Submission ID #: 68607
Scriptwriter Name: Pallavi Sharma
Project Page Link: https://review.jove.com/account/file-uploader?src=20925183

Title: Technical Approach for Infrared Tracking for Soft Tissue Navigation with a Holographic Head-Mounted Display and Preclinical Validation

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Author Questionnaire

1. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

2. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **Yes**

3. Filming location: Will the filming need to take place in multiple locations? **No**

Current Protocol Length
Number of Steps: 23
Number of Shots: 47

Introduction

Videographer: Obtain headshots for all authors available at the filming location.

1.1. **Nick Thomas de Groot:** The scope of this study, in The Princess Máxima Center for Pediatric Oncology, is to develop and validate an Augmented Reality system. This system should accurately align holograms of moving organs.

1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

NOTE: This statement is modified. If it is possible to cut the added phrase, please cut it

What are the current experimental challenges?

1.2. **Vera Josefien van Boheemen:** One current experimental challenge is validating that the hologram remains accurately aligned with the real-time position of a moving organ.

1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

What advantage does your protocol offer compared to other techniques?

1.3. **Nick Thomas de Groot:** Currently, Augmented Reality validation techniques have only been described for rigid anatomical structures like bones. However, our protocol offers the advantage that it can be used to validate Augmented Reality for moving organs as well.

1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

How will your findings advance research in your field?

1.4. **Vera van Boheemen:** This protocol will assist others in deploying holographic projects and accurately validating their augmented reality system in a preclinical setting.

1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

What research questions will your laboratory focus on in the future?

1.5. **Matthijs Fitski:** Our surgical lab will soon start with automated holographic tracking for multiple pediatric surgical cases. These movable organs are tracked based on machine learning algorithms and RGB-camera feeds.

1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

Videographer: Obtain headshots for all authors available at the filming location.

Protocol

2. Designing and Printing Custom Infrared Markers

Demonstrator: Nick Thomas de Groot

Videographer's NOTE: There were some extra shots all mentioned in the upload, so the editor will have some extra MCU.

2.1. To begin, open the 3D computer-aided design software and create a new file **[1]**. Select the **SOLID** *(Solid)* tab and click **Create Sketch** to start a new design for an infrared marker **[2]**. Add three or four small circles with a diameter of 3 millimeters by pressing **Center Diameter Circle [3]**.

2.1.1. WIDE: Talent launching the 3D CAD software and starting a new design file.

2.1.2. SCREEN: 68607_screenshot_1.mp4: 00:02-00:08

2.1.3. SCREEN: 68607_screenshot_1.mp4: 00:38-00:46.

2.2. Using the **Line** tool, connect the vertices of the triangle to the midpoints of the opposite sides, and draw lines connecting the circles to calculate the center point **[1]**. At the center point, draw a circle using **Center Diameter Circle**, then draw rectangles connecting this center circle with each of the smaller circles using the **2-point Rectangle** tool **[2]**.

2.2.1. SCREEN: 68607_screenshot_2.mp4: 00:10-00:40

2.2.2. SCREEN: 68607_screenshot_3.mp4: 00:46-00:48; 68607_screenshot_3.mp4 00:06-00:15, 01:04-01:10

2.3. Extrude the center circular base and connecting rectangles to a thickness of 2 millimeters **[1]**. Extrude the smaller circles to a thickness of 5 millimeters **[2]**. Press **Create**, then select **Thread**, and add threads to the three cones using an ISO *(I-S-O)* Metric Profile to fit 6.4 millimeter infrared reflective spheres **[3]**. Using the **3D Print** or **Export** function, export the final model as an object file **[4]**.

2.3.1. SCREEN: 68607_screenshot_4.mp4: 00:03-00:09, 00:46-00:56

2.3.2. SCREEN: 68607_screenshot_4.mp4: 01:16-01:23

2.3.3. SCREEN: 68607_screenshot_5.mp4: 00:03-00:19

2.3.4. SCREEN: 68607_screenshot_6.mp4: 00:01-00:15

2.4. Within the 3D computer-aided design software, select **Measure** to measure the X, Y, and Z coordinates of the infrared reflective spheres relative to the center point **[1]**. Measure the locations of the center points of each small circle in correlation to the center of the entire shape **[2]**.

2.4.1. SCREEN: 68607_screenshot_7.mp4: 00:00-00:05

2.4.2. SCREEN: 68607_screenshot_7.mp4: 00:05-00:26

3. Preparing the Holographic Application

3.1. Launch the game development software, import the IRTrackingOrgans_HoloLens *(I-R-Tracking -Organs-Holo-Lens)* project file and open the project **[1]**

3.1.1. SCREEN: 68607_screenshot_8.mp4: 00:03-00:16

3.2. Using a text editor, open the JavaScript Object Notation file saved in the Assets/StreamingAssets *(Assets-or-Streaming-Assets)* folder **[1]**. Adapt the file to define the custom infrared marker using the previously recorded coordinates and following the default format **[2]**.

3.2.1. SCREEN: 68607_screenshot_9.mp4: 00:00-00:17.

3.2.2. SCREEN: 68607_screenshot_9.mp4: 00:50-01:11

3.3. In the DINO *(Dino)* Unity tab, select **ToolManager** *(Tool-Manager)***,** click **ResearchModeController** *(Research-Mode-Controller)* followed by **JSON** file and **Parent transform**, then click **Create Objects & Apply JSON** Setting **[1].**

3.3.1. SCREEN: 68607_screenshot_9.mp4: 01:14-01:37

3.4. Import the created 3D infrared marker model **[1]**. Select the patient-specific 3D model and change its transform coordinates in the inspector window to match the position of the spawned markers in the scene **[2]**.

3.4.1. SCREEN: 68607_screenshot_10.mp4: 00:02-00:12

3.4.2. SCREEN: 68607_screenshot_10.mp4: 00:15-00:30

3.5. Then, drag the patient-specific 3D model into the scene to insert it **[1]**. Transform the patient's 3D model to align the infrared marker to its surface **[2]**. Position the infrared marker close to the center of the model to reduce positional error from the lever effect **[3]**.

3.5.1. SCREEN: 68607_screenshot_11.mp4: 00:05-00:13.

3.5.2. SCREEN: 68607_screenshot_11.mp4: 00:23-00:30, 00:46-00:53

3.5.3. SCREEN: 68607_screenshot_11.mp4: 01:12-01:20; 68607_screenshot_12.mp4: 00:06-00:10

3.6. Now, connect the patient scene to a button in the menu screen to allow for multiple case selections. Navigate to **Assets, Scenes,** and **Menu scene [1]**. In the **Hierarchy** window, go to **NearMenu4x2** *(Near-Menu-Four-By-Two)*, then to **ButtonCollection** *(Button-Collection)*, and select the relevant button **[2]**. In the **Inspector** window, go to **Basic Events**, and under **MenuScript.LoadScene** *(Menu-Script-Dot-Load-Scene)*, type the name of the patient scene **[3]**.

3.6.1. SCREEN: 68607_screenshot_13.mp4: 00:00-00:06

3.6.2. SCREEN: 68607_screenshot_13.mp4: 00:06-00:20

3.6.3. SCREEN: 68607_screenshot_13.mp4: 00:20-00:32

4. Validation of Holographic Visualization of Moving Organs

Demonstrator: Vera van Boheemen

Videographer NOTE: In two shots (4.9.2 and 4.12.1) I filmed with synchro scan on 280 degrees shutter angle to reduce jittering screen image.

4.1. Create or obtain a 3D model of a kidney phantom with realistic anatomical structures **[1].** Import the 3D model into a 3D CAD modeling software **[2]**. Then, use the **Solid, Create,** and **Hole** functions to integrate five registration pivot points on the side of the model. Set the **Hole Type** to Simple, **Hole tap Type** to Simple, **Drill Point** to Angle, **Height** to 0.5 millimeters, and **Diameter** to 4.0 millimeters **[3]**.

4.1.1. SCREEN: 68607_screenshot_14.mp4: 00:01-00:10, 00:16-00:18

4.1.2. SCREEN: 68607_screenshot_15.mp4: 00:00-00:11

4.1.3. SCREEN: 68607_screenshot_16.mp4: 00:03-00:07, 00:12-00:13, 00:21-00:30, 01:02-01:10

4.2. To fixate the electromagnetic reference sensor, create a cylinder with a hole and integrate it into the kidney model. Start a new sketch and use **Center Diameter Circle** to draw a circle and an inner circle with a diameter of 2.8 millimeters **[1]**. Extrude the outer circle by 16.5 millimeters. Then, go to **Modify** followed by **Combine**. Select both the 3D kidney model and the cylinder, choose **Join**, and confirm by clicking **OK [2]**.

4.2.1. SCREEN: 68607_screenshot_17.mp4: 00:00-00:31

4.2.2. SCREEN: 68607_screenshot_17.mp4: 00:33-00:35, 00:43-00:49, 01:47-01:55, 02:28-02:40

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4.3. Then, use the **Export** or **3D Print** function to export the final integrated model **[1]**.

4.3.1. SCREEN: 68607_screenshot_17.mp4: 03:57-04:04

4.4. Next, use a flexible or semi-flexible filament such as thermoplastic polyurethane to print the kidney phantom following the procedure described previously **[1-TXT]**.

4.4.1. Talent setting up a 3D printer and selecting thermoplastic polyurethane filament for printing the kidney phantom model. **TXT: See the 3D Slicer and SlicerIGT tutorial for EM tracking system configuration**

4.5. Place the field generator of the electromagnetic tracking system directly beneath the printed kidney phantom **[1]**. Remove all ferromagnetic objects from the surrounding environment to prevent electromagnetic field inhomogeneities **[2]**.

4.5.1. Talent positioning the field generator on the lab table and placing the phantom above it.

4.5.2. Talent clearing nearby metallic or magnetic items from the workspace.

4.6. Then, connect the electromagnetic sensor and the electromagnetic pointer to the tracking system **[1-TXT]**. Attach the electromagnetic reference sensor to the 3D model by fixing it securely inside the cylinder using glue **[2]**.

4.6.1. Talent plugging in the EM sensor and pointer into the tracking interface. **TXT: Ensure accurate visualization of tool transforms in 3DSlicer**

4.6.2. Talent applying glue and inserting the EM-reference sensor into the cylinder slot on the kidney phantom.

4.7. In 3D Slicer, import the 3D kidney model containing the pivot points **[1]**. Use the **Fiducial Registration Wizard**, select **Place a control Point**, and digitally assign the registration landmarks **[2]**.

4.7.1. SCREEN:68607_screenshot_18.mp4: 00:03-00:21

4.7.2. SCREEN: SCREEN:68607_screenshot_19.mp4: 00:00-00:18

4.8. To perform landmark registration in 3D Slicer, use the electromagnetic pointer to pinpoint the physical landmark points **[1]**. Press **Place a control point** at each physical location to register them in the software **[2]**. Then, calculate the rigid linear registration transform by pressing **Update [3]**.

4.8.1. Talent using the EM pointer to physically touch each landmark point on the phantom.

4.8.2. SCREEN: SCREEN:68607_screenshot_20.mp4: 00:04-00:19

4.8.3. SCREEN: SCREEN:68607_screenshot_20.mp4: 00:19-00:22

4.9. Now, apply the calculated registration transform to the 3D model to link it with the electromagnetic reference sensor **[1]**. Move the physical model and confirm that the digital version in 3D Slicer follows its motion **[2]**.

4.9.1. SCREEN: SCREEN:68607_screenshot_21.mp4: 00:03-00:19

4.9.2. Talent gently moving the physical phantom while the digital model moves in synchrony on screen.

4.10. Launch the holographic display device and open the holographic application configured earlier **[1]**. Then, navigate to the correct patient-specific 3D model that is currently visualized in 3D Slicer **[2]**.

4.10.1. Talent turning on the holographic device and opening the custom application.

4.10.2. SCREEN: 68607_screenshot_24.mp4:00:03-00:11, 00:30-00:34; 68607_screenshot_25.mp4: 00:04-00:09

4.11. Now, attach the infrared marker to the specified location using glue, ensuring the fitted 6.4-millimeter infrared reflective spheres are in place, as guided by the preoperative planning **[1]**.

4.11.1. Talent applying glue and positioning the infrared marker at the correct site on the phantom using visual cues.

4.12. Use the electromagnetic pointer to digitally identify the target points as seen through the holographic visualization **[1]**. Save the resulting set of EM sensor coordinates **[2]**.

4.12.1. Talent touching key anatomical locations with the EM pointer based on holographic overlays.

4.12.2. SCREEN: 68607_screenshot_22.mp4: 00:03-00:19

4.13. Calculate the error by comparing the saved target coordinates to the actual placed landmarks to validate the accuracy of the holographic visualization **[1]**.

4.13.1. SCREEN: 68607_screenshot_23.mp4 00:00-00:13

Results

5. Results

5.1. Across all participants, the Point Localization Error or PLE *(P-L-E)* showed a median value of 8.74 millimeters **[1],** with individual measurements ranging from 2.78 to 13.20 millimeters **[2].** Surgeon 2 consistently achieved the lowest PLE measurements, including the two most accurate localizations at 2.78 and 3.48 millimeters **[3].**

5.1.1. LAB MEDIA: Table 1. *Video editor: Highlight the final column labeled "PLE (mm)" for all rows in the table.*

5.1.2. LAB MEDIA: Table 1. Video editor: Emphasize the row with the lowest PLE value of 2.78 and the highest PLE value of 13.20.

5.1.3. LAB MEDIA: Table 1. *Video editor: Highlight the rows under "Surgeon 2" where PLE values are 2.78 and 3.48.*

5.2. The largest localization error was observed during the third measurement by Surgeon 3, with a PLE of 13.20 millimeters **[1].**

5.2.1. LAB MEDIA: Table 1. *Video editor: Highlight the third row under "Surgeon 3" in the PLE column, showing the value 13.20.*

Pronunciation Guides (American English)

1. Extrude

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/extrude (youtube.com, merriam-webster.com)
- **IPA**: /ɪkˈstruːd/
- **Phonetic Spelling**: ik-strood

2. Fiducial

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/fiducial (howtopronounce.com, merriam-webster.com)
- **IPA**: /fɪˈduʃəl/
- **Phonetic Spelling**: fi-doo-shuhl