Feasibility of a touch-free user interface for ultrasound snapshot-guided nephrostomy

Simon Kotwicz, Andras Lasso, Tamas Ungi, Gabor Fichtinger

Laboratory for Percutaneous Surgery, Queen's University, Kingston ON, Canada

ABSTRACT

PURPOSE: Clinicians are often required to interact with visualization software during image-guided medical interventions, but sterility requirements forbid the use of traditional keyboard and mouse devices. In this study we attempt to determine the feasibility of using a touch-free interface in a real time procedure by creating a full gesture-based guidance module for ultrasound snapshot-guided percutaneous nephrostomy.

METHODS: The workflow for this procedure required a gesture to select between two options, a "back" and "next" gesture, a "reset" gesture and a way to mark a point on an image. Using an orientation sensor mounted on the hand as input device, gesture recognition software was developed based on yaw, pitch and roll angles. Five operators were recruited to train the developed gesture recognition software. The participants performed each gesture ten times and placed three points on predefined target positions. They also performed tasks unrelated to the sought after gestures to evaluate the specificity of the gesture recognition. The orientation sensor measurements and the position of the marked points were recorded. The recorded data was used to establish threshold values and optimize the gesture recognition algorithm.

RESULTS: For the "back", "reset" and "select option" gesture, a 100% recognition rate was achieved. For the "next" gesture, a 92% recognition rate was obtained. With the optimized gesture recognition software no misclassified gestures were observed when testing the individual gestures or when performing actions unrelated to the sought-after gestures. The mean point placement error was 0.55 mm with a standard deviation of 0.30 mm. The mean placement time was 4.8 seconds.

CONCLUSION: The system that was developed is promising and demonstrates potential for touch-free interfaces in the operating room.

Keywords: nephrostomy, operating room interface, gesture recognition, touch-free interface

PURPOSE

During image-guided medical interventions clinicians are often required to interact with visualization software. Workflow and sterility requirements do not allow a physician to use traditional mouse and keyboard devices. One common practice is for the physician to delegate a portion of the computer control to an assistant who is guided by verbal instructions from the physician. This indirection tends to be both inefficient and error-prone. A number of alternatives have been proposed in research literature that avoid this type of awkward delegated control. One such approach has been to use a touch screen that is encased in a sterile bag (Strauss *et al.* 2006). Although this allows the physician to interact directly with the computer equipment, the use of a touch screen is complicated by its sterile cover and keeping the touch screen within the reach of the physician at all times can be difficult (Chojecki and Leiner 2009). Speech recognition is another solution that has been proposed but due to the often noisy environment of an operating room its use can be problematic (Schafmayer *et al.* 2000).

Recently, a number of camera-based gesture interaction systems have been proposed for the operating room. Graetzel *et al.* (2004) used a stereo camera setup for tracking a physician's hand and moving a pointer on a screen. *Hurka et al.* (2011) proposed using optically tracked surgical instruments that are already part of a surgical navigation system to replicate point and click mouse functions. Hartmann and Schlaefer (2012) investigated the use of the Kinect to control operating room lights and Gallo *et al.* (2011) looked into using the Kinect as means to interact and navigate medical images. Although camera-based gesture tracking systems are promising, the crowded environment of the operating room can make it difficult for the physician to stay in direct view of the camera.

In this study a PhidgetSpatial Precision 3/3/3 High Resolution[1] sensor with a 3-axis gyroscope, magnetometer, and accelerometer was used as input device for gesture recognition. The device is very affordable and does not suffer from line of sight issues that burden camera-based tracking systems. The gesture recognition software that was developed was designed specifically for ultrasound snapshot-guided percutaneous nephrostomy but could be used in other interventions that require a dedicated computer operator. Percutaneous nephrostomy is an interventional procedure used to drain fluid from the renal pelvis and relieve acute pressure in the kidney. This particular procedure allows the clinician to use an ultrasound snapshot to plan both entry and target points prior to needle insertion (Ungi *et al.* 2012). The workflow for this procedure requires the clinician to interact with the visualization software in order to plan a desired needle trajectory. The purpose of this study was to develop a complete gesture-based guidance module for ultrasound snapshot-guided percutaneous nephrostomy and in doing so be able to better evaluate the feasibility of a touch free interface in a real-time procedure.

METHODS

The orientation sensor used as input device for gesture recognition was designed to be worn under a sterile glove mounted on top of the hand (Figure 1). The workflow for ultrasound snapshot-guided percutaneous nephrostomy was analysed in order to determine the set of required gestures. The general workflow for this procedure is outlined below:

1. Select patient position relative to the clinician (patient's head on left or right side of clinician).
2. Take an ultrasound snapshot in a position where suitable entry and target points are visible.
3. Place point markers to specify both entry and target points on the ultrasound snapshot.
4. Provide real-time visualization to help the clinician follow the planned needle path.

The necessary gestures to navigate this workflow were identified. The workflow requirements called for a gesture to select between two options, a "back" and "next" gesture, a "reset" gesture and a way to mark a point on an image. A number of gestures for each action were developed and tested. Among these gestures those that fit best with the workflow of the procedure were selected. The selected gestures felt the most intuitive and interfered the least with the hand motion performed during normal manipulation of the needle and probe.

A gesture recognition system was developed differentiating gestures based on yaw, pitch and roll angles (Figure 2). The goal was to create a reliable gesture recognition algorithm using gestures that were both simple and easy to perform. Since consecutive workflow steps are laid out vertically in the user interface, a pitch down gesture to move to the next step and a pitch up gesture to move to the previous step made for an intuitive way to navigate the workflow. When the user is required to select between two different options these are laid out horizontally and therefore using yaw angles to determine which option the operator is selecting also made for an intuitive interface. Similarly when placing point markers on an image, pitch and yaw angles are used to give the illusion the marker is following the operator's hand motion. The yaw angle that is considered as the horizontal midpoint is calculated based on the operator's current hand position. It is adjusted every time the

[1] PhidgetSpatial Precision 3/3/3: http://www.phidgets.com/products.php?product_id=1044_0

operator's hand moves in a position that would otherwise move the marker outside the image. The horizontal midpoint is calculated similarly for the "select option" gesture.

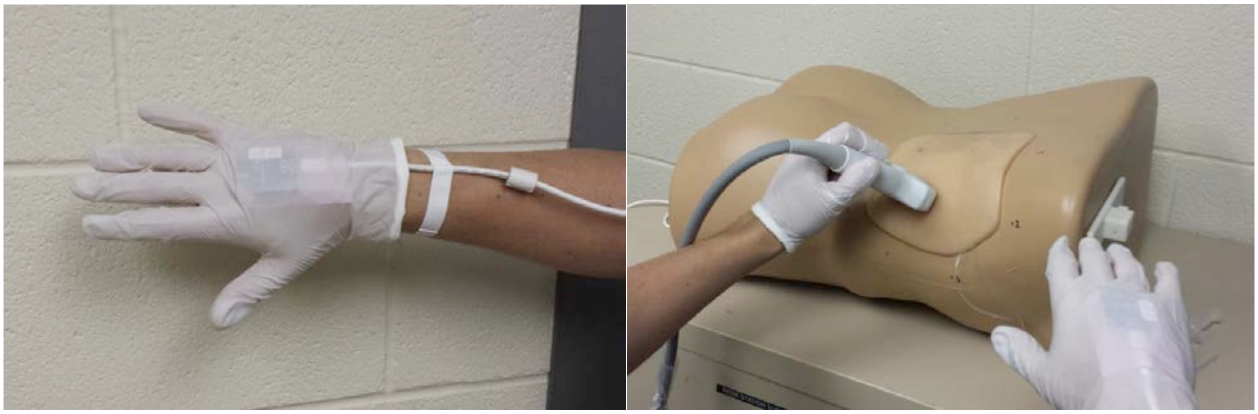


Figure 1. Orientation sensor mounted on the hand: experimental system setup (left) and taking an ultrasound snapshot of a phantom kidney (right).

In order to optimize the gesture recognition algorithm and evaluate the quality of the software, data was recorded from five operators performing the gestures. For the "back", "next", "reset" and "select option" gestures participants were given simple instructions on how to perform the gestures and were instructed to perform each gesture ten times waiting at least one second between each gesture. The only visual guidance that was given to the participants as they performed the gestures was for the "selection option" gesture where two options were presented and operators were told, for each gesture, to select one of the options. No feedback was given during testing as to whether each gesture had been recognized. The participants were then instructed to perform a number of tasks such as opening a zipper storage bag (to simulate opening a sterile needle) and scanning with the transducer. This data was recorded to identify motions that should not set off the gesture recognition system.

The recorded gesture data was replayed to evaluate and create an optimal algorithm for gesture recognition. For each gesture optimal angle rotations were manually determined to create an algorithm that had the highest possible recognition rate while avoiding any gesture misclassifications. The "select option" and "reset" gesture were not evaluated for potential gesture misclassifications together because they are never performed at the same step in the workflow. To evaluate the accuracy of marking a point using the orientation sensor, participants were given three predefined targets and were told to place a point on each target. Predefined target points were marked on a 230 mm by 176 mm ultrasound snapshot of the target anatomy (kidney in our case). One plausible needle entry point and two plausible needle target points (calyces in our case) were used as predefined target points. Both the existing and placed point positions were measured.

The gestures were also tested using the nephrostomy module that was developed. To simulate the procedure an electromagnetically tracked kidney phantom, ultrasound probe and 16cm hollow trocar needle with a tracked stylette were used. Input from these devices and the orientation sensor were sent to an Ultrasonix SonixTouch machine running the PLUS toolkit (Lasso *et al.* 2012) which was responsible for acquiring data and sending it to 3D Slicer[2] (Fedorov *et al.* 2012) in real-time at the rate of 10 samples per second. The gesture and nephrostomy modules were developed as extensions for 3D Slicer.

[2] 3D Slicer software platform: http://www.slicer.org/

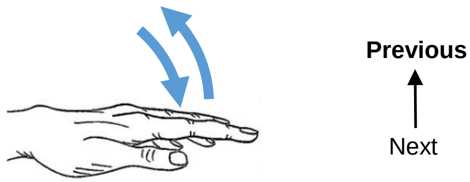
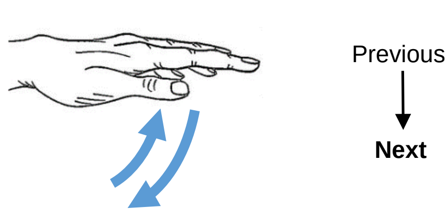
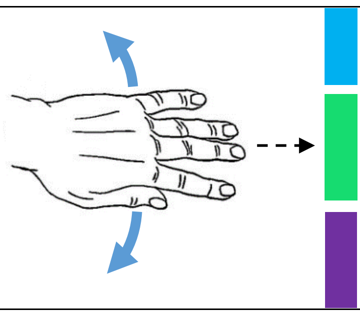
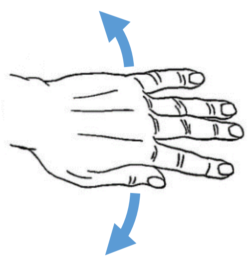
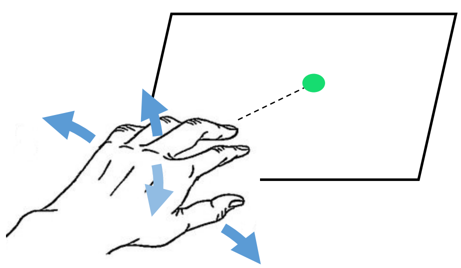
	**Back Gesture:** This gesture consists of moving the hand in a pitch up and then a pitch down motion. It is used to move one step back in the workflow.
	**Next Gesture:** This gesture consists of moving the hand in a pitch down and then a pitch up motion. It is used to confirm the current step and move to the next step in the workflow.
	**Select Option Gesture:** This gesture works by pointing the hand in the direction of the desired selection.
	**Reset Gesture:** This gesture consists of moving the hand in an “erase” motion (yaw left/right). It is used to undo the selection of a point or undo an ultrasound snapshot.
	**Placing Markers:** When placing a marker the marker moves with the direction the hand is pointing in. Holding the hand steady for 2 seconds will place the point. The colour of the marker gradually changes from green to red as the 2 seconds elapse.

Figure 2. Description of gestures that were developed and optimized.

RESULTS AND DISCUSSION

An optimized gesture recognition system was developed with the following properties. The pitch down gesture requires a 20 degree pitch down rotation followed by a pitch up rotation that is at least 60% of the pitch down rotation. At its mid-point the pitch angle must be at least 25 degrees below the horizontal. The pitch up gesture requires a 25 degree pitch up rotation followed by a pitch down rotation that is at least 40% of the pitch up rotation. At its mid-point the pitch angle must be at least 30 degrees above the horizontal. Each pitch gesture must be completed within 1 second. The erase gesture requires two 25 degree yaw rotations in opposite directions in under 0.6 seconds. The select option gesture requires a 25 degrees yaw angle to the left to select the left option and a 25 degree yaw angle to the right to select the right option. To place markers both yaw and pitch angles are used to give the x and y reference coordinates that can be used to calculate coordinates to place a marker. The x and y values provided range from -1 to 1 based on a yaw angle from -45 to 45 degrees and a pitch angle from -90 to 90 degrees. For both the select option and place marker gestures the yaw angle mid-point is rotated as needed to keep yaw angles within the angle range used. With the optimized gesture recognition software, a 100% recognition rate was achieved for the “back”, “reset” and “select option” gesture. For the “next” gesture, a 92% recognition rate was obtained. No misclassified gestures were observed when testing the individual gestures or when performing actions unrelated to the sought after gestures. To assess the accuracy of placing a point on the ultrasound snapshot, the distance between the target fiducials and the placed fiducials was calculated. The mean placement error was 0.55 mm with a standard deviation of 0.30 mm. Since this is within the average size of a calyx, this error was accepted and no further adjustments were made to the fiducial placement algorithm. The average time it took to place a point was 4.79 seconds.

The optimized gesture recognition software was linked with the nephrostomy module to create a complete gesture-based guidance module within 3D Slicer. A number of visualization tools were implemented to assist in creating an efficient needle trajectory during needle insertion. The needle, ultrasound probe, ultrasound snapshot and live ultrasound image are modelled in the 3D viewers. Two 3D views are used for guiding the needle insertion (Figure 3). The first 3D view shows the target and entry point overlaid on one another providing an easy way to line up the needle with the planned trajectory path. A status bar below tracks the progress of the needle tip from entry to target. The second 3D view is used to make sure the live ultrasound image lines up with ultrasound snapshot and verify that the kidney is in the same position it was when the ultrasound snapshot was taken. This is necessary because the kidney does not remain static in a breathing patient. Optional 2D viewers (Figure 4) are also provided to aid in needle navigation. These show the needle projection on the ultrasound snapshot and live ultrasound image.

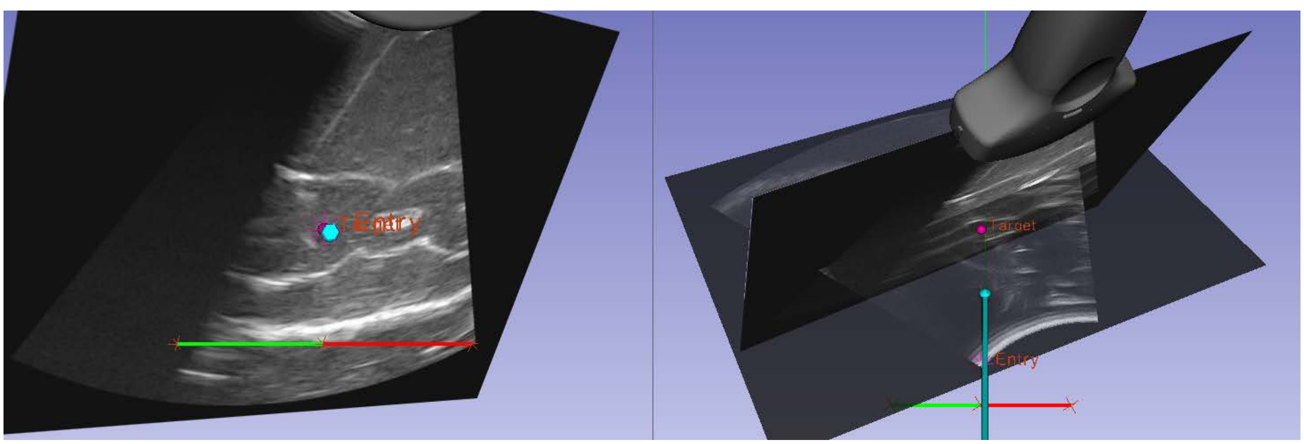


Figure 3. Nephrostomy module 3D visualization windows during needle insertion. Red/green ruler shows needle progress from entry to target.

Although a 100% recognition rate was not achieved for recorded gestures, it is conceivable that with little training and visual feedback one could obtain such results. The nephrostomy module was also created such that any step can be retraced, so that a software or user gesture error can always be undone. It would be desirable to train the gesture recognition software on a larger user base to investigate the reproducibility of these results. Results may also differ if a series of gestures were allowed to occur in rapid succession but this would be fairly uncommon within the workflow of the nephrostomy module that was developed.

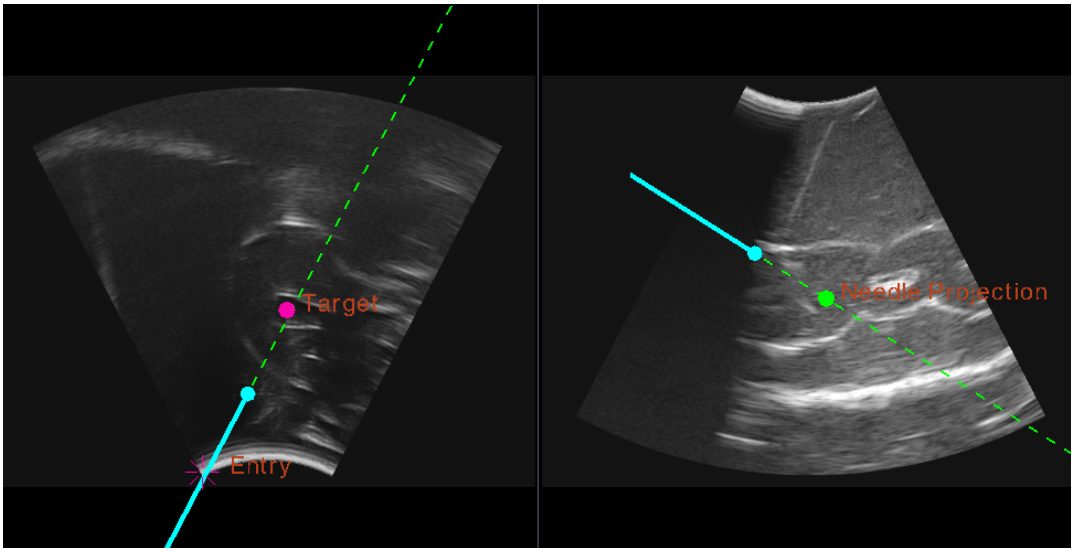


Figure 4. Nephrostomy module 2D optional visualizations to aid in needle placement. Ultrasound snapshot (left) and live ultrasound image (right).

Recently some notable gesture recognition devices have been developed which may allow for more complex and reliable gesture recognition software to be implemented. One of these is a wireless gesture control armband called MYO[3] which measures both orientation data and muscular electrical activity to determine finger position and motion. The first shipment of MYO gesture control armbands will be reaching consumers in early 2014.

In conclusion, a gesture recognition and user interface module for image-guided percutaneous nephrostomy was developed using an inexpensive sensor device. The system demonstrates potential for touch free interfaces in the operating room. Further work is required to identify a suitable device that can be worn by a physician and to evaluate its performance in an operating room setting.

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[3] MYO gesture control armband: https://www.thalmic.com/myo/

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