FAMU-FSU College of Engineering

Team 523:
Mixed Reality Wearable for 3D Body Tracking

Team Introductions

Timothy Rubottom
Project Manager & System Integration

Joshua Segall
Design Engineer

Caleb Pitts
Fabrication Engineer

Matthew Bigerton
Test Engineer

Josiah Bazyler
Mechatronics Engineer

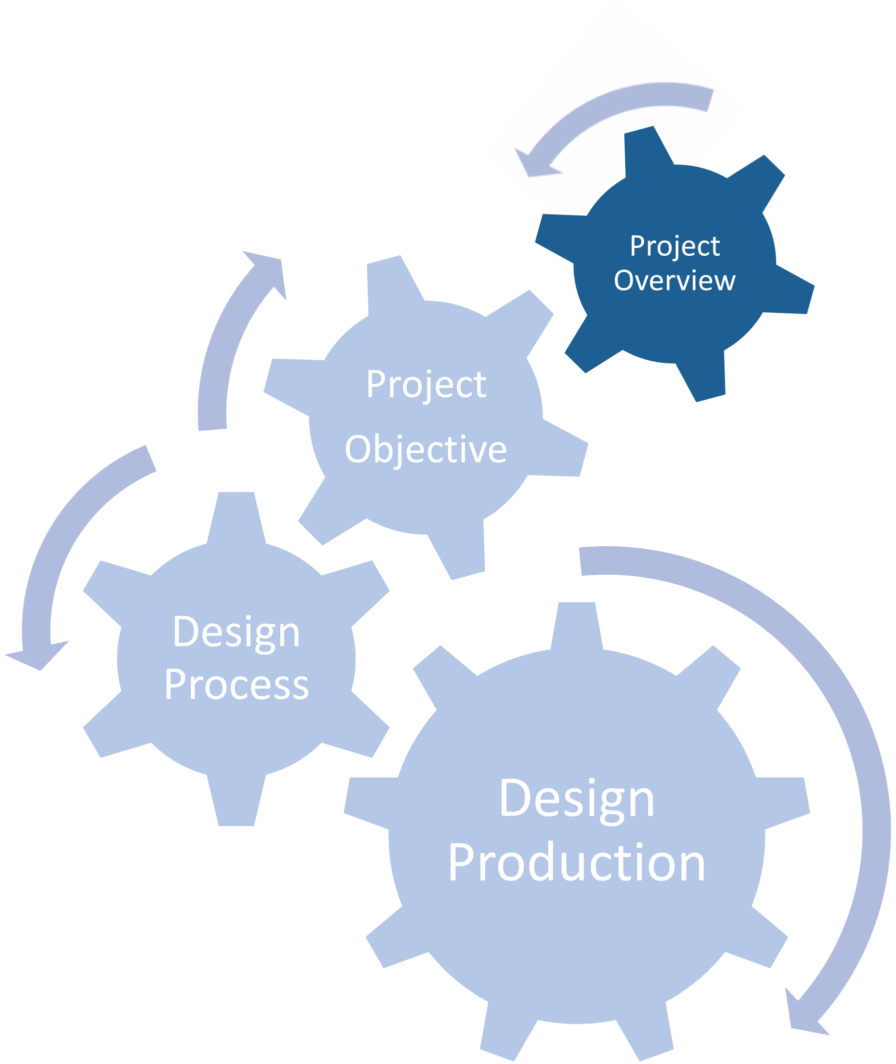
Sponsor and Advisor

Philanthropic Contributor
Yubin Xi, Ph.D.
Human Factors Engineer

Academic Advisor
Shayne McConomy, Ph.D.
SD Professor

Timothy Rubottom

Project Overview



Timothy Rubottom

Project Overview

- Anthropometry is the measurement of the size and proportions of the human body.
- Anthropometric scans typically output a 3D figure that can be used for body measurements and for Engineering design.

Figure 1: 3D CAD Image of Different Hand Views

Timothy Rubottom

Project Overview

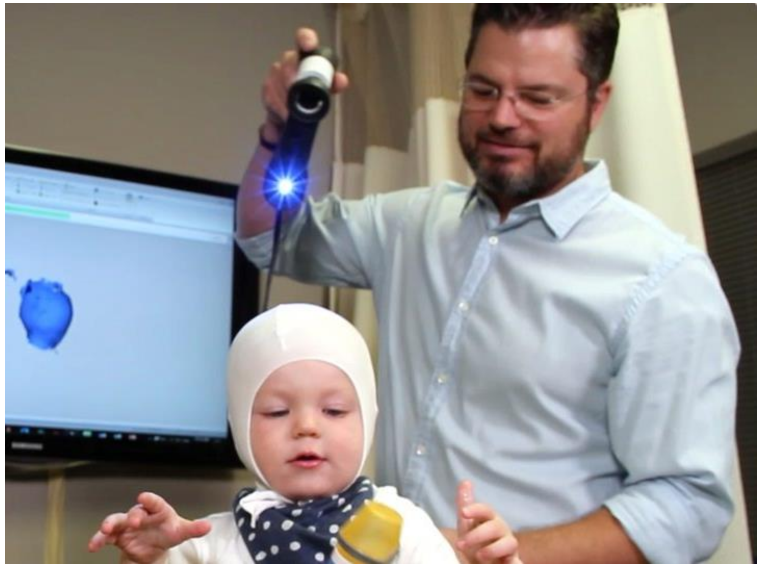


Figure 2: Measuring of baby's head

Figure 3: Helmet produced by the scan measurement

- Here is an example of a full scan cycle from scan to production.

Timothy Rubottom

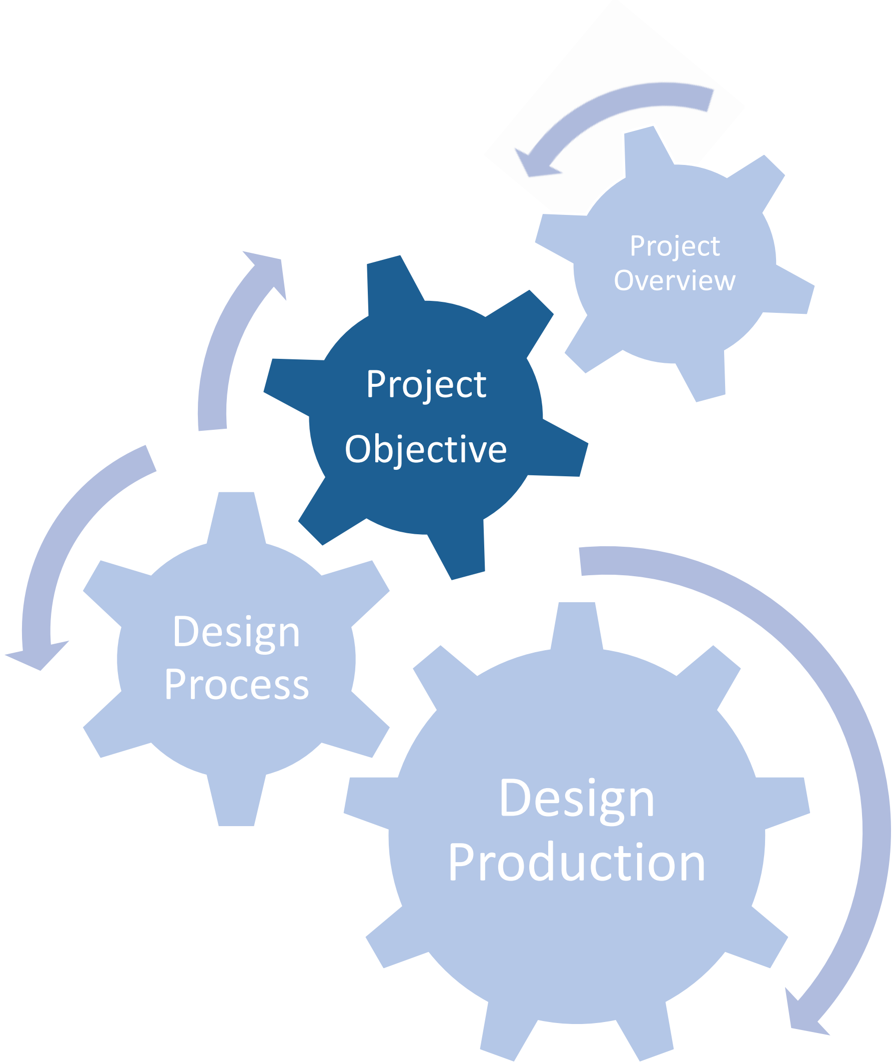
Project Overview

- Currently, scan participants are given verbal instructions on where and how to position and orient themselves for an anthropometric scan.
- This process is tedious and time consuming for the scan technician.

Figure 4: Example of positioning solutions

Timothy Rubottom

Project Objective



Timothy Rubottom

Objective

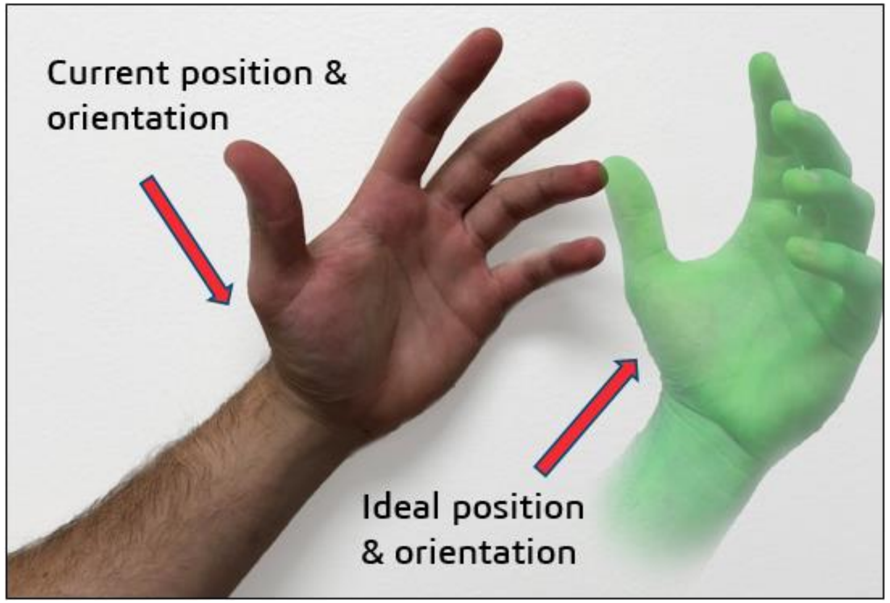
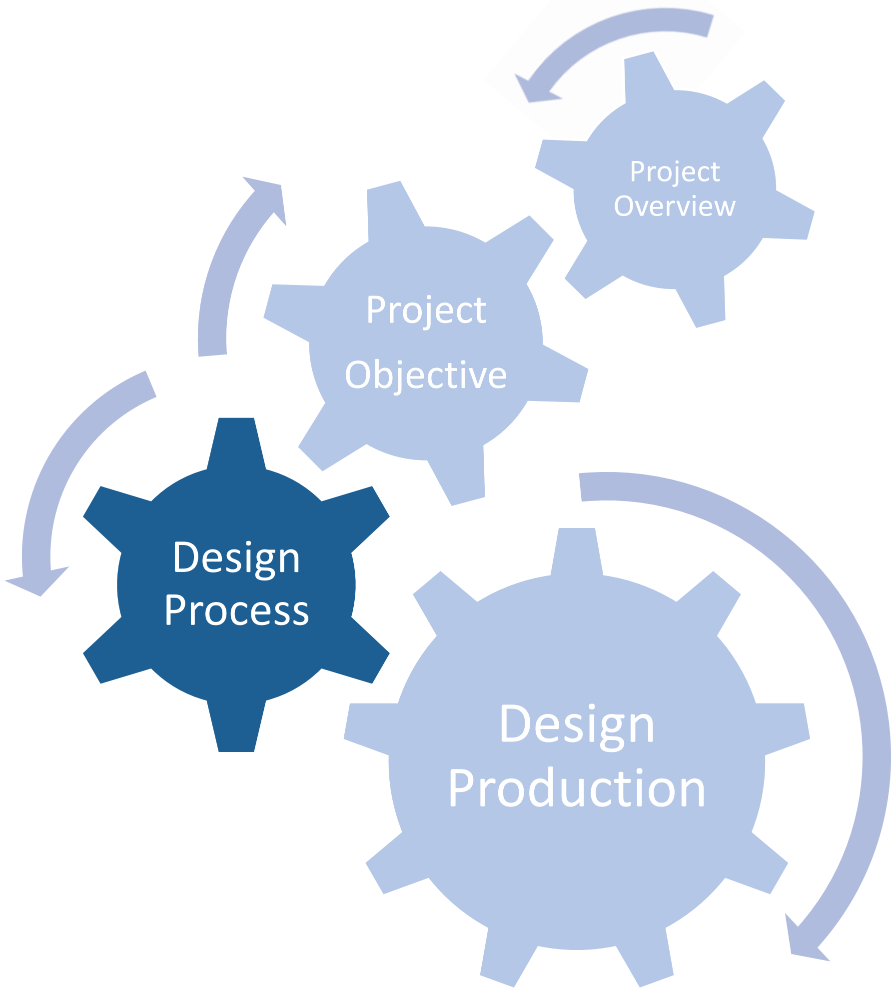


Figure 5: Example of a Visualization

The objective of this project is to provide a user interface for a participant in a 3D body scan environment in order to shorten the duration of the overall process by reducing the amount of instructions given by the scan technician to position/orient the participant.

Timothy Rubottom

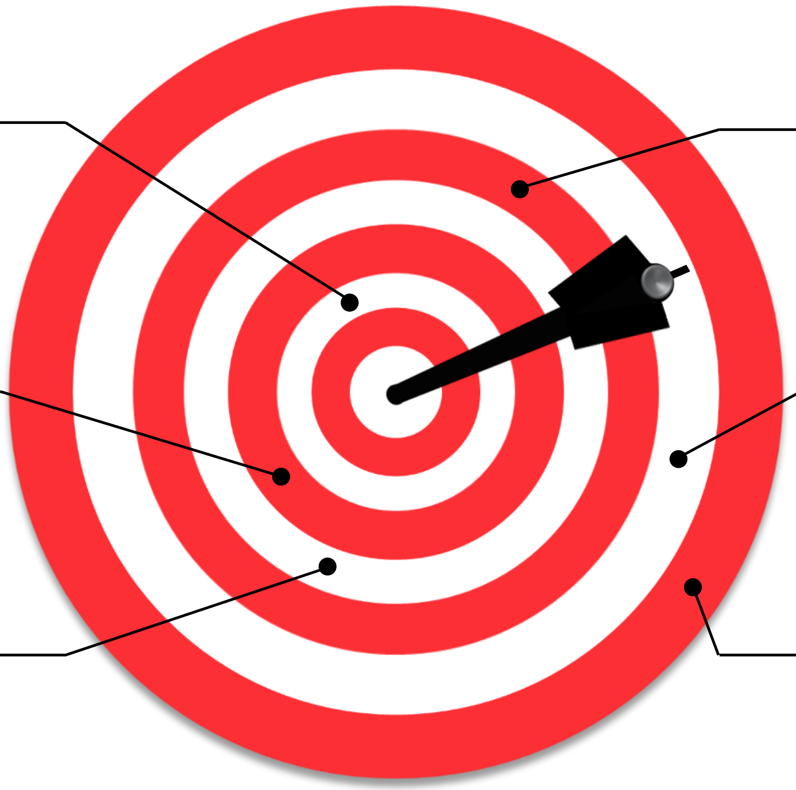
Design Process



Joshua Segall

Customer Needs

1. The device must indicate to the user that the participant has found the proper position and orientation.
2. The device must cease operating upon the successful fulfillment of the ideal pose.
3. The device must indicate to the participant the ideal location and orientation for accurate scans.



4. The device must complete its intended function without the assistance of other devices.
5. The device requires a method for power control.
6. The device must minimally impact the participant.

Joshua Segall

Customer Needs

The device must indicate to the user that the participant has found the proper position and orientation. **1.**

The device must cease operating upon the successful fulfillment of the ideal pose. **2.**

The device must indicate to the participant the ideal location and orientation for accurate scans. **3.**

4. The device must complete its intended function without the assistance of other devices.

5. The device requires a method for power control.

6. The device must minimally impact the participant.

Joshua Segall

Functional Decomp.

- Functional Decomposition acted as a funnel for the ideation process.

- From top to bottom, the boxes become more and more specific.

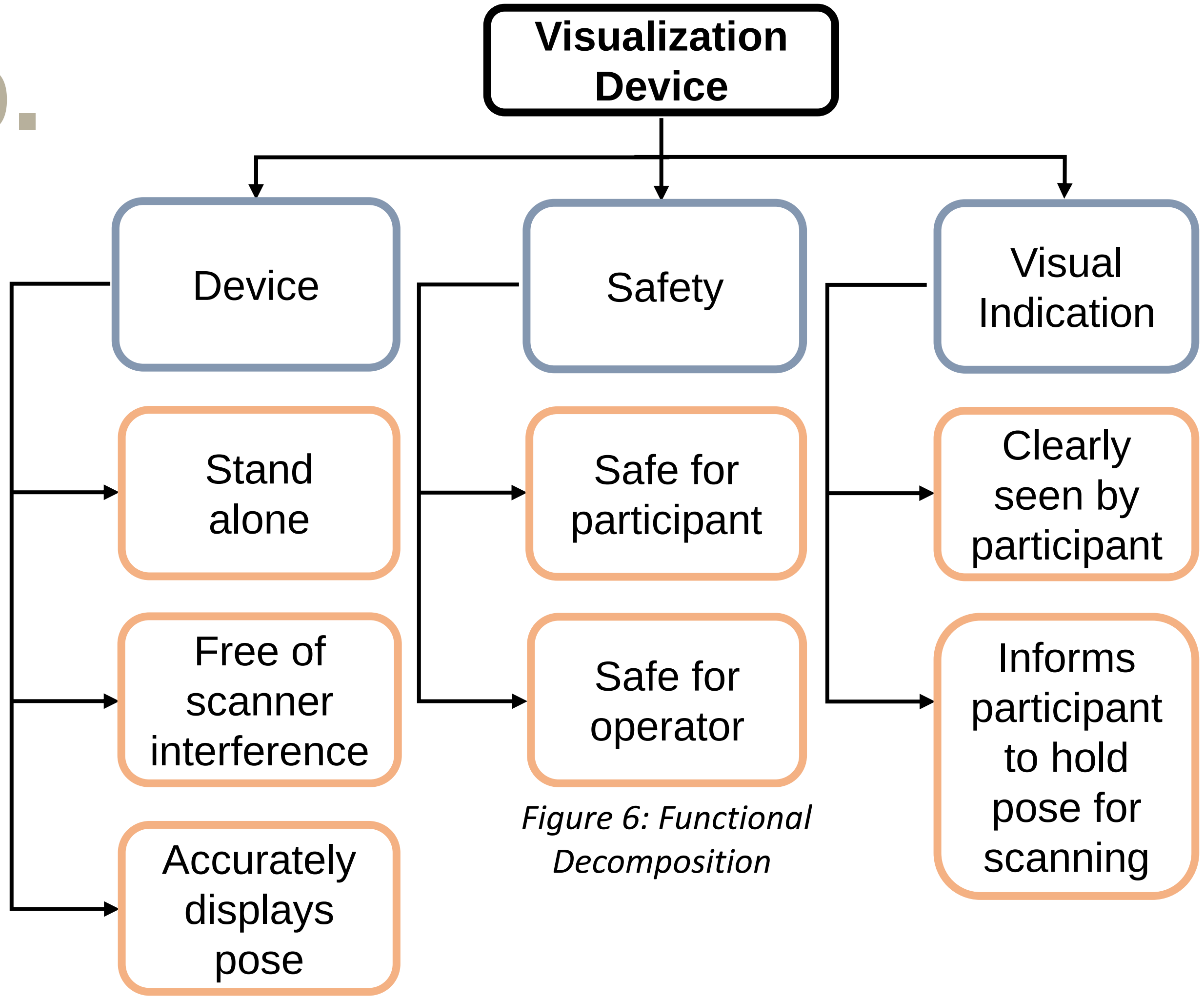


Figure 6: Functional Decomposition

Joshua Segall

Targets & Metrics

- Functional decomposition led to a large set of targets & metrics (T&M) that was determined to be necessary for a successful design.

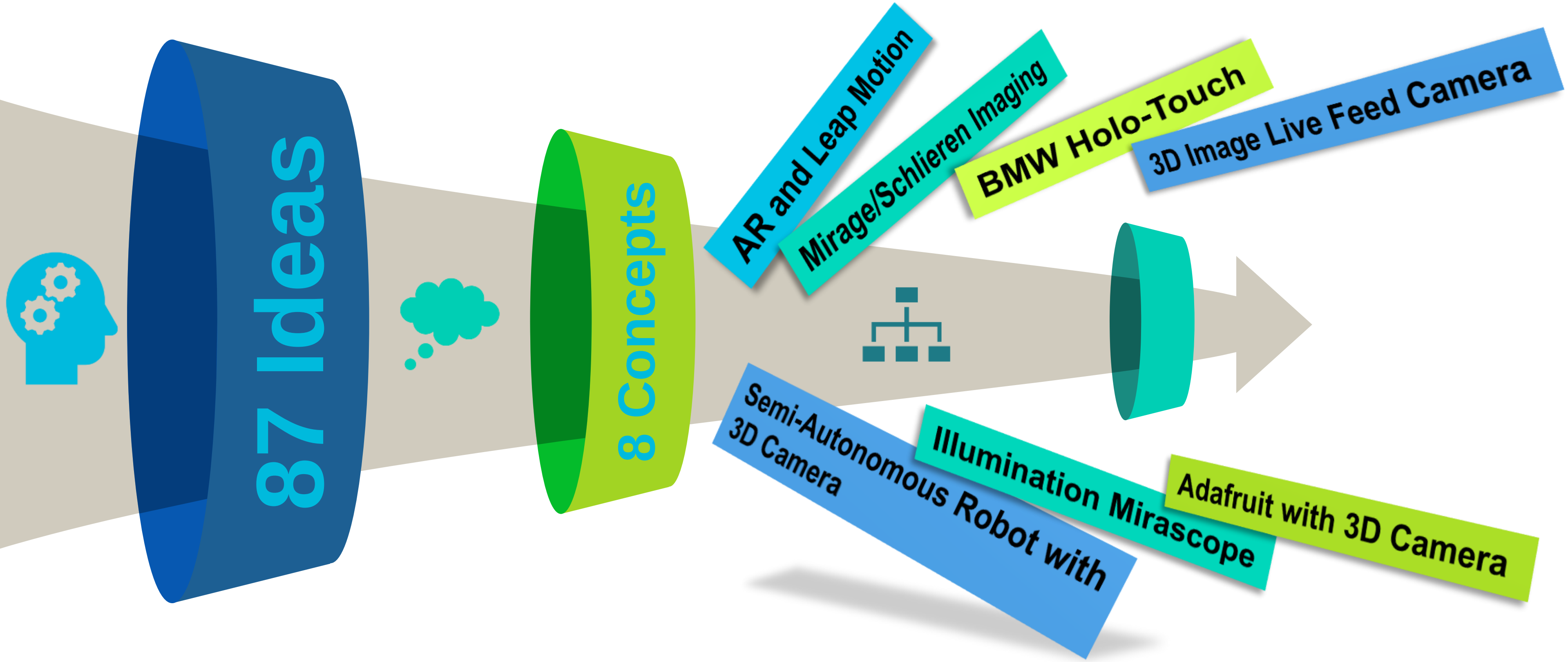
- These are the most important T&M from the original list.
  - They satisfy industry/governmental standards.

Table 1: Customer Needs Table

Mixed Reality Wearable For Body Tracking			
Main Functions	Sub-Functions	Metrics	Targets
Device	Self-Contained	Dimensions (in)	≤ 30 x 30 x 30
		Weight (lbs)	≤ 25
	Free of Interfernece	Distance From Scanner (m)	~ 1
Safety	Safe For Participant	Brightness Level (Lumens)	≤ 200
Visual Indication	Signals Participant to Hold Position	Time in designated location and Orientation (Seconds)	< 30

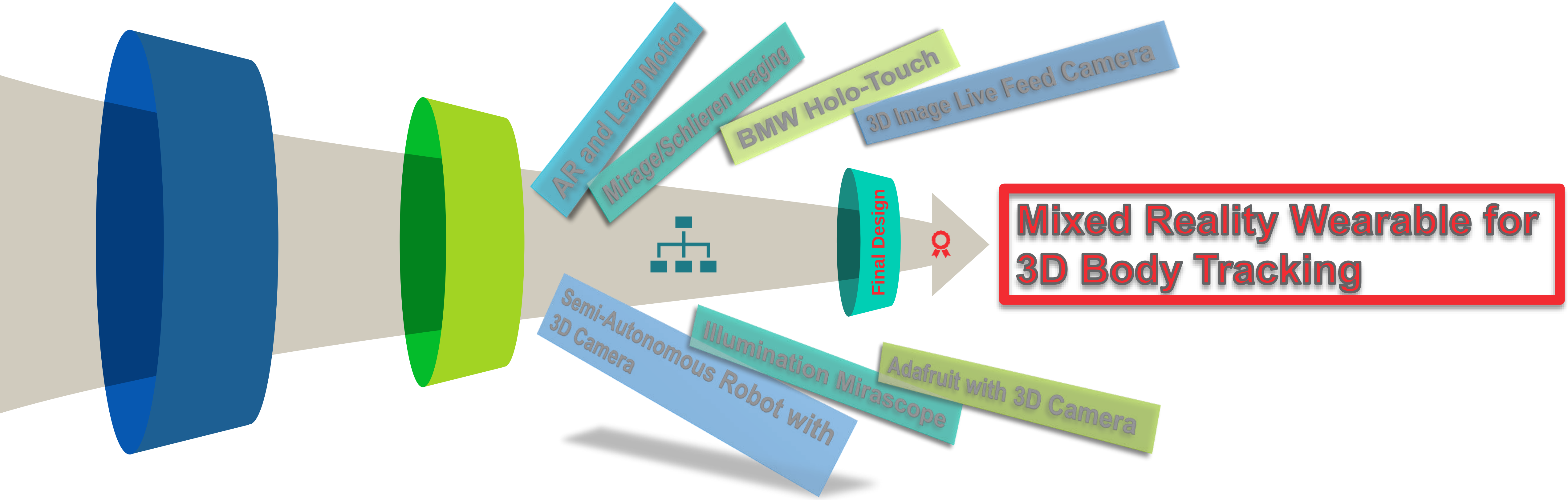
Joshua Segall

Concept Generation: Overall Design



Joshua Segall

Concept Generation: Overall Design



Joshua Segall

Concept Selection: Overall Design

- AHP shows the results of our re-calculated concept selection.

- Final selection found that the Mixed Reality Wearable was in fact the best selection.

Table 2: Analytical Hierarchy Process

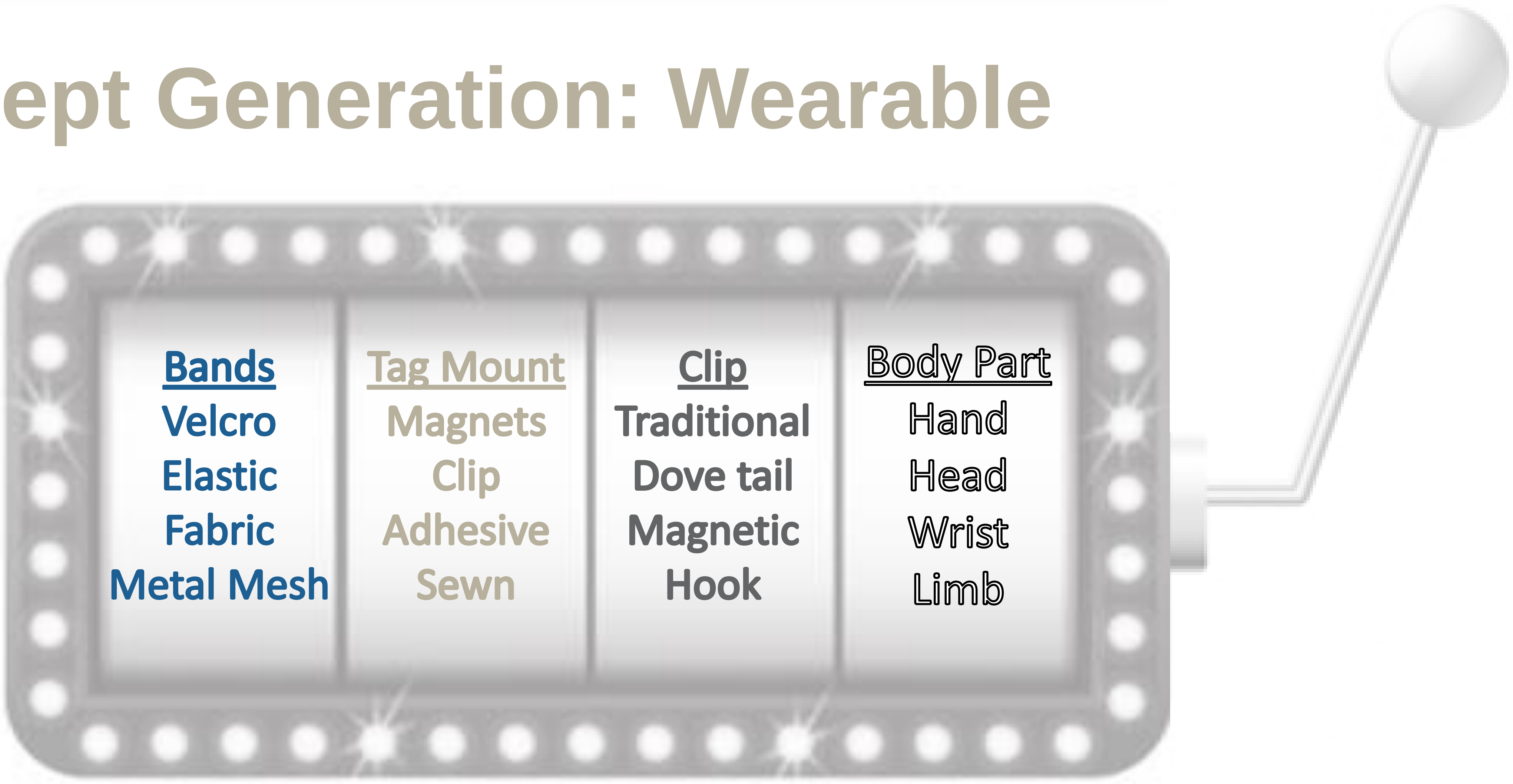
SELECTION:	Mixed Reality Wearable	Adafruit w/ 3D Camera	Semi-Automatis Robot w/ 3D Camera
Design Volume	0.64	0.36	0.10
Weight	0.45	0.10	0.45
Distance from Scanner	0.45	0.23	0.22
Tolerance of Depth Measurement	0.57	0.15	0.29
Brightness Level/Intesity Level	0.60	0.20	0.20
Operationg Temperature:	0.70	0.10	0.10
Resolution	0.60	0.20	0.20
Operating Time	0.43	0.36	0.30
SUM	4.44	1.70	1.86

Table 3: Final Selection

FINAL CONCEPT WEIGHTED	
Mixed Reality Wearable	0.56
Adafruit w/ 3D Camera	0.21
Semi-Autonomous Robot w/ 3D Camera	0.23

Joshua Segall

Concept Generation: Wearable



Caleb Pitts

Concept Selection: Wearable Design

Table 4: Wearable Concept Selection

		Scale (1,3,6)											
Needs:	Weight:	Idea 1	I 1	Idea 2	I 2	Idea 3	I 3	Idea 4	I 4	Idea 5	I 5	Idea 6	I 6
Multiple Tags	6	6	36	6	36	3	18	6	36	3	18	6	36
Easy Removal	12	6	72	1	12	3	36	6	72	1	12	6	72
Consistant Placement	10	6	60	3	30	3	30	6	60	6	60	3	30
Aesthetics	2	3	6	3	6	9	18	1	2	3	6	6	12
Versatile Placement	4	6	24	1	4	3	12	6	24	3	12	3	12
Easy to put on/tighten	8	6	48	3	24	3	24	6	48	6	48	3	24
	Totals	246		112		138		242		156		186	
	Rank	1		6		5		2		4		3	

Figure 7: 3D Printed Hand with Wearable Attached

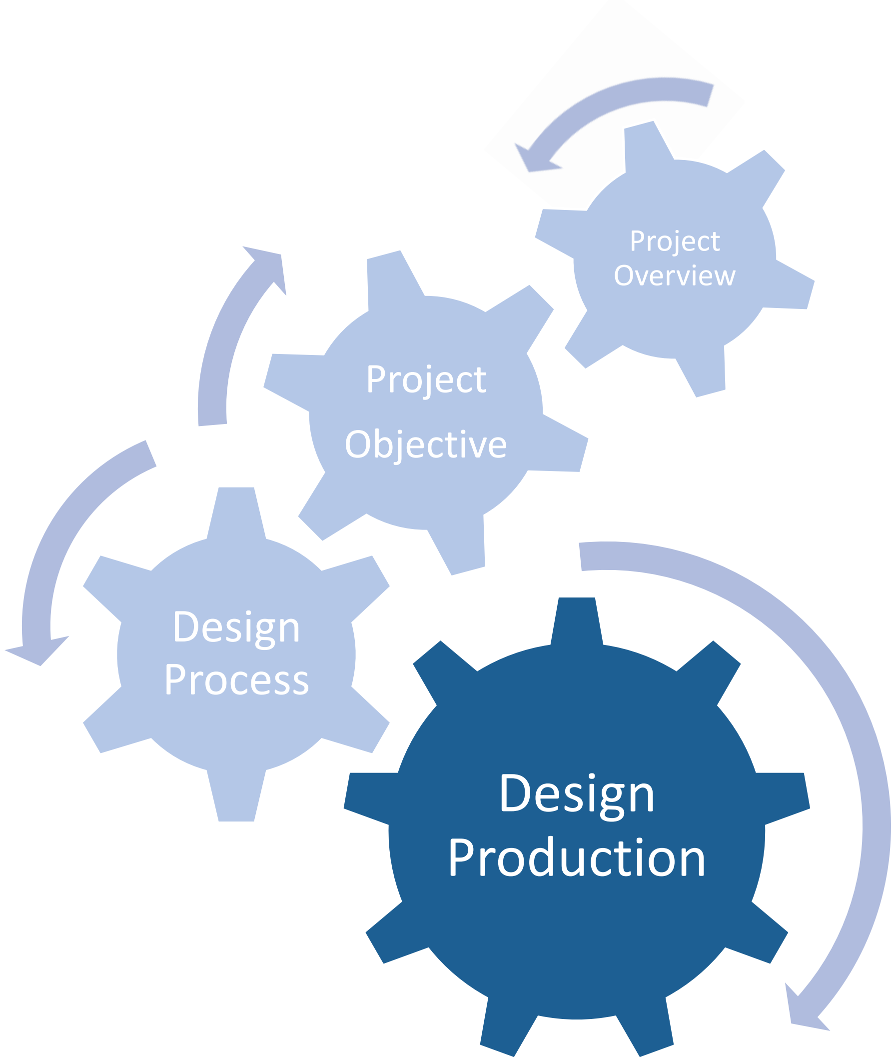
Winner:

Elastic Band with AprilTags Clipping on, with Dove Tail release

Figure 8: 3D Printed Wearable

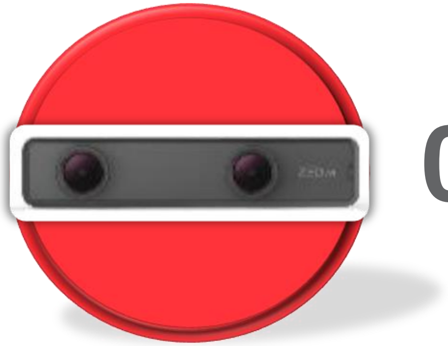
Caleb Pitts

Design Production

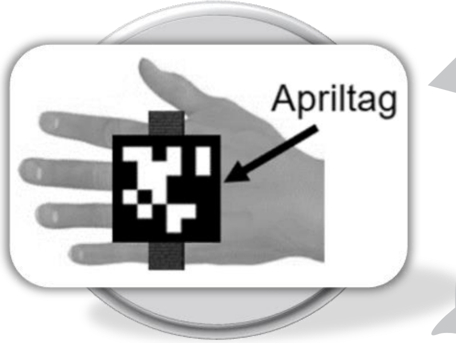


Josiah Bazyler

Design Components



01 **ZED Mini:**
This 3D camera is mounted on the monitor.



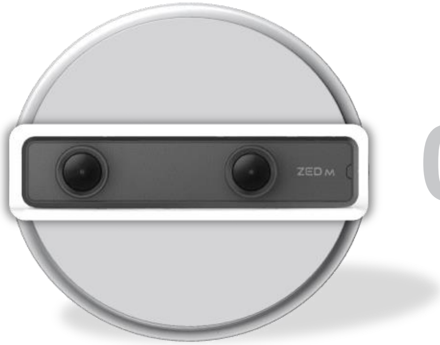
02 **Wearable:**
AprilTags attach to this.

03 **NVIDIA Jetson TX2:**
This computer tracks the AprilTags through Robot Operating System (ROS).

04 **Steady State Monitor:**
Information is displayed here through Rviz (a virtual world).

Josiah Bazyler

Design Components



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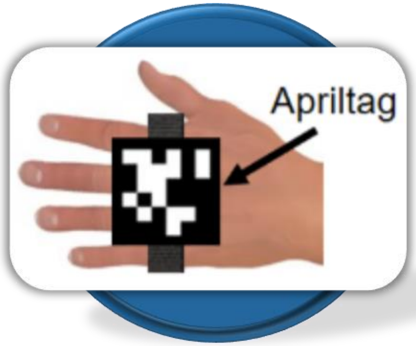
Wearable:
AprilTags attach to this.

02



03

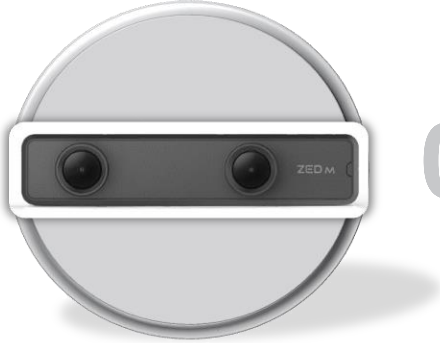
NVIDIA Jetson TX2:
This computer tracks the AprilTags through Robot Operating System (ROS).

Steady State Monitor:
Information is displayed here through Rviz (a virtual world).

04

Josiah Bazyler

Design Components



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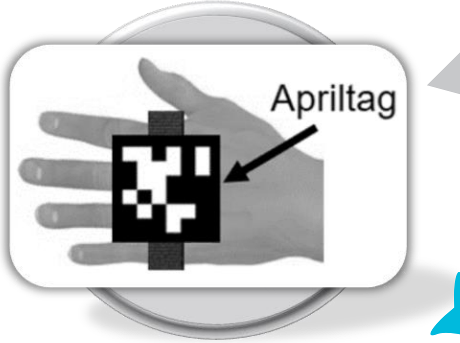

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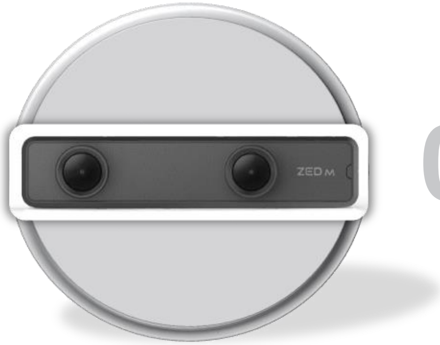

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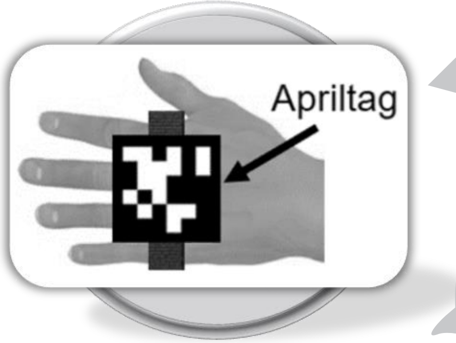

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Josiah Bazyler

Self-Instructed Software Initialization

Linux

1. Operating System

ROS
Robot Operating System

2. Meta-Operating System

python™

3. Programming Language

4. Programming Language

XML

5. Meta-Programming Language

Five (5) Fundamental Software's

Josiah Bazyler

Software Implementation: ROS

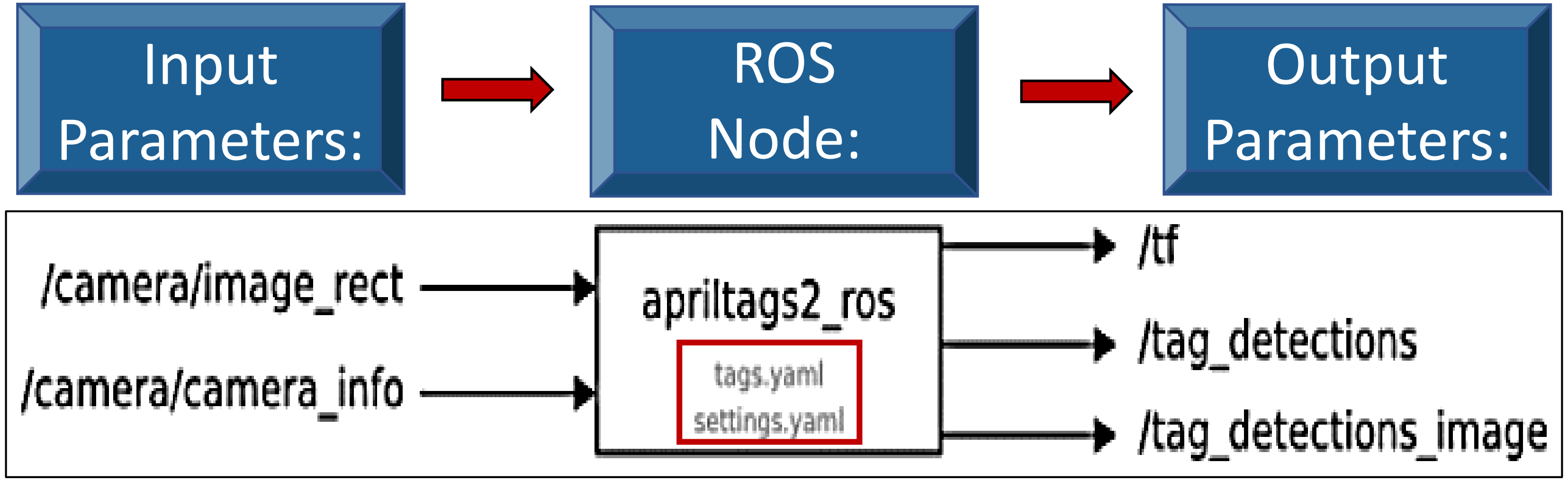

Figure 9: Inputs and Outputs of the "apriltags2_ros" Node

Josiah Bazyler

ENDLESS. ERROR. MESSAGES.

```
lin@Lin-ros:~/catkin_ws$ roslaunch ti_mmwave_rospkg rviz_1443_3d.launch
... logging to /home/lin/.ros/log/781d2e38-1979-11e8-bd3a-000c290d8e3b/roslaunch-Lin-ros-22241.log
Checking log directory for disk usage. This may take awhile.
Press Ctrl-C to interrupt
Done checking log file disk usage. Usage is <1GB.

started roslaunch server http://Lin-ros:40141/

SUMMARY
========

PARAMETERS
 * /mmWave_Manager/command_port: /dev/ttyACM0
 * /mmWave_Manager/command_rate: 115200
 * /mmWave_Manager/data_port: /dev/ttyACM1
 * /mmWave_Manager/data_rate: 921600
 * /mmWave_Manager/max_allowed_azimuth_angle_deg: 90
 * /mmWave_Manager/max_allowed_elevation_angle_deg: 90
 * /rosdistro: kinetic
 * /rosversion: 1.12.12

NODES
  /
    mmWaveQuickConfig (ti_mmwave_rospkg/mmWaveQuickConfig)
    mmWave_Manager (ti_mmwave_rospkg/ti_mmwave_rospkg)
    rviz (rviz/rviz)
    static_tf_map_to_base_radar_link (tf/static_transform_publisher)

auto-starting new master
process[master]: started with pid [22251]
ROS_MASTER_URI=http://localhost:11311

setting /run_id to 781d2e38-1979-11e8-bd3a-000c290d8e3b
process[rosout-1]: started with pid [22264]
started core service [/rosout]
process[mmWave_Manager-2]: started with pid [22274]
process[mmWaveQuickConfig-3]: started with pid [22278]
process[static_tf_map_to_base_radar_link-4]: started with pid [22282]
[ INFO] [1519487013.905256673]: mmWaveQuickConfig: Configuring mmWave device using config file: /home/lin/catkin_ws/src/ti_mmwave_rospkg/cfg/1443_3d.cfg
[ERROR] [1519487013.914902097]: Skipped loading plugin with error: XML Document '/home/lin/catkin_ws/src/ti_mmwave_rospkg/mmWave_nodelets.xml' has no Root Element. This likely means
 the XML is malformed or missing..
process[rviz-5]: started with pid [22284]
[ INFO] [1519487013.947285294]: Initializing nodelet with 2 worker threads.
[ INFO] [1519487013.952507632]: waitForService: Service [/mmWaveCommSrv/mmWaveCLI] has not been advertised, waiting...
[ERROR] [1519487014.026504587]: Skipped loading plugin with error: XML Document '/home/lin/catkin_ws/src/ti_mmwave_rospkg/mmWave_nodelets.xml' has no Root Element. This likely means
 the XML is malformed or missing..
[ERROR] [1519487014.026949662]: Failed to load nodelet [mmWaveCommSrv] of type [ti_mmwave_rospkg/mmWaveCommSrv] even after refreshing the cache: According to the loaded plugin descr
iptions the class ti_mmwave_rospkg/mmWaveCommSrv with base class type nodelet::Nodelet does not exist. Declared types are  depth_image_proc/convert_metric depth_image_proc/crop_fore
most depth_image_proc/disparity depth_image_proc/point_cloud_xyz depth_image_proc/point_cloud_xyz_radial depth_image_proc/point_cloud_xyzi depth_image_proc/point_cloud_xyzi_radial d
epth_image_proc/point_cloud_xyzrgb depth_image_proc/register image_proc/crop_decimate image_proc/crop_nonZero image_proc/crop_non_zero image_proc/debayer image_proc/rectify image_pr
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most depth_image_proc/disparity depth_image_proc/point_cloud_xyz depth_image_proc/point_cloud_xyz_radial depth_image_proc/point_cloud_xyzi depth_im
epth_image_proc/point_cloud_xyzrgb depth_image_proc/register image_proc/crop_decimate image_proc/crop_nonZero image_proc/crop_non_zero image_proc/d
```

Josiah Bazyler

Software Results

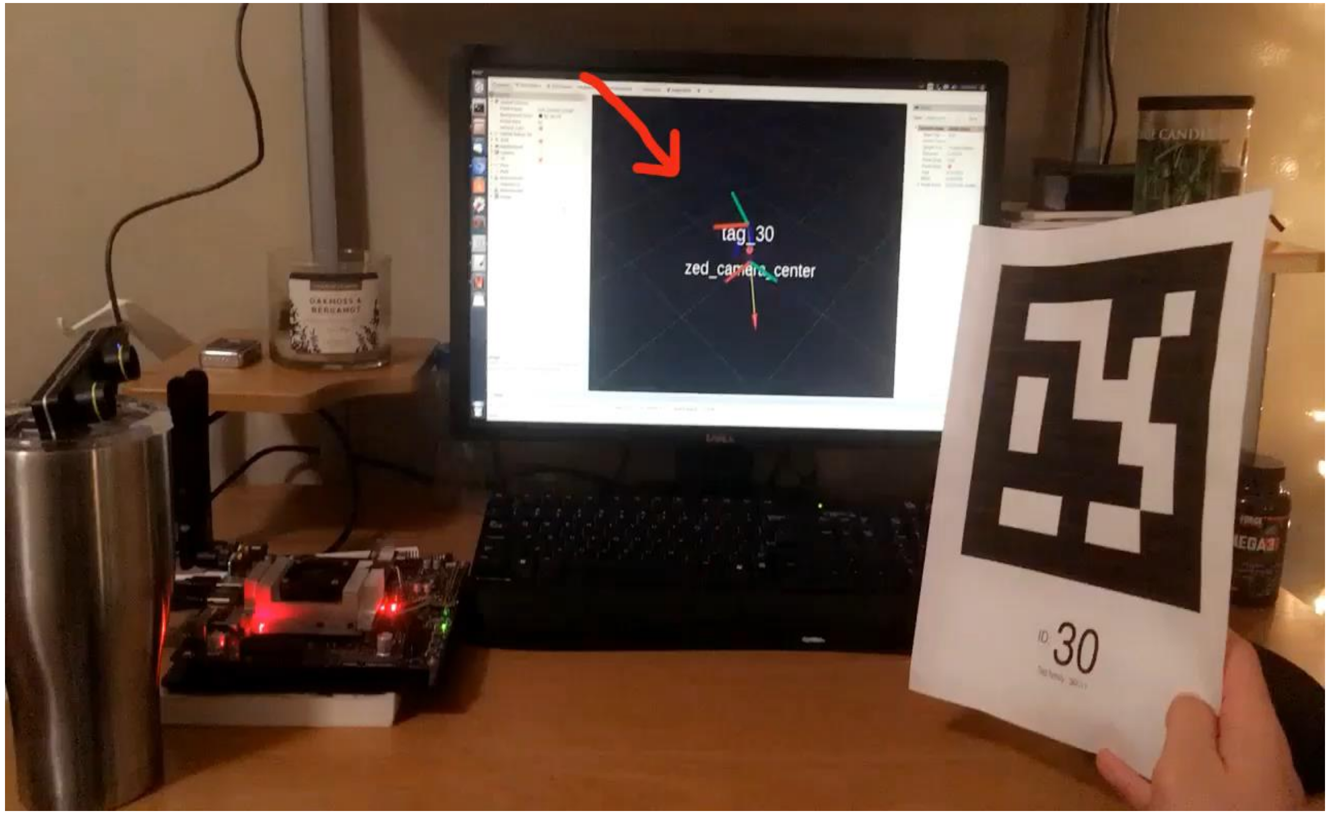


Figure 10: Video of the AprilTag Being Tracked with the Old Code

Josiah Bazyler

Software Results

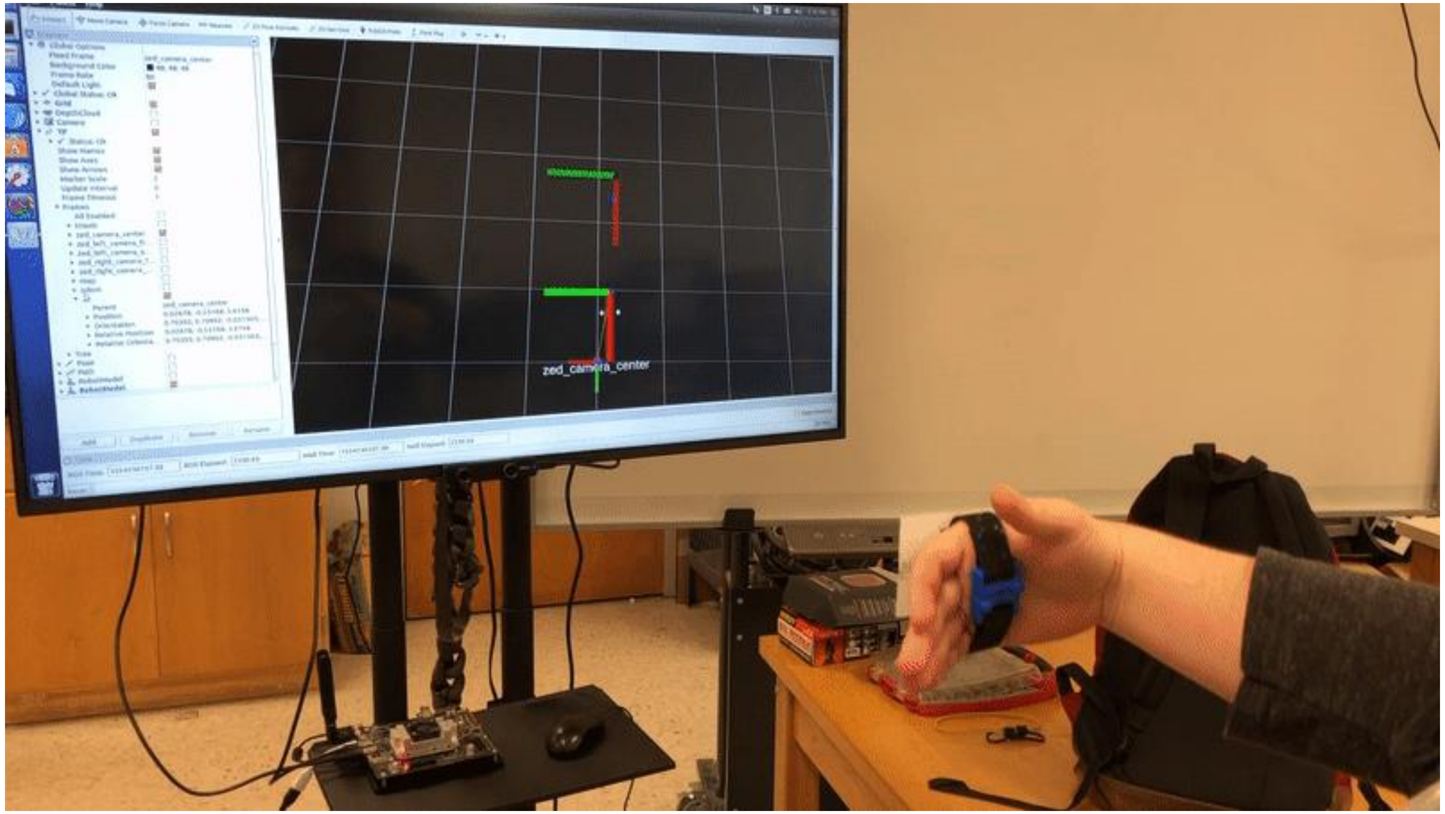


Figure 11: Video of the AprilTag's "Triaxis" Attempting to Mesh with the Universal Robotic Description Format (URDF) Model of a "Triaxis" in the Ideal Pose with the New Code

Josiah Bazyler

Wearable Iterations

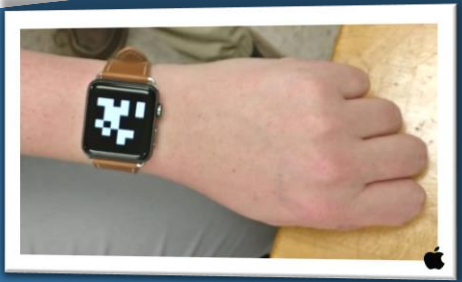


Figure 12: Apple Watch Concept

Figure 13: Magnetic Bracelet Concept

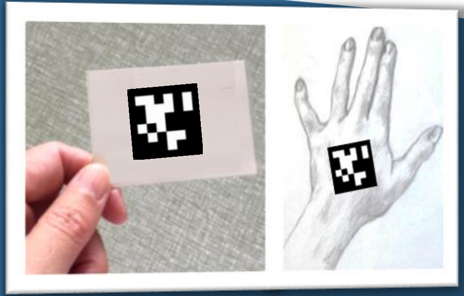


Figure 14: Temporary Tattoo Concept

Caleb Pitts

Final Wearable Iteration

- For the final design we went back to the Velcro band for both tightening and attaching the AprilTag.
- Using Velcro to attach the AprilTag to the band allows for placement to be adjusted easily.
- Uses magnetic clasp for easy removal without shifting hand position.

Figure 15: Final Design for the Band and Attachment of the AprilTag(s)

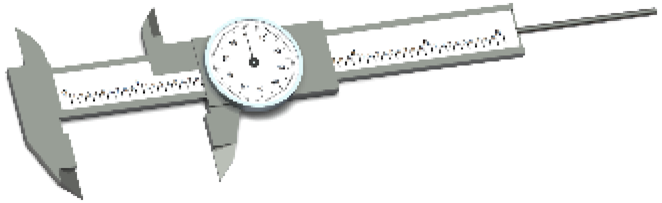
Caleb Pitts

Testing

Matthew Bigerton

Design Testing and Validation

1. Scan Pose Time Validation



2. Consistency and Precision Testing

Matthew Bigerton

Testing Method

- The scan pose time validation and consistency and precision tests were conducted simultaneously using the following procedure:
  1. Direct participants to the table with the written instructions to read and the wearable on it.
  2. Instruct the participant to put on the wearable.
  3. On the participant’s mark, the stop watch starts.
  4. Once the participant has meshed their pose as best as possible, detach the wearable and let fall to ground.
  5. Stop the stopwatch and record the final time and position/orientation data from Rviz.
- 27 trials were completed (n=27).

Figure 16: Design Testing

Matthew Bigerton

Scan Pose Time Validation

Sponsor Targets:
Locate and position/orient in under 3 minutes (180 seconds).

Results:

Table 5: Time Results Summary

Time Distribution (seconds)	
MIN	4.87
MAX	55.86
MEDIAN	19.27
QUARTILE 1	15.6525
QUARTILE 3	21.775
MEAN	20.50
STDEV	10.63

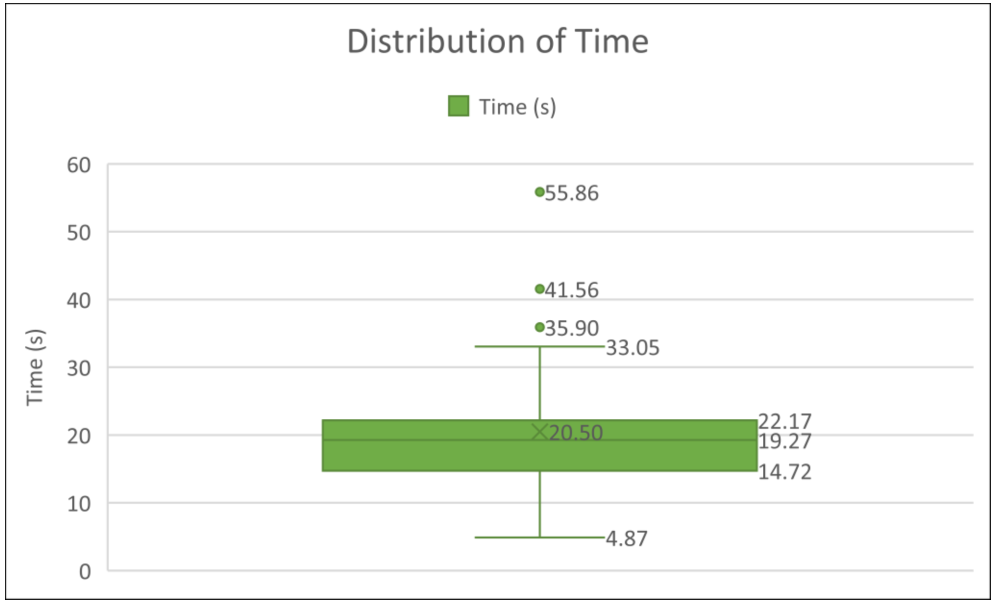


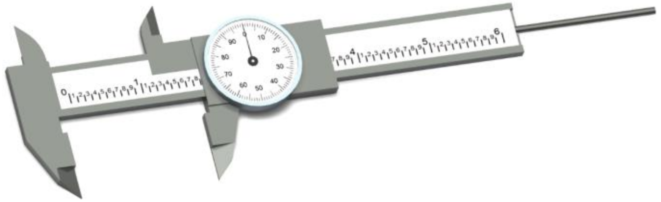
Figure 17: Test Timing Results

Matthew Bigerton

Consistency and Precision Testing

Sponsor Targets:

- The participant position needs to be within an error of 3±1 centimeters (0.098±0.01 feet).
- The participant orientation needs to be within an error of 0.05±0.01 rad (Euler angle).



Planned test:

- This test determined the accuracy of our design's ability to guide a participant to the ideal pose.
- Position and orientation data are recorded and analyzed.

Matthew Bigerton

Position Testing Results

Table 6: Position Difference Results—Summary

Difference in Ideal and Actual Position			
	x_diff (ft.)	y_diff (ft.)	z_diff (ft.)
MIN	0.001	0.001	0.014
MAX	0.076	0.323	0.276
MEDIAN	0.010	0.020	0.044
QUARTILE 1	0.004	0.009	0.026
QUARTILE 3	0.022	0.041	0.092
MEAN	0.016	0.042	0.078
STDEV	0.017	0.069	0.078

- The distribution of each axis is skewed up (toward the higher values).
- Each distribution has at least 2 outliers.
  - Outliers present make the median is more suitable to represent the data than the mean.
  - All the medians are within the error limit of 0.098±0.01 feet.

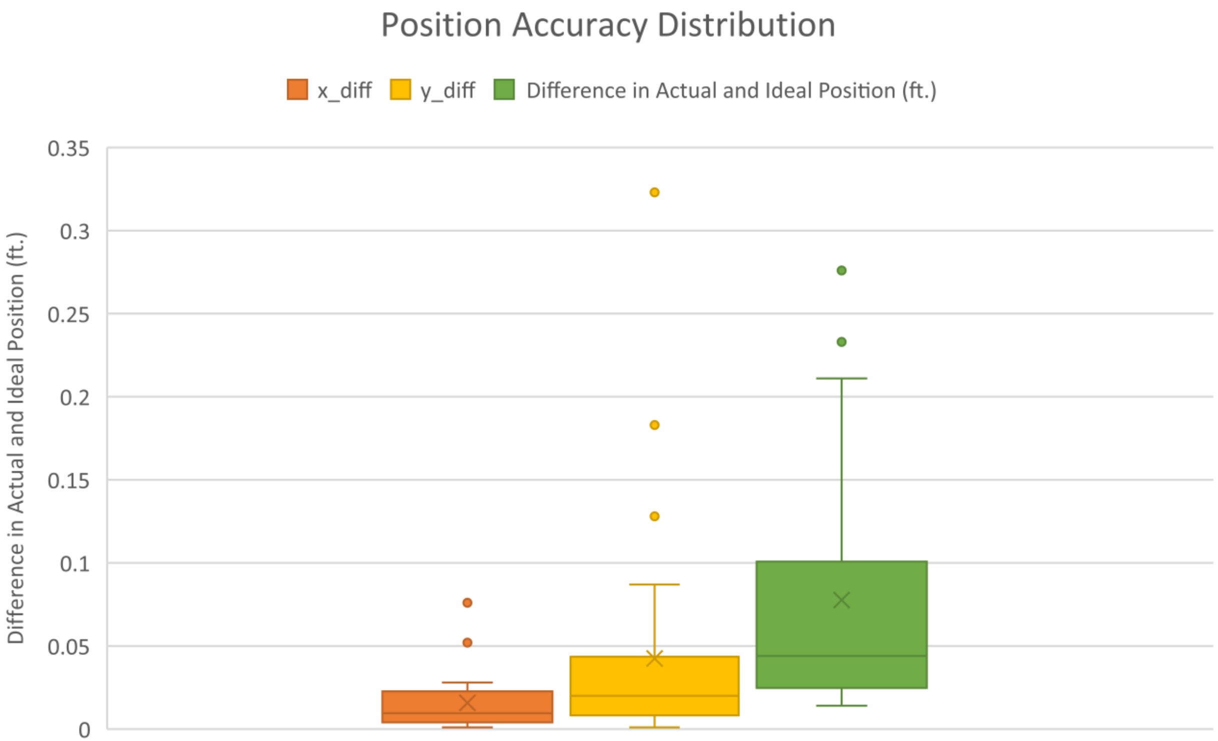


Figure 18: Position Test Results

Matthew Bigerton

Orientation Testing Results—Roll

Table 7: Roll-Angle Difference Results—Summary

Difference in Ideal and Actual Orientation			
	roll_diff	pitch_diff	yaw_diff
MIN	0.001	0.001	0.001
MAX	0.048	0.056	0.309
MEDIAN	0.004	0.006	0.031
QUARTILE 1	0.002	0.003	0.020
QUARTILE 3	0.009	0.013	0.069
MEAN	0.008546	0.010482	0.049897
STDEV	0.010756	0.012035	0.058807

- The roll angle distribution is skewed up (toward the higher values).
- The roll distribution has 3 outliers.
  - Outliers present make the median more suitable to represent the data than the mean.
- The median is within the error limit of 0.05±0.01 rad (Euler Angle).

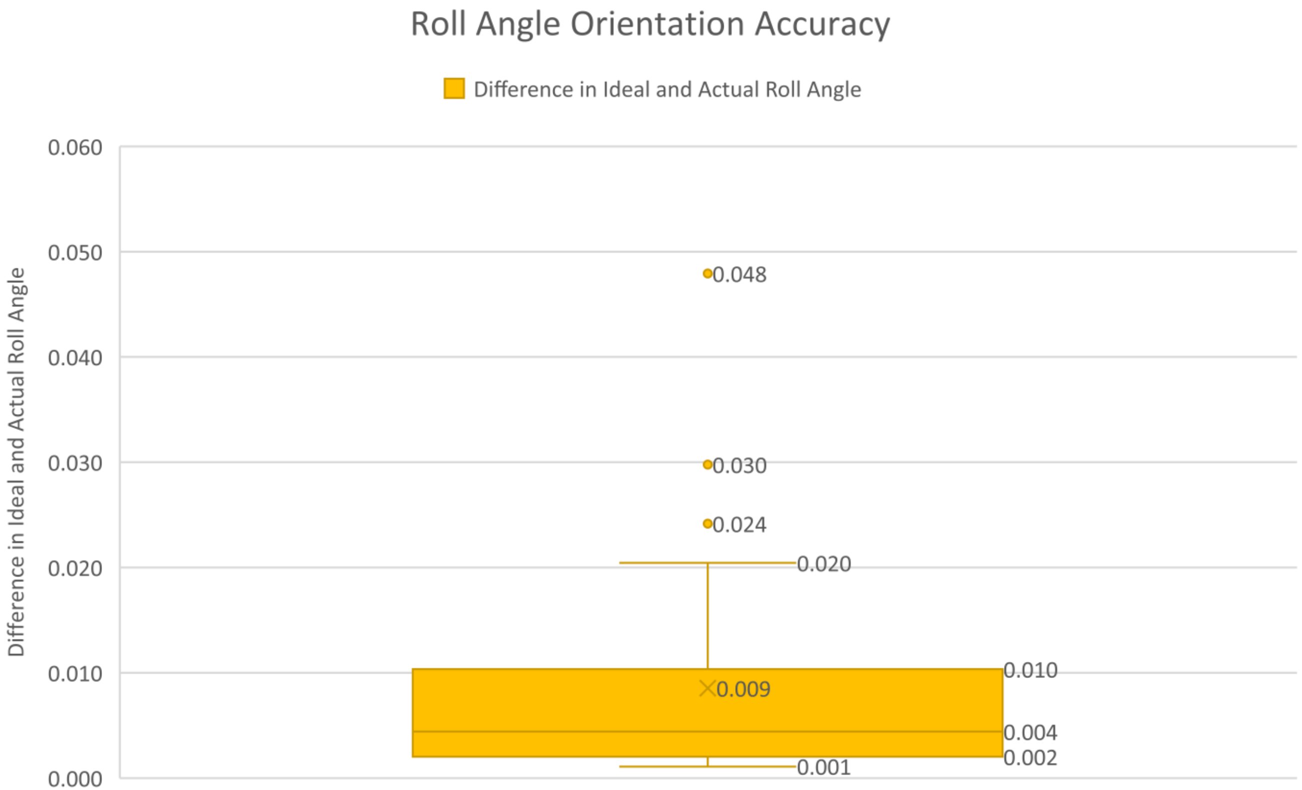


Figure 19: Orientation Test Results—Roll

Matthew Bigerton

Orientation Testing Results—Pitch

Table 8: Pitch-Angle Difference Results—Summary

Difference in Ideal and Actual Orientation			
	roll_diff	pitch_diff	yaw_diff
MIN	0.001	0.001	0.001
MAX	0.048	0.056	0.309
MEDIAN	0.004	0.006	0.031
QUARTILE 1	0.002	0.003	0.020
Quartile 3	0.009	0.013	0.069
MEAN	0.008546	0.010482	0.049897
STDEV	0.010756	0.012035	0.058807

- The pitch angle distribution is skewed up (toward the higher values).
- The pitch distribution has 1 outlier.
  - Outliers present make the median more suitable to represent the data than the mean.
- The median is within the error limit of 0.05±0.01 rad (Euler Angle).

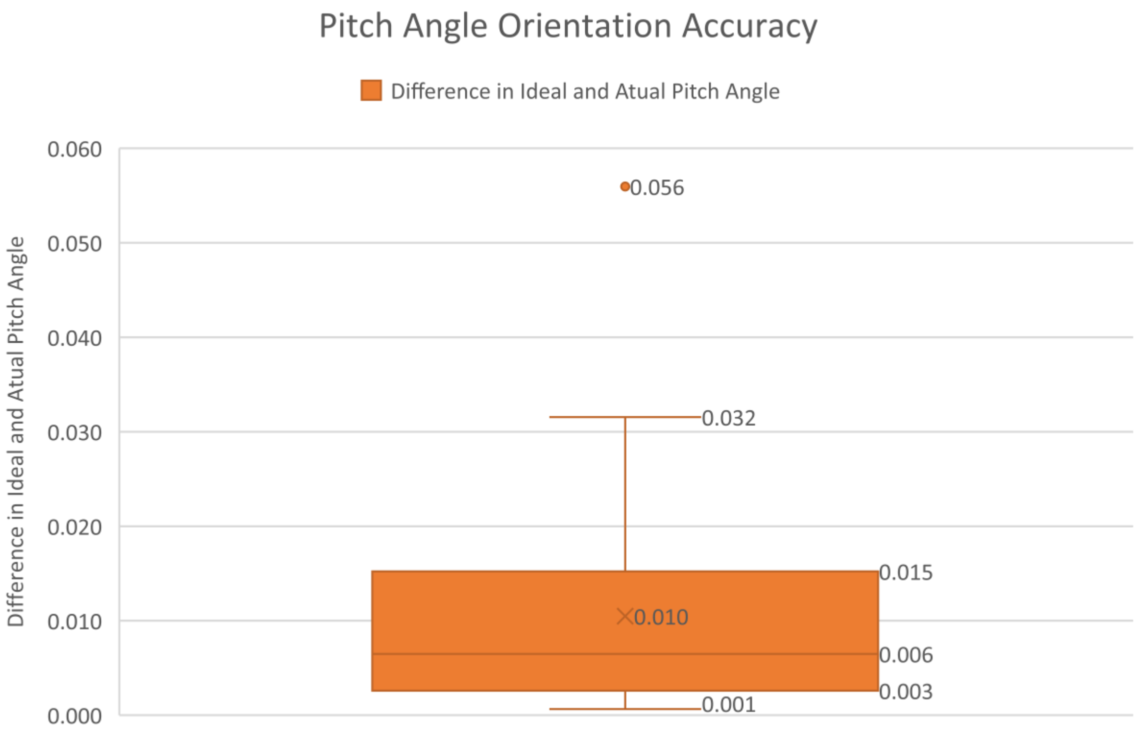


Figure 20: Orientation Test Results—Pitch

Matthew Bigerton

Orientation Testing Results—Yaw

Table 9: Yaw-Angle Difference Results—Summary

Difference in Ideal and Actual Orientation			
	roll_diff	pitch_diff	yaw_diff
MIN	0.001	0.001	0.001
MAX	0.048	0.056	0.309
MEDIAN	0.004	0.006	0.031
QUARTILE 1	0.002	0.003	0.020
QUARTILE 3	0.009	0.013	0.069
MEAN	0.008546	0.010482	0.049897
STDEV	0.010756	0.012035	0.058807

- The yaw angle distribution is skewed up (toward the higher values).
- The yaw distribution has 1 outlier.
  - Outliers present make the median more suitable to represent the data than the mean.
- The median is within the error limit of 0.05±0.01 rad (Euler Angle).

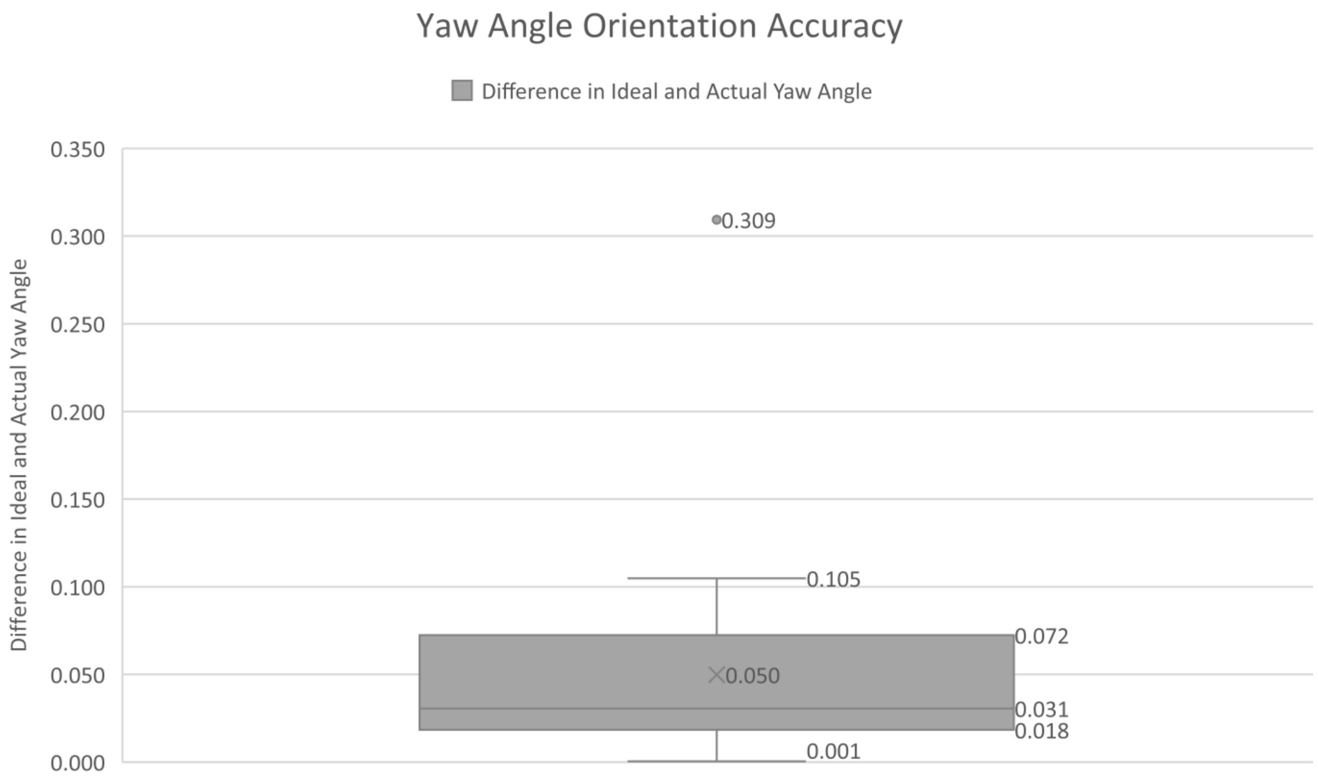


Figure 21: Orientation Test Results—Yaw

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Testing Remarks

- An approximately symmetric/normal distribution is ideal.
  - Normal distributions are easily represented as a bell-curve.
- An approximately normal distribution can be achieved in 2 possible ways:
  1. Increasing n (number of trials).
  2. Eliminating Outliers
- Increasing the number of completed trials by a factor of 2 or 3 will greatly help the symmetry.
  - A goal would be n=100.
- Eliminating outliers can drastically change the shape of a distribution (reverse apparent skew).

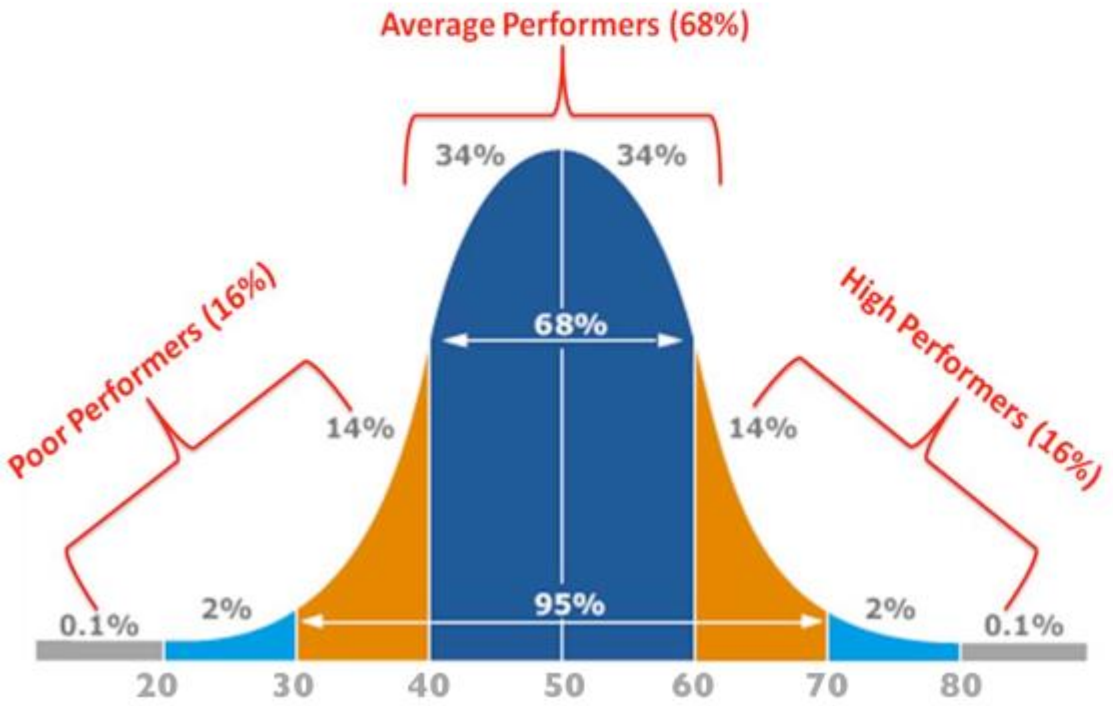

Figure 22: Bell Curve Distribution

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Conclusion

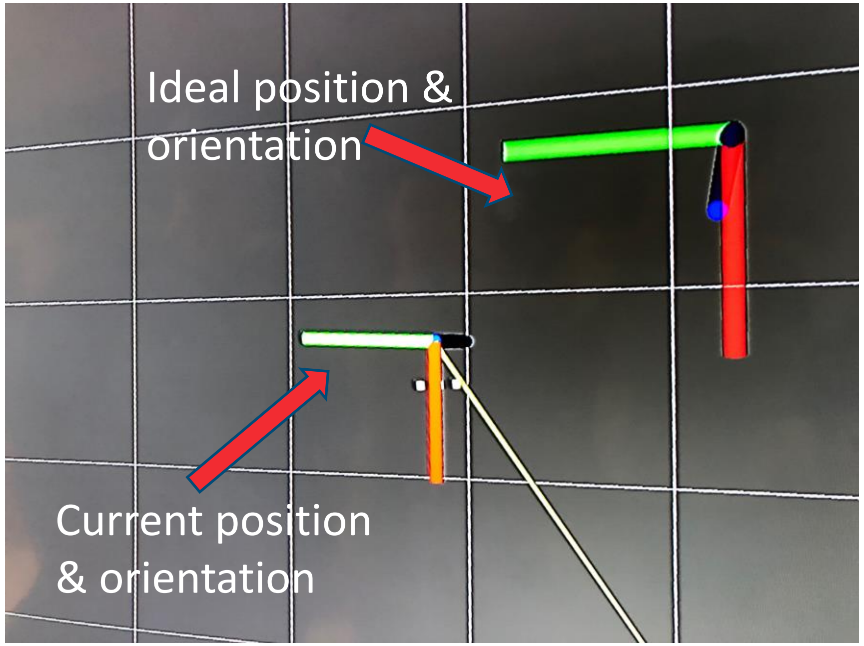

Figure 23: Sample of a Visualization

The objective of this project was to provide a user interface for a participant in a 3D body scan environment in order to shorten the duration of the overall process by reducing the amount of instructions given by the scan technician to position/orient the participant.

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Most Important Points

1. AprilTags can now be tracked using ROS and the 3D camera.
2. The wearable created satisfies the design criteria.
3. The design components are all complete and ready for application.
4. The meshing of the CAD image and the AprilTag(s) in the virtual reality world has proven difficult, but is possible.

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Lessons Learned

1. Keeping the sponsor/customer's needs and wants as the most important determining factors is challenging throughout the design process.
2. Scoping a project with minimal prior knowledge is incredibly difficult.
3. Maintaining a Project timeline and schedule plays a pivotal role in project success.
4. Determining useful testing and validation of a virtual design can be troublesome.

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References

1. Garrido-Jurado, S., Muñoz-Salinas, R., Madrid-Cuevas, F., & Marín-Jiménez, M. (2014). "Automatic generation and detection of highly reliable fiducial markers under occlusion," *Pattern Recognition,47*(6), 2280-2292. doi:10.1016/j.patcog.2014.01.005
2. Malyuta, D. (2017). "Navigation, Control and Mission Logic for Quadrotor Full-cycle Autonomy," Master thesis, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA.
3. Romero-Ramirez, F. J., Muñoz-Salinas, R., & Medina-Carnicer, R. (2018). "Speeded up detection of squared fiducial markers," *Image and Vision Computing,76*, 38-47. doi:10.1016/j.imavis.2018.05.004
4. Wang, J. & Olson, E. (2016). "AprilTag 2: Efficient and robust fiducial detection," in *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS).*

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Questions?