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Bachelor Thesis **Final Presentation**

Visualization of Complex Bone Fractures in Augmented Reality During Reduction Surgery

Technische Universität München + Johns Hopkins Whiting School of Engineering

Clinical Context

What are complex bone fractures?

- Comminuted fracture (multiple fragments)
- Severe soft tissue damage
- Loss of bone

Figure 1: Radiograph and volumetric rendering from a high-energy tibial plafond fracture with severe comminution (~15 fragments) [1].

[1] *P. T. Thaddeus. "Virtual Pre-Operative Reconstruction Planning for Comminuted Articular Fractures." PhD thesis. University of Iowa, 2010.*

Clinical Context

How are complex bone fractures treated?

- Open Reduction Internal Fixation (ORIF)

[2] Winchester Hospital. url: http://www.winchesterhospital.org/health-library/article?id=539804 (visited on 07/01/2018).

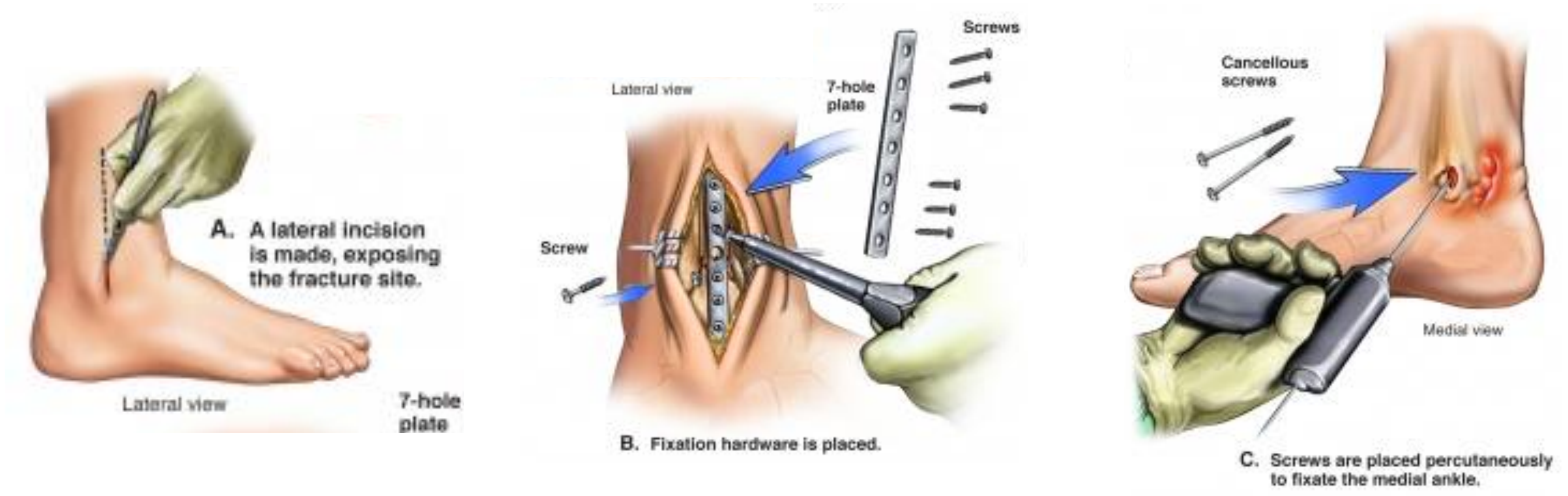


Figure 2: ORIF surgery of the ankle [2].

Problem Statement

- Mental transformation from 2D monitors to 3D surgical space
- Leads to limited spatial understanding of complex fracture
- **Locating** fragments and finding correct **alignment** becomes ”jigsaw puzzle”

> *“Many times you open up and all of a sudden [...] you see all these little pieces of bone and you are trying to figure out what to do. It can be pretty frustrating.” [3]*
>
> – Dr. Richard Rogachefsky, Orthopaedic Surgeon

- **Duration** of interventions increases and **complications** might arise

[3] *R. Rogachefsky. Treatment of Severely Comminuted Intra-Articular Fractures of the Distal End of the Radius by Open Reduction and Combined Internal and External Fixation. url: https://www.youtube.com/watch?v=tyk-hXM1cTk (visited on 07/01/2018).*

Research Goal

- Goal — Assist surgeon with intra-operative **visualization** of CT Data
- Technique — Augmented Reality, HMD
- Hardware — HoloLens
- Software — 3D Slicer, Unity
- Workflow

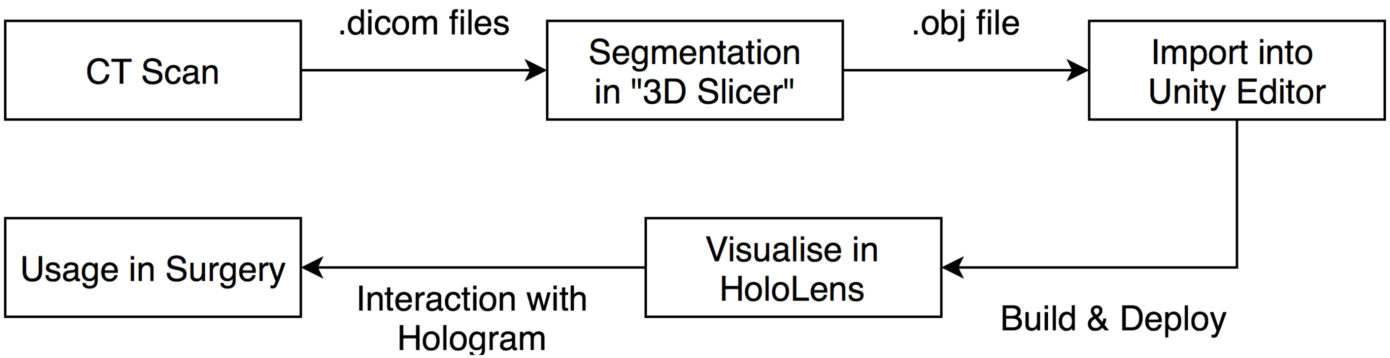


Figure 3: Operating Room Scenario [1, 4].

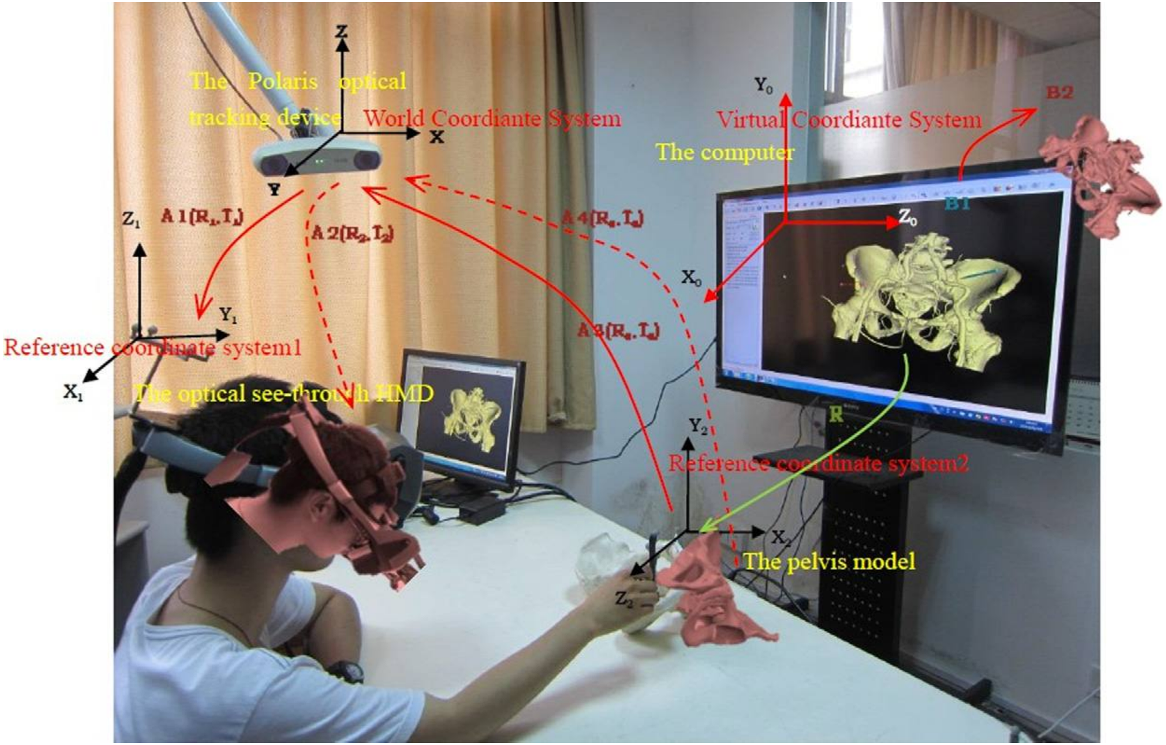
[4] *Engadget. url: https://www.engadget.com/2016/10/11/duke-tests-hololens-for-brain-surgery/ (visited on 07/01/2018).*

Related Works (1)

Figure 4: **Chen et al. (2015)** – AR-based surgical navigation system facilitates preoperative surgical planning, registration, and intra-operative tracking [5].

- OST HMD (nVisor ST60, NVIS)
- Optical tracking device (Polaris Vicra, NDI Inc.)

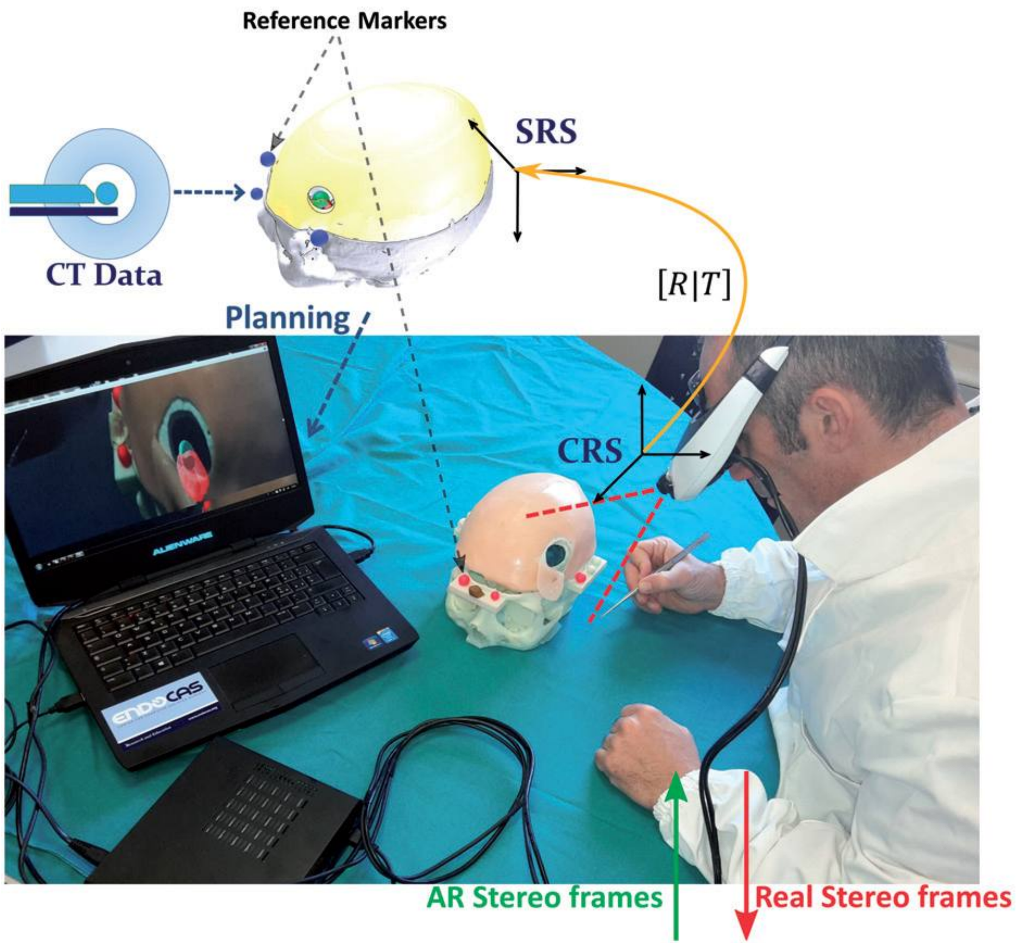
[5] *X. Chen, L. Xu, Y. Wang, H. Wang, F. Wang, X. Zeng, W. Qiugen, and J. Egger. "Development of a surgical navigation system based on augmented reality using an optical see-through head-mounted display." In: Journal of Biomedical Informatics 55 (Apr. 2015).*



Related Works (2)

Figure 5: **Cutolo et al. (2017)** – AR system based on a VST HMD that can aid in complex neurological lesion targeting [6].

- 3D viewer (Sony HMZ-T2)
- Two external USB cameras (5 megapixels)

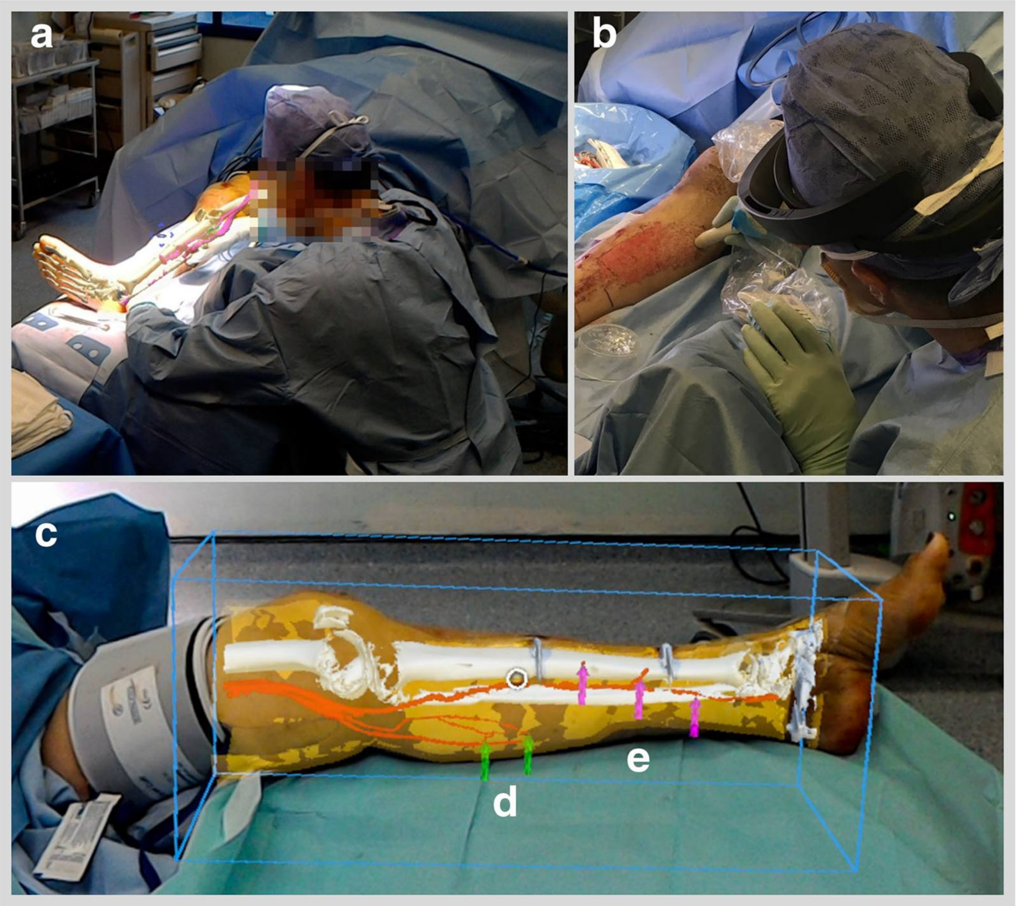


[6] *F. Cutolo, A. Meola, M. Carbone, S. Sinceri, F. Cagnazzo, E. Denaro, N. Esposito, M. Ferrari, and V. Ferrari. "A new head-mounted display-based augmented reality system in neurosurgical oncology: a study on phantom." In: Computer Assisted Surgery 22.1 (2017)*

Related Works (3)

Figure 6: **Pratt et al. (2018)** – 3D overlay of models to identify the subsurface location of vascular perforators [7].

- OST HMD (Microsoft HoloLens)
- Segmentations from CTA



[7] *P. Pratt, M. Ives, G. Lawton, J. Simmons, N. Radev, L. Spyropoulou, and D. Amiras. "Through the HoloLens™ looking glass: augmented reality for extremity reconstruction surgery using 3D vascular models with perforating vessels." In: European Radiology Experimental 2.1 (Jan. 2018)*

Research Gap

Chen et al. (2015)	Cutolo et al. (2017)	Pratt et al. (2018)
• Optical see-through • Marker based registration • Complex Setup	• Video see-through • Marker based registration • Complex Setup	• Optical see-through • Manual registration • Simple setup

Research Gap

- Optical see-through
- Non-registering
- Simple setup (high ease of use)

Segmentation in 3D Slicer

- Segment Editor module in 3D Slicer
- Region growing algorithm

Figure 7: Segmentation process.

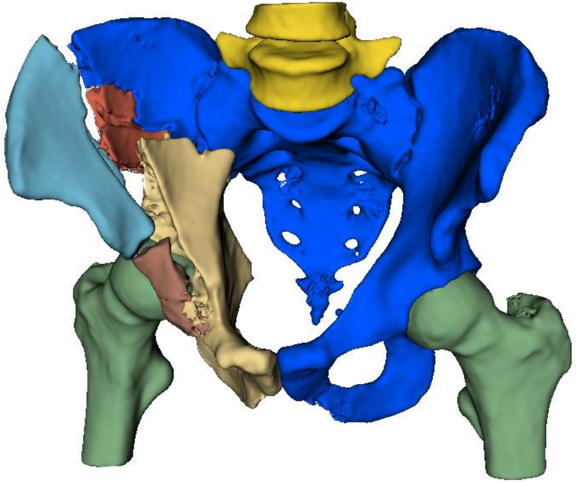


Figure 8: Resulting 3D Model.

Segmentation in 3D Slicer

- Leakage problem: misclassification of tissue
- Pronounced in distal regions of long bones
- Solution for now: manual reworking

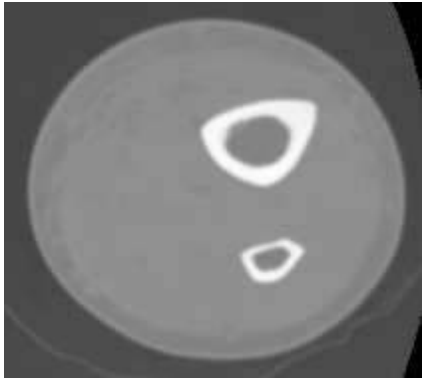


Figure 9: Intact proximal midshaft of the tibia [8].

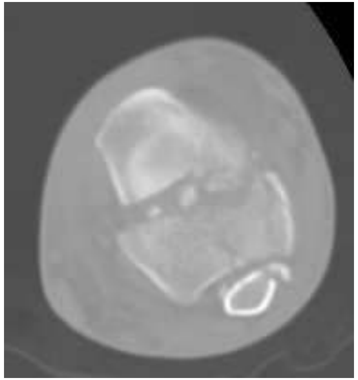


Figure 10: Comminuted fracture of the distal tibia [8].

[8] *A. Willis, D. Anderson, T. Thomas, T. Brown, and J. Marsh. "3D reconstruction of highly fragmented bone fractures." In: Proceedings of SPIE - The International Society for Optical Engineering 6512 (2007).*

What about Rapid Prototyping?

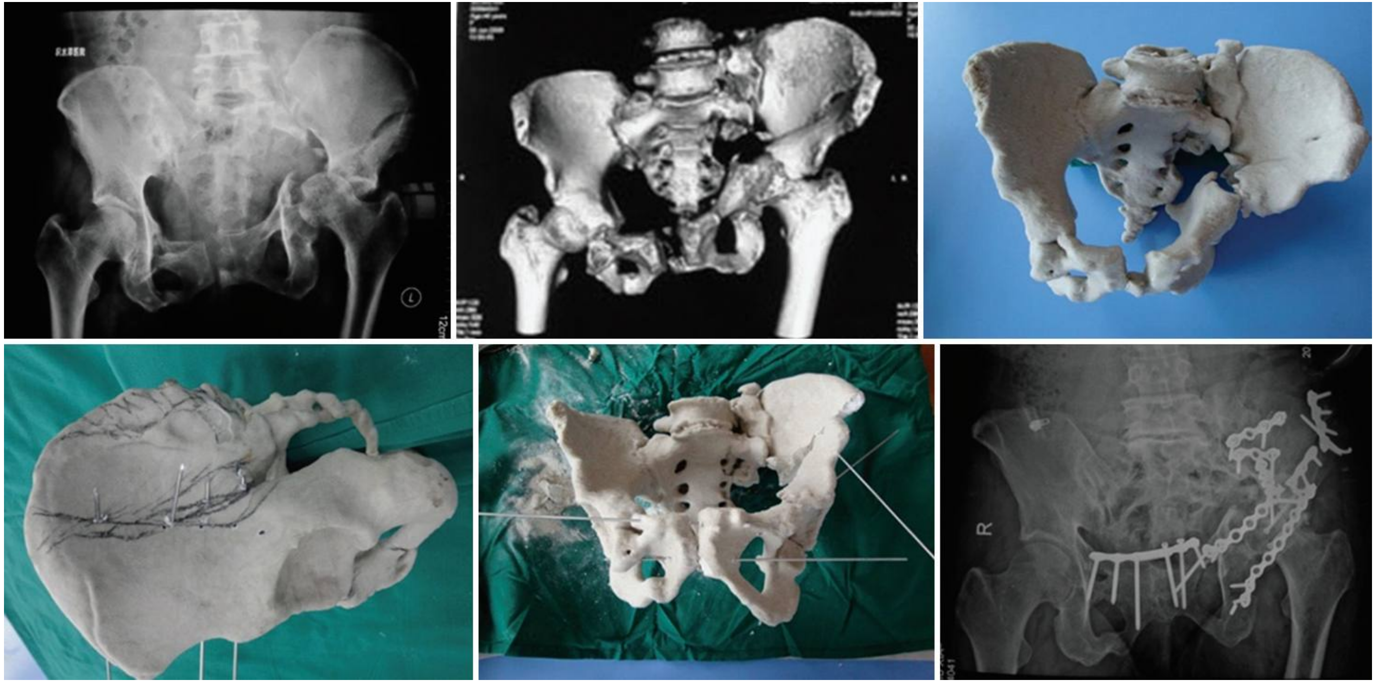


Figure 11: Rapid prototyping in orthopedic surgery [9].

[9] *Wu, Xin-Bao, et al. "Printed three-dimensional anatomic templates for virtual preoperative planning before reconstruction of old pelvic injuries: initial results." Chinese medical journal 128.4 (2015)*

Comparison RP and AR in Orthopedics

Rapid Prototyping	Augmented Reality (HMD)
• Tangible models	• Non-tangible models
• Multiple viewers	• Single viewer
• Model sterilization necessary [10]	• HMD sterilization necessary
• Non-flexible approach	• Flexible approach
• Long printing times	• Almost immediate use
• Cost of printing and storing models	• No additional costs

[10] *P. Fürnstahl, S. Wirth, L. Nagy, and A. Schweizer. "Advantages and pitfalls in computer assisted orthopedic surgery planning using rapid-prototyped guides." In: RTejournal- Forum für Rapid Technologie 2014.1 (2014).*

Comparison RP and AR in Orthopedics

Rapid Prototyping	Augmented Reality (HMD)
Tangible models	Non-tangible models
Multiple viewers	Single viewer
Model sterilization necessary [10]	HMD sterilization necessary
Non-flexible approach	**Flexible approach**
Long printing times	Almost immediate use
Cost of printing and storing models	No additional costs
Pre-operative tool	**Intra-operative tool**

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Graphical User Interface

- Anchored to gaze
- Kept at head level

- Nested menu
- Controls states
- Hide / show

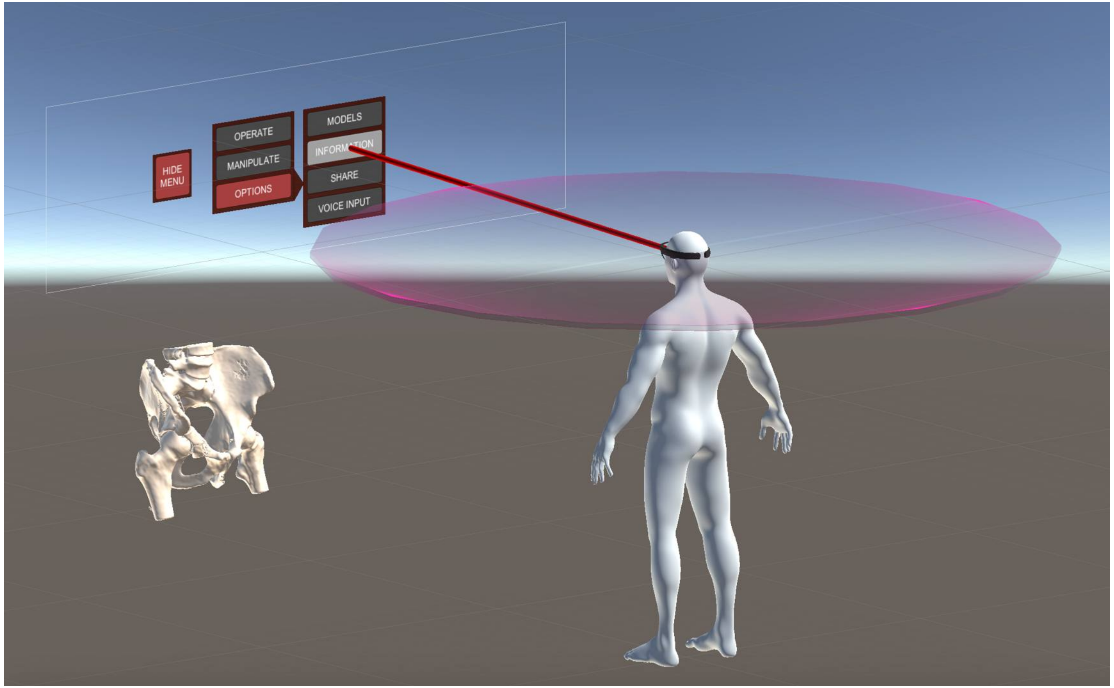
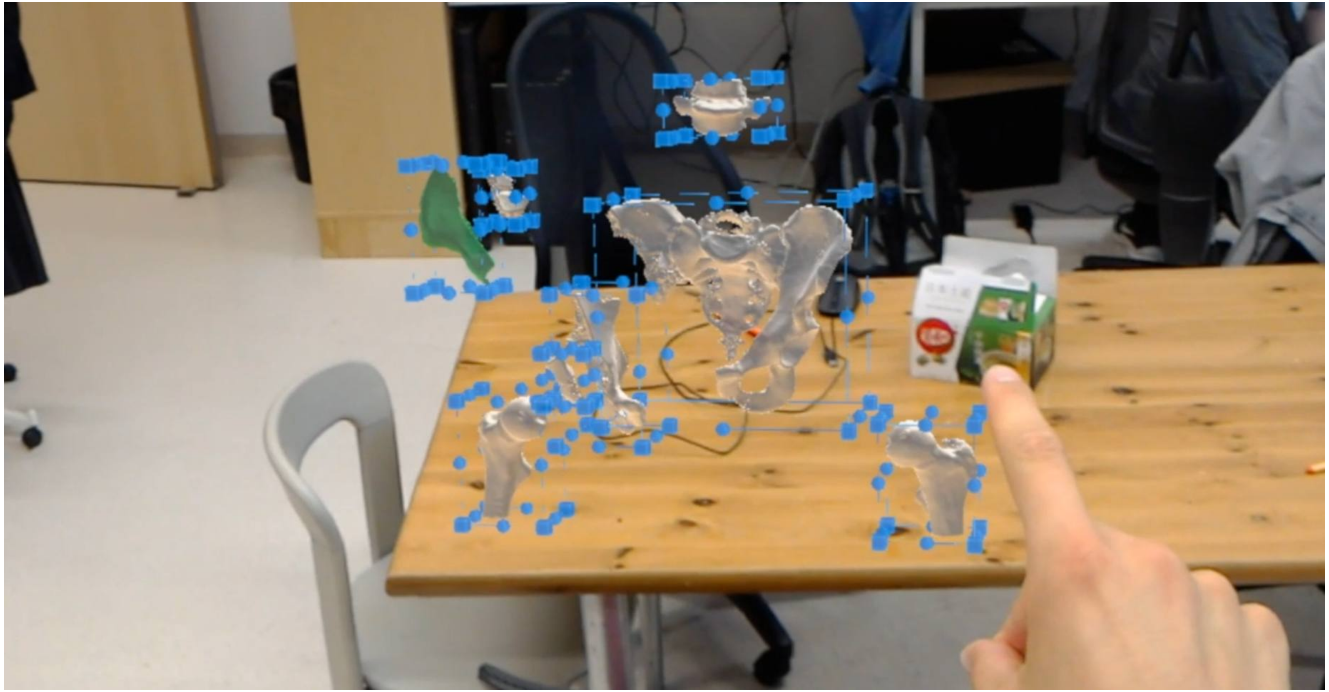


Figure 12: Spatial setup of application.

Application Demo Video



Video available at
https://www.youtube.com/watch?v=WQMYF8R2ZdI

Clinical Evaluation

- Demonstration to four orthopedic trauma surgeons
- System Usability Score results
  - On average: 81.9 → ”good”
  - Three of four: 90 → ”best imaginable” [11]
- Comments box for improvements

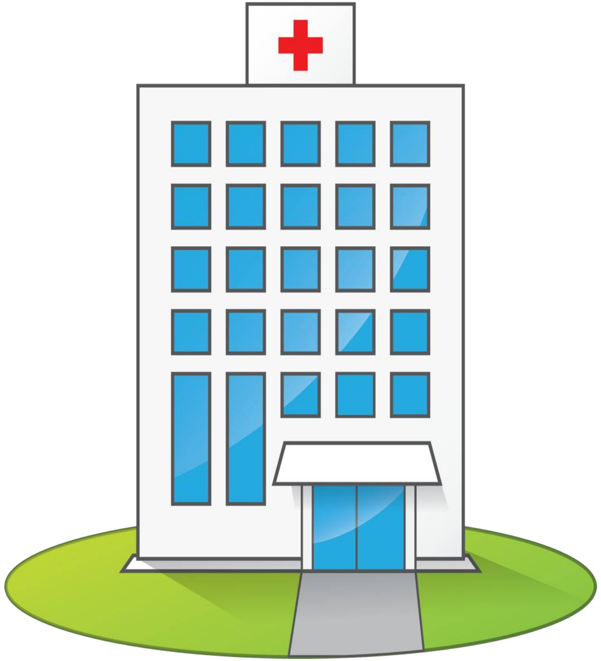
Figure 13: A surgeon evaluating the AR system.

[11] *A. Bangor, P. Kortum, and J. Miller. “Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale.” In: J. Usability Stud. 4 (Apr. 2009), pp. 114–123.*

Clinical Evaluation – Feedback on Feasibility

- Problem identified correctly
- Useful for intra-operative guidance, e.g.:
  - complex fractures of the acetabulum
  - comminuted intra-articular fractures
  - oral and maxillofacial surgery
- More economic than 3D printing

- 1 surgeon: system not mature enough for intra-operative guidance, pre-operative planning better
- Walking around models not possible in limited space of operating room



Clinical Evaluation – Feedback on Application

- Sensible GUI structure
- Easy to use
- Playful interaction with models in *Expand* and *Transform Fragments* states

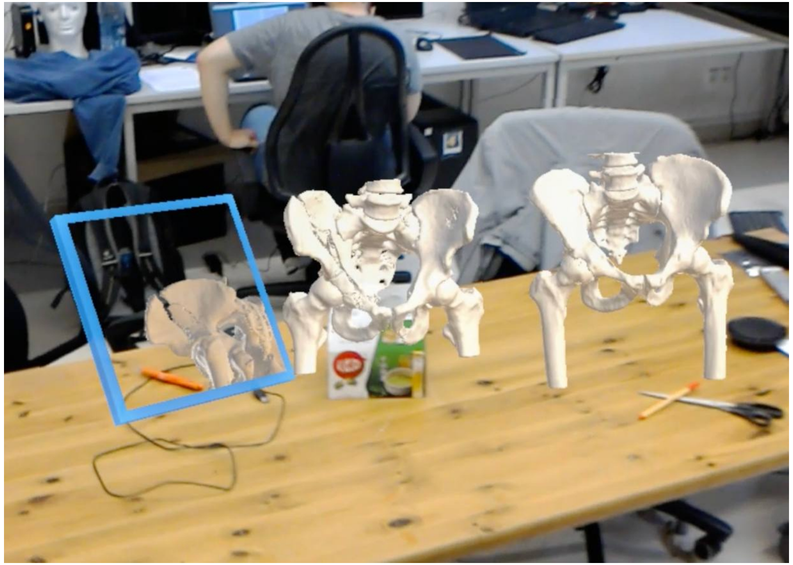


Figure 14: Screenshot from application.

Clinical Evaluation – Feedback on HoloLens

- Visualization quality

- Lightly tinted glass
- Wearing comfort

- Small field of view
- Battery life
- Gesture input → user training

Figure 15: Microsoft HoloLens.

Clinical Evaluation – Feedback on Future Development

- Expand software to other types of surgical interventions (tumor resection)

- Wireless streaming of the footage captured by HoloLens including the virtual models to other devices (e.g., computers or smartphones)

- Display of CTA data and original 2D CT image sequences

- Soft tissue simulation

Future Work (1)

- Study with trauma surgeons from Rechts der Isar on ”Pre-operative classification of complex fractures using Augmented Reality”

- Increase degree of workflow automation (especially segmentation)

- Integrate VR pre-operative planning tool into AR application
  1. Assessment of CT volume by surgeon in VR
  2. Bring fragments into nearly correct position
  3. Automatic bone reconstruction (≈ ICP), 3D Slicer Extension
  4. Integrate planning data into AR system

Future Work (2)

- Display pre-operative image data from MRI or X-ray
- Display intra-operative image data from C-arms
- Incorporate real-time information (anesthetic data, blood pressure, heart rate, body temperature and breathing rate)
- Test new means of input (e.g. haptic remote controls or gesture tracking based on Electromyography)

Figure 16: Vital signs.

Other image sources

- Hospital clipart https://www.clipartmax.com/download/m2i8H7N4i8i8A0Z5_hospital-clipart-transparent-background-hospital-clipart/ (visited on 11/08/2018)
- HoloLens picture https://www.microsoft.com/de-at/p/microsoft-hololens-commercial-suite/944xgcf64z5b?activetab=pivot%3aoverviewtab (visited on 08/11/2018)
- Future work clipart https://losangeles.cbslocal.com/2015/09/28/l-a-health-administrator-helps-prepare-the-future-work-force/ (visited on 11/08/2018)
- Vital signs picture https://www.videoblocks.com/video/normal-vital-signs-on-bedside-icu-monitor-patient-stable-after-heart-surgery-h77wezdaiu2xj3zm (visited on 11/08/2018)

Any **questions**,
suggestions or **ideas**?