Object Shape and Sensor Placement

SteamVR™ Tracking

Introduction

The **Object Design and Integration Overview** document outlined the process of designing a tracked object for SteamVR™ Tracking. This document will expand on developing the shape of an object and proper placement of sensors.

The first objective is to establish the design targets and determine the needed level of tracking. An example will then be used to demonstrate how the initial shape is determined. Obstructions will be positioned and the part will be simulated to determine initial sensor placement. The results will be analyzed and another iteration will be completed to further improve tracking. Once sensor placement is expected to produce good tracking results, they'll be moved to a CAD package and adjusted to conform to any geometric considerations.

Establishing Design Targets

One of the first steps for any design is to determine the required level of tracking. An object intended to be an HMD (head mounted display) should have high accuracy tracking to avoid user nausea. A controller may be able to sacrifice some tracking accuracy and still perform as desired. Quantifying the level of accuracy needed is difficult because of the complexity of the system. A better method is to use an existing tracked object as a benchmark, simulate the sensor placement, and compare results. The JSON file for a tracked object can be downloaded from the object and simulated without a 3D file. Though the 3D model acts as an obstruction, sensors generally face outward and should only be minimally affected.

To download the JSON file off an existing tracked object, use the lighthouse_console utility. In the prompt, type the following:

```
lh> downloadconfig <filename>.json
```

The downloadconfig command will download the JSON file off the device and save a local copy as "<filename>.json." Learn more about connecting to a tracked object using lighthouse_console by reviewing the **Testing Object Connectivity** document.

Creating Initial 3D Model

Practical Considerations

It is common that the initial shape of a product will be created by an industrial designer or industrial design team. An industrial designer has the difficult task of coming up with a shape that solves usability issues while adhering to company brand standards. An additional complication of designing a tracked object for SteamVR is that tracking is highly dependent on the object shape. While general assumptions can be made about how well a certain shape will track, small geometry changes could have significant effects on performance. It can be argued that the ability to track well is the most important aspect of a tracked object. An object may look aesthetically pleasing, but if it doesn't track well in SteamVR the product will fail functionally.

The best results will occur when either the industrial designer is familiar with designing a tracked object for SteamVR or works closely with someone who has that knowledge. Early collaboration between the industrial design, mechanical engineering, and electrical engineering teams should occur before any major architectural decisions are made. Without this input, there is significant risk that major changes could be required. The constraints may seem restrictive but full understanding will give the design team the best opportunity to create an aesthetically appealing product with good functionality.

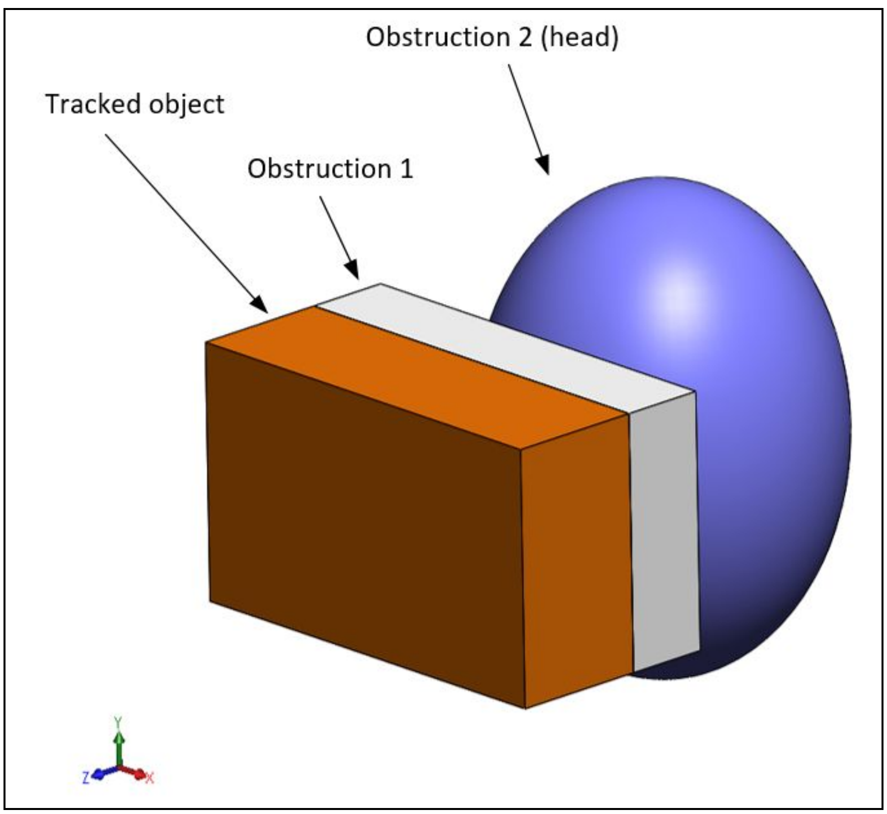
The first component of good tracking is sensor placement. Simulation tools can be used to make predictions about how well a set of sensors will track an object. Some designs will never be able to track well. Early simulation with hmd_designer will help reveal these issues and can prevent spending too much time on an inadequate design. After sensors are in good spots and simulating well, it's also important to build a prototype and test. Project schedules should build in time for multiple sensor placement iterations and testing. Sensor placement will be discussed in further detail throughout this document.

The second component of good tracking is sensor coverings. The sensor covering is what is placed between the sensitive electronics and the environment. It can be used to both conceal the sensor and protect it. Since it is in the optical path between the base station and the sensor, it too has some strict requirements that may affect the look and feel of the product. The most significant are that the covering needs to be flat and parallel over the top of the sensor. The material needs to allow IR light to pass while blocking light in the visible spectrum. Materials that do this well typically end up being darkly colored. The outer surface of the cover must be textured to reduce reflection and allow it to act as if it were a diffuse material. Lastly, the covers should be kept thin and placed directly above the sensor. Many of these requirements have flexibility but expect that experimentation will be required to verify tracking performance. For more information on coverings please reference the **Sensor Covering** document.

Modeling and Export

A simple 3D CAD model of an HMD was created for demonstration purposes. Though the geometry is simplified, the process is very similar to what was used in the design of the Reference Object. Solidworks will be used to manipulate 3D geometry but any CAD package should work with minor alterations to the procedure.

A Solidworks part file was created containing three different solid bodies. The first was a body for the tracked object and is where sensor placement will occur. The two remaining bodies are obstructions that tell hmd_designer what sensor placement locations should be avoided. Obstruction 1 is the back side of the tracked object which will likely be covered by the face adapter, displays, lenses, and strap attachments. Obstruction 2 represents a human head. Other body parts could be added but the effectiveness of obstacles becomes smaller the farther away it is from the tracked object.



The above model is fine for a first pass simulation. It captures the general shape, it is close to the right size, and the key obstructions are represented. As the design converges and the geometry becomes more complex, so should the model in the simulation. It will be useful to include obstructions for straps, knobs, cables, and areas of user interaction.

Note the axis definition in the above model. The part is built so that the front of the tracked object is in the positive z-direction. While results won't be affected, this will position the front of the tracked object in the middle of the hmd_designer output plots.

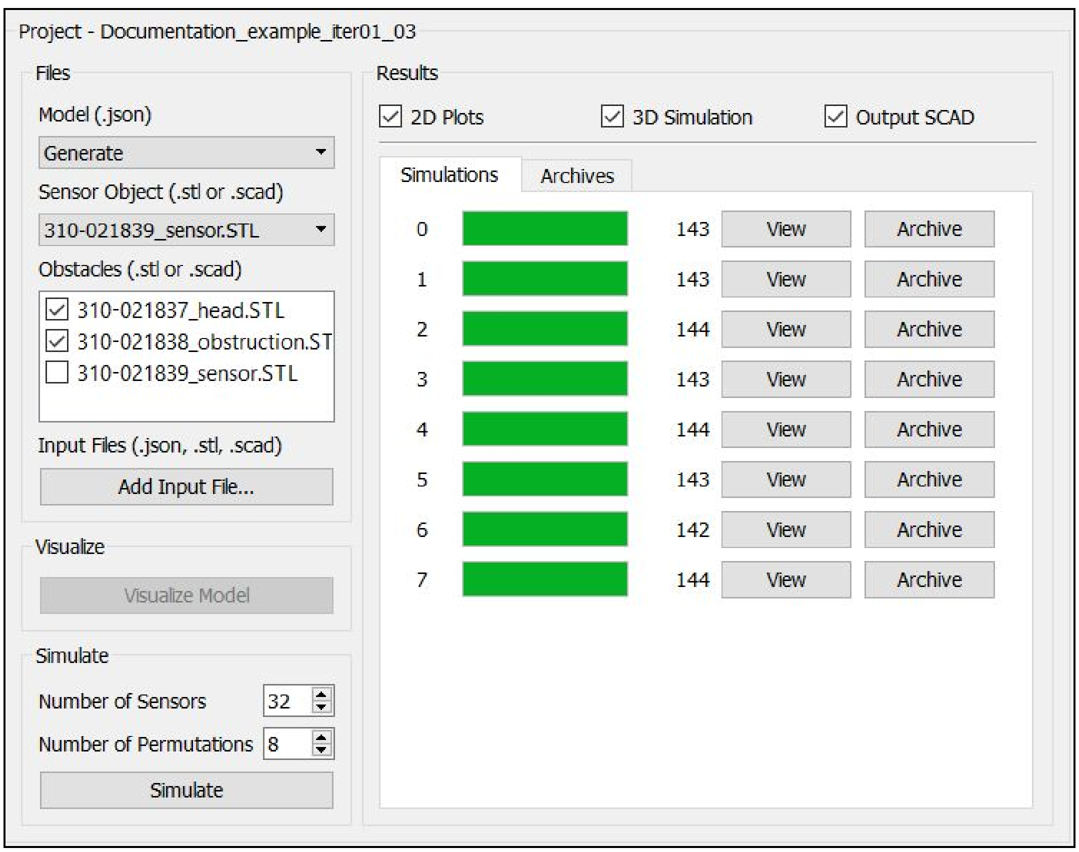
Each body was saved in its own STL file from the multibody part. There are many ways to save an STL file but the key is that all the STL files have the same origin. This ensures that when they are imported into hmd_designer they will be positioned properly.

Sensor Placement and Simulation

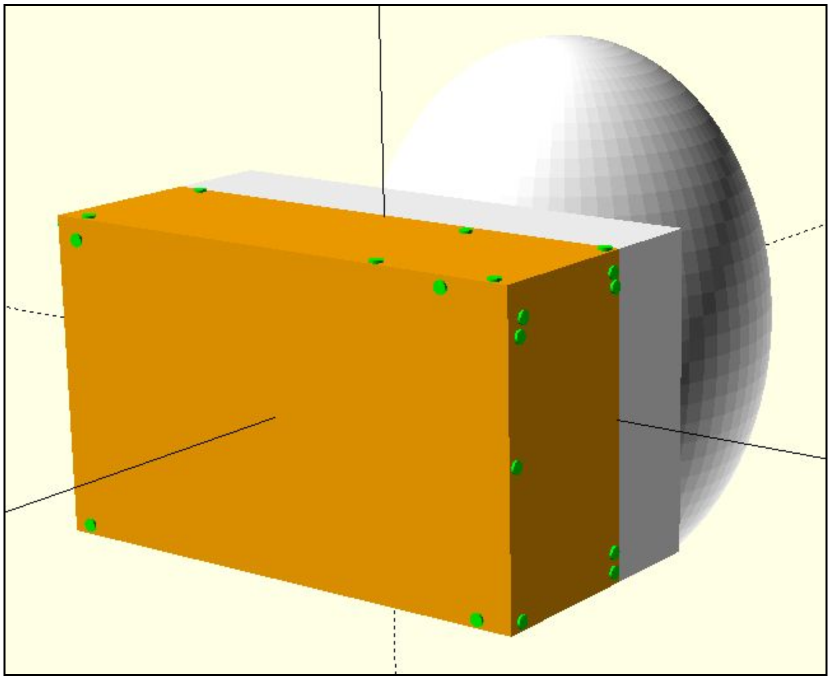
Hmd_designer is a Valve developed tool that automatically places sensors on shapes and optimizes their placement to yield the best tracking performance. For information on its use please reference the **Simulation User Manual** document.

Initial Sensor Placement and Evaluation

Continuing the example from above, a new project was created in hmd_designer. The three STL files were loaded and the sensor object and obstacles were designated. A simulation was run with 32 sensors and 8 permutations. 32 is the maximum number of sensors and serves as a good check. If tracking is poor with the maximum number of sensors the object may never track well.

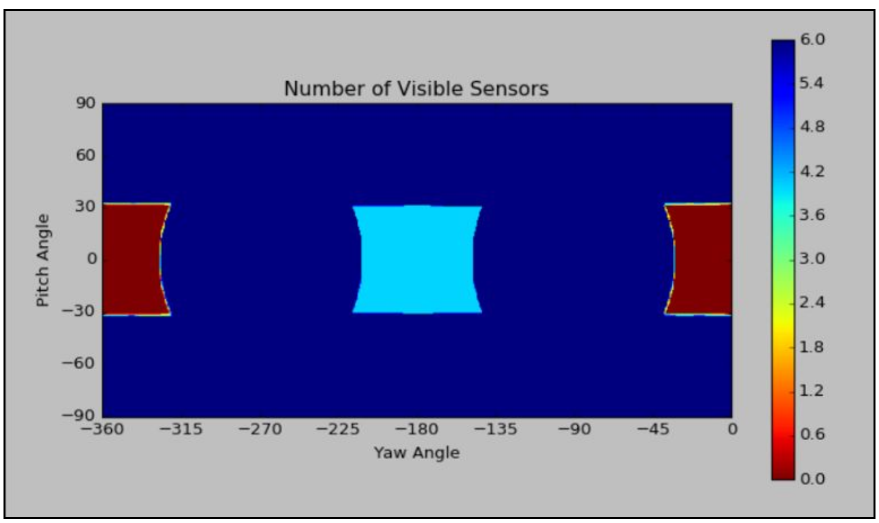


When the simulation finishes there will be a number of simulation results each with their own quality number. Quality numbers cannot be compared between projects, only within them. There is not much difference between the quality numbers above but we can ascertain that simulation 6 gives the best results. Clicking the View button opens up several output windows containing results from the simulation. The following evaluation is specific only to the example object. Review **Interpreting Simulation Output** for a better understanding of the results produced by hmd_designer.



The OpenSCAD window shows the sensor object, the two obstacles, and the sensor placement. Note that hmd_designer tends to place sensors near the edges of the parts. This is in an effort to maximize baseline and reduce pose translation error. Some of the edge positions may not be realistic due to geometric constraints but hmd_designer will take as much space as it is allowed. Another takeaway is multiple sensors are very close to one another. Since the duplicates are on the same face, they could be removed without much loss of performance.

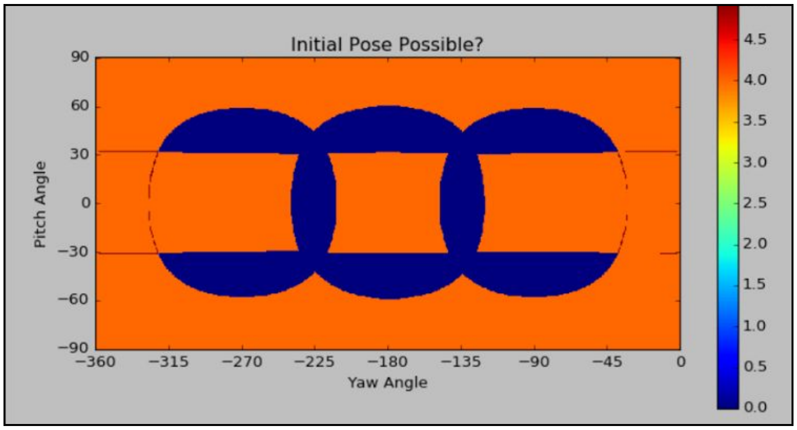
One of the other output windows contains four graphs with the headings Number of Visible Sensors, Pose Rotation Error, Initial Pose Possible?, and Pose Translation Error.

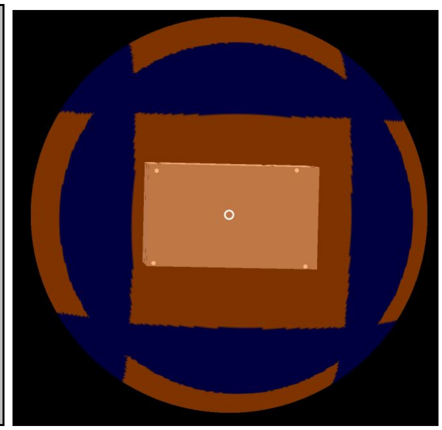


The Number of Visible Sensors plot tells how many sensors can be seen from certain poses. Four visible sensors are required to begin tracking. It appears that there are sufficient sensors to begin tracking at all but the back side of the object. This is expected since the backside is completely blocked off with an obstruction.

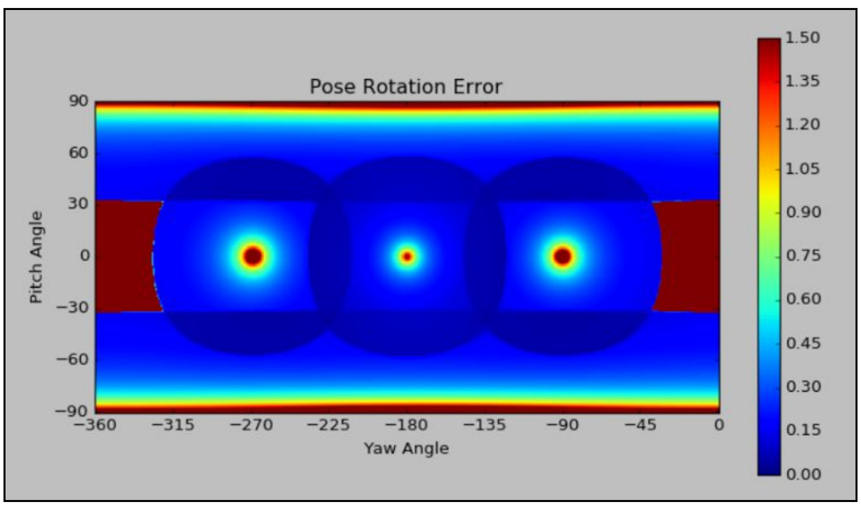
The Initial Pose Possible? graph plots the ability of an object to boot from certain poses. The booting requirements are that four sensors are visible and they are non-coplanar. Any of the three sensors can form a plane but the fourth must be 8mm away from that plane. The object can boot wherever the plot is dark blue. Areas of orange have enough visible sensors but will not boot because they do not meet the the coplanarity requirement.

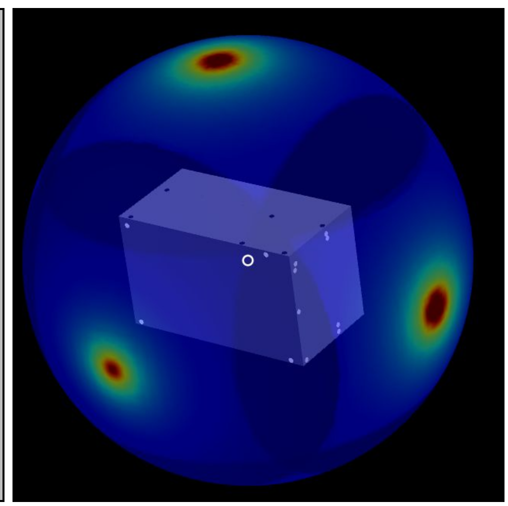
The graph is mostly orange indicating that there are not enough sensors out of plane to boot the object. Evaluating the 3D plot from the front shows that four sensors are clearly visible but they are coplanar.





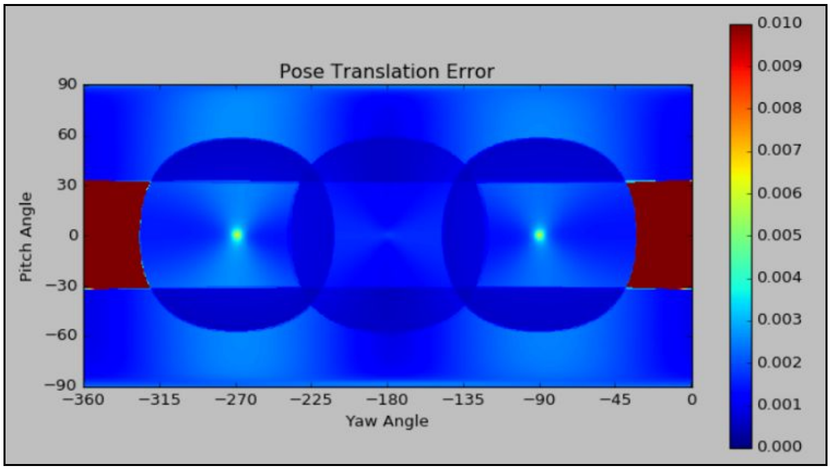
The Pose Rotation Error plot displays the amount of rotation error present in different poses. Depth of sensor placement and distance between the sensors are the key determinant of rotation error. When the sensors are coplanar, rotation about any axis within the plane results in only minimal displacement between the sensors in the x and y-directions on the plane.

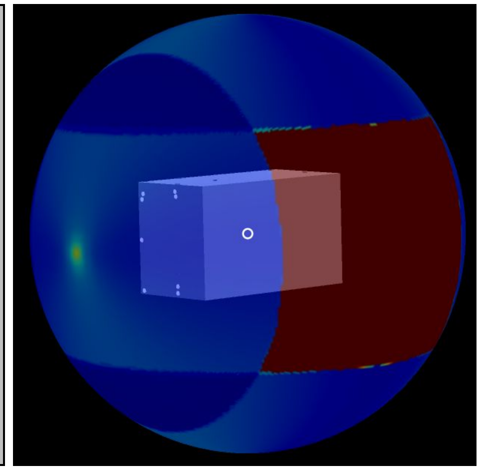




Blue areas of the Pose Rotation Error plots represents good performance while red and brown areas are bad. The results are generally blue but there is an area of rotation error in the center of each flat face. This makes sense as there is no way to see a non-coplanar sensor in these orientations. There is also a lot of rotation error on the back side of the object. Again, this makes sense since the back side is blocked off

The last plot is for Pose Translation Error and ensures that there is enough distance between the sensors so they can be translated in space without error. Blue areas again represent good performance while red and brown indicate poor translation error. Good translation performance is determined by multiple, visible sensors with sufficient distance between them in at least two axes.

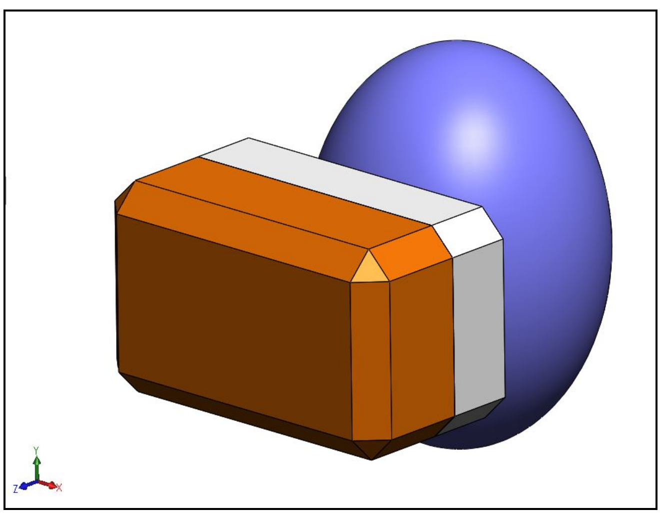
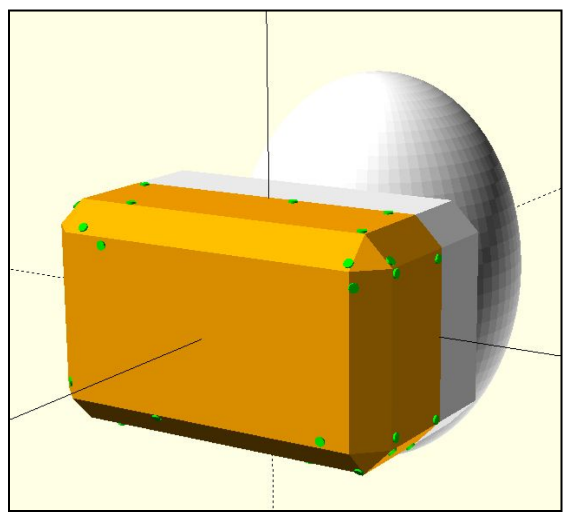




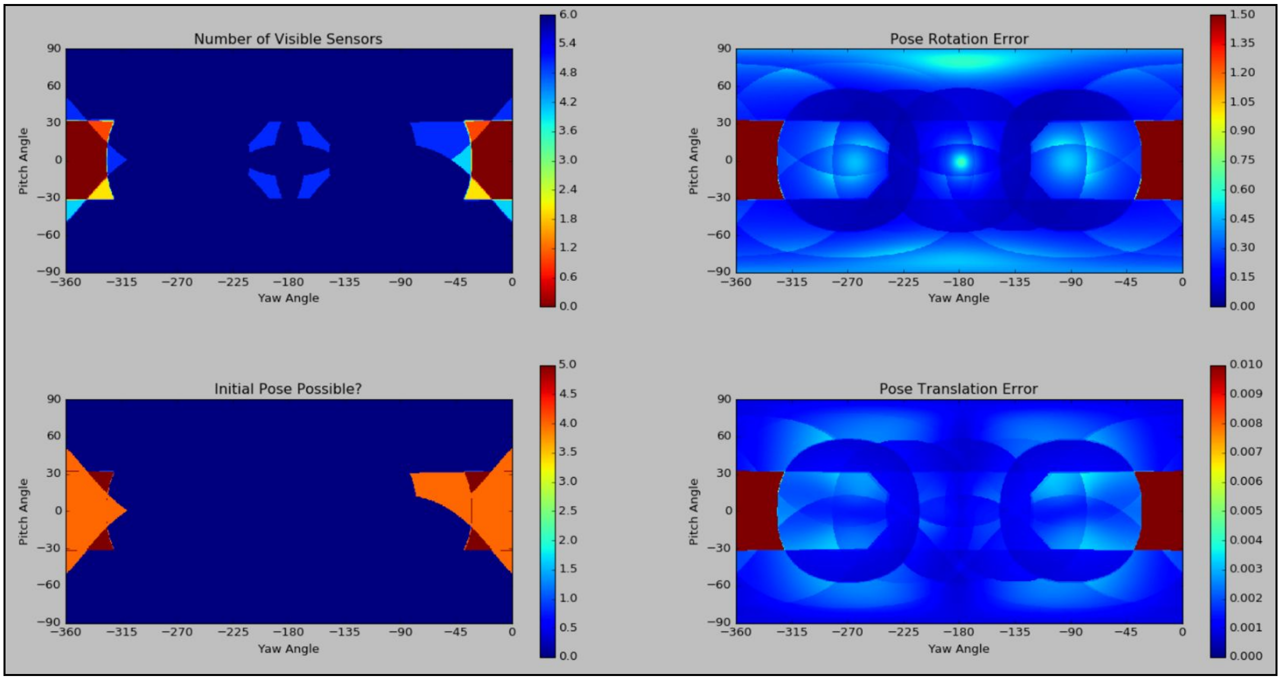
The graph is mostly blue with a couple of green spots on the center of the side faces. The back is dark red indicating significant translation error. One of the characteristics of an HMD-type tracked object is that they are typically wide enough to have few problems with translation error. Controller-type tracked objects have less distance between sensors and poorer translation error. Translation error on the side of this object can be improved by moving the sensors closer to the back edges of the face.

Sensor Placement Iteration

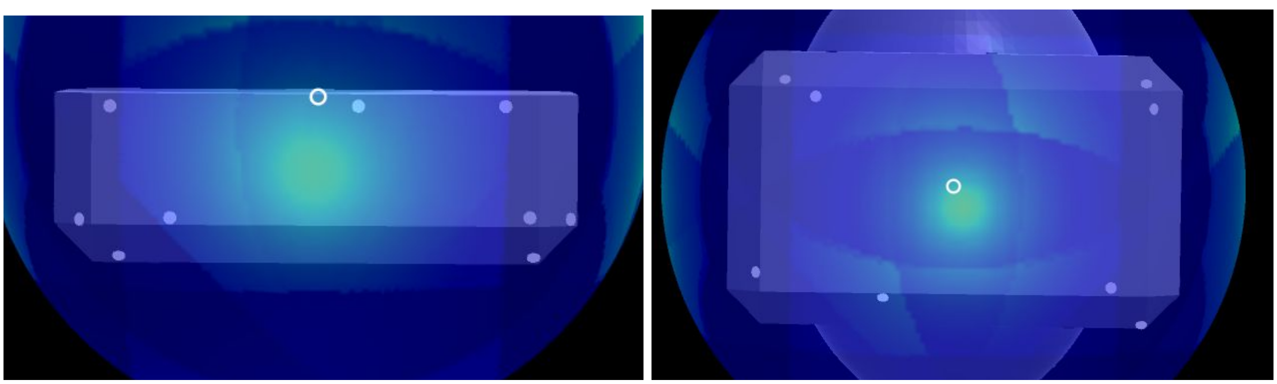
One of the major problems with the design so far has been having enough non-coplanar surfaces to maximize booting ability and minimize rotation error. A large chamfer was added to each visible surface to give the sensors more orientations at which they could be placed. The right side image below shows the results of the sensor placement. Nearly every new face has a sensor while the sensors remain located in the corners of the faces.

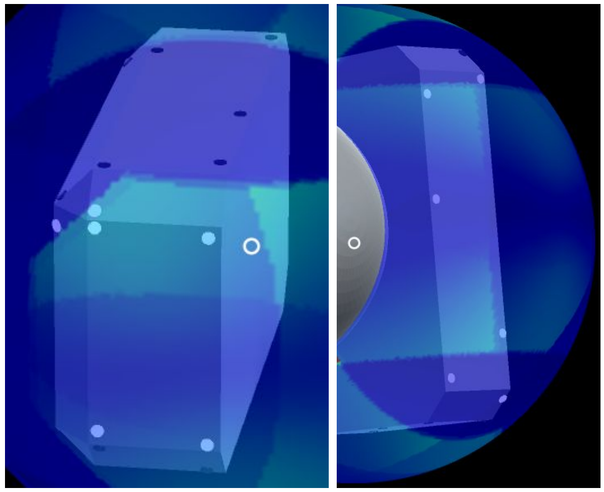
The resulting plots output from hmd_designer are below.



Both the graphs for the Number of Visible Sensor and Initial Pose Possible? have improved. The Pose Rotation Error plot has also reduced the spots of high rotation error at the center of each face. The green regions remaining indicate that the sensors on the newly created chamfers aren't far enough out of plane.



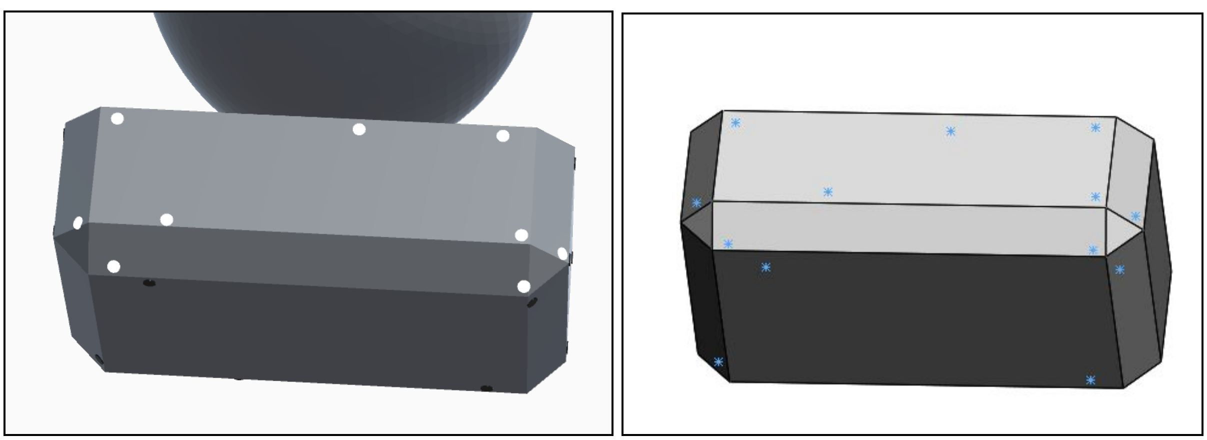
The Pose Translation Error plots have also improved. The trouble areas are on the edges of the object when viewed from the back. The sensors appear close together as there is little baseline between them.



Based on the second round of sensor placement iteration, we could improve results further by creating more opportunity for non-coplanar sensors. This could be done by creating larger chamfers, adding a draft to the side walls, or adding surface protrusions. There is also a major blind spot at the back of the object. By increasing the sides past the edges of the obstacles, sensors could be placed to face backwards further reducing pose translation and pose rotation errors. For the purpose of this exercise, further iteration will not be pursued. If this were a product intended for mass production, several more iterations would take place. The cycle would be ended once the plots from hmd_designer started matching or surpassing those of the chosen benchmark product.

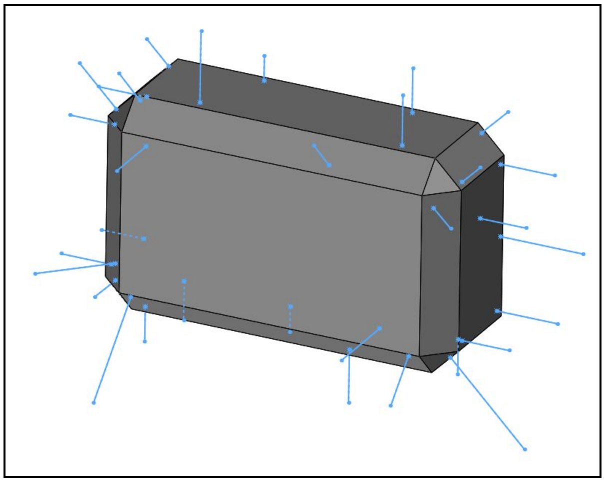
Adding Sensors to CAD Model

Once simulation plots start looking good and the external geometry is generally agreed upon by industrial design, mechanical engineering, and electrical engineering, sensors can be added to the CAD model. It's easiest to do the initial translation by hand. Use the simulated sensor locations to manually determine placement in 3D CAD. In the Solidworks CAD package this can be done by placing sketch points in a 3D sketch on the desired surfaces.

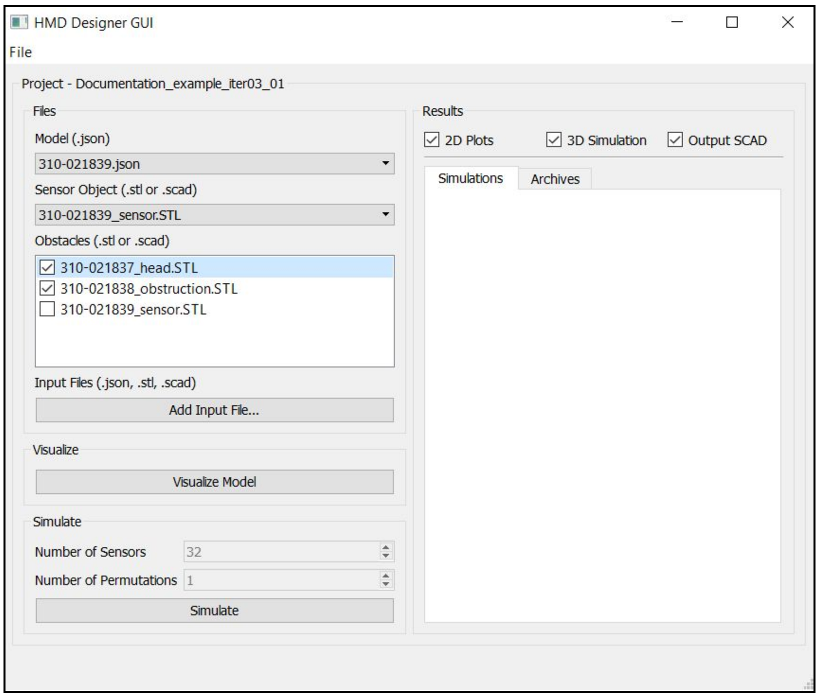


This is a good opportunity to make minor tweaks to the sensor positions. If two sensors are close to one another and on the same plane it is probably fine to eliminate one. Sensors too close to the edge can be moved towards the center of the face. Remember that placement needs to account for material thickness, the location of the sensor center, and the size of circuit board the sensor is connected to. Don't be afraid to tweak sensor placement a few millimeters in any direction. As long as the sensor remains on the same plane the results shouldn't be affected too significantly.

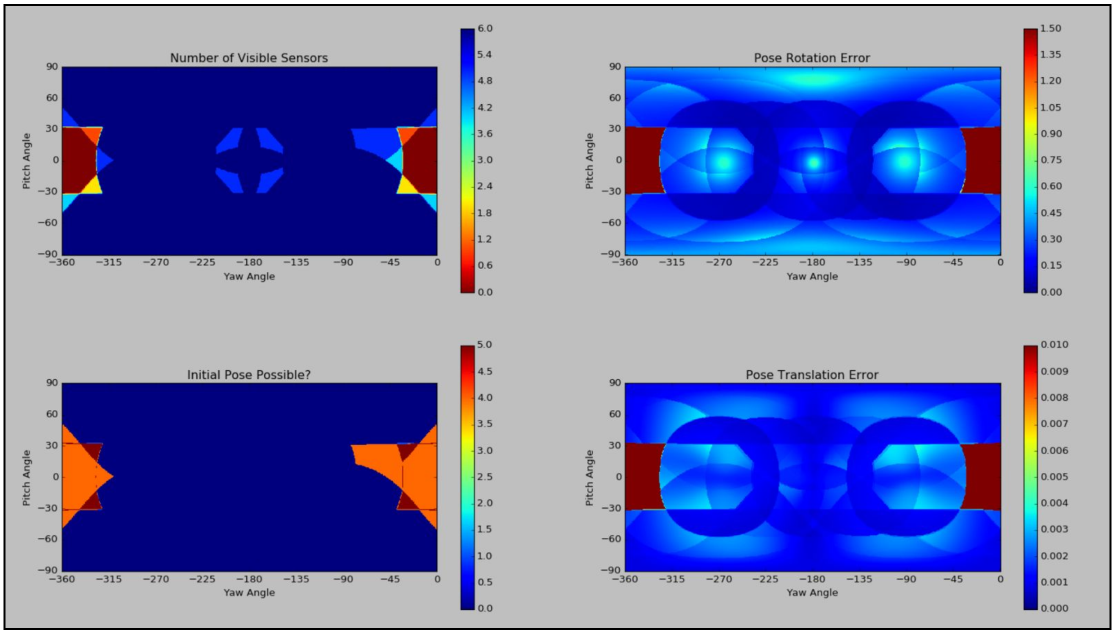
The next step is to export the JSON file from the 3D CAD file and simulate the results to confirm translation hasn't changed the expected performance. Follow the **Extracting Sensor Data from CAD** document to properly create a JSON from a 3D CAD file.



Simulate sensor placement with the newly created JSON file in hmd_designer.



Since there is no iteration, the simulation should finish quickly. Comparing the results to the last simulated sensor placement created by hmd_designer we see they look similar. The Pose Rotation Error has some pronounced hot spots in the centers of the front and side faces. This may be due to the sensors being moved away from the edges to account for geometric restrictions.



Now that the effects of sensor placement translation from simulation to 3D CAD have been realized, larger changes can be made. These could include sensor elimination or sensor placement for symmetry. Whatever the changes, be sure to simulate to verify performance compared to the benchmark product.

After sensors have been added to the 3D CAD model and are yielding good simulation results it’s time to verify sensor placement through prototyping. Simulation is no substitute for actually building an object with sensors and testing it in SteamVR. For more information on creating a prototype see the **Rapid Prototyping Objects** document.