Evaluating Colored VR Navigation for Laminectomy and Mastoidectomy

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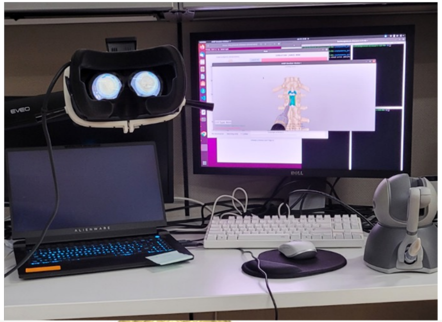
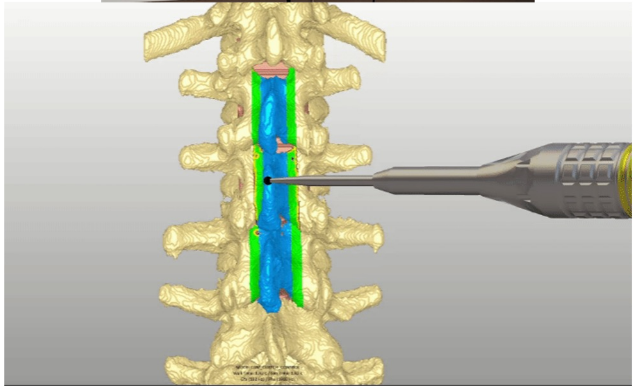
Project Background

- **Colored VR navigation** using signed-distance functions (SDF)
- Execute **user-study** on laminectomy
- Execute **feasibility-study** on mastoidectomy





[4] A. Munawar, Z. Li, P. Kunjam, N. Nagururu, A. S. Ding, P. Kazanzides, T. Looi, F. X. Creighton, R. H. Taylor, M. Unberath, Virtual Reality for Synergistic Surgical Training and Data Generation, Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization 10 (4) (2022) 366–374, arXiv:2111.08097 [cs]. doi:10.1080/21681163.2021.1999331. URL http://arxiv.org/abs/2111.08097

Selected Literature

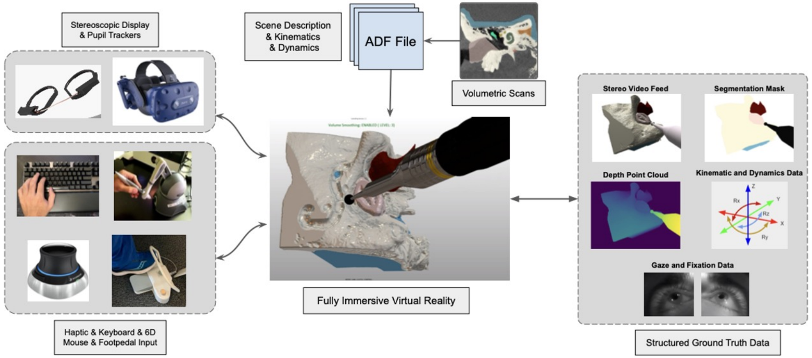
[1] A. Munawar et al., “Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond” Technical

[2] H. Ishida and J. A. Barragan et al., “Improving Surgical Situational Awareness with Signed Distance Field: A Pilot Study in Virtual Reality” Technical

[3] F. Heinrich et al., “HoloPointer: a virtual augmented reality pointer for laparoscopic surgery training,” Int J Comput Assist Radiol Surg, vol. 16, no. 1, pp. 161–168, Jan. 2021, doi: 10.1007/s11548-020-02272-2. Clinical

FIVRS

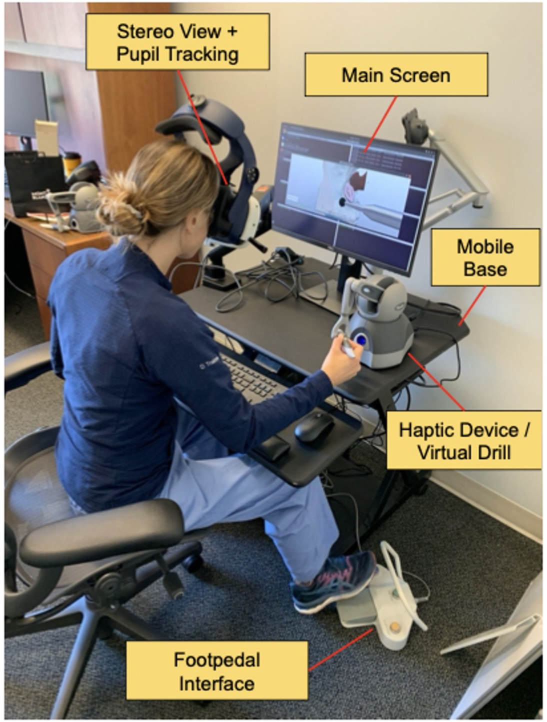
- **Title**: Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond
- **First author**: Adnan Munawar
- **Relevance**
  - Technical outline for VR drilling simulator we will use



[1] A. Munawar et al., “Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond”

Technical Approach

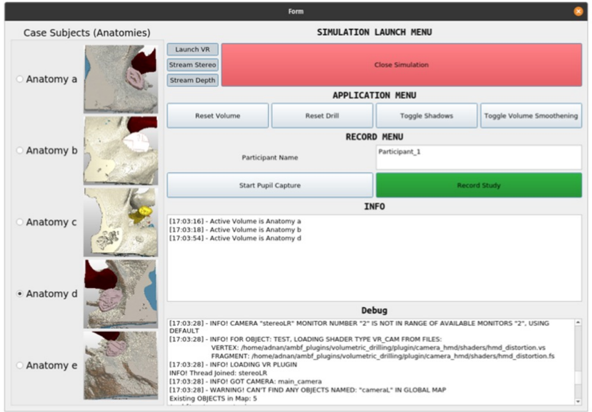
- **Hardware**
  - Linux OS
  - HTC Vive Pro (VR headset)
  - Phantom Omni (haptic device)
    - Model 4 burr types
  - Keyboard, 6D mouse, foot pedal

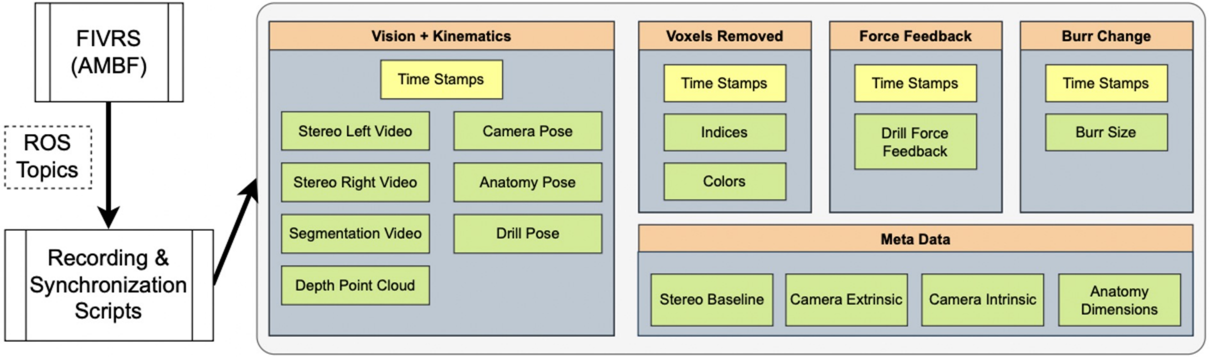


[1] A. Munawar et al., “Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond”

Technical Approach

- **Software**
  - AMBF plugin
  - GUI
  - ROS/Python data extraction





[1] A. Munawar et al., “Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond”

Technical Approach

- Focused on **haptic** and **audio feedback**
- **Haptic force**

$$\vec{F}_{\text{haptic}} = \vec{F}_{\text{collision}} + \vec{1} \cdot A_{\text{drill}} \cdot \sin\left(ft\right)$$

- **Audio drilling pitch**

$$p_{\text{pitch}} = A_{\text{audio}} - ||\vec{F}_{\text{collision}}||/||\vec{F}_{\text{max}}||$$

- **Visual feedback** via text overlays when user drilled near sensitive anatomy
  - Shadowing and online smoothing for visual fidelity

[1] A. Munawar et al., "Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond"

Critical Review

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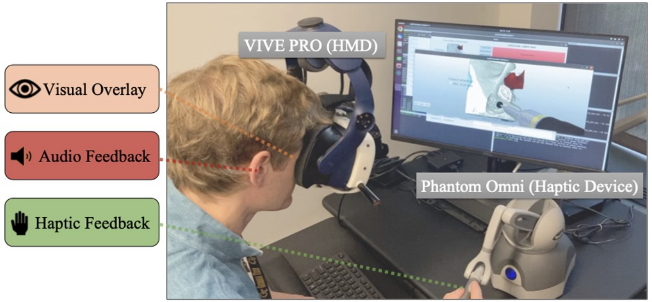
Pros	Cons	Takeaways
Technical outline for VR drilling simulator. Open-source code for research/public use.	• Asynchronous data extraction • Underdeveloped visual feedback • Lacked explanation of how gazing data was analyzed	VR simulator is effective and next-steps include 1) robust clinical testing 2) development of feedback systems

SDF Pilot Study

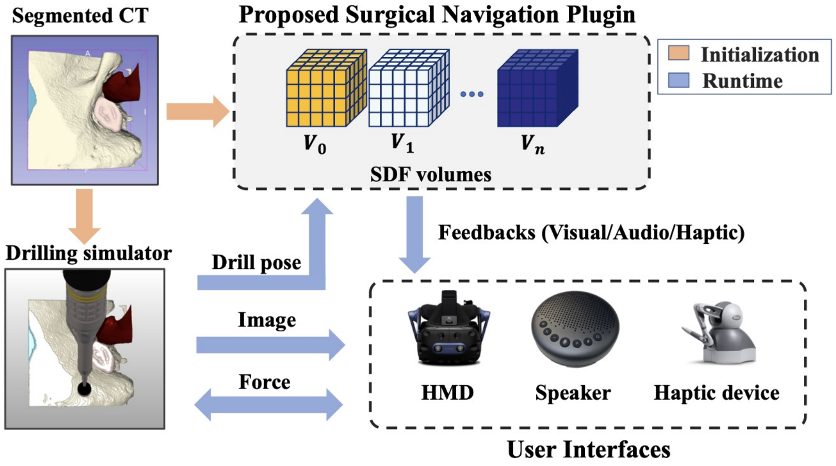
- **Title**: Improving Surgical Situational Awareness with Signed Distance Field: A Pilot Study in Virtual Reality
- **First authors**: Hisashi Ishida, Juan Antonio Barragan
- **Relevance**
  - Description of SDF-based VR simulator used in our project
  - Models data collection and analysis



[2] H. Ishida and J. A. Barragan et al., "Improving Surgical Situational Awareness with Signed Distance Field: A Pilot Study in Virtual Reality"

Technical Approach

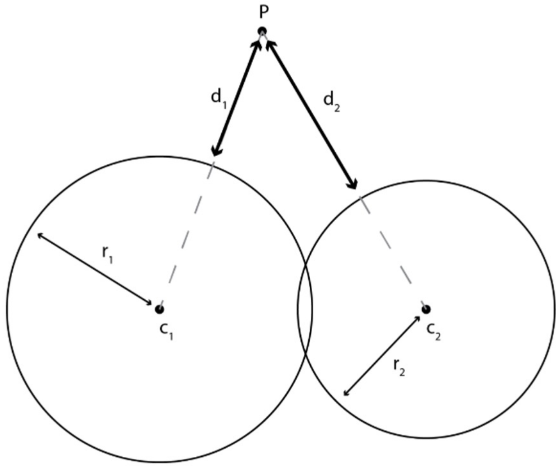
- Input segmented CT/MRI scans
- Compute Signed Distance Field (SDF) volumes and query distances for user feedback



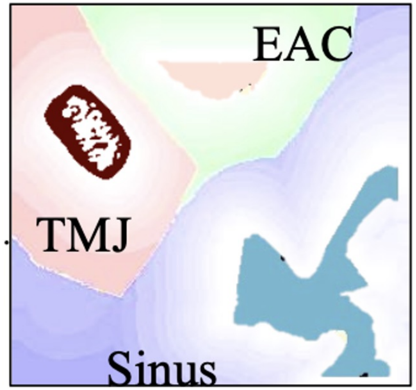
[2] H. Ishida and J. A. Barragan et al., “Improving Surgical Situational Awareness with Signed Distance Field: A Pilot Study in Virtual Reality”

Technical Approach

- Signed Distance Field (SDF) is a function to compute distance from drilling tool to closest anatomy



(e) Combined



https://jasmcole.com/2019/10/03/signed-distance-fields/
[2] H. Ishida and J. A. Barragan et al., "Improving Surgical Situational Awareness with Signed Distance Field: A Pilot Study in Virtual Reality"

Technical Approach

- Basic EDT to compute a SDF

1	1	1	1
1	0	0	1
1	1	0	1
1	1	1	1
1	1	1	1

→

∞	∞	∞	∞
1	0	0	1
4	1	0	1
∞	∞	∞	∞
∞	∞	∞	∞

→

2	1	1	2
1	0	0	1
2	1	0	1
5	2	1	2
8	5	4	5

$$g_{ijk} = \min_{x} \{(i-x)^2;\ f_{xjk} = 0, 1 \le x \le L\}.$$

$$h_{ijk} = \min_{y} \{g_{iyk} + (j-y)^2;\ 1 \le y \le M\}.$$

Pilot Study

- **Goal**: evaluate the utility of audio, visual, and haptic feedback
- **Subjects**: three experienced surgeons, one medical student
- **Data**: quantitative (completion time, number of unintended voxels remove) and qualitative (NASA-TLX) on two CTs

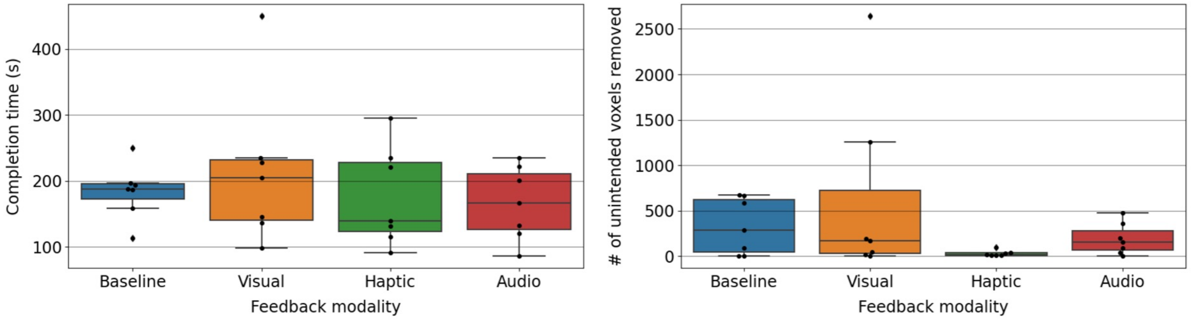


Fig. 6: User study objective metrics. (a) Completion time per anatomy and (b) number of unintended voxels removed.

[2] H. Ishida and J. A. Barragan et al., "Improving Surgical Situational Awareness with Signed Distance Field: A Pilot Study in Virtual Reality"

Critical Review

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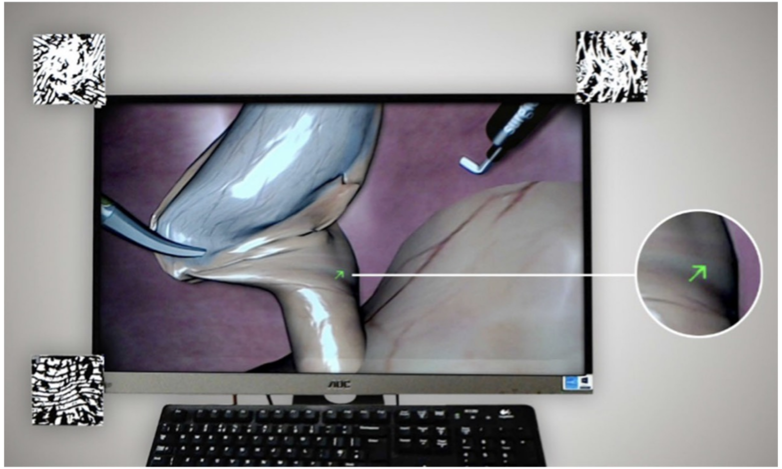
Pros	Cons	Takeaways
Evaluated **three distinct feedback** mechanisms (visual, audio, haptic) independently in virtual-reality simulator.	• Few subjects **(n=4)** for study and small number of CTs (n=2) • Did not compare **between surgeons**	Visual feedback could be **improved** with specific anatomical guidance and less confusing display.

HoloPointer

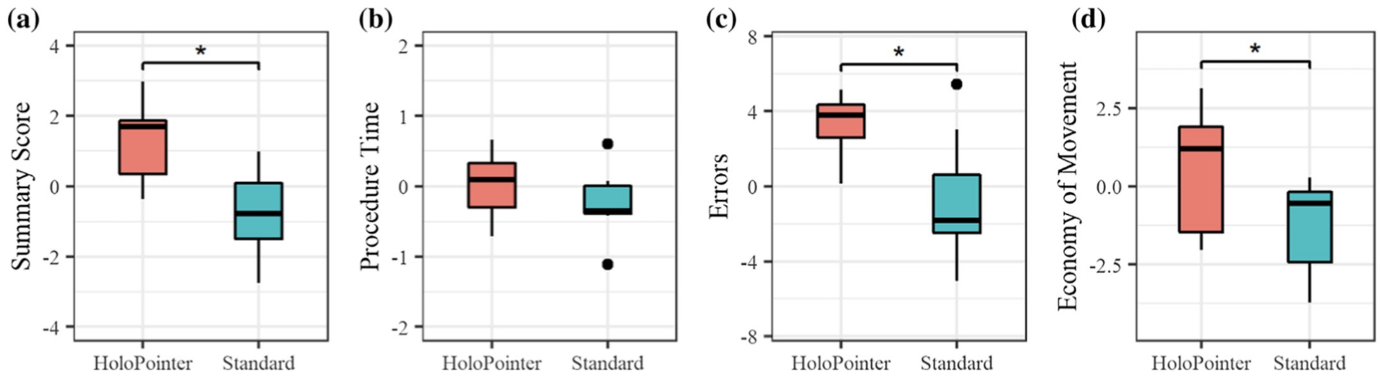
- **Title**: HoloPointer: a virtual augmented reality pointer for laparoscopic surgery training
- **First author**: Florian Heinrich
- **Journal**: IJCARS

- **Relevance**
  - Virtual technology for different surgical training
  - Outlines user study protocol



User Study

- **Goal**: evaluate the utility of HoloLens as a training tool
- **Subjects**: one senior surgeon (trainer); seven junior residents, one senior resident, one consultant (trainees)
- **Data**: z-scores for procedure time, errors, economy of movement; subjective feedback questionnaire



Critical Review

Pros	Cons	Takeaways
Similar **study outline** (two conditions per subject) to what we've proposed.	• **Omission** of experienced surgeon results • **Lacked granularity in z-scores** due to summation • **Limited subjective feedback** • **Limited technical** details	**Adaptable** user study design that established efficacy of HoloLens AR training platform.

Conclusion

- **FIVRS:**
  - Technical framework for VR Drilling simulator with feedback
- **SDF**:
  - More accurate tool-anatomy measurements using SDFs
- **HoloPointer**:
  - Adaptable user study design