MR in OR: First analysis of AR/VR visualization in 100 intra-operative Freehand SPECT acquisitions

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Abstract

For the past two decades, medical Augmented Reality visualization has been researched and prototype systems have been tested in laboratory setups and limited clinical trials. Up to our knowledge, until now, no commercial system incorporating Augmented Reality visualization has been developed and used routinely within the real-life surgical environment. In this paper, we are reporting on observations and analysis concerning the usage of a commercially developed and clinically approved Freehand SPECT system, which incorporates monitor-based Mixed Reality visualization, during real-life surgeries. The workflow-based analysis we present is focused on an atomic sub-task of sentinel lymph node biopsy. We analyzed the usage of the Augmented and Virtual Reality visualization modes by the surgical team, while leaving the staff completely uninfluenced and unbiased in order to capture the natural interaction with the system. We report on our observations in over 100 Freehand SPECT acquisitions within different phases of 52 surgeries.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Artificial, augmented, and virtual realities—;

1 Introduction

Medical Augmented Reality (AR) is a much researched field, with increasing numbers of publications on hardware and technology [6, 31, 19, 32], visualization [22, 10, 11, 23], usability studies [12, 5, 17, 7] and experimental work [16, 24]. While many previous publications created excellent insight for the community on how to achieve realistic blending of real-world information with virtual data, the actual application of these technologies has so far often been limited to laboratory setups [31, 27] or limited real-life studies, e.g. on very few selected cases [16] or cadaver and phantom studies [26].

In this work, for the first time, we present observations and data analysis concerning the usage of a commercially developed and clinically approved surgical navigation system, which incorporates monitor-based Mixed Reality (MR) visualization, during real-life surgeries. We analyze the usage of interchangeable Augmented and Virtual Reality (VR) visualization modes by the surgical team and report on our observations in over 100 Freehand SPECT acquisitions within different phases of 52 surgeries.

Perhaps the only comparable study to this one is the study of Wang et al., who reported on the usage of CamC [16], a prototype system used during a limited round of early clinical trials [26, 28]. In that study, approximately 40 cases in which a camera-augmented mobile C-arm x-ray system was used intra-operatively, were documented and analyzed. A workflow-oriented study was used to reveal that radiation exposure can be significantly reduced in specific workflow steps, due to the augmentation of the x-ray image with a real-time camera video stream. These steps, such as patient localization, skin incision placement or tool posture adaptation, are common to many surgical procedures. Thus, due to the study, very specific advantages of AR visualization modes were found, sometimes unexpectedly, for particularly common workflow steps.

In this report, we are following a similar approach. We report on the usage of a different device, which shares the possibility to augment the real-world image with virtual information, visualized on a monitor. The device we present is a Freehand SPECT device, allowing flexible 3D reconstructions of radioactive emissions from the tissue marked by specific tracer substances. The device combines a regular, hand-held radioactive counter, namely a gamma probe, with an optical tracking system. The acquisition is performed in a freehand motion, i.e. without restricted or prescribed hand motion patterns, upon which an approximation of the emitting source is calculated in 3D. Section 2.3 will explain the system in more detail.

Two main view modes allow the users to interact with the system. One view, the AR view, offers an overview of the surgical site to the user, by projecting the 3D reconstruction on the video image of the body. The second view, or VR view, is a purely virtual visualization of the 3D reconstructed radiation distribution from the view of the gamma probe, without visual reference to the anatomy. The separate view modes, including their appearance and motivation are presented in more detail in section 2.3.

Our study presents the natural interaction of the surgical staff with these two view modes. *The particularity of our study and also one of our main contributions is that no individual interacting with the system was informed about the intent of creating this study, nor about the originally intended usage of the two view modes. The interaction with the system was left deliberately uninfluenced and thus inherently unbiased.* In fact, the purpose of the 13-month usage period was to investigate how users interacting naturally and in an unbiased manner with the system, would utilize the view modes and under which circumstances.

In order to formalize the study, we tied the observation to a particular workflow step, namely the reconstruction of the radioactively labeled nodes before and after incision and excision of sentinel lymph node biopsies. The exact medical background is ex-

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plained in more detail in section 2.1, while the workflow steps and the difference between pre-incision and post-excision scans are explained thoroughly in section 2.2. Due to the workflow-oriented analysis, we are able to report on observations and draw conclusions from them, which we present in section 3, one of them being that with a significant tendency, the users tended to prefer one of the two view modes for certain atomic sub-tasks. In the discussion, we will argue on why this observation is highly relevant for the medical AR community.

2 Materials and Methods

2.1 Medical Background

Sentinel lymph node biopsy (SLNB) is applied to some cancer patients to determine the nodal stage of their disease. This is mostly assured by injecting a tracer material near the tumor, which are transported by the lymph vessels to the lymph node(s) in the drain of the tumor. These lymph nodes are called the sentinel lymph node(s), short SLNs. Under control of a proper imaging modality, the SLNs can be localized pre- or intra-operatively.

In the last two decades, several methods have been introduced for mapping of the SLNs and the high diagnostic accuracy of the sentinel strategy has led to a rapid acceptance of the approach. Therefore the SLNB is widely used now in routine clinical practice [15].

The most commonly used tracers for SLN mapping are radioactive isotopes such as technetium-99m, which allows lymphatic mapping using 2D planar scintigraphy and/or 3D SPECT/CT imaging. Unfortunately, these images are mostly available only preoperatively and cannot be used directly during surgery. Nevertheless, small, hand-held one-dimensional gamma-probes [1, 13] or two-dimensional gamma cameras can be used during the SLNB procedure [25, 21]. However, intra-operative 3D nuclear imaging would improve the overall quality of the surgery and the SLN detecting rates by providing depth information in contrast to the two hand-held radiation detecting devices [18].

With this motivation behind, Wendler et. al. introduced the Freehand SPECT technology, which allows to do 3D reconstructions with tracked 1D gamma probes [29]. In a pre-operative validation study they achieved mapping of at least one SLN in 87.5% of the 85 patients, with a sensitivity of 83.33% compared to the SPECT/CT [30]. After this initial success, Freehand SPECT system has been brought to the operating room (OR) for feasibility studies in SLNB procedures in breast cancer and melanoma patients [8, 14, 4].

2.2 Surgical Workflow

For SLNB procedures within our university hospital, gamma probe-guided localization is applied in routine using technetium-99m radioisotope as the tracer material and conventional gamma probes for radiation detection.[1] A simplified workflow of the SLNB procedure only under gamma probe guidance is shown in Figure 1.

In the pilot studies in our university hospital where Freehand SPECT is used intra-operatively, the surgical workflow had to be modified (Figure 2). Before starting with the surgical procedure, a Freehand SPECT scan is done and the reconstruction is visualized on the monitor to be interpreted by the users. The incision is made based on the readings of the gamma probe as well as according to the reconstructed 3D Freehand SPECT image. After the incision, the sentinel lymph nodes are localized either only using the acoustic signal of the gamma probe or in combination with the 3D navigation Freehand SPECT system provides, if needed. After the SLN(s) are removed, another Freehand SPECT scan is done for quality assurance of the surgery. If a further hot spot is detected, then the reconstruction is compared with the pre-incision image and

[1]Depending on the indication, injection of an additional coloring material before incision is also used in combination to assure a visual verification of the SLN and to achieve better SLN detection rates.

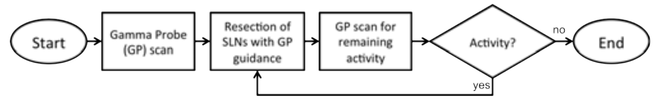


Figure 1: Basic Workflow of a SLNB procedure without Freehand SPECT

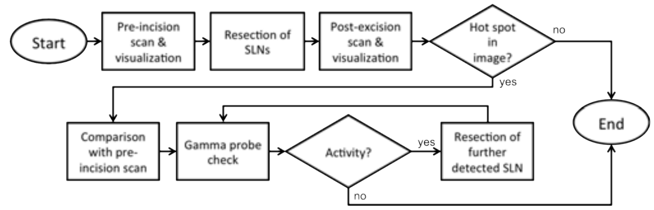


Figure 2: Basic Workflow of a SLNB procedure with Freehand SPECT

the shown hot spot is also checked with the gamma probe to determine if it is a lymph node or just remaining activity in the lymphatic vessels. Further detected lymph nodes are also to be removed until the surgeon is sure that there is no relevant remaining activity in the volume of interest. In case of an additional but hard-to-find lymph node, the surgeon might decide to leave it inside, if the SLN(s)s with major uptake were resected already.

2.3 System Description

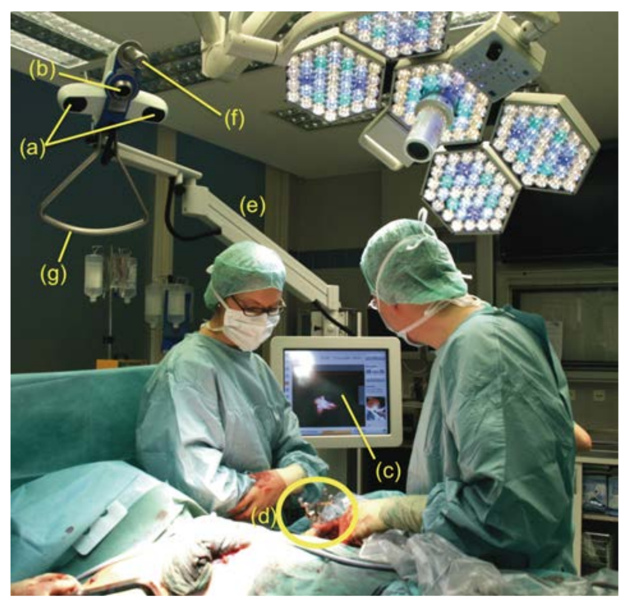
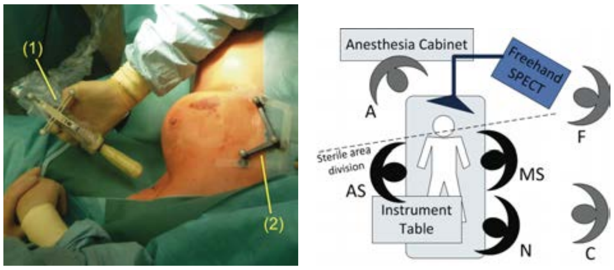


Figure 3: Freehand SPECT device in the operating room. (a) Infrared tracking cameras. (b) video camera for AR visualization. (c) Touch-screen monitor for visualization and user interaction. (d) Gamma probe in a sterile foil and sterile tracking target attached. (e) Positioning arm. (f) Sterile handle. (g) Unsterile handle.

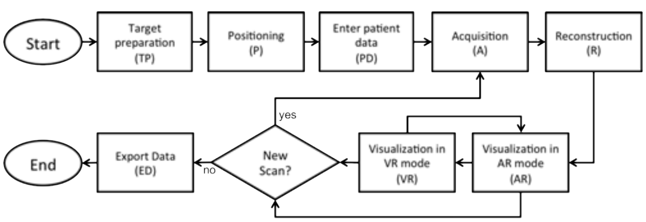
Freehand SPECT system used in this study (Figure 3) was a prototype of the *declipseSPECT* cart system (SurgicEye GmbH, Germany), which includes a *Gamma-Probe System* gamma detector (Crystal Photonics, Germany) for radiation detection and a *Polaris Vicra* infrared optical tracking system (Northern Digital, Canada) for spatial positioning, which is assured by special tracking targets with retro-reflective markers attached (Figure 4(a)). For data ac-



(a) (b)

Figure 4: (a) Tracking targets of the Freehand SPECT system. (1) Sterile probe target attached to the gamma probe in sterile covering for tracking the position and orientation of the probe throughout the surgery. (2) Sterile patient target serving as a reference coordinate system for displaying the 3D Freehand SPECT reconstruction relative to the patient. (b) An example OR setting for a SLNB procedure for the left breast under Freehand SPECT guidance in our university hospital: (MS) main surgeon, (AS) assistant surgeon, (N) sterile nurse, (C) circulator, (A) anesthetist, (F) Freehand SPECT technician

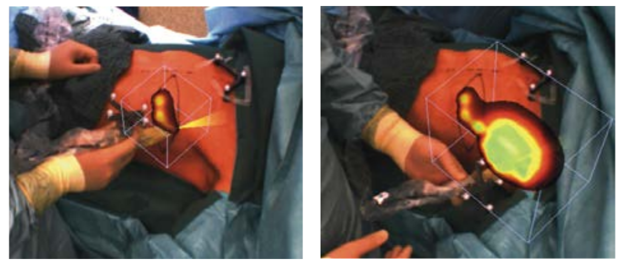
quisition and synchronization as well as for computation of the 3D reconstruction, a PC is integrated into the housing. A touch-screen monitor is provided to the users for visualization and user interaction. For facilitating augmented reality visualization, a video camera is also mounted and calibrated accordingly. The system presents an tracking accuracy of 0.25mm RMS within the tracking volume (approx. 50x50x50 cm3). The tracking error at the tip of the instruments is below 1mm and the overall accuracy of the system including image reconstruction lies at 5mm.



Freehand SPECT workflow stage	TP	P	PD	A	R	AR	VR	ED
AR view	no	no	no	yes	no	yes	no	no
VR view	no	no	no	no	no	no	yes	no
Probe target	yes	yes	no	yes	no	no	yes	no
Patient target	yes	yes	no	yes	no	yes	yes	no
Monitor interaction	no	no	yes	yes	no	yes	yes	yes
Positioning arm	no	yes	no	no	no	no	no	no

Figure 5: Internal workflow of the Freehand SPECT system.

The device workflow and the key components involved in the particular workflow stages are shown in Figure 5. For using the Freehand SPECT system intra-operatively, the gamma probe needs to be covered with a sterile foil as usual and a sterilized tracking target needs to be attached to the probe. Disposable sterile tracking spheres should be attached to both the probe and the patient targets to assure the optical tracking. Later, the Freehand SPECT should be positioned in such a way, that the cameras of the system have the best field of view with respect to the region to be scanned, i.e. with the least amount of occlusions and without disturbing the sterile OR crew in their standard workflow. After entering the patient data in the device database, the Freehand SPECT acquisition can be started. In this workflow step, only the AR visualization is available, which is used to guide the scanning person during the acquisition process (Figure 6). After approximately 2 minutes of scanning, the device computes the 3D reconstruction, which is later visualized on the monitor first in AR mode. However, in this workflow step there are two different view modes available for the users (Figure 7). For easier and better interpretation of the reconstructed volume, the parameters such as threshold and filtering for the visualization can be adjusted in both viewing options. After the proper visualization, the users can either make another Freehand SPECT scan of the patient, e.g. the post-excision scan for quality assurance as mentioned in the previous section, or they can export the data in a USB Flash Drive and close the application.



(a) (b)

Figure 6: Visualization during the Freehand SPECT acquisition. AR is used to guide the users with respect to the scan coverage. Color augmented over the video shows the amount of information collected on the region (green/yellow = sufficient information, red/black = insufficient information)

2.4 Analysis Method

The surgical OR is a complex domain and there are several different actors involved depending on the procedure, the indications and the complexities [2, 9]. In the case of the SLNB, the *surgical team* within our university hospital can be basically defined as the team including the main surgeon, the assistant surgeon, the anesthetist, the sterile nurse, the unsterile nurse (circulator) and the Freehand SPECT technician (Figure 4(b)).

The intra-operative usage of Freehand SPECT is mostly an interplay of the surgeons and the Freehand SPECT technician. Depending on the requests of the surgeons, the Freehand SPECT technician interacts with the touch-screen monitor of the device, since the surgeons are sterile. He/she guides the surgeons on how to scan the region of interest and tries afterwards to find the optimal contrast parameters (thresholds). Therefore he/she actually is the person who interacts with the Freehand SPECT device most. However, the final decision of how long the device will be used and if any further depth measurement and 3D navigation is needed is made by the main surgeon. This is similar to the general user interactions in the OR as discussed in [20, 9].

We would like to stress that during the observation period the system users were neither exposed to the plan to conduct this study report nor to technical terms such as *AR* and *VR*, which would have revealed the design goal of the respective view and consequently biased the system user. The two visualization modes were not presented as two particular user interface (UI) paradigms, but the surgical staff was only educated of both UI options and they chose to use different view modes serving best their needs. In order to minimize bias towards any of the UI options, all features of the system were explained for each of these options. The training was also performed according to a fixed content in order to avoid variation from trainee to trainee. During the surgical procedure, the surgeon, the supporting staff and the Freehand SPECT technician were jointly selecting and switching the view modes, according to the current surgical workflow step and the view mode most suitable for each

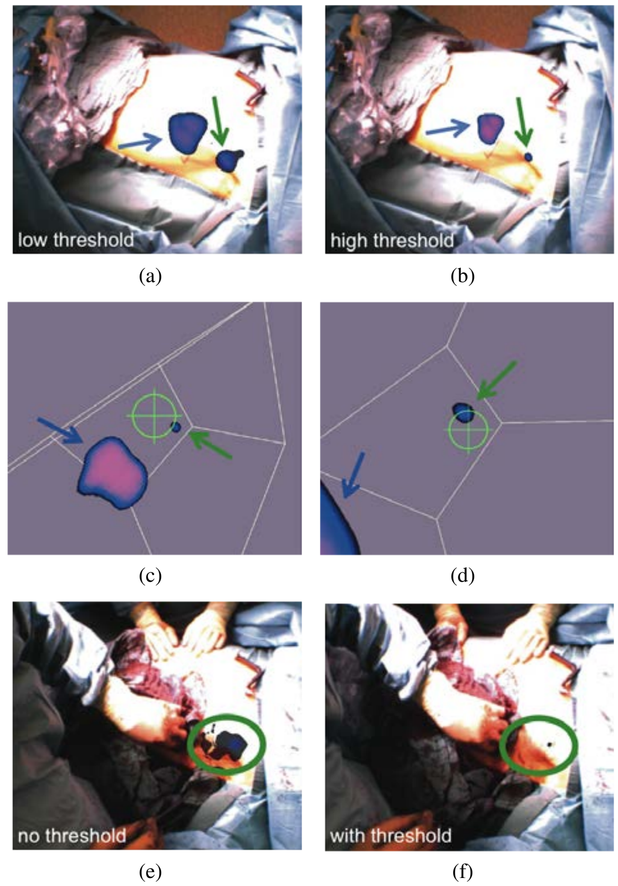


Figure 7: Screenshots from the Freehand SPECT application in different surgical workflow steps and in different visualization modes. Blue arrows indicate the injection spot, green arrows show the SLN conglomerate. (a) Pre-incision reconstruction in AR view. (b) Pre-incision reconstruction in AR view with different threshold parameters. (c)-(d) Pre-incision reconstruction in VR mode for 3D navigation. (e) Post-excision reconstruction with no threshold showing homogeneous activity in the scanned area in AR view. (f) Thresholded post-excision reconstruction showing no major hot spot in the region of interest in AR view.

particular task, aiming only at optimal patient care. We will therefore not differentiate between different actors and consider the surgical team as a whole when talking about the *user* henceforth.

For this work, 46 patients who have undergone sentinel lymph node biopsy with intra-operative Freehand SPECT guidance are analyzed. The indications vary between early stage melanoma (13x), breast (31x) and vulvar cancer (2x). These patients were operated either in the Gynecology or in the Surgery Department of the Klinikum rechts der Isar, Munich, Germany. The time interval is between March 2010 and April 2011.

These 46 surgeries resulted in 52 pre-incision and 48 post-excision Freehand SPECT scans. This is due to the fact that some patients have undergone SLNB in more than one body region (e.g. bilateral breast cancer, vulvar cancer or some cases of melanoma). The different count of the pre-incision and post-excision scans are due to the time constraints in the OR and also due to the technical and practical problems encountered in between. Furthermore, in some cases the measurement with the gamma probe was enough for the surgeon to make sure that there is no more activity left in the region of interest and therefore the post-excision scan was not necessary.

For the analysis of the chosen visualization mode, the screenshots generated by the Freehand SPECT system are studied. The screenshots were automatically captured within the surgery at a frequency of 0.2Hz and saved as a sequence of JPEG images in separate folders dedicated for each acquisition. For calculation of the AR/VR ratios, the screenshots are reviewed twice, manually. In average the evaluation of a single acquisition took 5 minutes. Evaluation sessions of not more than 10 patients were enforced to avoid concentration errors. The usage has been documented by counting the screenshots for each of the visualization modes, for the time interval when the users were using the system explicitly. Since in the current VR visualization of the system the users cannot relate to the anatomy of the patient directly, especially in cases where it is not easy to identify the SLN in the reconstructed image, it is also analyzed if the users switched back to AR mode in between while using VR for navigation. Moreover, based on the screenshots, the adjustments of the thresholds in the displayed reconstruction are analyzed separately for the AR and the VR modes, as described in Section 2.3.

Pre-incision and post-excision datasets are analyzed separately, because they cannot be compared directly due to different requirements of the corresponding surgical stage. For the post-excision images it could also be determined if the users chose to compare the image with the previous one, aka the pre-incision image and if yes, in which of the viewing modes. The final screenshot counts are used to calculate the actual usage time and the ratio of AR vs. VR usage for each acquisition. The means and the standard deviations are calculated over the resulting ratios for each acquisition in both workflow stages.

3 Results

3.1 Data Analysis

In our observed usage scenario, it is important to distinguish between the pre-incision and the post-excision Freehand SPECT scans, since they occur in two different workflow stages and are aiming at different goals. The former is mostly used to localize the activity region, which can be used for navigation and the latter is mainly used for checking the quality of the removal procedure and possibly detecting the remaining activities.

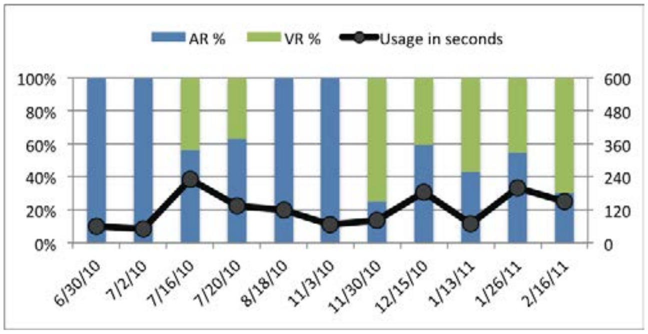
In the pre-incision data, the AR/VR ratio is 64.0% to 36.0% with standard deviation 25.8% whereas in the post-excision data it is 86.4% to 13.6% with standard deviation 23.0%. The average system usage time during the pre-incision and the post-excision visualization stages were 3.15 and 1.56 minutes, respectively.

In 51 of 52 pre-incision scans (98.1%) the AR was the choice of visualization for setting the proper threshold values. The only acquisition (1.9%) for which this is not the case is a second pre-incision scan of the same patient in a different region of interest. Therefore, a new adjustment of the threshold values was not needed, due to the fact that the values from the first scan assured a proper visualization.

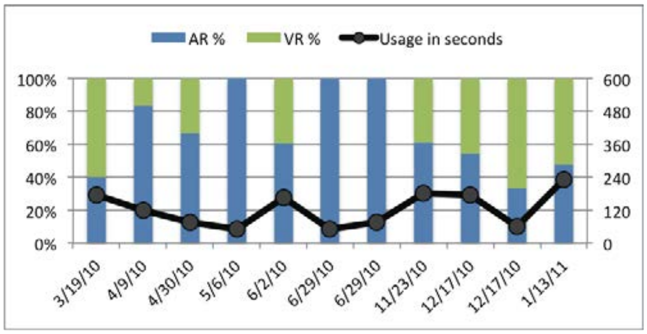
Although threshold adjustment is also available in the VR mode, the surgical team interacting with the device used this functionality additionally only in 3 of 52 pre-incision acquisitions (5.77%) whereas the threshold sliders remained untouched in the VR mode in 38 of 52 acquisitions (73.1%). In 11 of 52 pre-incision scans (21.2%), the surgical team chose not to use VR mode at all.

In those 41 of 52 acquisitions where they used VR with the pre-incision image, the surgical team switched back to AR at least once in 35 acquisitions (67.3% of total, 85.4% of VR cases).

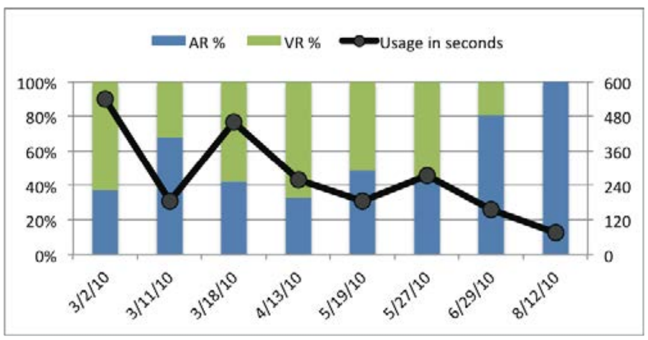
For the post-excision acquisitions, the statistics are a little different. In 32 of 48 datasets (66.7%), the VR is not chosen at all. This is not surprising with regard to the surgical workflow. Post-excision scans are done for quality assurance of the surgical procedure, which means that the goal is to make sure that there is no remaining activity in the volume of interest. In most of the cases,



(a) Surgeon 1 pre-incision



(b) Surgeon 2 pre-incision

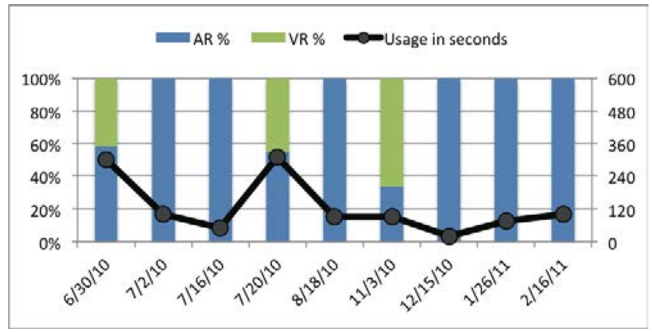


(c) Surgeon 3 pre-incision

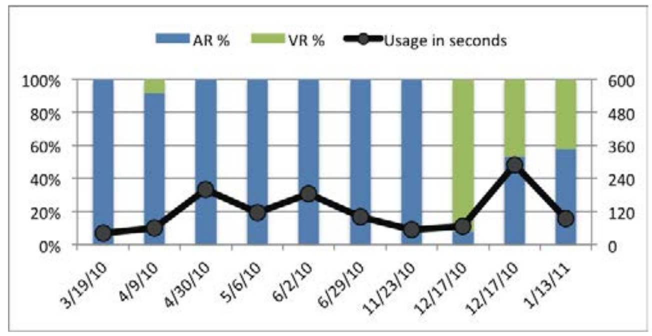
Figure 8: The average usage of the surgical teams led by three different main surgeons for pre-incision images

the AR view of the reconstructed image was enough for the surgical team to decide that no further resection is needed. When this was the case, the VR or 3D navigation in the volume became unnecessary.

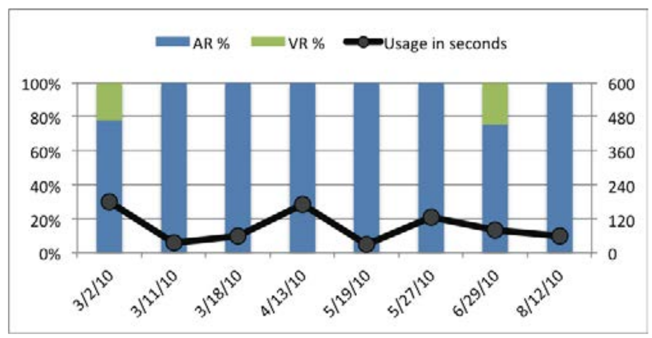
In 12 of 48 post-excision images (25.0%), readjustment of the threshold sliders was not needed, whereas in 36 cases (75.0%), the users tried to find better threshold values for the newly acquired image. The usage here very much depends on the people involved: For some teams, it was enough to compare the pre-incision and post-excision images with the same threshold values (Figure 7(b) and 7(f)) whereas some users did not rely on the values from the first scan and wanted to adjust them again for the newly acquired image so that they would not oversee a radioactive (*hot*) spot with lower radioactive uptake which could be possibly a further SLN. Setting the lower threshold to a lower value would include more background activity in the visualized Freehand SPECT reconstruction. In such a case, a homogeneous distribution with no particular uptake should be interpreted as residual activity and not as a further SLN (Figure 7(e)). In 2 of 16 (12.5%) cases where VR is used in the post-excision images (4.2% in total), the thresholds were also adjusted in the VR mode.



(a) Surgeon 1 post-excision



(b) Surgeon 2 post-excision



(c) Surgeon 3 post-excision

Figure 9: The average usage of the surgical teams led by three different main surgeons for post-excision images

Again in 13 of those 16 cases (81.3%, 27.1% in total), the surgical team chose to switch back to the AR visualization at least once during the interaction with the device after choosing VR for 3D navigation in the reconstructed volume.

To assure that no further SLN is remaining in the scanned area, a comparison of the post-excision scan with the pre-incision image can be done. By checking the hot spots shown in the pre-incision image with the post-excision image and the acoustic sound of the gamma probe in real-time, the surgical team can be sure that there is no remaining hot spot in the region of interest. In the 48 post-excision scans we analyzed, this functionality is used only in 29 cases (60.4%), whereas it is waived in 13 cases (27.1%). Unfortunately, in 6 of 48 cases, the pre-incision image was not available during the post-excision usage (12.5%). Furthermore, in 27 of the remaining 29 cases, the comparison is done in the AR mode (93.1%, 56.3% of total), while in one case only the VR mode (3.5%, 2.1% of total) and in one case both modes were utilized (3.5%, 2.2% of total).

As mentioned in section 2.4, we considered the actors in the OR as a whole during this study. However, the actual usage is very much dependent on the main surgeon involved, since he/she plays the role of decision maker for how effectively and how long the Freehand SPECT system will be used. Therefore it was interesting to investigate the usage time and the AR/VR ratio based on different main surgeons involved for their tendencies.

The 52 surgical procedures on 46 patients we analyzed for this work were led by 14 different main surgeons, some of them encountered the system for the first time and therefore had limited experience with it whereas some had the opportunity to use the system intensely several times. For the three main breast surgeons who have used the system most, we analyzed the usage over time in both the pre-incision (Figure 8) and the post-excision data (Figure 9). The average usage time and the average AR/VR usage ratio for the teams of these three main surgeons are plotted in Figure 10.

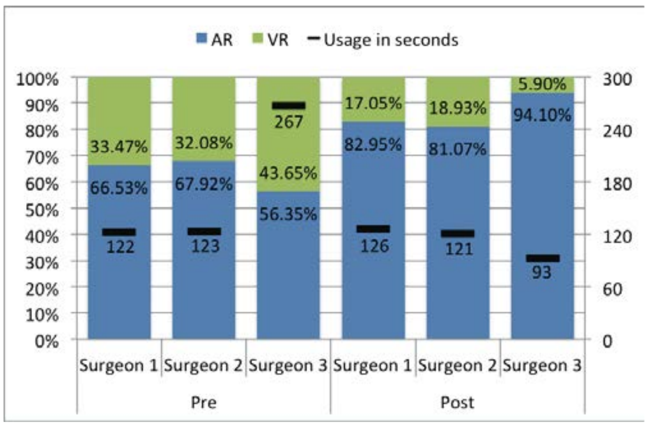


Figure 10: Analysis of the surgical teams of three different main surgeons. The surgical teams of Surgeon 1 and Surgeon 2 have similar usage characteristics in contrast to the teams of Surgeon 3

Based on these graphs, different characteristics of the main surgeons can be identified. The statistics for the surgeon 3 differs from the other two surgeons both in the usage time and in the AR/VR ratio. As emphasized in Figure 10, surgeon 1 and surgeon 2 had a tendency to use the Freehand SPECT imaging system during both the pre-incision and the post-excision phases ca. 2 minutes long in average whereas surgeon 3 used the device in the pre-incision phase more intensely (4.5 minutes on average) and in the post-excision phase more briefly (1.5 minutes on average). The higher usage time and VR percentage in the pre-incision phase as well as the lower usage time and VR percentage in the post-excision phase for surgeon 3 could indicate that the teams led by the surgeon 3 used the Freehand SPECT device more likely for intra-operative 3D navigation during the excision procedure. Based on this comparison, in contrast to surgeon 3, the other two surgeons used Freehand SPECT more likely to confirm the radioactivity in the volume of interest for the incision, but not for image-guided excision.

3.2 Additional Observations

As mentioned earlier, in order to avoid any influence of our study on the normal usage pattern and the user interaction with the target system, we did not inform any of the OR crew about our study plans, within 13 months of observations. Since some of the surgical team members were frequently present during different surgical sessions, we decided to not use any formal usability evaluation approaches like questionnaires and interviews within that period. However, after finishing the last surgeries, we had series of discussion sessions with main members of the surgical teams, who were mostly exposed to the system and interacted with the device, in order to get further qualitative feedback on the usability of the system within their surgical procedure. In this section we highlight the main issues mentioned in regard to the usage of this MR-based system within the OR context.

Similar to many other AR applications, the Freehand SPECT system overlays co-registered and tracked virtual and real objects on the video images thanks to real-time tracking. A pair of calibrated infrared cameras is used to track retro-reflective targets. The tracking accuracy strongly depends on the positioning of the Freehand SPECT device, which usually takes place during the preparation phase. The quality of the reconstructed model and the generated AR and VR images also depends on tracking accuracy. Moreover, due to the presence of the OR crew and other intra-operative equipment, repositioning the device is only possible in a limited manner, moving the camera head. This emphasizes the importance of the positioning of the device before the surgery starts, which should be done by an experienced and trained person. Unsuitable placement of the device may further lead to improper and unreliable AR visualization. An example for such a case is shown in Figure 11 where the right axilla is not visible in the camera view during the surgery due to inappropriate positioning of the system (Figure 11(b)), and the users had to switch to the VR mode (Figure 11(d)). This also explains the seventh column in (Figure 8(a)), which corresponds to this particular surgery, where the VR percentage is much higher than other surgeries of the same surgeon as well as the other two main surgeons, although the system is used less than average.

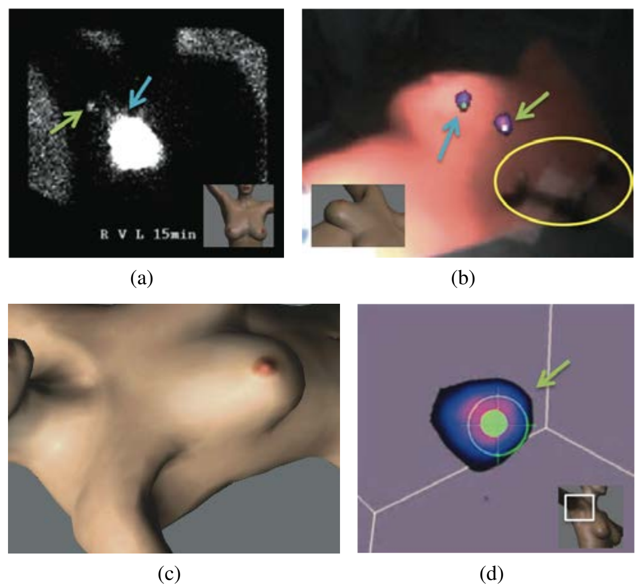


Figure 11: Example case for bad AR visualization due to positioning problems. Blue arrows indicate the position of the injection spot, green arrows mark the SLN. (a) Scintigraphy image of the patient showing one SLN in the frontal view. (b) Confusing AR image during surgery. The patient target (circle) is placed on the sternum. The SLN is actually deep in the axilla, but seems to be on top of the breast in the AR view. (c) Illustration for a better camera position for proper AR visualization. (d) Visualization of the SLN using VR and depth measurement.

In order to have proper visualization in the VR mode, both tracking targets have to be in the field of view of the optical tracking head of the Freehand SPECT system. Furthermore, the presence of many people around the patient in the sterile field increases the chance of occlusion. Thanks to the flexible design of the camera head, its placement and orientation can be changed to overcome these issues. However, in the VR view mode this can be more challenging, compared to AR, due to the necessity to track both targets.

Other mentioned aspects could be categorized under the human-machine interaction. In the OR domain, due to the setup used in our hospital until April 2011, the surgeon, who is the main user of the system, cannot directly touch the device and should forward his commands to a technician or nurse standing next to the device. Although the voice-based control may be useful for interacting with discrete functionalities, it has shown limited applicability for parametric features, where the user should modify a numeric value, such as threshold [9, 2]. In some situations this can slow down the interaction process where there are too many parameters to set during the operation. For the Freehand SPECT device there are few parameters which mostly can be initialized automatically. Furthermore, to achieve a proper image quality, suitable illumination and lighting condition should be considered. The proper distance of the visualization screen to the target user, the main surgeon in the case of the SLNB, plays an important role in increasing the user satisfaction, based on our observations during this work.

As seen in section 3.1, AR was the choice of visualization more often compared to VR in the procedures with Freehand SPECT that we analyzed. However, this does not imply that AR is superior to VR. The usage of AR and VR strongly depends on the requirements within the current surgical workflow stage. AR was generally used to obtain a big picture of the activity distribution over the patient anatomy; however the VR mode was mostly preferred whenever more accurate measurement and localization was required. According to the users, having two complementary viewing modes improved the overall usefulness of the device.

The results presented here were not subject of an experimental design with fixed hypothesis and controlled boundary conditions in the OR, like device placement, OR team, lighting, patient characteristics, clinical indication, etc. Thus a generalization cannot be made based on its statistics. It provides as a phase I study however sufficient data for the planning of a controlled phase II study capable of evaluating in details and with proper statistical significance and power the contribution of this technology to the clinical output. Such a study could be performed as a randomized or matched study comparing the procedure with the conventional non-MR-guided one. The age of the users, their knowledge of computers and the influence of the training could also be some further aspects that may be considered.

4 Discussion and Conclusion

In this paper, we presented a study of the usage of AR/VR visualization within 100 acquisitions of the novel Freehand SPECT imaging within real operating rooms. This is one of the first intra-operative devices, which makes full use of AR as well as VR visualization. Our analysis of the choice of user interface, mainly confirms the importance of the analysis of the surgical workflow and the need for adoption of the user interface and visualization hardware and software to particular flow of subtasks within a surgical procedure. For each phase of the procedure, e.g. pre-incision or post-excision imaging, the OR team tends to prefer a particular mode of visualization. For some subtasks, e.g. setting proper threshold values for the reconstruction, AR has been the preferred visualization mode, while for other subtasks, e.g. image-guided resection of the lymph node, the preference goes to VR.

Based on our observations, we think that the final solutions would benefit by having alternate viewing modes, which may be more suited for different conditions. In fact, hybrid solutions may be the ones which will get accepted not only due to their flexibility but also because they offer wider ranges of customization. A surgical technique or a particular surgeon may opt for VR in a particular phase of the surgery because of need for precise measurement of the absolute size of an anatomical target; another one may prefer the AR because of its ability of localizing the target within patient's anatomical context.

We believe that such flexibilities will also be needed both for the choices of tracking and display technology. Optical tracking for example could provide co-registered views of tracking targets and surgical site and therefore ease the generation of advantageous AR views, while other tracking technology may cope better with the limited space and crowdedness of OR within different phases of the procedures.

Hybrid display solutions may also offer different advantages for various subtasks of surgical procedures. In some phases, the surgeon prefers the surgical crew to share the information in order to provide further assistance and in other phases he or she may prefer direct in-situ visualization for better performing a particular task. Unfortunately, although the technology used in head-mounted displays is advancing every day, current HMDs are not yet optimized in terms of size, weight, resolution, cabling and ease of use. Also, in this specific application, since AR is only needed for a short period of time and in fact more as a general guidance and confirmation rather than for precise localization and navigation, it is not justified both in terms of costs and in terms of efforts in adapting the new technology.

One could also consider other possible AR display technologies, such as semi-transparent display [3], however in order to bring AR and VR techniques into the operating room, the smoothest path is to start with choices which do not introduce considerable changes to the surgical workflow and environment and require minimum training. Such considerations increase the chance of acceptance of the technology by surgeons.

The OR domain is a complex one. The study of this particular domain is fully required for the design and integration of AR and VR solutions, which can revolutionize the computer assisted interventions by providing the most valuable information, at the right time and in the right format within such interventions with the final goal of the improvement of outcome in terms of increasing success rate of surgical procedures and decreasing the morbidity.

This paper reports on one of the first clear successes of MR-based visualization solutions as integrated parts of an intra-operative imaging device. Still there is place for further analysis on the impact of this solution on the clinical output. Such analyses if performed in a controlled way will provide hard numbers on the efficacy of MR in terms of time saving, accuracy and errors in the procedure. The surgical theatre will most probably welcome more and more such solutions in the upcoming years as the medical community gets used to such interfaces and takes advantages of their capabilities as such solutions get also more and more adjusted to the complex and dynamic requirements of different phases of various surgical procedures.

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