney biopsy process.

### E. Data Collection and Analysis

We have used eye tracking data to decide whether all or some of the information displayed on the SI has been relevant for the participants performing the cryoablation task. The Behavioral and Gaze Analysis (SMI BeGaze™) analysis software has been used to visualize, extract and analyze the eye tracking parameters [7]. Areas of interest (AOI) on the SI have been defined before the task execution started. Dwell time, fixation counts and average fixation duration concerning

each AOI have been measured. The dynamic attention maps summarize the information about the most time-spent areas of the SI. Additionally, the fixation patterns and statistical parameters have been visualized by altering the color of the grid of AOIs (Gridded AOI) overlaid on the SI screen considering the amount of fixations. It is possible to compare the varying stimuli such as CTs, cursor movement through various slices independent of its content using Gridded AOI. Fixation counts and durations have also been used to quantify aspects of gaze behavior that reflect efficient use of the SI. We have also used subjective evaluation techniques, National Aeronautics and Space Administration Task Load Index (NASA-TLX) to measure the mental workload, and Short Post-Assessment Situational Awareness (SPASA) to measure situation awareness (SA) of the surgeons during the use of SI.

## III. RESULTS

The participant specific fixation counts and the results of the statistical analysis were presented in Fig. 4. The circles showed the amount of fixations in each CT image AOI separately for each participant. The gray dashed line showed the uniform distribution. The green dots represented the fixation counts, which are significantly ( $p < 10^{-3}$ ) larger than what would be expected by chance. For each significant data-point, the black error bars provided 95% bootstrap confidence intervals (CIs) of the null-hypothesis distribution of maximum fixations in a AOI. Thus, the green dots would be expected to fall into these intervals, if all AOIs had received similar amount of fixations. The CI images shifted along the y-axis since the number of fixations was different for each CI image computation. The data clearly showed that participants focus on 2 or 3 AOIs, and neglected the rest. Importantly, participants' selected AOIs differed to some degree. Three of the images used by PA were in the upper row, the only looked-at CT image in the bottom-row receiving 7 fixations only. Both PB and PC spent time looking at two CT images shown in the lower row; but the favorite CT image of PB was yet another CT image in the lower part. These results conclusively showed that the presentation of 8 CT images was redundant for the participants. As a result of the first experiment, SI has been revised and the number of CT images displayed for entry and target point selection for kidney cryoablation was reduced to two.

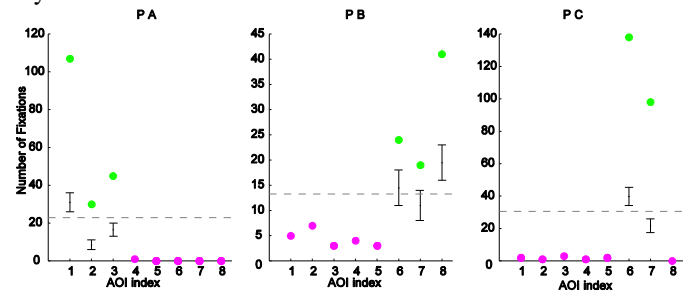


Fig. 4. Participant Specific Fixation Counts for First Experiment

When SI had been revised, time required to complete the task by the participants had been decreased (Table I). In the first experiments, the three participants (PA, PB, and PC) had

completed the task in 100, 72, and 159 seconds, respectively. When the SI had been modified, the participants (PD, PE, PF) needed only 62, 38 and 32 seconds, respectively, to complete the task.

TABLE I. TOTAL TIME EACH PARTICIPANT SPENT DURING TASK EXECUTION

	Total Time (s)	Relative time on CT images (%)	Median Fixation Duration (ms)
PA	100	61	168
PB	72	55	172.5
PC	159	59	169
PD	62	28	144
PE	38	73	262
PF	32	79	302

The amount and duration of fixations on displayed CT images displayed had shown differences between the first and second experiments. In the first experiment, the participants had spent 61%, 55%, and 59% of their total viewing time fixating the CT images. The fixations of two participants covered 73% (PE) and 79% (PF) of viewing time, indicating a relative increase in visual information acquisition after SI had been modified. Surprisingly, this statistic was a modest 28% for the PD because PD had used the sliders for changing the zoom level and the contrast of CT images frequently. A closer inspection of the fixation properties revealed that whereas PD made frequent use of both axial and coronal CT images (63 and 28 fixations, respectively), the other two participants (PE and PF) rarely visited the coronal CT images (one and four fixations on the coronal image respectively). Moreover, for PE and PF of the second experiment, the fixation durations were relatively longer, which suggested, that they received more continuous information upon the initiation of a fixation. Permutation tests revealed that the fixation durations of PE and PF were longer than the durations observed for the participants of the first experiment ( $ps < 0.05$ ). The fixation durations of the PD were not significantly different than the fixation durations measured during the first experiment (all  $ps > 0.2$ ). Thus, the decrease in the number of CT images presented on the SI led to shorter task execution times, and for two of the three subjects (PE and PF), the fixation data suggested that they benefited only from the axial CT image with relatively long lasting fixations.

Overall mental workload and situation awareness of participants had been evaluated when second experiment was completed. The overall workload was 3, 3.93 and 3 for PD, PE and PF, respectively. Overall mental workload of surgeons related with SI was low as it was aimed. Furthermore, overall SA scores of surgeons were 3.89, 3.7 and 3.78 for PD, PE and PF, respectively, which were considerably high.

#### IV. DISCUSSION AND CONCLUSIONS

This preliminary study highlights design of a SI for pre-operative planning of cryoablation of a kidney tumor using a user-centered approach (UCD), and evaluation of SI using subjective (questionnaires) and objective (eye tracking) methods to obtain the optimum SI configuration.

Possible configurations of the SI, which comprise various combinations of menu-based command controls, visual display of multi-modal medical images, 2D and 3D models of the surgical environment, graphical or tabulated information, visual alerts, etc., have been developed.

An eye tracking technology has been used to find an optimum SI configuration. Two experiments of a simulated cryoablation of a kidney tumor task with surgeons have been conducted to evaluate the proposed SI. Sequence, entry time, dwell time, revisits, average fixation, first fixation and fixation count parameters have been extracted from recorded eye movements through SMI BeGaze for scientific and statistical analysis. Specifically, by analyzing the distribution of fixation locations, we have revealed that the presence of 8 CT images in the first version of the SI has been redundant for the surgeon. The task execution time for the same task has decreased, and the participants have spent their time mostly on the AOI when the number for CT images on SI has been reduced. Furthermore, overall mental workload of surgeons related with SI has been found low, and situation awareness scores have found to be considerably high.

In the future, we plan to continue revision of the developed SI, include the real-time cryoablation protocol (intra-operative planning), and plan to collect eye tracking data in more difficult surgery-like tasks such as cryoneedle control.

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