AUGMENTED REALITY AIDED CRANIOFACIAL SURGERY

CIS2 FINAL PRESENTATION

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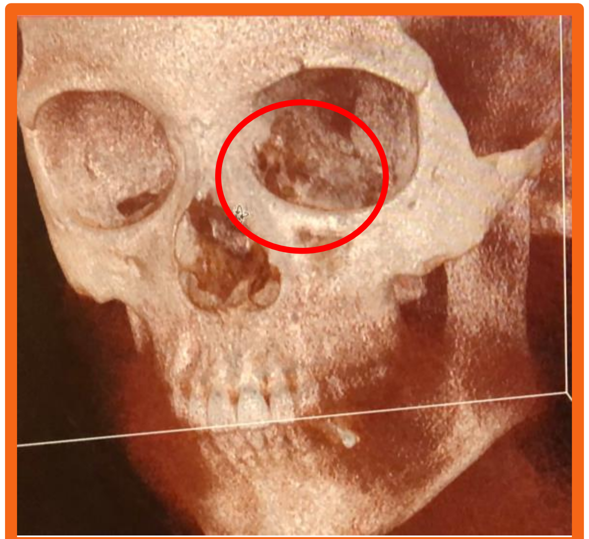
Mentors: Dr. Peter Kazanzides, Ehsan Azimi, Dr. Cecil Qiu, Dr. Sashank Reddy

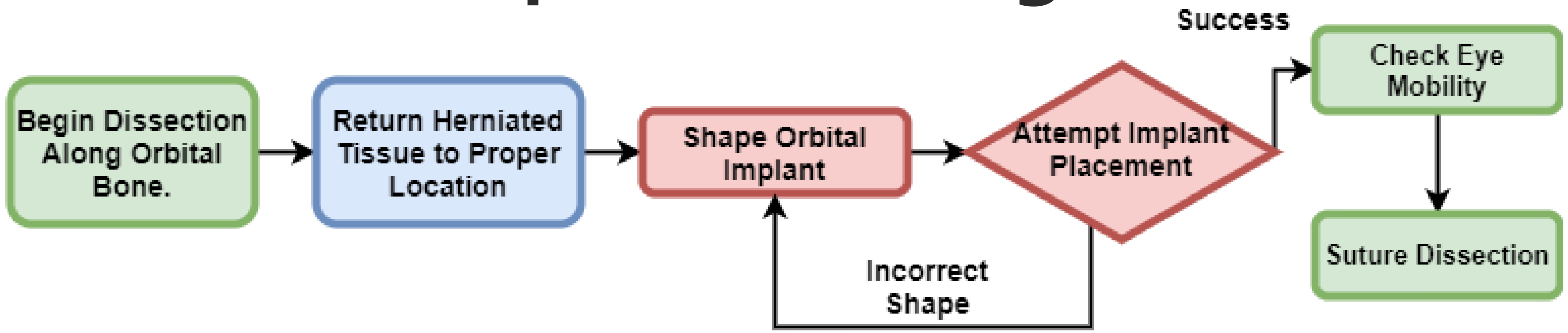
Background

Reconstruction:
- A concave plate is placed along the wall of the eye socket to prevent tissue from entering fracture cavity.
- Hard to place.
    - Low visibility
- Misplacement can result in injury to sensitive tissue.
- Long operating time.



Orbital Floor Fracture:
- Due to pressure on the eye from blunt trauma, the medial wall and orbital floor can fracture.
- Fracture repair requires manipulation of delicate and complex structures in a tight, compact space.
- Surgeons struggle with visibility in the confined region.

Current Intraoperative Surgical Workflow:



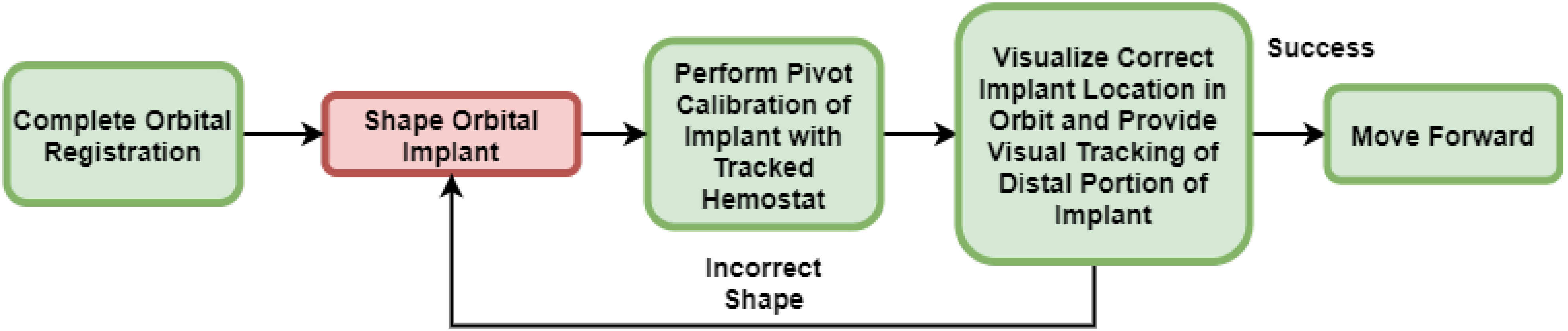
Length of Time for Completion Gradient:

GREEN ~ Standard

BLUE ~ Slow Step

RED ~ Time Limiting Step

Simplified Implant Placement:



Project Deliverables

Point/surface registration method for orbital socket

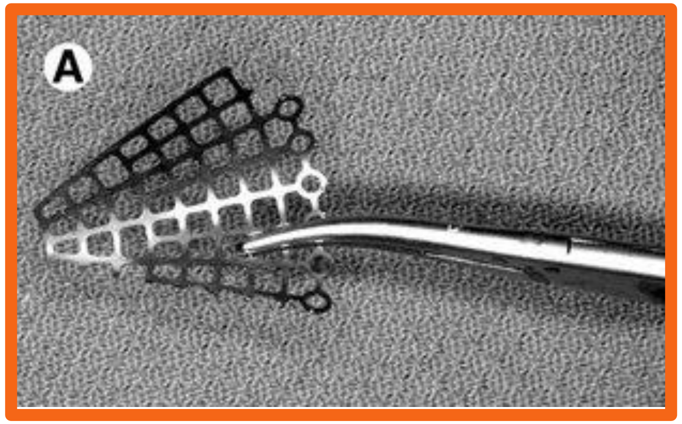
- Min: Target registration error (TRE) <4mm – camera-based tracker accuracy
- Expected: TRE <3mm - camera-based tracker accuracy
  Max: TRE <2mm - camera-based tracker accuracy

Calibration of implant with respect to tracked hemostat

- Min: Pivot Calibration of the distal edge of the implant (only model the distal edge)
- Expected: Use calibrated pointer to model the implant distal edge
  Max: Use calibrated pointer to model the entire implant

Visualize position of tracked implant respect to CT

- Min: Visualization on 3D slicer (OpenIGTlink to update model)
  Expected: Visualization in AR system (HoloLens) (Completed in unity, have not built HoloLens application)
- Max: A comparison between 3D slicer implementation and Hololens implementation

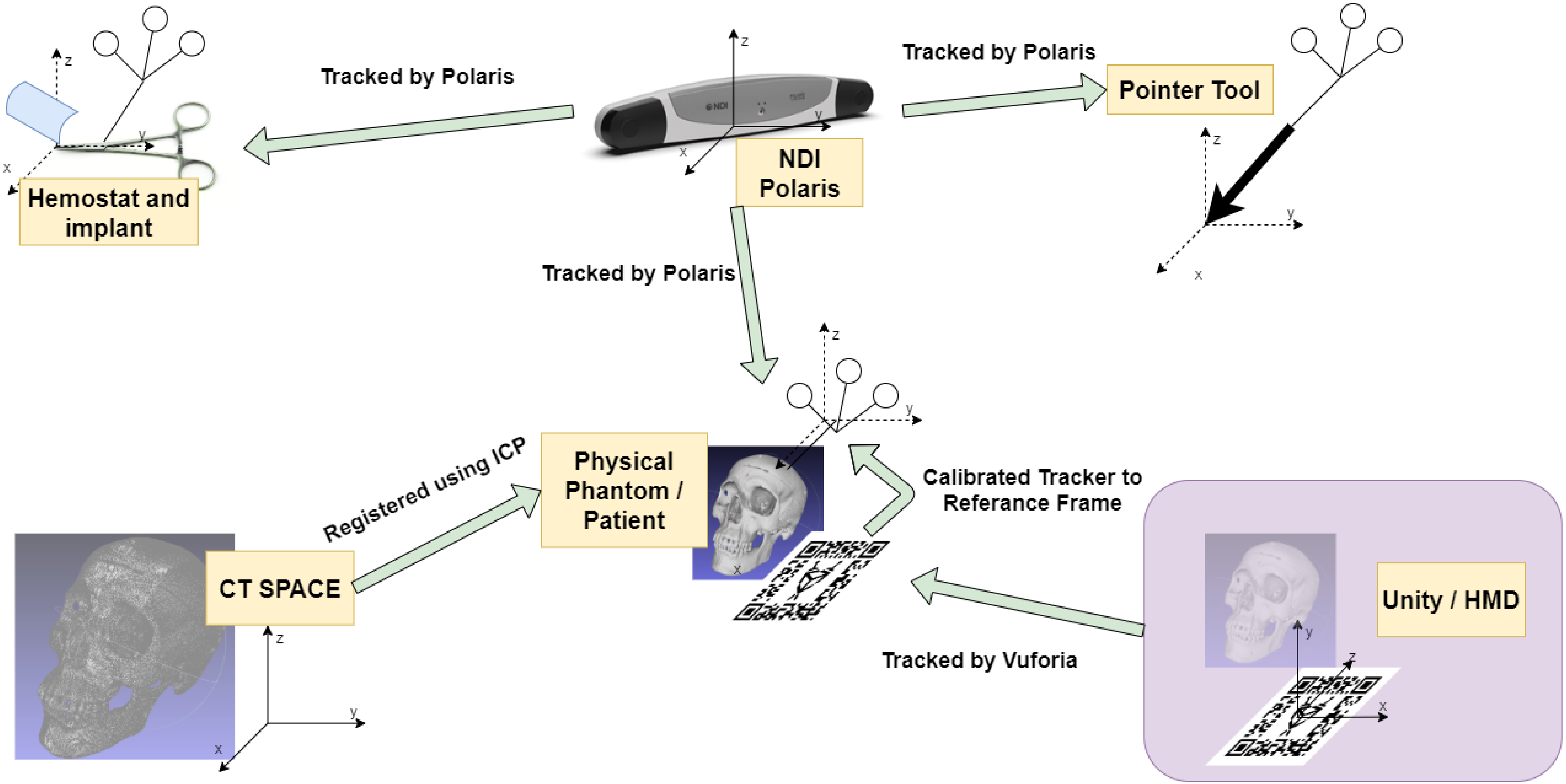


Pictures Courtesy of :
Dr. Peter Kazanzides

https://pngtree.com/freepng/check-mark-icon_3566317.html

[1] Kazanzides, P. (2020). Navigation for Orbital Floor Fracture Repair. [PowerPoint Slides]

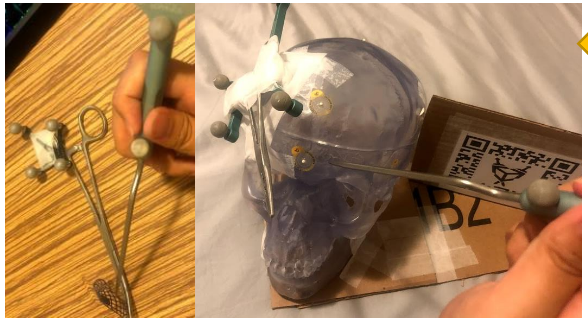
Transformation Diagram



System Diagram and Procedure

1.

2.



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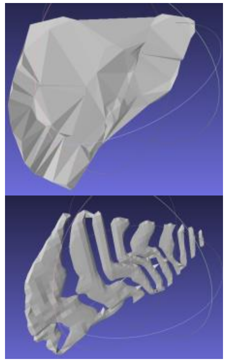

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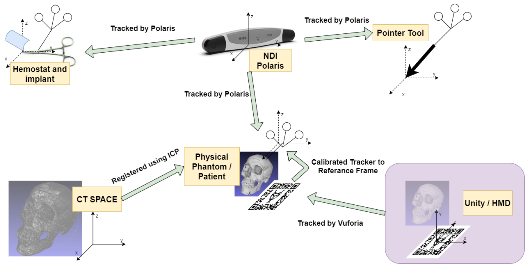

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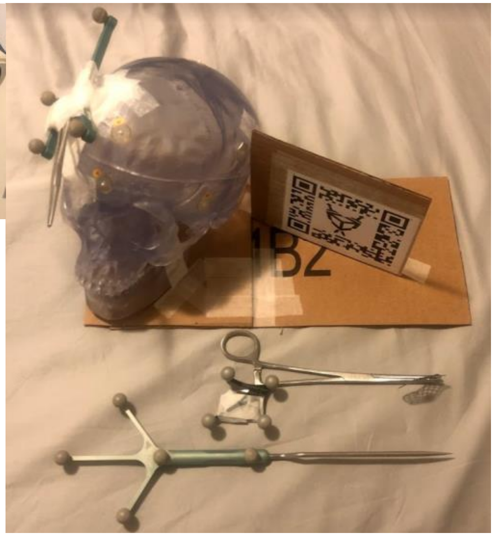


Server in Python

1 Tool and marker calibration

2 Implant and skull model surface sampling

3 Implant model creation

4 Registration and transformation calculation

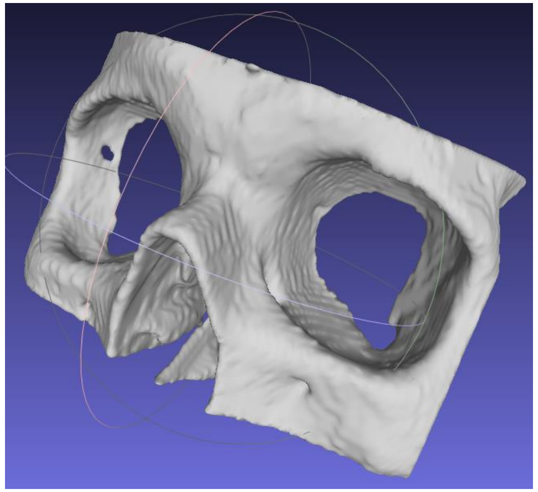
5 UDP communication

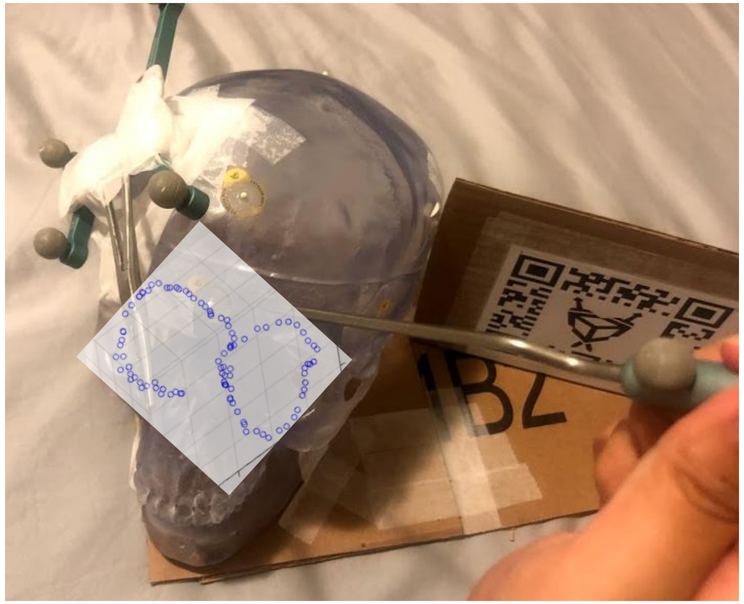
Client in Unity

Skull and implant models local transformation wrt. virtual space anchor (an AR marker)

Other Components

1. Iterative closest point algorithm
    - Convergence depends on coverage of the collected points





2. Polaris interface: Scikit Surgery NDI Tracker.
   https://pypi.org/project/scikit-surgerynditracker/

Registration Errors [updated May 8th]

Fiducial-based TRE:

1.6366 mm and 1.0700 mm on two different anatomic features

```
In [6]: anatomy
Out[6]:
array([[40.51786847, 42.6836939 , 43.39452785],
       [48.87653658,  9.11703356, 86.00934911]])

In [7]: sAnatomy = np.empty(anatomy.shape)
   ...: for i in range(2): # calculate anatomy features TRE
   ...:     sAnatomy[i] = np.matmul(rotReg, anatomy[i].reshape((3,1))).reshape((3,))+pReg

In [8]: sAnatomy
Out[8]:
array([[  1.10252554, -36.68493422, 122.6952669 ],
       [ 47.81188296, -62.86808334, 134.74888217]])
```

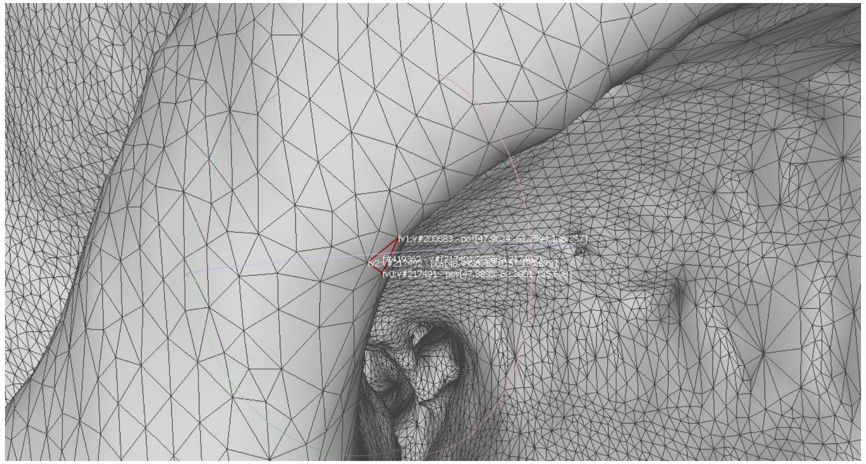
ICP made fiducial-based registration worse

```
In [8]: RInit
Out[8]:
array([[-0.38939654, -0.56499392,  0.72742848],
       [-0.84153704, -0.10280361, -0.53032709],
       [ 0.37441386, -0.81866555, -0.43543194]])

In [9]: pInit
Out[9]: array([   9.42965542,   24.81368453, 161.36384895])

In [10]: rotReg
Out[10]:
array([[-0.39174915, -0.55868462,  0.73102948],
       [-0.84133562, -0.10407423, -0.53039884],
       [ 0.372407   , -0.82282443, -0.42927028]])

In [11]: pReg
Out[11]: array([ -2.61006749,  16.12047    , 162.30599916])
```



Registration Errors [updated May 8th]

Fiducial-based residual:

average: 0.63 mm

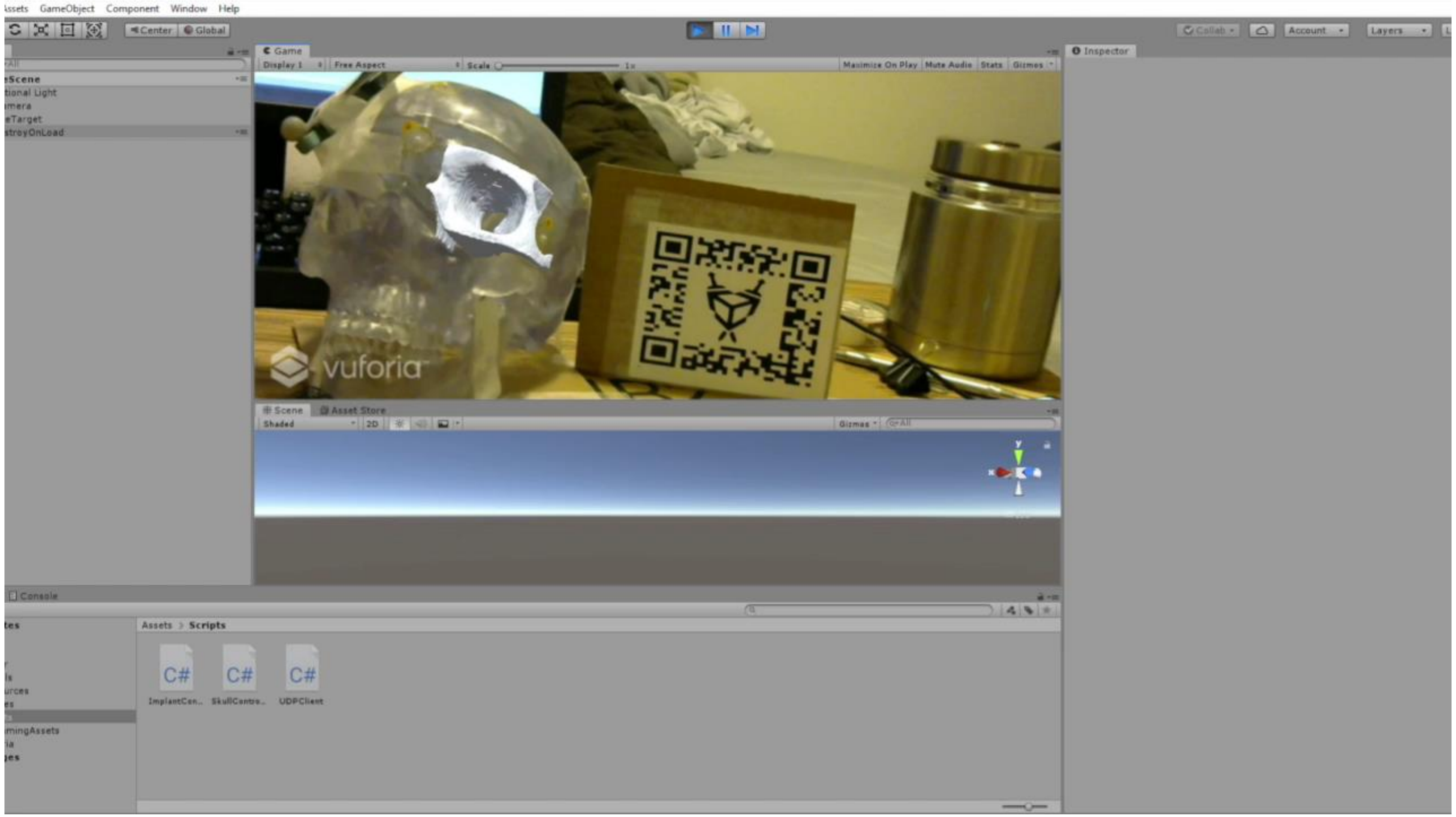
```
In [5]: errOut
Out[5]:
array([2.82017338e-01, 4.30686313e-01, 6.18952960e-01, 8.01866070e-01,
       1.06956782e+00, 3.77309077e-01, 1.42531037e+00, 1.47654863e+00,
       1.27701261e+00, 1.06331956e+00, 3.98391130e-01, 3.45641408e-01,
       4.15968170e-01, 6.12442359e-01, 3.15566916e-01, 4.69687345e-01,
       2.93488087e-01, 1.64534857e-01, 9.68886293e-02, 4.11399495e-01,
       8.76715509e-01, 1.14619768e+00, 1.07829923e+00, 8.91741661e-01,
       7.70077287e-01, 6.60747791e-01, 5.94917893e-01, 8.95713766e-01,
       1.07238014e+00, 5.10908706e-01, 1.64360498e-01, 5.80184873e-02,
       1.53815466e-01, 4.71525606e-01, 5.69511240e-01, 4.44973097e-01,
       2.04209973e-02, 4.09292634e-01, 4.89770778e-01, 3.10466509e-01,
       4.38394085e-01, 1.26051026e-01, 7.12700917e-01, 1.73182311e-01,
       9.03376515e-02, 2.17247275e-02, 1.24642449e-02, 9.05903591e-01,
       9.12581720e-01, 6.56569724e-01, 4.07983858e+00, 3.36545139e+00,
       1.43568190e+00, 5.80473187e-01, 7.39682553e-01, 3.04683036e-01,
       7.21706608e-01, 3.15624828e-01, 6.66696404e-01, 2.26368695e-03,
       9.37809093e-01, 1.08477280e+00, 1.18106322e+00, 1.14492922e+00,
       7.38218510e-01, 1.92061260e-01, 6.39154295e-01, 4.22355514e-01,
       2.61990567e-01, 8.03043695e-01, 1.34539998e+00, 6.69223091e-01,
       7.37179114e-01, 7.04615471e-01, 6.35628278e-01, 3.96072014e-01,
       3.75252033e-01, 2.78824479e-01, 4.30492227e-01, 1.17668824e+00,
       3.93683649e-01, 1.29647298e-02, 3.82815920e-01, 2.39401647e+00,
       8.04316264e-01, 6.55825339e-01, 1.02688041e-02, 2.57357131e-02,
       1.20058573e-01, 2.75782516e-01, 4.89343420e-01, 1.60134773e-01,
       1.24258441e-01, 3.91215469e-01, 6.18248285e-01, 1.68615691e-01,
       4.00706327e-02, 4.56749228e-01, 2.40809597e-01, 9.47483019e-01])
```

Fiducial initialized ICP residual:

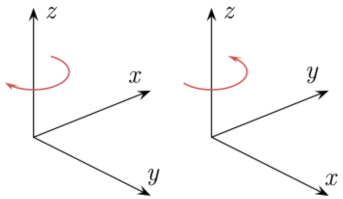
average: 2.33 mm

```
In [8]: errOut
Out[8]:
array([1.71475043e-01, 7.24013949e-01, 2.35577483e+00, 6.69540858e-01,
       1.01768886e+00, 2.77936851e+00, 3.41491353e+00, 3.39027310e+00,
       2.13915945e-01, 3.22135116e+00, 1.13633514e+00, 7.22151481e-03,
       1.94160148e-02, 6.96053764e-01, 8.11864269e-01, 1.71036322e+00,
       4.61358834e-01, 4.71457205e-01, 8.39550446e-02, 4.03402870e-02,
       1.76158299e-01, 3.06826678e+00, 3.23529895e+00, 3.02592271e+00,
       2.09625504e+00, 6.22370804e-01, 7.71861472e-01, 2.00552069e+00,
       1.99483575e+00, 2.71346840e+00, 3.66600087e+00, 6.39127764e-01,
       3.06852978e+00, 3.97464408e-01, 1.96107648e-01, 1.18816550e+00,
       4.54235848e-01, 5.54169274e-01, 2.21254825e+00, 1.14899088e+00,
       4.32411081e-01, 3.94762266e-01, 1.50985547e-01, 1.38387895e-01,
       1.00627263e+00, 1.61878582e+00, 1.73019068e+00, 4.59128436e-02,
       4.83543543e+00, 6.51123961e+00, 1.48032233e+00, 4.35495205e-01,
       2.18189201e+00, 4.21746662e+00, 5.48140024e+00, 2.44649310e-01,
       1.11904007e+00, 6.88096117e-01, 1.46905811e+00, 3.88613624e-01,
       2.03817613e+00, 1.98016549e+00, 5.82988602e+00, 1.36593125e+00,
       9.43169100e-01, 1.52881556e+00, 8.36338755e-01, 1.22247548e+00,
       1.13120635e+00, 8.39426896e-01, 4.17823952e-01, 2.11364737e+00,
       1.94090979e+00, 2.56305283e-01, 2.02742417e+00, 3.07270501e+00,
       1.81333091e+00, 2.78010830e-01, 2.64875552e+00, 2.84244061e+00,
       3.19375144e+00, 4.62857548e+00, 5.82885459e+00, 5.47646610e+00,
       7.44076807e+00, 8.00446228e+00, 8.09242315e+00, 7.03821346e+00,
       6.29292027e+00, 6.87168235e+00, 6.81813192e+00, 7.32589845e+00,
       6.08753053e+00, 4.16358373e+00, 1.91658704e+00, 2.46538416e+00,
       4.10419098e+00, 1.49062624e+00, 4.83237871e+00, 4.68129157e+00])
```

Visualization

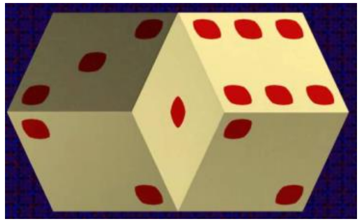


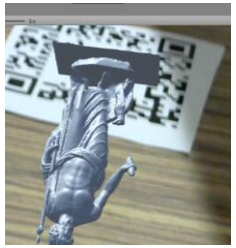
Challenges



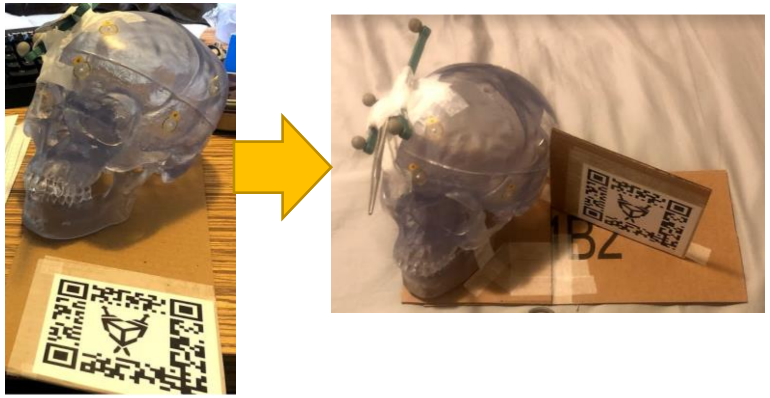
1. Unity handedness - solved
   a) Calculate, convert, send
      https://github.com/bingogome/CISII_Orbital/tree/master
   b) Convert, calculate, send
      https://github.com/bingogome/CISII_Orbital/tree/lefthanded

2. Vuforia tracking problem - solved
   - "Optical illusion" – AR marker facing up or down





Solution:



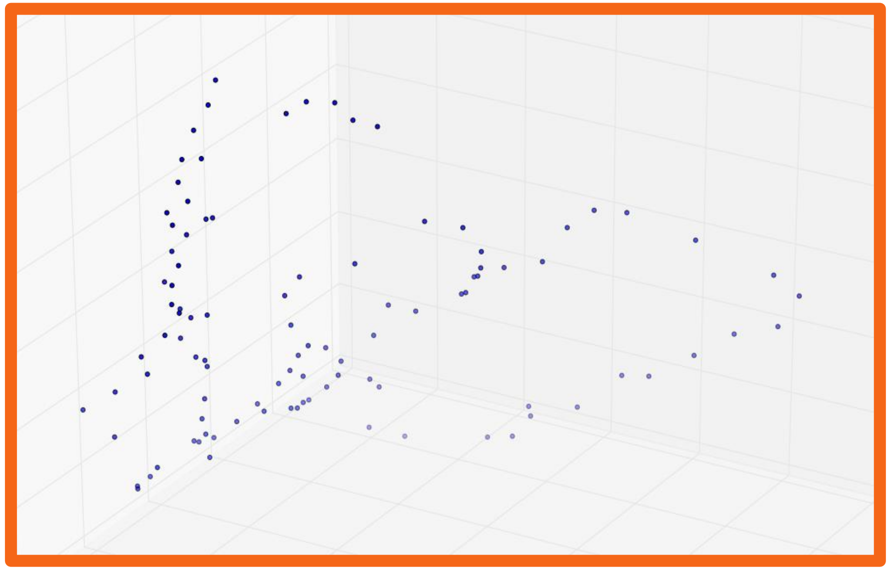
3. Bad rendering visualization
   - Virtual object error – need calibration
     - E. Azimi, L. Qian, N. Navab, and P. Kazanzides. Alignment of the Virtual Scene to the Tracking Space of a Mixed Reality Head-Mounted Display. Retrieved from: https://arxiv.org/pdf/1703.05834.pdf. 2019
   - "Jumping implant" – need smooth movement

4. Transformation chain issue - solved
   - Maximize code reusability: Double-edged sword
   - code logic vs. debugging effort

Calibration – Implant Model Creation

Implant Model Generation

- Points along the implant are captured with respect to the hemostat using a tracked pointer.
- Data is parsed and surface mesh is created, then converted into a tessellated model.
- The model is then transferred to Visualization tool.
- Allows for the generation of Implant models after each shaping iteration.
- Provides Surgeon accurate visual representation of the implant.



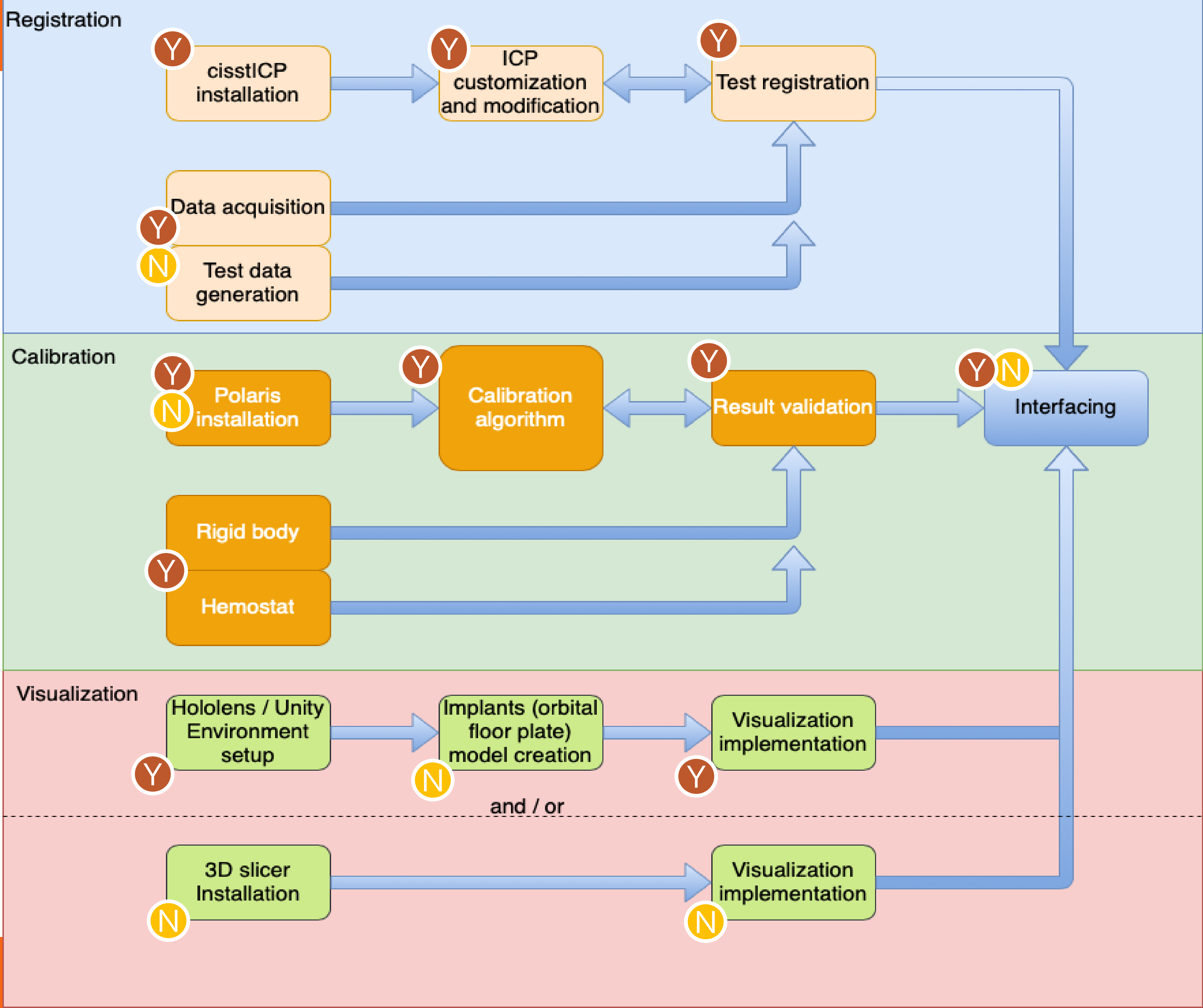
Point Collection to Tessellated Model

Team Management Diagram

- Both worked in conjunction on reports and presentations.

Y Yihao Liu

N Nikhil Davé



What We Learned

Implementation

1. Know the tools.
   - 工欲善其事，必先利其器
   - (A good engineer sharpens her/his tools if she/he desires success.)
2. Actual validation and debugging takes longer then building application.
3. Sleep well when stuck on something for a long time.
4. Proper time management and communication go a long way.
5. Investigate possible issues and ways to solve them, more often then not they can be solved on your own, before asking for help.

Soft Skills

1. Learned how to present scholastically.
2. Learned how to make elevator pitches.
3. Developed technical writing skills.

Technical Skills

1. Learned how to use 3D Slicer (ND), Vuforia (YL).
2. Interfacing with tracking system is non-trivial.
3. Coding/Documentation skills.

Future Steps and Goals

Finish up 3D Slicer Visualization

- Were very close to completion.
- Had no connectivity issues with Polaris.
- Problem with Plus Toolkit Implementation.

Create Application for Hololens

- Would like to create a functional application on HoloLens Display.
- Transferable from Unity application.

User study of Application

- Having a phantom user study will aid in application validation

Clinical Use

- Finally we would like to see our system in clinical use.
- Possible Research Publication.

Image Source: https://consultqd.clevelandclinic.org/how-augmented-reality-shaped-cleveland-clinics-total-face-transplant/

Thank you!
Special thanks to our mentors and Wenhao Gu!

Reading List

Hussain, R., Lalande, A., Guigou, C., and Bozorg Grayeli, A. (2019). Contribution of Augmented Reality to Minimally Invasive Computer-Assisted Cranial Base Surgery, *IEEE Journal of Biomedical and Health Informatics*.

Gsaxner C., Pepe, A., Wallner, J., Schmalstieg, D., and Egger, J. (2019). Markerless Image-to-Face Registration for Untethered Augmented Reality in Head and Neck Surgery, MICCAI 2019.

Li, Y., Chen, X., Wang, N., Zhang, W., Li, D., Zhang, L., Qu, X., Cheng, W., Xu, Y., Chen, W., and Yang, Q. (2018). A wearable mixed-reality holographic computer for guiding external ventricular drain insertion at the bedside, Journal of Neurosurgery JNS, 131(5), 1599-1606.

Chen, X., Xu, L., Wang, Y., Wang, H., Wang, F., Zeng, X., Wang, Q., and Egger, J. (2015). Development of a surgical navigation system based on augmented reality using an optical see-through head-mounted display, Journal of Biomedical Informatics, Volume 55, 2015, Pages 124-131

Bong, J. H., Song, H. J., Oh, Y. , Park, N., Kim, H., and Park, S.. (2018). Endoscopic navigation system with extended field of view using augmented reality technology, Int. J. Med. Robot., vol. 14, no. 2, pp. e1886

Inoue, D., Cho, B., Mori, M., Kikkawa, Y., Amano, T., Nakamizo, A., Yoshimoto, K., Mizoguchi, M., Tomikawa, M., Hong, J., and Hashizume, M.. (2013). Preliminary study on the clinical application of augmented reality neuronavigation, J. Neurol. Surg. Part A, vol. 74, no. 02, pp. 71-76

Lapeer, R. J., Jeffrey, S. J., Dao, J. T., García, G. G., Chen, M., Shickell, S. M., Rowland, R. S., and Philpott, C. M.. (2014). Using a passive coordinate measurement arm for motion tracking of a rigid endoscope for augmented-reality image-guided surgery, Int. J. Med. Robot., vol. 10, no. 1, pp. 65-77