

Eye Gaze Contingent Ultrasound Interfaces for the *da Vinci*[®] Surgical System

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Abstract—Current practice of intra-operative ultrasound requires an assistant due to the fact that surgeon’s hands are occupied with surgical tools. This process can be tedious and prone to error. This work presents three novel designs in one common framework to provide surgeons with further autonomy in using ultrasound. Leveraging the *da Vinci* Research Kit, the interfaces incorporate eye gaze and voice recognition into the *da Vinci*[®] Surgical System for ultrasound machine control.

I. INTRODUCTION

Robot-assisted laparoscopic surgery is widely adopted with a prominent example being the *da Vinci*[®] Surgical System (Intuitive Surgical Inc., Sunnyvale, CA). The *da Vinci*[®] features a stereo endoscope, motion scaling, and hand tremor-filtering to improve the surgeon’s capabilities. The benefits of robot-assisted surgeries for patients include faster recovery times and fewer surgery complications [1].

While ultrasound imaging is often used intra-operatively during robot-assisted surgery, in part due to its real time and non-ionizing nature, there is a challenge in performing it efficiently. Surgeons usually instruct their assistants to adjust the ultrasound parameters to obtain the optimal images, because their hands are occupied with surgical tools. This process can be tedious and prone to error due to miscommunication and non-intuitive control [3].

Eye gaze control has shown to be a promising modality in robot-assisted surgery, such as actively for instrument control [6] or passively for camera scene stabilization [5]. A retro-fit eye gaze tracker [7] has been designed for the *da Vinci*[®] Surgical System. Improvements upon previous design include a new hardware configuration and the adaptation of the *ExCuse* pupil detection algorithm and a glint detection algorithm [2], [4].

This work aims to integrate eye gaze tracking with ultrasound control to increase the surgeon’s autonomy in the operating room and increase the use of ultrasound imaging in a robot-assisted setting.

II. MATERIALS AND METHODS

A. System Setup

The proposed system is composed of a ultrasound control application software, the *da Vinci* Research Kit (dVRK) developed by Johns Hopkins University, a SonixTouch ultrasound machine (BK Ultrasound, Peabody, MA), a custom eye gaze tracker [7], and a microphone. The control application

interfaces with the *dVRK* through Robot Operating System (ROS) for motor control and sensor reading. It sends commands to the ultrasound machine, and acquires a stream of ultrasound images. It uses the eye gaze tracker to obtain eye gaze position and the microphone for voice recognition. The ultrasound control application containing ultrasound image stream and parameters is displayed within the *da Vinci* surgeon console real-time.

B. Graphical User Interface (GUI)

A GUI incorporating four commonly used ultrasound parameters (zoom, gain, depth and Doppler mode including color gain) is designed. The ultrasound image is displayed prominently. The four parameters are in a circular layout to maximize the space for ultrasound images and decrease the difficulty for eye gaze selection [8]. One increase button and one decrease button are designed to adjust ultrasound parameters. A position input is used for pointing and a confirmation input is used to confirm or cancel a selection of a button. The GUI occupies the full display screen inside the surgeon console with endoscopic views hidden.

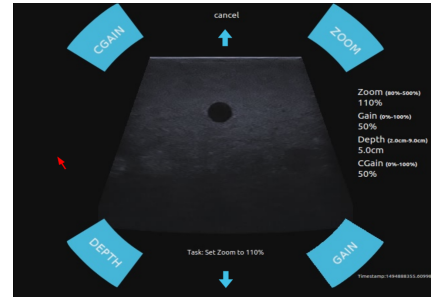


Fig. 1: GUI layout with parameter buttons and increase/decrease buttons shown in blue.

C. Interfaces

Three novel interfaces for remote ultrasound control based on *dVRK* and *ROS* are designed.

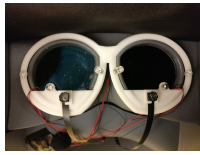
Master tool manipulator (MTM) mode: this interface is designed to be similar to the normal operation of the *MTMs*. The 2D planar position offset of the *MTM* from the initial position when the application starts is used for the position input. A dominant *MTM* gripper is set based on the user’s dominant hand. The click of the dominant *MTM* gripper is for confirmation and the click of the other gripper is for cancellation. A spring-damper haptic feedback model is built around both *MTMs* with $F = k(x) \cdot \vec{x} + c \cdot \dot{\vec{x}}$,

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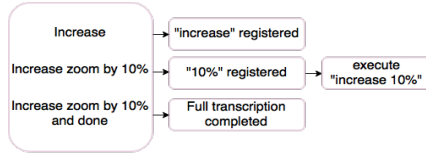
where the spring constant k is a nonlinear position dependant variable to provide significantly more feedback under large movements. When the user holds the gripper and moves away, a continuous change in value will be made.

Eye gaze with master tool manipulator (EMTM) mode: this interface is introduced so that the tool position is maintained, which reduces the risk of incident due to tool movement. The point of gaze from the eye gaze tracker is used for the position input. The confirmation input comes from the MTMs. The detection area around all GUI buttons is set to be larger than the buttons to ease the selection with eye gaze. When the user holds the gripper and looks away, a continuous change in value will be made.

Eye gaze with voice recognition (EV) mode: this interface allows for hand-free ultrasound adjustment in case surgeon's hands occupied. The point of gaze from the eye gaze tracker is used for the position input. Google Cloud Speech API is used to transcript the audio to text. The words "confirm" and "cancel" are used for confirmation input. Instead of using the increase and decrease buttons, voice commands such as "increase zoom by 10%" are used to adjust the parameters. To increase the voice recognition speed, a fast command detection algorithm is designed. Instead of waiting for the full sentence to be processed, the algorithm detects key words to execute the commands (Fig. 2b).



(a) Eye gaze tracker



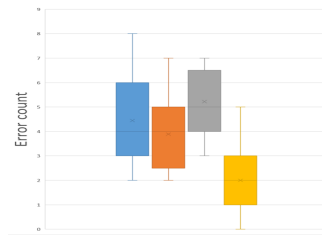
(b) Fast voice command detection algorithm

Fig. 2: Interfaces

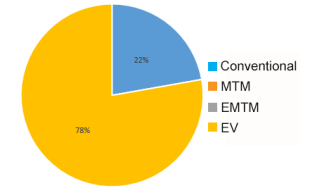
III. RESULTS

A user study (n=9) of subjects from Biomedical Engineering was performed to evaluate the efficacy of the interfaces in comparison to the conventional approach of dictation to an assistant. After a training session with each interface, participants were asked to perform well-instructed ultrasound tasks on a CIRS 040GSE Ultrasound Phantom with the ultrasound probe placed at the center. There were five types of tasks in total including adjusting each parameter to a specified value and switching between Doppler and B-mode. There were 20 tasks with each interface. The order of tasks was randomized, but with the same initial state and achieving state. Each participant used all four interfaces in a random order. After using each interface, participants filled in an adapted version of Nielsen Attributes of Usability Questionnaire. The completion time of all tasks, error of parameter adjustment and *etc.* were recorded as evaluation metrics for efficacy. Study results showed that *EV* achieved the lowest mean error rate (Fig. 3a) and was felt by the majority of the participants to be the most efficient interface (Fig. 3b).

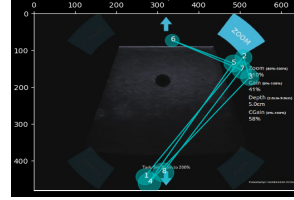
A protocol of scan-path and heat-map was developed for cognitive analysis (Fig. 3c, 3d).



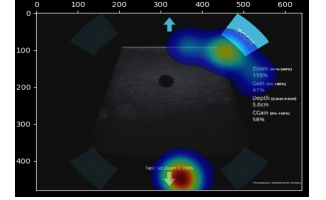
(a) Error count of parameter adjustment



(b) Distribution of perception for the most efficient interface



(c) Scan-path for eye gaze



(d) Heat-map for eye gaze

Fig. 3: Results

IV. DISCUSSION AND CONCLUSIONS

This work presents three novel interfaces for ultrasound control in a robot-assisted setting, incorporating eye gaze tracking and voice recognition. Each interface allowed the surgeon to perform ultrasound scanning without the need of an assistant, increasing their autonomy. Preliminary user study results showed that the combination of eye gaze tracking and voice recognition were received positively with low user error rate. However, optimization to each interface and an improved user study are required. Eye gaze tracking has the potential to improve the way surgeons interact with their instrumentation and increase surgical autonomy.

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