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Application of Natural User Interface Devices for Touch-free Control of Radiological Images During Surgery

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***Abstract*—Natural User Interface (NUI) systems can enable the scrubbed clinician to assume direct control of medical image interaction while maintaining sterility in the Operating Room. Surgeons and radiologists trialed a touch-free image control system based on the Leap Motion and Microsoft Kinect v2 controllers. Feedback was reported on the perceived utility and usability of both devices. The speed and accuracy of the two controllers was measured. Results showed marginal to average acceptability of both controllers. Surgeons and Interventional Radiologists found Microsoft Kinect to have better utility and to be potentially useful for the majority (54%) of them. The accuracy of the Leap Motion sensor was superior and comparable with that of a computer mouse. A link was established between the system usability and the perception of utility with better usability translating into better utility. Advantages and limitations of each device are highlighted. Design improvements and deployment considerations are discussed.**

Keywords- Human-computer Interaction (HCI), Natural User Interface (NUI), System Usability Scale (SUS), Radiology, Surgery

I. INTRODUCTION

The U.S. Centre for Disease Control (CDC) defines Surgical Site Infection (SSI) as "*an infection that occurs after surgery in the part of the body where the surgery took place*". Despite modern protocols and improved techniques for cross infection control SSIs remain common and account for almost a third of all healthcare-associated infections among hospitalized patients [1]. The CDC estimates that 157,500 SSI associated with inpatient surgeries occurred in 2011 in the U.S. [2]. Any physical object in the Operating Room (OR) can contribute to the spread of infection. Schultz *et al.* reported that 95% of the tested computer keyboards in a tertiary hospital have confirmed positive for microorganisms [3]. The computer keyboard and mouse have been shown to have a greater rate of microbial contamination compared to other items within a surgical ICU [4].

The requirement to routinely interact with medical images in the OR using traditional mouse and keyboard challenges the capability of the scrubbed clinicians to maintain asepsis. Touch-free interface systems offer a solution to this problem by enabling direct and dynamic image control without any physical contact. A number of studies have demonstrated the feasibility of utilizing Commercial Off-The-Shelf (COTS) sensors such as the Microsoft Kinect (Microsoft Corporation, Redmond, WA, USA) and Leap Motion (Leap Motion Inc., San Francisco, CA, USA) for touchless medical image interaction in the OR [5-16].

Further to maintaining sterility, employing gesture based interactions can enhance the way healthcare professionals use imaging data in the OR by reducing the need for representation when manipulating images. Using Natural User Interface (NUI) can also decrease the cognitive load when interacting with 3D virtual environments [17]. For example, Gallo demonstrated a Kinect-based 3D interface with up to nine degrees of freedom [8] and Kirmizibayrak *et al.* found that certain tasks such as volume rotation and target localization are performed more effectively using hand gestures rather than traditional computer mouse [18]. In addition, the use of NUI can create new opportunities for imaging practices and surgical team collaboration such as the ability to discuss and collaboratively interpret medical imaging and review intervention plans [6].

In order to successfully realize the potential benefits from the NUI systems in clinical settings, the technology has to be both useful and usable. Effective convergence of utility and usability in the implementation of an interactive computer system is essential [19] and both factors are considered of equal importance [20]. The perceived usefulness of an information technology system is established as a key determinant of its use and acceptance in the healthcare setting [21]. Equally, the usability of a clinical information system is essential for its adoption and use [22]. It is therefore important that NUI image control systems devised for use in the OR are evaluated in terms of their utility and usability in order to ensure the success of their ultimate design and implementation [23, 24].

In this paper the utility and usability of the Microsoft Kinect for Windows v2 and Leap Motion NUI devices are evaluated and compared. The measurement of usability is formalized by using an established, valid and reliable method. Additionally, the study findings are compared to the findings of Tan *et al.*, who established that the majority (69%) of radiologists in an interventional radiology practice find Microsoft Kinect potentially useful [5], are applicable for the Microsoft Kinect v2 and Leap Motion sensors, when used by surgeons and radiologists.

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II. Materials and Methods

A mixed method design study was performed in a non-sterile, controlled setting. The study received Institutional Review Board approval from the University of Dublin, Trinity College and from St. James's Hospital, a large academic teaching hospital. Informed consent was obtained from all participants. The study incorporated a quantitative assessment of the two sensors (Microsoft Kinect for Windows v2 and Leap Motion) together with a standard computer mouse, and a qualitative field study. The quantitative assessment involved recording results from a pre-defined measurement task (measuring the size of an anatomical structure) to assess the speed and accuracy of each of the three input devices. The qualitative component involved a semi-structured questionnaire with a number of 5 and 3 point Likert scale questions as well as several open questions. Perceived usability was measured using the System Usability Scale (SUS) as a reliable and valid instrument for psychometric assessment of usability [25, 26].

The method for system utility assessment from the study of Tan *et al.* was reused in order to allow for comparison of results [5]. In their study, they asked: "*Do you feel that this system would be useful in an interventional radiology practice?*" This question was modified to reflect the wider range of clinical specialties in the population sample of this study and to identify the specific device: "*Do you feel that a NUI system based on the Microsoft Kinect / Leap Motion controller would be useful in your practice?*" One additional question using similar wording was added to allow for internal consistency assessment: *"Do you feel that a NUI system based on the Microsoft Kinect / Leap Motion controller will give you a greater degree of control in your practice?"*

The NUI medical image control system used in the trial was provided by TedCas Medical Systems, a healthcare technology company, at no cost and solely for the purposes of this research. An iterative design phase, involving two clinicians, was completed prior to performance assessment of the two sensor devices. The complete standalone system consisted of:

- One TedSIGN appliance with an integrated Leap Motion controller. The appliance was running Windows 7 OS and included the ClearCanvas Open Source diagnostic image review software. It was connected to a 17" Dell LCD monitor.
- A laptop computer running Windows 8.1 OS with an instance of the TedCas TedGapp application integrated with the ClearCanvas Open Source diagnostic image review software. The computer interfaced with the Microsoft Kinect for Windows v2 controller via USB. It was connected to a 17" Dell LCD monitor.

For the objective measurements of the speed and accuracy, ten residents in radiology were recruited as study participants and asked to measure the diameter of an anatomical structure in a specified radiological image (descending thoracic aorta, CT scan slice) five times with each of the three input devices: Leap Motion, Microsoft Kinect v2 and a mouse.

For the analysis of the subjective perception of the system utility and usability, a total of forty two clinicians, including the ten radiology residents, were enrolled as participants and required to trial both motion controllers and to complete the study questionnaire. In order to minimize the potential similarity bias, the first device to be trialed by each participant was alternated between the Leap Motion and Kinect v2. Two short video tutorials, one for each device, were prepared in collaboration with TedCas. Printed task instructions were also provided. For each device, every participant followed a five step procedure:

1) *Viewed the video tutorial.*
2) *Answered the two questions on utility.*
3) *Performed a predefined task which involved scrolling to a predetermined image, zooming and measuring an anatomical structure.*
4) *Completed the System Usability Scale (SUS) questionnaire.*
5) *Answered the two utility questions once more.*

Three-way Analysis of Variance (ANOVA) was used to compare the accuracy and the speed of measurement of the three input devices. The null hypothesis is that all three devices have the same performance. In conjunction with the ANOVA test, the Tukey's HSD (Honest Significant Difference) Test was used to compare each pair of input devices separately. The Wilcoxon Signed-Rank Test was used to compare the SUS ordinal scale usability measures for Microsoft Kinect v2 and Leap Motion. This test was chosen because study participant SUS scores for the two sensor devices are paired data as they belong to a single individual. The null hypothesis is that there is no difference in the usability of the Microsoft Kinect v2 and Leap Motion sensors. The Fisher's Exact Test was used to examine the significance of association between the subject's age, computer literacy, prior gaming experience, prior familiarity with the sensors, clinical specialty, level of training and their perception of the usability and utility of each of the sensor devices.

III. Results

Based on three sets of fifty measurements (one set for each of the three interface devices: Microsoft Kinect for Windows v2, Leap Motion and a wireless computer mouse), performed by the ten radiology residents, it was established that:

- The speed of measurement of the Microsoft Kinect and Leap Motion controllers was comparable (11.33s and 11.25s average *time to measure*, respectively) but considerably lower than that of the computer mouse (3.12s). The analysis of variance test confirmed that the Microsoft Kinect and Leap Motion mean *time to measure* was statistically equivalent ($p = 0.93$).
- The accuracy of the Microsoft Kinect was the poorest, with the anatomical structure measurement data points spread over a larger range of values. In contrast, the Leap Motion data set had a mean anatomical structure measurement that is statistically comparable to that of the PC mouse ($p = 0.415$).

A total of forty clinicians provided valid questionnaire responses. More than half (60%) of these were less than 40 years of age, with the remainder aged between 40 to 60 years. Diagnostic Radiologists comprised 30% (n=12) of the study participants. The remaining 70% (28) were Surgeons or Interventional Radiologists. The surgical specialties represented included Cardiothoracics (n=2), Urology (n=2), Gastrointestinal (n=5), Otolaryngology (n=1), Orthopedics (n=4), Maxillofacial (n=4), Plastics (n=3) and Vascular (n=4). With regard to the level of professional training, 37.5% (n=15) of the study participants were attending physicians / consultants and the rest were residents. The majority of the study participants self-reported good computer skills (82.5% (n=33) were comfortable installing software) and marginal gaming experience (77.5% (n=31) did not play any video games). The NUI medical image control system and both sensor devices were a novelty for the clinicians participating in the study. None of them had any prior experience with Leap Motion while only 20% (n=8) had used Microsoft Kinect in the past.

System usability was rated as proposed by Bangor, Kortum and Miller [27]. Analysis of the SUS scores of all study participants determined that the usability of both motion sensors was statistically comparable (p=0.251), with both devices scoring marginal acceptability rating. When the responses of Diagnostic Radiologists were excluded, the Microsoft Kinect v2 controller performed better with regard to its perceived usability (p=0.029) and its rating was acceptable (Table I).

TABLE I. ACCEPTABILITY BASED ON THE AVERAGE SUS SCORES

Participants	***Leap Motion***	***Microsoft Kinect v2***
All participants	Marginal, High (63.4)	Marginal, High (66.1)
Surgeons and Interventional Radiologists	Marginal, High (63.8)	Acceptable (71.7)

Analysis of the association between the SUS score and the study participants' age, level of training, gaming experience, self-reported computer proficiency, and prior experience with the sensors showed no statistically significant relationship.

In terms of utility, half of the participants (20 of 40) rated Microsoft Kinect v2 as potentially useful in their practice while only 38% (15 of 40) did so for the Leap Motion controller. The preference for the Microsoft Kinect v2 sensor was even more evident when the responses of the Diagnostic Radiologists were excluded from the results with more than half of the Surgeons and Interventional Radiologists (54%, 15 of 28) rating the Microsoft Kinect v2 system as potentially useful. In contrast, only 39% of them (11 of 28) perceived Leap Motion as having good utility. Analysis of the association between the system utility and the study participants' age, level of training, gaming experience, self-reported computer proficiency, and prior experience with the sensors only found that younger study participants considered the Leap Motion interface more useful than older ones (p = 0.04). None of the participants had any prior experience with the Leap Motion sensor.

There was a statistically significant link found between the reported system usability and its perceived utility, with better usability resulting into better system utility and poorer usability leading to poorer perception of utility. This was valid for both sensors when the responses of the Diagnostic Radiologists were excluded from the data set (Table II). Furthermore, the comparison of user responses, before and after them trialing the NUI medical image control system, showed that for 37.5% (14 of 40) of the participants there was a deterioration in their perception of the Leap Motion utility. For Microsoft Kinect v2, which was rated higher in terms of usability, deterioration in perceived utility was observed in only a quarter (10 of 40) of all cases.

TABLE II. UTILITY VS. USABILITY (FISHER'S EXACT TEST)

Study	***Leap Motion***	***Microsoft Kinect v2***
All participants	p=0.054 (non-significant)	p=0.022 (significant)
Surgeons and Interventional Radiologists	p=0.025 (significant)	p=0.036 (significant)

Answers to the unstructured questions were provided by more than half (53%) of the forty study participants. These responses covered a broad spectrum of views about the utility and usability of the two systems. The general consensus, however, was that the systems can be useful. This is in line with the results from the utility analysis. The following four responses illustrate the variance of opinions:

"*Not sure about the role in current practice.*"

"*Limited usefulness to surgery, IR. Most image manipulation is performed prior to any intervention. If needed during a procedure, something has gone wrong.*"

"*Excellent idea which would be extremely useful.*"

"*Concept brilliant*"

The value of a system which allows for touchless medical image control within the sterile environment of the OR was clearly articulated: "*Good idea especially for CT guided procedures and IR. I see how it would be very useful in theatre also as I have scrubbed out as surgical SHO [Senior House Officer or resident] in order to look at images!*" The NUI system usability shortcomings were also highlighted "*Good idea. Will obviously need work + tweaks [sic].*"

Opinions about the two sensors varied. The Microsoft Kinect sensor was often found tiresome to use ("*Arm got tired!!!*", "*Tiring having to keep arm elevated*") and less accurate for taking measurements ("*needs to be more accurate*"). It was, however, the one which more people saw better potential in due to its "*Bigger sensor field.*" Overall, albeit its present implementation limitations, the Microsoft Kinect was acknowledged to have "*potential if can be improved*".

Contrariwise, some people preferred the Leap Motion with some considering it a "*Very sleek interface.*" Its better accuracy was acknowledged: "*Better than Kinect in terms of more reproducible measurements and less variability*" and some participants offered their explanation of why they think the sensor is more accurate: "*Closer to screen so easier to control detail, i.e. diameter of vessel [sic]*". The smaller field of view of the Leap Motion sensor was found to be a disadvantage for use in the OR by a number of participants: "*Control panel width/range short. Have to stay too close to interface as a scrubbed surgeon.*"

IV. Discussion

A. Accuracy of measurements

Microsoft Kinect for Windows v2 was found to have poorer measurement accuracy. Contributing factors for this can be inadequate size of the display monitor, user position outside the sensor field of view, the poorly designed gesture controls and the chosen motion-smoothing algorithms.

The Microsoft Kinect v2 requires the operator to stand 1.5 to 2 meters from the display which can impact on the intelligibility of the displayed biomedical image in the case of a 17 inch display. The chosen level of zoom, which differed between users, can further compound this issue. The THX visual reproduction quality assurance system recommends a 50 inch class HDTV for viewing distance of 1.5 to 2.2 meters [28], thus a larger in size and well positioned display can improve on the measurement accuracy. Furthermore, participants who were shorter in stature were located at the edge of the Microsoft Kinect v2 sensor's field of view and as a result tracking of their gestures was of poorer quality. Mounting the sensor in a manner that allowed for finer tilt adjustments resolved this issue. Therefore, an important aspect of the NUI medical image control system deployment is the ability to maintain direct line of sight between the sensor and the clinician.

The choice of gestures can also impact on the accuracy of measurements. For both sensors, the system required the clinician to hold their hand still for two seconds in order to begin or finish a measurement. This was found to be insufficient for the Microsoft Kinect v2 as in certain cases, when the user slowed down in order to accurately select a start or an end point, the measurement was completed prematurely. An earlier version of the NUI system allowed for mouse "click" type gestures, such as those outlined by Soutschek, Penne, Hornegger, and Kornhuber [29]. These were purposely removed from the gesture vocabulary used for the study as an issue was observed where the cursor position changed during the "click" gesture (make a fist for Kinect and finger tap for Leap Motion). Bowman, Kruijff and Poupyrev call this the "Heisenberg effect" [30]. One possible way to avoid this issue is to implement gestures based on both hands [31] and voice commands [32].

Hand tremor and general noise due to factors such as ambient lightning, position relative to the sensor device and rounding effects can impact on the precision and accuracy of gesture recognition. Both Leap Motion and Microsoft Kinect for Windows v2 have smoothing filter functions included as part of their software development tools. One area for further investigation is the use of filtering algorithms to improve the accuracy of the NUI system. Four such filters are evaluated by Edwards and Green in their study [32]. Tan *et al.* [5] have described one smoothing algorithm they have utilized to enable fine movements for their Kinect-based intraoperative image control system.

B. Speed of operation

Based on the study results, the computer mouse outperformed considerably both sensor devices in terms of speed of measurement. The NUI system requirement to hold the user's hand still for a total of four seconds, in order to complete one measurement, is partially contributing to the longer *time to measure* of the two motion controllers. NUI controllers have been shown as capable of performing equally or better than a computer mouse in terms of their speed of operation however this can be achieved with sufficient practice [12, 33]. The fastest *time to measure* for both Microsoft Kinect v2 and Leap Motion sensors was nearly half of the respective average values. This indicates that the *time to measure* can be improved on through practice. Therefore, organizing structured training is an important aspect of any prospective NUI system deployment.

C. System usability

The average usability ratings of the two study systems were relatively poor with only Kinect achieving an acceptable score. Nevertheless, all participants were able to successfully complete the specified task. This is in line with the findings of Soutschek, Penne, Hornegger, and Kornhuber [29] and other NUI systems studies who report that proper handling of the system is relatively easy to attain. Microsoft Kinect was identified as the better performing device. This is despite the fact that users found it physically tiresome and exerting bigger physical effort than the Leap Motion controller. Francese, Passero and Tortora report similar findings [34].

An important determinant of the system utility is its gesture vocabulary. O'Hara *et al.* advise that the gesture vocabulary should be devised with due consideration for the clinical context of use and the strict constrains of intraoperative practices [6]. The gesture vocabulary of the evaluated NUI system was limited to a small set of commands, more specifically images set and scan slice scrolling, windowing, pan and zoom and the basic measurement commands. These commands were perceived to be the most commonly used and of most relevance within the OR practice, an approach also adopted by Strickland, Tremaine, Brigley, and Law in the design of their system [9]. Furthermore, it was noted by some of the study participants that having functions which allow the user to reset the image view when using the zoom, pan and window commands can improve the system usability. This type of functions have previously been employed by Ebert *et al.* and O'Hara *et al.* [10, 16]. A notable feature is also the ability to lock (engage) and unlock (disengage) the NUI system [6, 9, 35]. This functionality was available in the Microsoft Kinect v2 variant of the TedCas NUI system but it was not implemented for the Leap Motion interface.

The gesture recognition accuracy can be enhanced using contextual information such as user head and torso orientation or delay between commands and command history [11]. Utilizing speech recognition is another way to augment the gesture interface system. Recent studies, however, caution the use of voice commands due to the background noise in the OR [6] and the varying accents of the clinicians [11]. In the case of the Microsoft Kinect sensor, which is equipped with a microphone array, using voice interactions for certain type of discrete commands, such as reset view, is appropriate and can be useful [16]. This can also help reduce the physical effort associated with the Kinect interface.

D. System utility

In terms of utility, the study results showed that more than half (54%) of the participants, who were Surgeons or Interventional Radiologists, considered the NUI medical image control system based on Microsoft Kinect v2 useful. These results, despite being positive, are less favorable than the ones reported by Tan *et al.* [5]. In their investigation, during a similar research trial involving 29 interventional radiologists, 69% of the participants found the Microsoft Kinect based Touchless Radiology Imaging Control System (TRICS) as potentially useful. In both studies, the age profile of the participants was similar. Here, however, a wider variety of clinical specialties were represented with Interventional Radiologists comprising only 7.5% of the population sample. The variance in perceived usefulness across sub-specialties, with certain specialists more likely to find the devices potentially useful, can in part account for the difference in results of the two studies. In this study, Orthopedic and Vascular surgeons reported the highest perceived utility.

The established link between the system usability and system utility indicates that poor usability translates into poor perception of utility. The observed drop in perceived utility, following the actual use of the two motion controllers by the study participants, further validates that shortcomings in the system usability negatively impact on its utility. The poorer usability of the Leap Motion controller can thus rationalize the result that only 39% of the participating Surgeons and Interventional Radiologists found the device categorically useful.

E. Future developments

A number of new COTS sensors are being currently developed and will be soon generally available. Some examples are the MYO gesture control armband [15], the Eye Tribe eye tracker (The Eye Tribe Aps, Copenhagen, Denmark) and the Neyya thumb ring motion sensor (Fin Robotics Inc., Palo Alto, CA, USA). These can all be used as NUI system input devices, separately or in tandem with the Kinect and /or the Leap Motion sensors. An essential feature of a NUI system using multiple input devices will be the ability to fluidly switch between the different interfaces or to integrate their input data. Bigdelou, Schwarz, Benz, and Navab present framework architecture of a component system which integrates the Microsoft Kinect sensor input with the input of a system of four wireless orientation sensors [36]. This type of NUI system can potentially address the issues of IR interference and no line of sight.

F. Future research recommendations

1) Understanding the individual surgical practices and their specific requirements and establishing the optimal gesture vocabulary.

2) Establishing the type and amount of practice required in order to achieve optimal user performance.

3) In situ evaluation of the impact of the NUI system on existing workflow and work practices in the OR.

4) NUI system technology acceptance evaluation and research into the factors facilitating system adoption.

These can benefit both system developers and hospital stakeholders by informing what is necessary for a successful implementation, adoption and operation of a NUI system for medical image control in the OR.

G. Strengths and limitations

This study builds on previous research on the application of NUI systems for image control in surgery and formalizes the usability evaluation by employing the valid and reliable System Usability Scale (SUS). Considerable effort was made to recruit the participants randomly. Nevertheless, clinical doctors with general interest in technology might have been more inclined to take part and this may have introduced participation bias. In addition, the fact that the quantitative and qualitative experimental data has been collected solely by the principal investigator may have introduced a degree of measurement bias [37].

V. CONCLUSION

This study reaffirms that a NUI system for gesture control of radiological images using COTS sensors is feasible and that it can benefit the practice of surgery by enabling touchless interactions with imaging data in sterile clinical environments. The deployment of the NUI system in the OR should be carefully assessed and planned, particularly with respect to the sensors placement and the choice of display. The NUI system usability can be enhanced by implementing design changes which improve its accuracy as well as the system gesture vocabulary. The Kinect sensor can benefit from the implementation of voice commands. Integrating the input from different types of sensors can improve the system consistency and reliability. Further research is required to establish the design features, implementation guidelines and user practice requirements that can ensure positive operation in varying clinical areas.

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