

Experimental Assessment of a Novel Touchless Interface for Intraprocedural Imaging Review

John Chung^{1,2}  · David M. Liu^{1,2,3}

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Abstract

Purpose To examine the feasibility of a novel technology platform that enables real-time touchless interaction with radiology images in both a simulated and an actual clinical setting.

Materials and Methods This platform offers three different modes for image interaction. The gesture recognition mode uses a depth camera to detect the user's hand gestures which are translated to image manipulation commands. The light projection mode uses the same camera to detect finger point-and-tap movements above the icons which are projected on a surface to activate the commands. The capacitive sensing mode is enabled by a handheld, portable device, over which finger movements are detected by capacitive sensors to control the image review. Following initial feedback, light projection and capacitive sensing modes were selected for further testing by comparing with the conventional mode of image interaction in time trials for performing a series of standardized image manipulation tasks. Finally, the usability of the technology platform was examined in actual clinical procedures.

Results The light projection and the capacitive sensing modes were evaluated in the time trials and exhibited 60%

and 71% reduction in time, respectively, relative to the control mode ($p < 0.001$). Clinical feasibility for this platform was demonstrated in three actual interventional radiology cases.

Conclusion Accessing, navigating, and extracting relevant information from patient images intraprocedurally are cumbersome and time-consuming tasks that affect safety, efficiency, and decision-making during image-guided procedures. This study demonstrated that the novel technology addressed this issue by allowing touchless interaction with these images in the sterile field.

Keywords Touchless image navigation · Human–computer interaction · PACS · Interventional radiology

Introduction

Review of intraprocedural imaging during an interventional radiology (IR) procedure is common and often crucial, but current practice is suboptimal [1–4]; it requires the operator to either leave the sterile field to use a computer or to direct an assistant to do so while the operator watches. It too often leads to diversions and cumbersome communication that negatively affect efficiency and decision-making during image-guided procedures [3, 5–9]. To overcome the limitations of the current practice, researchers have previously explored the use of voice commands to conduct image manipulation; however, this did not perform as expected due to the sensitivity of the voice recognition

✉ John Chung
john.chung@vch.ca

¹ Department of Radiology, University of British Columbia, Vancouver, BC V5Z 1M9, Canada

² Interventional Radiology Services, Vancouver General Hospital, G782, Jim Pattison Pavilion South, 899 West 12th Avenue, Vancouver, BC V5Z 1M9, Canada

³ School of Biomedical Engineering, University of British Columbia, Vancouver, BC V6T 1Z3, Canada

systems to the ambient noise that exists in the operating room [10]. Another approach was to provide a sterile touch interface console to provide image navigation controls near the operating table. In order to fulfill the needs of physicians, hand gesture-based recognition technologies have been developed to make image manipulation possible in the sterile environment [11–17]. Most of these efforts have not been rigorously tested to withstand the constraints and meet the challenging requirements of the IR suite and practice. A review of the literature on these technologies revealed mixed results on the benefits and readiness for use in a clinical setting [2].

In this study, we assessed a new touch-free human-machine interface (HMI) technology platform that employs a novel approach in the detection of hand and finger movements to intuitively control navigation and manipulation of radiology images within the sterile operative space (for example, over the drape). This platform has been designed, in contrast to current offerings which utilize consumer-facing sensor interfaces, to integrate smoothly into current practice, requiring minimal training and changes to existing workflow in the IR suite. The current study sought to determine whether use of this novel technology platform would result in time reduction by conducting an experimental assessment in a simulated setting. Additionally, we examined the clinical feasibility of the platform in a consecutive series of procedures in the IR suite.

Materials and Methods

There were three phases in this study: preliminary assessment, simulated time trials, and clinical validation.

Preliminary Assessment

Initially, the technology platform was designed to offer three user interfaces (or modes) for manipulation of images: gesture recognition mode, light projection mode, and capacitive sensing mode. The gesture recognition mode (Fig. 1A) utilizes an integrated 3D depth camera in an overhead configuration such that the physician's hand is held horizontally below the camera. It operates by means of real-time 3D image processing that correlates the physician's hand gestures with a defined hand gesture vocabulary. Detection of a given hand gesture results in the activation of a desired Image Manipulation Command (IMC; i.e., scroll, zoom, window/level, and pan) which is then transmitted to the imaging workstation.

The light projection mode (Fig. 1B) utilizes the same 3D depth camera and projection module in a similar overhead configuration but requires a surface upon which to project graphic content. It operates by means of projecting virtual icons for each IMC (i.e., symbols for scroll, zoom, window/level, and pan) over a desired sterile surface in the IR suite. Finger point-and-tap movements above the projected icons activate the desired IMC and allow for manipulation of the images.

Lastly, the capacitive sensing mode (Fig. 1C) does not require an optical detection mechanism, unlike the aforementioned modes. Icons associated with the different IMCs are marked on the surface of a plastic-enclosed handheld pad. The physician's finger taps and movements in the 3D space above the surface of the pad are detected by a capacitive sensor array inside the pad and then interpreted by a customized signal processing algorithm in order to manipulate the images according to the activated IMC.

Fig. 1 User interfaces for the novel image navigation platform. Control and manipulation of images are enabled by three different modes: **A** gesture recognition, **B** light projection [18], and **C** capacitive sensing [19]

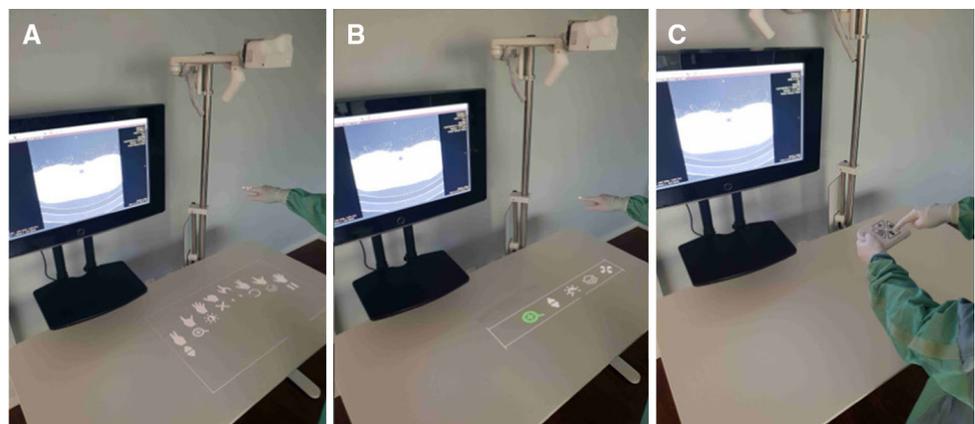


Table 1 The protocol used for the simulated time trial*Time trial protocol*

Preparation

Wear gown and gloves

Stand in front of the mobile workstation in the simulated operative space (in CESEI)

Load PACS viewer on mobile workstation

Load chest CT data set with multiple series

Start on the top of the image series

Timed sequence

Timing begins

For light projection or capacitive sensing modes:

1. Select 3rd series (axial arterial phase)
2. Magnify and pan until image fits screen such that the anterior abdominal wall touches the top margin of the screen and the back touches the bottom margin of the screen
3. Change the window and level to the 'bone' preset
4. Scroll to image 322

For conventional mode:

1. Remove gown and glove, enter control room, and sit in front of workstation
2. Select 3rd series (axial arterial phase)
3. Magnify and pan until image fits screen such that the anterior abdominal wall touches the top margin of the screen and the back touches the bottom margin of the screen
4. Change the window and level to the 'bone' preset
5. Scroll to image 322

Timing stops (add 3 min to the conventional mode to approximate time for re-gowning and re-gloving in actual cases)

Simulated Time Trials

Simulating the IR suite environment, the experiments were conducted at the Centre of Excellence for Simulation, Experimentation, and Innovation (CESEI) facility located

in and operated as part of Vancouver General Hospital. In this setting, participants first underwent user training with both experimental modes of image interaction and then were given 5 min of practice time. They then performed a standardized sequence of image manipulation maneuvers

Table 2 Clinical validation and the benefits of using the touchless technology

Procedure	Summary of the procedure	Utilization of the touchless technology
1. Chemoembolization of hepatocellular carcinoma	The procedure involved superselection of a branch of the hepatic arterial circulation to deliver drug-eluting microparticles into the arterial supply of a hepatocellular carcinoma	The touchless technology allowed repeated in-suite review of the preprocedure CT to identify key arterial anatomy, such as vertebral level of the celiac trunk origin, origin and course of the right hepatic artery, as well as origin and course of the target arterial branch. This eliminated the need to scrub out to review images, making the procedure more efficient (see Fig. 3)
2. Embolization of gastroduodenal artery (GDA) pseudoaneurysm	The procedure involved selection of a GDA branch from which the pseudoaneurysm arose, followed by combined coil and plug embolization of both the 'front door' and 'back door' of this branch	The touchless technology allowed repeated in-suite review of the preprocedure CT to identify key arterial anatomy, from celiac trunk origin to GDA origin and take-off of the target GDA branch, eliminating the need to scrub out to review images and rendering the procedure more efficient (see Fig. 4)
3. Coiling of splenic artery aneurysm	The procedure involved selection of a splenic artery aneurysm followed by coil and ethylene vinyl alcohol copolymer embolization of the 'front door' and two 'back doors' of the aneurysm	The touchless technology allowed repeated in-suite review of the preprocedure CT to identify key arterial anatomy, particularly of the orientation of the aneurysm 'back doors', eliminating the need to scrub out to review images and rendering the procedure more efficient (see Fig. 5)

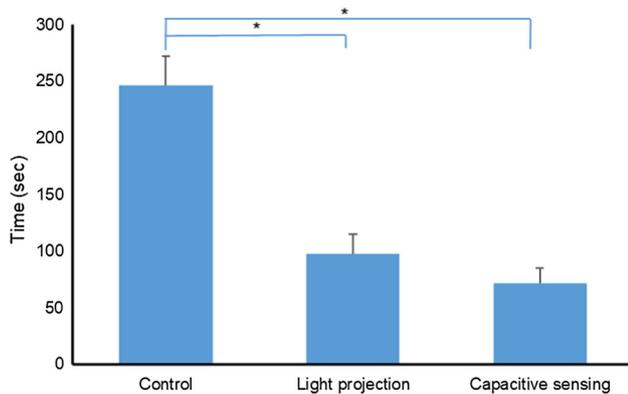


Fig. 2 Time trials for a standardized simulated series of image manipulation. Both the light projection and capacitive sensor modes of interaction demonstrated statistically significant reduction of the measured time when compared with the control mode of interaction. *Denotes $p < 0.001$

with the duration of time recorded by following the time trial protocol presented in Table 1. These were designed to simulate the scenario of an actual imaged-guided procedure. The same set of maneuvers was repeated in a control mode, whereby the participants reviewed the images using conventional means (i.e., scrubbing in/out of the sterile field and utilizing a computer in the control room).

Seven board-certified radiologists were recruited to participate in the simulated time trials. Statistical analyses were performed to identify significant differences between the various modes of image interaction. The distributions of the recorded times for each mode were tested for normality using the Shapiro–Francia test, and homogeneity of variance across the different modes was confirmed using the Fligner–Killeen test. Analysis of Variance (ANOVA) was then used to test for statistically significant differences among mean times for each mode. Finally, post hoc Tukey HSD tests were performed to determine exactly which modes differed. Statistical significance was set at $p \leq 0.05$.

Clinical Validation

In the third part of the study, the technology platform was integrated in the IR suite in three consecutive cases to confirm its clinical feasibility. Informed consent was obtained from the patients.

Results

Preliminary Assessment

We conducted a preliminary assessment of the technology platform by evaluating the usability of the three modes. The ten subjects involved in the preliminary assessment

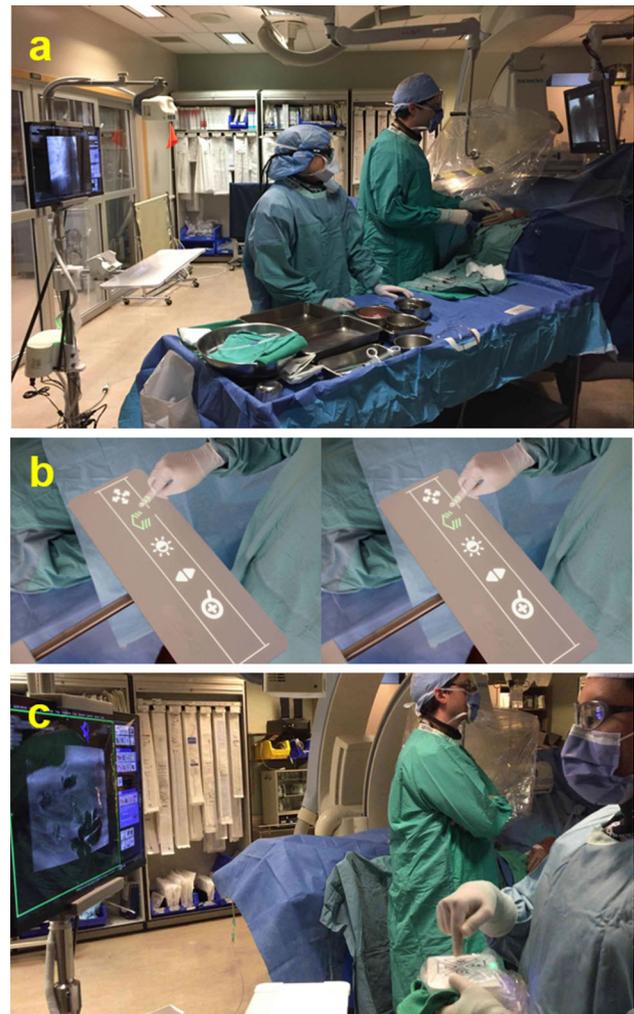


Fig. 3 Chemoembolization of hepatocellular carcinoma. **A** The light projection mode is ready to be used while the procedure is in progress. **B** The user is interacting with the light projection mode on a tabletop for image manipulation (changing the data series) [18]. **C** The user is reviewing patient images using the capacitive sensing device [19]

were all board-certified interventional radiologists; they collectively reported a preference for the light projection and capacitive sensing modes over the gesture recognition mode. Overall, the feedback revealed that the gesture recognition mode enabled reliable detection, but required memorization of a set of hand gestures to correlate with the commands. Furthermore, participants advised the need for a user guide to be referenced intraprocedurally. Therefore, it was not easy to adopt and thus removed from the experiments hereafter.

Simulated Time Trials

The two preferred image modes were then quantitatively assessed for usability in a time trial setting. Tests for

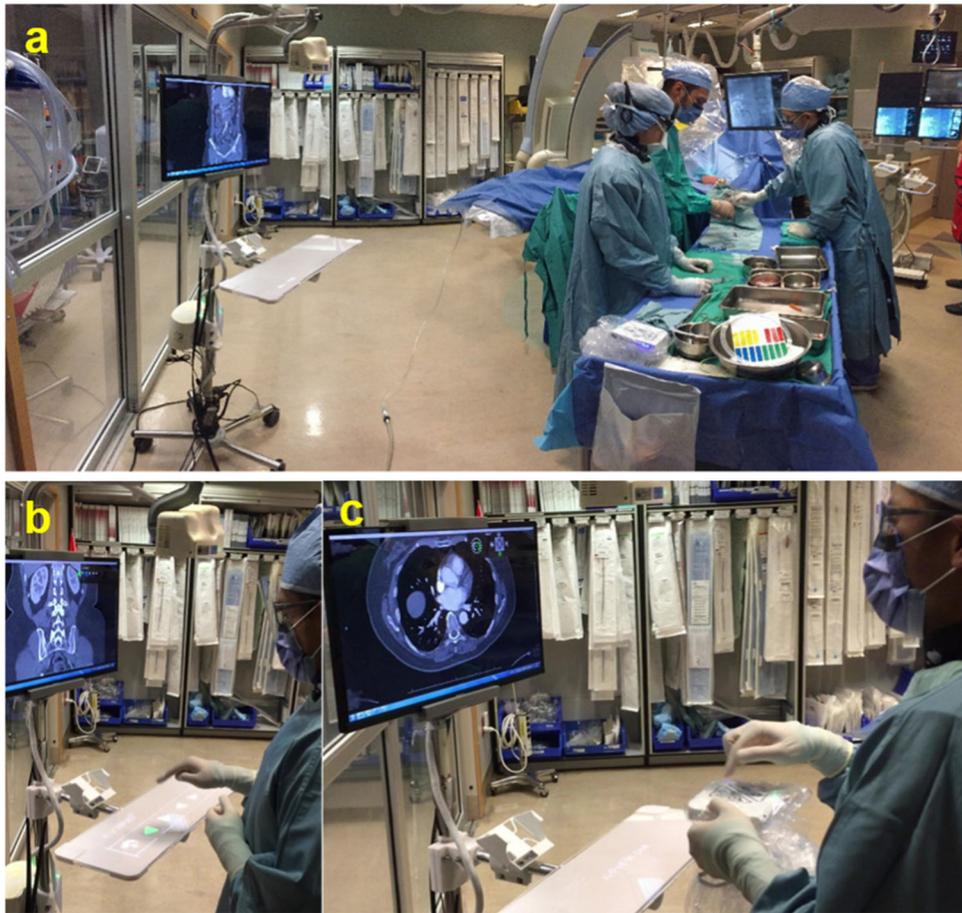


Fig. 4 Embolization of gastroduodenal artery pseudoaneurysm. **A** The procedure is in progress while the touchless image navigation device is ready. The user is controlling image review with **B** the light projection mode and **C** the capacitive sensing mode to scroll through the image frames of a series

normality indicate that the image manipulation times for the different modes are approximately normally distributed. Additionally, the modes demonstrate homogeneity in variance. Analysis by ANOVA revealed that at least one of the means is significantly different from the others (p value < 0.001 , $\alpha = 0.05$). Subsequent pairwise comparisons between each mode performed using the post hoc Tukey HSD test show that the mean image manipulation times for light projection mode (98 ± 17 s) and capacitive sensing (71 ± 13 s) mode are both significantly less than that of the control mode (246 ± 26 s) ($p < 0.001$) (Fig. 2). Precisely, use of light projection resulted in a 60% reduction in time relative to the control, while capacitive sensing demonstrated a 71% reduction in time relative to the control mode. The capacitive sensing mode trended toward a reduction in mean time relative to the light projection mode, although the difference is not statistically significant ($p = 0.057$).

Clinical Validation

A summary of the clinical validation of the novel technology in three actual IR cases is provided in Table 2. Overall, the technology platform performed well without errors or interruptions. The technology platform also contributed in all cases by enabling intraprocedural review of patient images, which eliminated the need to unscrub and conduct the review in the control room.

Discussion

Human–computer interactions (HCI) in IR and surgery are a growing area of research and development. Our study demonstrated that the novel HCI-based technology platform allowed touchless interaction with radiological images in the sterile field. Results showed evidence of time reduction in a simulated, standardized experimental setting. Furthermore, we examined the feasibility of integrating this

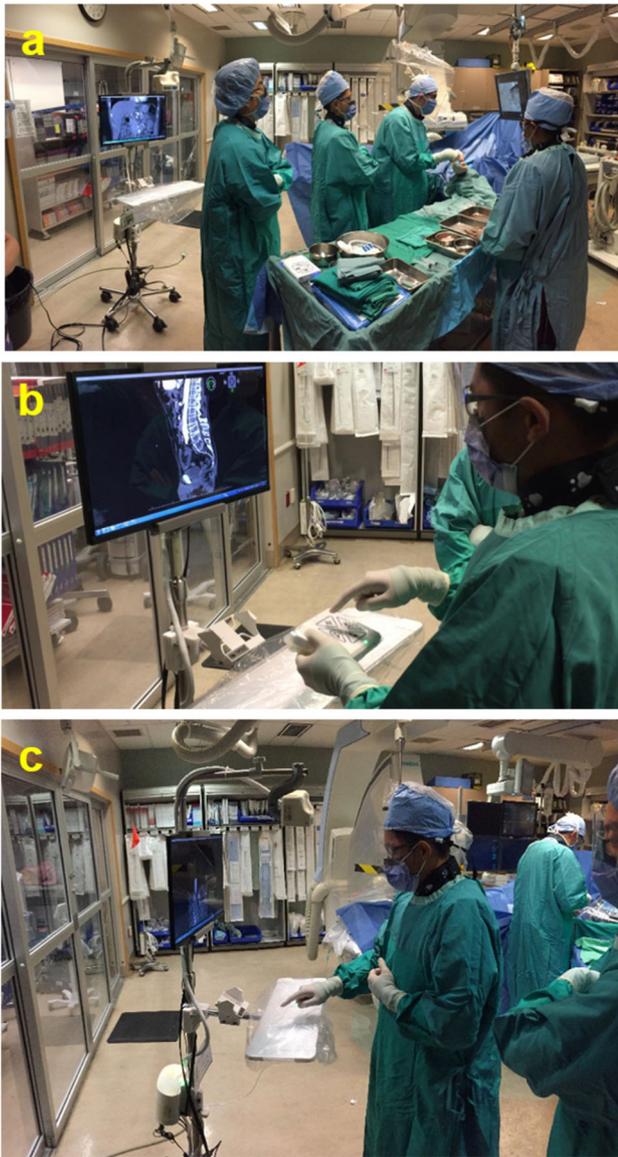


Fig. 5 Coiling of splenic artery aneurysm. **A** The image navigation device is ready while the procedure is in progress. **B** The user is implementing the capacitive sensing device to scroll through the images. **C** The user is using the light projection mode to review an image

technology into several actual clinical cases. These cases demonstrated that this platform allowed improved procedural efficiency by eliminating the need to scrub out to review images.

A review of the current literature shows that prior studies featured developments based primarily on either Kinect or Leap Motion Controller platforms with hand/limb gestures as the mode of image interaction and control [2]. Results from the experiments have been mixed. Overall, these studies reported short training times and ease-of-use responses from the study participants; however, several findings revealed a considerable rate of false-positive

movement detection or indefinite benefits over the existing mode of image interaction, such as the conventional keyboard and mouse [11–17]. While further developments have targeted enhancing user interaction by integrating adjunctive modes of input (such as voice recognition, myoelectric control and inertial sensing), most of the reviewed studies were limited to laboratory investigations with little evidence of actual trials in the clinical setting [10, 20].

The current study demonstrates evidence of applicability of the touchless image navigation for few cases tested. Further studies are underway to further evaluate its role in specific clinical therapies in the IR suite, as well as the operating room.

Author's Contribution JC and DML are advisors of NZ Technologies Inc.

Compliance with Ethical Standards

Conflict of interest JC and DML are advisors of NZ Technologies Inc.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Consent for Publication Consent for publication was obtained for every individual person's data included in the study.

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