# Neurosurgical burr hole placement using the Microsoft HoloLens

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## ABSTRACT

**PURPOSE:** Tracked navigation systems are generally impractical in bedside neurosurgical procedures, such as a twist-drill crainiostomy for the removal of a subdural hematoma, where the use of navigation could optimize the placement of the drill in relation to the underlying fluid. We use the Microsoft HoloLens to display a hologram floating in the patient's head to mark a burr hole on the skull.

**METHODS:** A 3D model of the head, hematoma and burr hole is created from CT and imported to the HoloLens. The hologram is interactively registered to the patient and the burr hole is marked on the skull. 3D Slicer, Unity, and Visual Studio were used for software development. The system was tested by 6 inexperienced and 1 experienced users. They each performed 6 registrations on phantoms with fiducial markers placed at 3 plausible burr hole locations on each side of the head. Registration accuracy was determined by measuring the distance between the holographic and physical markers.

**RESULTS:** Inexperienced users placed 98% of the markers within the clinically acceptable range of 10 mm in an average time of 4:46 min. The experienced user placed 100% of the markers within the acceptable range in an average time of 2:52 min.

**CONCLUSION:** It is feasible to mark a neurosurgical burr hole location with clinically acceptable accuracy using the Microsoft HoloLens, within an acceptable length of time. This technology may also prove useful for procedures that require higher accuracy of drill location and drain trajectory such as the placement of external ventricular drains.

**KEYWORDS:** Augmented reality, HoloLens, head-mounted display, neuronavigation, subdural hematoma, burr hole placement

## 1. INTRODUCTION

Tracked navigation is commonly used for complex neurosurgeries, but the required equipment is expensive, large, and time consuming to use. Traditional methods of tracked navigation, including the Stealth S8 system (Medtronic, Dublin, Ireland) and Brainlab Cranial Navigation software (Brainlab, Munich, Germany), require large carts of equipment, are operated by specialized technicians, and are therefore not ideal for bedside procedures. Importantly, these technologies require fixing a patient's head to the bed with pins which limits their use to the operating theatre. A twist-drill craniostomy for the removal of subdural hematomas is a common bedside procedure performed without tracked navigation. A comparative study performed by Horn *et al.* showed that a twist-drill craniostomy should be considered the first line of treatment for a subdural hematoma as it is less invasive and does not require general anesthetic, compared to a craniotomy completed in an operating room [1]. The coronal suture and superior temporal line are the typical anatomical landmarks used to locate the drilling location using the patient's CT scans. Incorrect placement of twist drill holes may result in injury to underlying brain tissue, profuse venous sinus bleeding, epidural hematomas [2], and incomplete drainage especially when subdural collections are chronic and loculated [3,4]. These common complications caused by a twist-drill craniostomy could be reduced by using a navigation tool rather than anatomical landmarks to determine the drill location. Therefore, there is a need for an inexpensive and light-weight navigation tool that can be rapidly operated at a bedside location without a specialized technician.

We propose the use of augmented reality headsets, such as the Microsoft HoloLens, as light-weight surgical navigation tools. Our study assesses the use of the Microsoft HoloLens for augmented reality surgical navigation. The Microsoft HoloLens is an optical see-through head-mounted display and is considered the best performing technology currently available and the most suitable for clinical use [5]. We investigated the feasibility of using a holographic model to accurately locate a burr hole location. Based on communication with clinicians, it was determined that the typical drill size for a craniotomy is 14.0 mm and 4.0 mm for a twist-drill crainiostomy. The clinical goal is to place a marker at a drill location within a 10.0 mm range of accuracy, the clinically acceptable range for the removal of a subdural hematoma.

# 2. METHODS

## 2.1 Proposed Clinical Workflow

To diagnose and assess a subdural hematoma in an emergency, a CT scan of the patient is taken. Due to the unplanned nature of the scans and therefore the limited time available, these CT scans are completed without the use of markers on the patient's skull. The resulting images are received either as DICOM data or a set of JPEG images. To use the Microsoft HoloLens as a navigation tool, these images would then be imported to the open source platform, 3D Slicer (www.slicer.org) [6]. The Segmentation module within Slicer would be used to perform a threshold segmentation of the patient's skin to create a 3D model (Figure 1). Virtual markers would then be placed on the model at the desired drill location, as well as any locations required for the chosen method of registration.

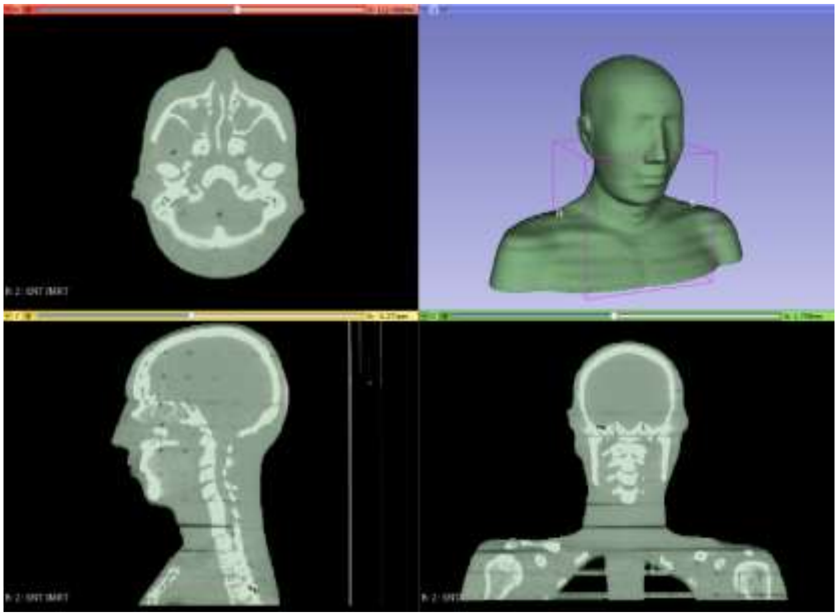

**Figure 1:** Modelling of the patient's head in 3D Slicer from a CT scan.

These models would then be imported to the HoloLens application in which a series of tools are provided to complete a surface registration of the model on the patient. This registration is approximate and completed using the surgeon's judgement of the rotation and position of the model. Once the surgeon is satisfied with the accuracy of the surface registration, the holographic marker at the drill location would be made visible. The surgeon could then place a mark on the patient at this location before removing the headset to begin drilling the burr hole.

## 2.2 Registration

The HoloLens application first instructs the user to place small holographic markers using locations of three fiducial markers placed in 3D Slicer (Figure 2-1). The first marker is placed on the tip of the patient’s nose and the second marker is placed at the outer corner of their right eye. The second marker will then be shifted to maintain the fixed distance between the fiducial points as specified in 3D Slicer. An axis of rotation is created between the first and second markers to allow the third marker to be rotated into place at the outer corner of the left eye using the fixed alignment between all three fiducial points. This process completes the initial registration by aligning the model with these markers. After the initial registration, the model can be further aligned using tools for smaller adjustments. Tools are provided for the user to rotate or translate the model about a chosen axis or direction. Photos of the registration process and tools included in the application are shown in Figure 2.

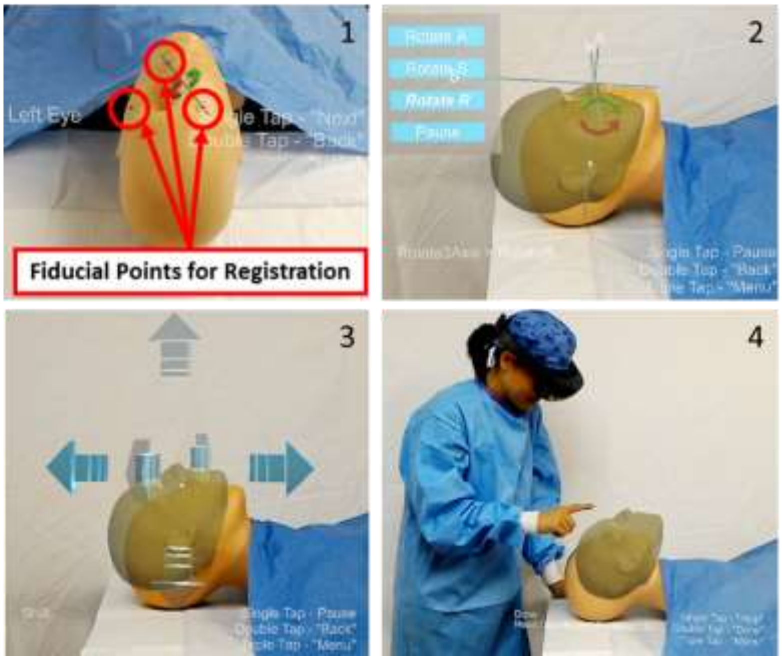

**Figure 2:** The registration process with fiducial markers (1), the tool for rotating the model (2), the tool for translating the model (3), and a view of the model in relation to the surgeon (4).

Once an accurate registration of the model is completed, the user can adjust which layers of the model are seen. Visibility of layers within the full model can be toggled by the user to view different combinations of the skin, brain, hematoma, and fiducial markers. Note that due to an offset created by the HoloLens camera, photos cannot be taken to accurately show what the user can see. To show what the user can see, a photo was taken by intentionally translating the model to compensate for this offset and achieve a photo of a proper registration (Figure 3).

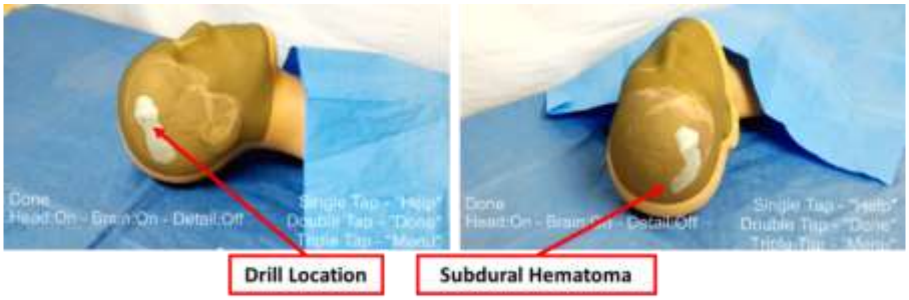

**Figure 3:** Multiple views of the final registration of the model with the burr hole marker (red), brain, and subdural hematoma visible to the user.

## 2.3 Implementation

An application was developed for the Microsoft HoloLens using Unity and Visual Studio software. Several high-level components from the HoloToolKit repository were used within the application, including the Input Manager and HoloLens Camera. The remaining components and their corresponding code were created specifically for this application. To support inexperienced users, instructional videos were prepared for the use of each tool. Help windows were also provided for quick explanations and a list of available commands. A combination of tracking the user's gaze, voice commands, and HoloLens AirTap gestures was implemented. This allows the user to navigate the application using their preferred method of input.

The models used within Unity were exported from 3D Slicer as OBJ files, which is currently the only 3D model file format supported by both 3D Slicer and Unity. To improve rendering speed within Unity, the models were first reduced in size using the decimation feature of 3D Slicer's Surface Toolbox module. The fiducial markers placed in 3D Slicer were also imported to Unity as CSV files, which were then parsed within the Unity software to store position variables. Using these positions, the model itself is translated on initialization of the program such that the tip of the nose, as identified in 3D Slicer, is the centre of rotation for all tools within the application.

## 2.4 Experimental Setup

Two plastic phantoms were used to qualitatively measure the accuracy of the surface registration. 2.0 mm diameter stainless steel ball bearings (BBs) were attached to each phantom in six locations to represent potential drill locations (Figure 4-1). CT scans were then taken of these phantoms to create models of the phantoms' skin using 3D Slicer and the Segmentation module (Figure 4-2). Fiducial markers were placed on the model at the locations of the six BBs, as seen on the CT scans. Then, the shapes of the BBs were removed from the 3D models in Slicer to ensure that they would not be visible to the user during the registration process. Virtual markers were also placed in Slicer at the tip of the phantom's nose, and the outer corners of both eyes for completing the registration (Figure 4-3). The 3D models and the virtual markers were imported into the HoloLens application to perform surface registrations.

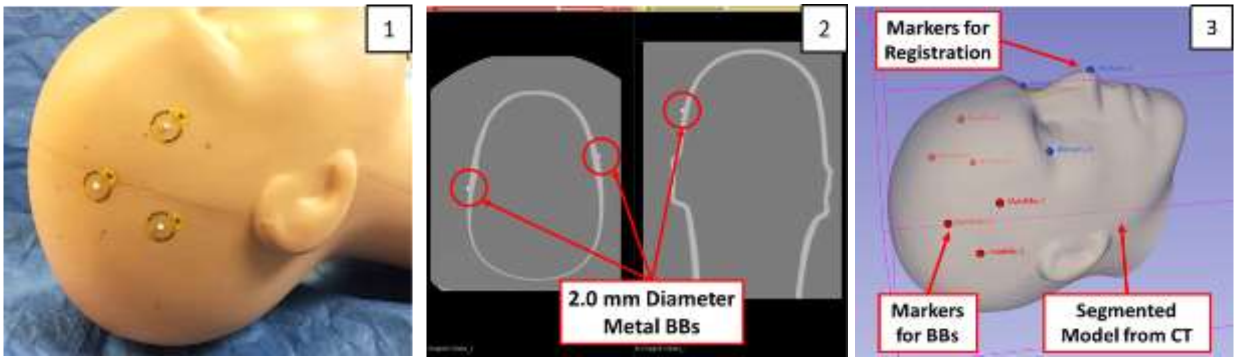

**Figure 4:** The plastic phantom with 2.0mm diameter metal BBs (1), CT scans of the phantom showing the location of the BBs (2), and the segmented model and fiducial points created from the CT scans in 3D Slicer (3).

The surface registration of each phantom was completed 3 times by 7 different participants. Of the 7 participants, 6 were beginners and had no previous experience with the application. One participant had a high level of experience and was used for comparison. Before completing the 6 registrations, the participants each completed two initial registrations while watching instructional videos and receiving support from an experienced user.

Each user performed the registration as explained earlier in Section 2.2. Then, the user made 2.0 mm diameter holographic markers visible at the locations specified in Slicer to represent the six BBs. The user that performed the registration determined which range of accuracy each holographic marker was located in using the marks on the 10.0 mm radius base of each BB (Figure 5). Similar to clinical applications in which a burr hole is only drilled on one side of the patient's head, only results from the 3 markers on the side of the phantom facing the user were used to assess the accuracy of the registration. The registration process was also timed to determine if the time taken to register the model was reasonable for clinical use.

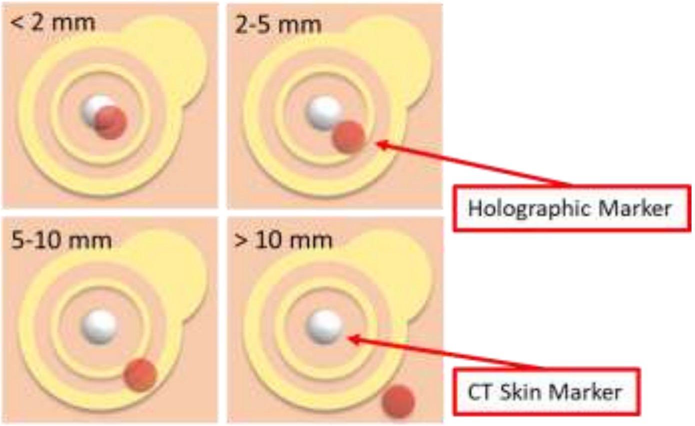

**Figure 5:** The different ranges of accuracy for the placement of the holographic marker using the marks on the base of each BB.

## 3. RESULTS AND DISCUSSION

Results in Table 1 show that inexperienced users placed 98% of the markers, on the side of the phantom facing the user, within the clinically acceptable range of 10 mm and the experienced user placed 100% of the markers within the clinically acceptable range. On average, the inexperienced users took 4 minutes and 46 seconds to complete the registration, while the experienced user on average took only 2 minutes and 52 seconds.

**Table 1:** Percentage of marker placements within each range and the total percentage of markers within a clinically acceptable range as performed by both inexperienced and experienced users.

| User's Level of Experience | < 2 mm | 2-5 mm | 5-10 mm | > 10 mm | Within Acceptable Range (< 10 mm) |
|---|---|---|---|---|---|
| Low | 35% | 24% | 39% | 2% | 98% |
| High | 50% | 0% | 50% | 0% | 100% |

**Table 2:** Average, minimum, and maximum lengths of time taken to complete the registration process as performed by both inexperienced and experienced users.

| User's Level of Experience | Minimum Time (M:S) | Maximum Time (M:S) | Average Time (M:S) |
|---|---|---|---|
| Low | 2:18 | 9:39 | 4:46 |
| High | 2:15 | 3:39 | 2:52 |

A potential limiting factor for burr hole placement that will need to be assessed is the effect of hair on the patient's head. In general, a twist-drill crainiostomy, among other neurosurgical procedures, does not require the patient's head to be shaved. Unfortunately, the presence of hair results in the loss of visibility of the back curvature of the skull. Further testing will need to be completed to ensure that the model can be registered to the patient's head, with the same level of accuracy as in the results collected above, without this curvature as a guide.

During development, it was noted that the Microsoft HoloLens has a translational shift in the holograms based on the user's perspective and location in the room relative to a hologram anchored in space. This shift can be attributed to errors in the spatial mapping of the room completed by the HoloLens. This, however, does not in any way affect clinical performance because we will always register the hologram on the side of the burr hole. The opposite side will be inaccessible as it is draped for the procedure. For the sake of completeness, we also assessed the level of inaccuracy introduced by this translational shift using results from the markers on the opposite side of the phantom. Only 78% of the markers on the opposite side of the phantom were accurately placed within the clinically acceptable range of 10 mm. It was useful to assess this error for potential applications of the Microsoft HoloLens other than the placement of burr holes. A further limitation is that the HoloLens software cannot currently account for movement of the patient. While this is not a limiting factor for burr hole placement, the user will need to re-register the hologram for guiding the placement of the drain tube after drilling the initial hole.

Both limitations, including the translational shift and tracking patient movement, may eventually be overcome with further developments in the Microsoft HoloLens technology. The current spatial mapping available to developers creates and combines a series of meshes as the user moves around the room. These meshes can be used to detect basic shapes such as floors, walls, and tables as flat surfaces on which to place holograms. However, they are not currently detailed enough to detect smaller features such as a patient's head or specific facial features, meaning the spatial mapping cannot be used to track the patient's movement (Figure 6). This low level of detail also causes a drift in the holograms that results in the translational shift and a lower level of accuracy in the markers on the opposite side of the phantom. A new mesh is created when the user moves to the other side of the room and does not consistently match up with the previous mesh such that the hologram is locked in the same place.

**Figure 6:** The spatial mapping mesh created by the HoloLens of the phantom.

Previous studies have been completed to assess the overall stability of the HoloLens and its ability to keep holograms from drifting in space. For example, a study completed by Vassallo *et al.* found a displacement error of 5.83 ± 0.51mm after introducing a variety of movements and potential disruptions to the spatial mapping of the room [7]. However, Vassallo's experiment only gathered results from one location relative to the holograms, resulting in a level of accuracy similar to the results we collected from markers on the side of the phantom facing the user. As suggested by the results of both Vassallo's study, as well as ours, further testing is needed to better assess the stability of the HoloLens from different perspectives and locations around the room [7].

A potential method for overcoming issues with stability, as well as tracking patient movement, is the use of marker tracking using the Unity plug-in, Vuforia. In an evaluation of the Microsoft HoloLens recently completed by Evans *et al.* a proof of concept application was built to guide the user through an assembly process [8]. While this study and assessment was designed for HoloLens applications in manufacturing rather than the medical field, their experience with the HoloLens spatial mapping was similar. They found that the mapping was not detailed enough to identify individual components in the assembly process and highlight them to the user. To improve the accuracy of detecting components, marker-based tracking was used with the Vuforia plug-in [8]. Vuforia relies on an RGB camera to detect an image on each marker. The size and orientation of that image is then used to determine the position of the marker in relation to the user. Holograms can then be locked on to this position to accurately orient them in space. Evans *et al.* found this solution accurate enough for the purposes of assembly instructions, however the accuracy of the Vuforia marker-based tracking would need to be better assessed to determine if it is accurate enough or beneficial for use in surgical applications [8].

## 4. CONCLUSION

Initial results from this study suggest that it is feasible to use the Microsoft HoloLens to accurately mark a burr hole location to within a clinically acceptable range of 10.0 mm. It was shown that the accuracy of the registration increases with the user's level of experience. The high level of accuracy achieved by inexperienced users indicates that the learning process for the application is short and does not require a significant amount of practice. The time required to complete the registration also significantly decreases with a high level of experience to approximately 3 minutes.

The investigation of augmented reality as a new navigation tool is critical for the future of surgical navigation as it provides a cheap and light-weight alternative to traditional tracked navigation systems. The promising results from this study will lead to continued development with the Microsoft HoloLens for neurosurgical burr hole placement. We have also recently received ethics approval (Human Research Ethics Board) to commence clinical trials, with the goals of achieving an improved workflow and better assessment of the accuracy of the tool. Development will also be completed with the HoloLens for more complex neurosurgical procedures that require higher accuracy of location and trajectory. Among these more complex procedures is the placement of external ventricular drains.

Further applications for the Microsoft HoloLens as a neurosurgical navigation tool include surgical planning, surgical navigation, and medical education or training, as suggested by the survey study completed by Kim *et al.*, which reported these as the three main surgical applications for augmented reality [9]. As a first step towards introducing the HoloLens to the clinical workflow, the HoloLens can be used to check the placement of burr holes located by surgical residents in training to assess the students' proficiency in this skill.

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