Visualization of the Effects of Multipath on NAVAID Antenna Patterns

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BIOGRAPHY

Chad Mourning is an Assistant Professor of Computer Science at Ohio University. His research interests include Computer Graphics, Virtual & Augmented Reality, and Simulation & Modelling. He currently serves as lead developer on the Ohio University NAVAID Performance Prediction Model. Chad's other related projects include development of a low-altitude weather network for advanced air mobility of UAVs, and Machine Learning of safety applications using virtualized training data. Chad earned his Ph.D. in Electrical Engineering and Computer Science from Ohio University in 2015.

Simbo Odunaiya is currently a Senior Research Engineer with the Avionics Engineering Center and an Adjunct Faculty in the School of Electrical Engineering at Ohio University in Athens, Ohio, United States of America. Simbo is currently involved in the development of mathematical models of electromagnetic scattering for Instrument Landing System (ILS), VHF OmniRange (VOR), and Navigation Radar performance predictions. His past work includes the development of a mathematical model for predicting the effects of buildings and other structures on the VHF Omni-Range, the Instrument Landing System, and Radar. He also developed a method that offers the possibilities to reduce the scattering effects of buildings on the Instrument Landing system localizer. He previously worked at the Federal Civil Aviation Authority (now known as the Nigerian Airspace Management Agency - NAMA) in Lagos, Nigeria. He holds a Ph.D. in Electrical Engineering earned at Ohio University in 1995.

ABSTRACT

The Ohio University Navaid Performance Prediction Model (OUNPPM) is a popular software package for the certification of navigational aids at airports around the world. OUNPPM's primary function is to calculate multipath interference from nearby structures and users have the ability to model their scenario in a 3D virtual world. Until recently, OUNPPM did not include any way to visualize the pattern-in-space of the navaid signal or the multipath error. This paper is an extension of our work recently presented at the International Symposium on Visual Computing [1] and demonstrates an isosurface-based approach of visualizing the direct+multipath pattern-in-space, and how it is incorporated into real-time use of the OUNPPM software. This paper also includes a few canned examples of common scenarios for the localizer, such as: nominal patterns, hardware faults, plate scatterers at various orientations, etc. as well as visualizations of glideslope examples and some visualizations of a new approach at change detection. The intention of this new feature is to assist users with their engineering judgements in determining exactly which scatterers are impacting the pattern at the intersection of the flightpath of concern, decreasing the overall time and cost necessary to find a certifiable configuration for an airport. This papers briefly covers the history of antenna pattern visualization, explains the methodology of the iso-surface approach, provides the aforementioned examples captured from the software, and concludes with recommendations for future work to improve the overall usefulness for users.

INTRODUCTION

The Ohio University NAVAID Performance Prediction Model is a tool for calculating the effects of multipath on navigational aids such as localizer, glideslope, and VOR. The purpose of this paper is to introduce the new antenna pattern visualization features within the Ohio University NAVAID Performance Prediction Model (OUNPPM) visualization tool. Antenna pattern visualization is not a new feature; in the 1980s computer visualizations of single antenna elements were already possible [2], and by the 1990s researchers were visualizing the patterns of entire arrays [3]. However, we were unable to find any terrain-scale visualization of antenna patterns perturbed by multipath from nearby scatterers. This is likely due to difficulty in cleanly parameterizing the multipath from an arbitrary number of arbitrarily shaped and arbitrarily orientated scatterers. Given that this calculation is the purpose of OUNPPM, work began on an attempt at this sort of visualization.

This paper will show a handful of examples of these visualizations, including visualizations for both localizer and glideslope. We will start with ideal antenna pattern visualizations, and then show asymmetries caused by hardware faults and scatterers. A new feature completed since our previous work presented at the 2021 International Symposium on Visual Computing [1] is the addition of visualizations of change detection in the patterns, which will also be discussed in this paper. We hope that this visualization can aid in engineering judgements in the development of new antennas or as part of the design of airport layouts.

METHODOLOGY

Typical use of OUNPPM calculates the field strengths of the navigational aid on one of the predefined, common inspection flight paths. These paths are discretized into a collection of individual points, and the calculations are made at each point individually. Because of the discrete approach, a voxelized grid of points can be used in place of the inspection paths. The field strengths represent a three-dimensional scalar field of normalized complex amperages. Since we now have a rectilinear grid of scalar values, we can create an iso-surface using the standard Marching Cubes [4] algorithm. Iso-surfaces were also selected because of an existing implementation in the OUNPPM codebase, other volumetric rendering options may be explored later.

EXAMPLES

This section contains examples of the antenna pattern + multipath visualization feature of OUNPPM. All of these visualizations are of iso-surfaces constrained to a 3000ft x 3000ft x 3000ft cube beginning 100 feet in from the NAVAID, centered laterally, and beginning 1 foot above the ground.

Ideal Localizer Antenna Pattern

The following images are from a Wilcox 14-10 antenna (the default option in OUNPPM). The four sub-images represent, from left to right, the Course CSB, Course SBO, Clearance CSB, and Clearance SBO. The iso-surface is for 1e-6 microamps.

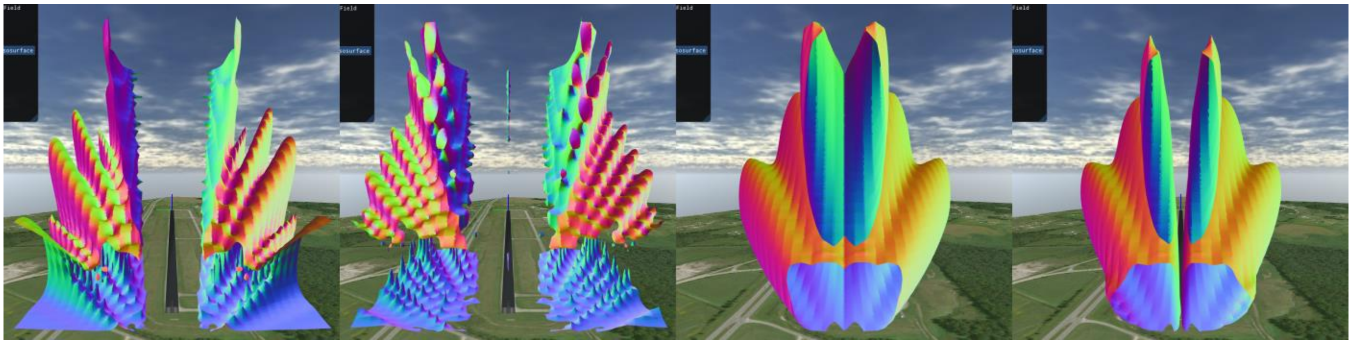

Figure 1: Ideal Localizer Antenna Pattern from above the NAVAID.

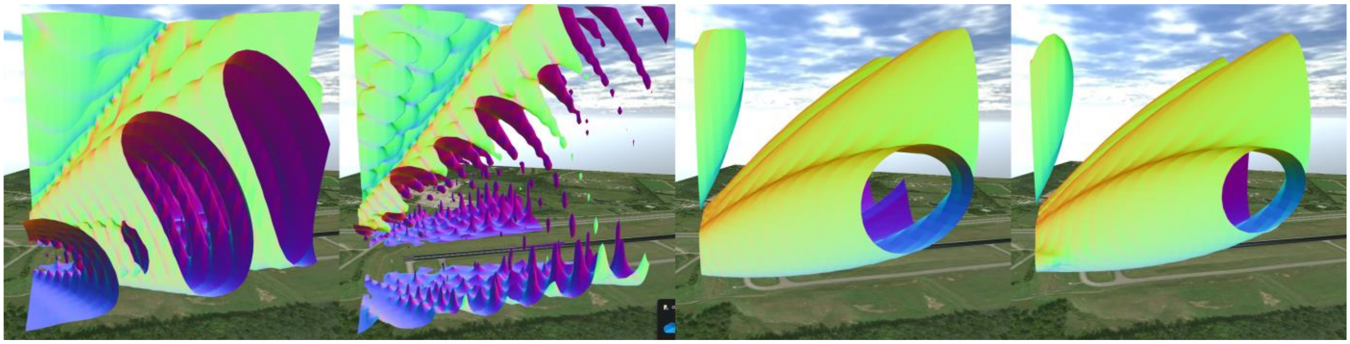

Figure 2: Ideal Localizer Antenna Pattern from the Side

Localizer Antenna Pattern Bent by Hardware Fault

The following image show the ideal localizer pattern on the left, and a disrupted pattern on the right. A 90-degree phase fault was added to the innermost righthand element. Notice the flattening of the pattern on the righthand side, but also the reduction in “ridges” on the lefthand side of the pattern.

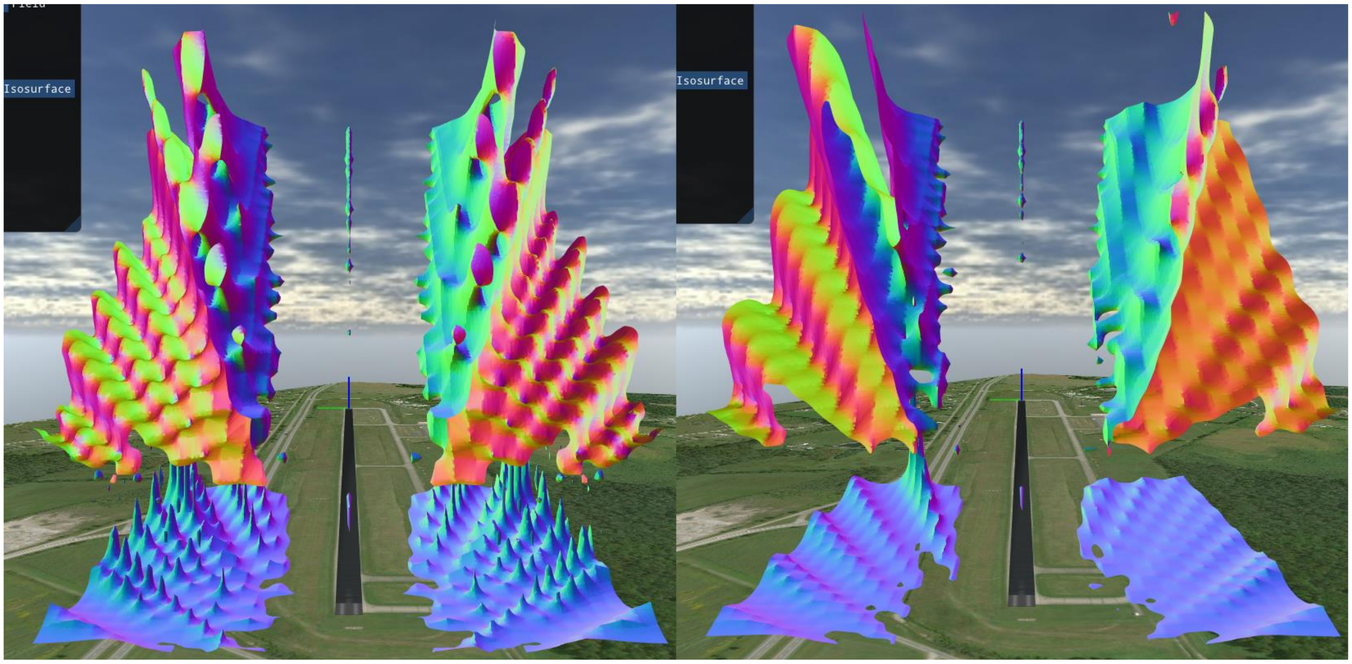

Figure 3: A Localizer with a Hardware Fault

Localizer Antenna Pattern Perturbed by Scatterer

The following image shows a localizer pattern that has been altered by a scatterer. The scatterer can be seen in red in the lower half the image. The change can be seen in the circle. The change was not obvious and was only noticeable to the user by rapidly toggling between the two patterns. This observation was the impetus for the development of the change detection visualizations to be shown later.

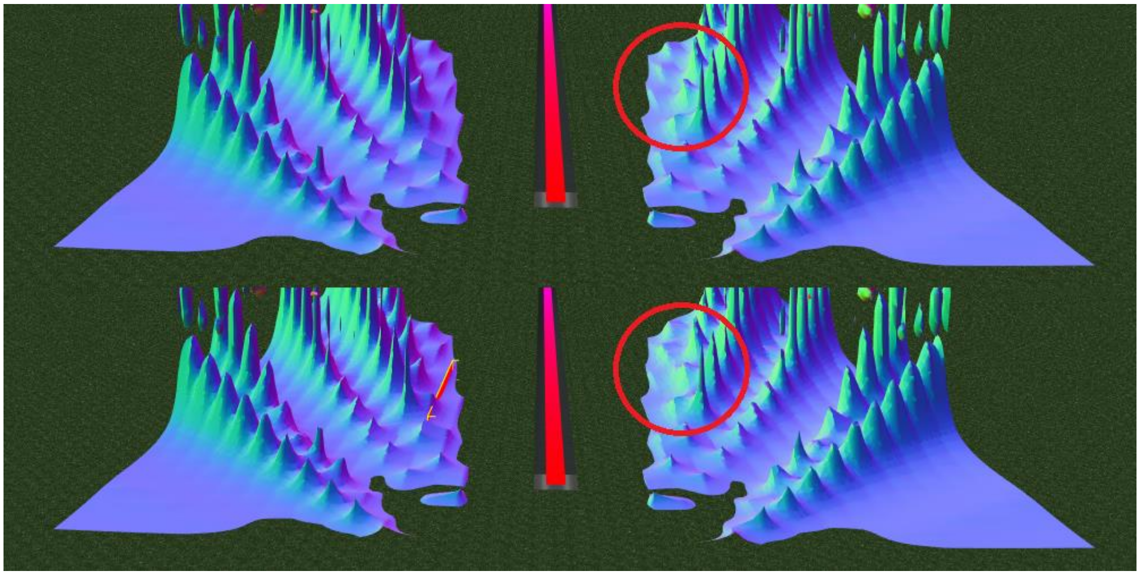

Figure 4: A Localizer Pattern Perturbed by a Scatterer

Scattered Field of Scatterer

In addition to visualization of the antenna patterns perturbed by the reflected field of the scatterer, it is possible to illustrate the scattered field in isolation. The following image is the visualization of the scattered field, reflected by the scatterer in red. This is an iso-surface, so a particular value was selected; in this case, a high value which created an iso-surface near the ground. As the value was reduced, the iso-surfaces would generate at increasing elevation angles.

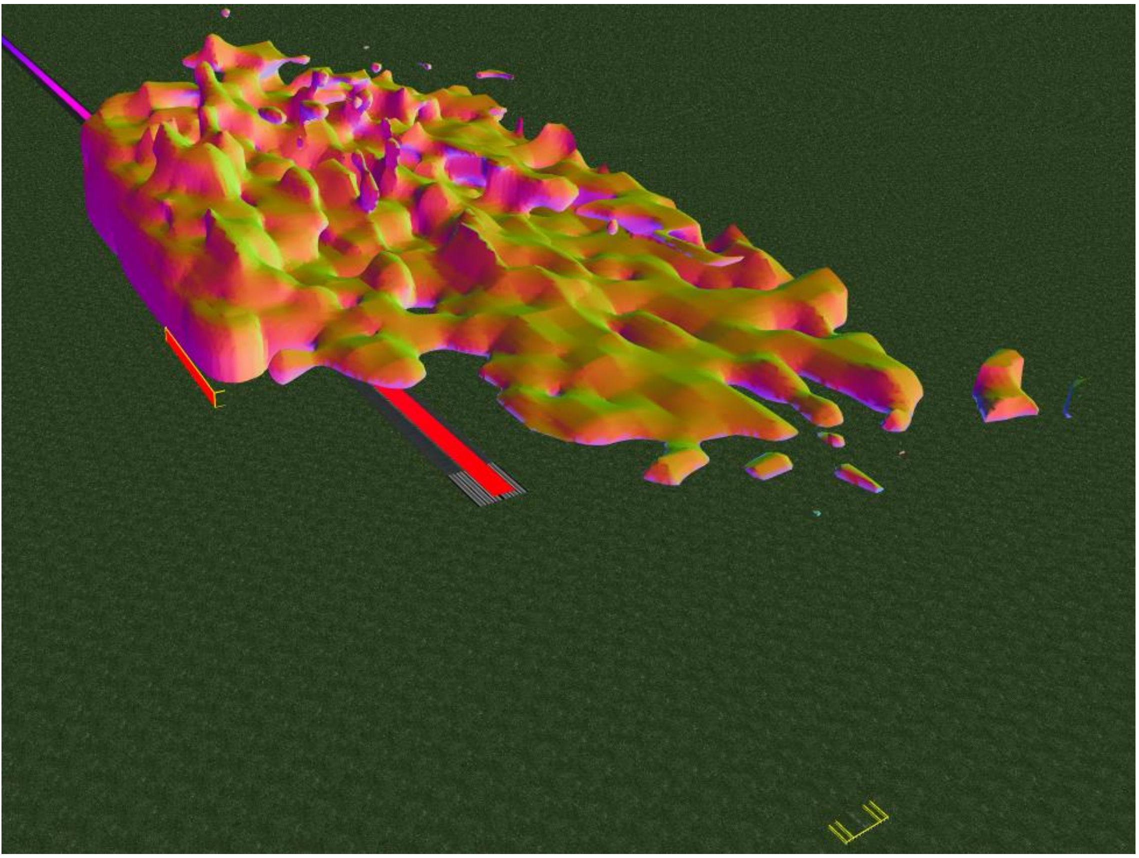

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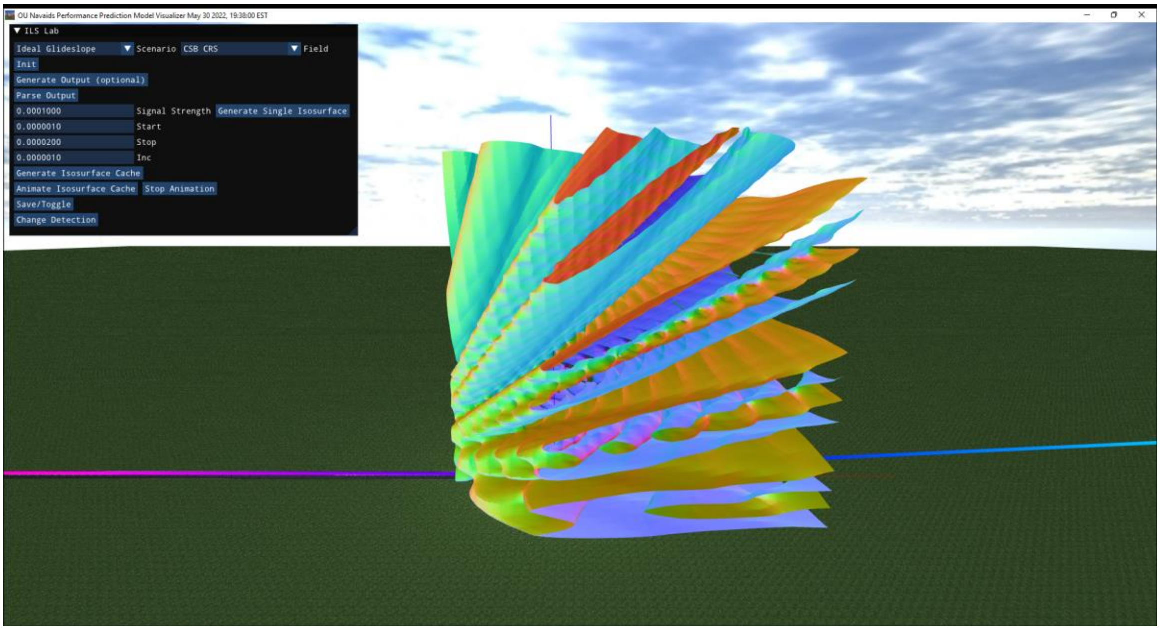
Figure 5: The Scattered Field of a Plate Scatterer

Ideal Glideslope Antenna Patter

The following image is the ideal pattern of the Course CSB signal of a Capture Effect Glideslope viewed from the side with an iso-surface of 1e-4 microamps.



OU Navaids Performance Prediction Model Visualizer May 30 2022, 19:38:00 EST

Ideal Glideslope

Scenario CSB CRS

0.0001000 Signal Strength

0.0000010 Start

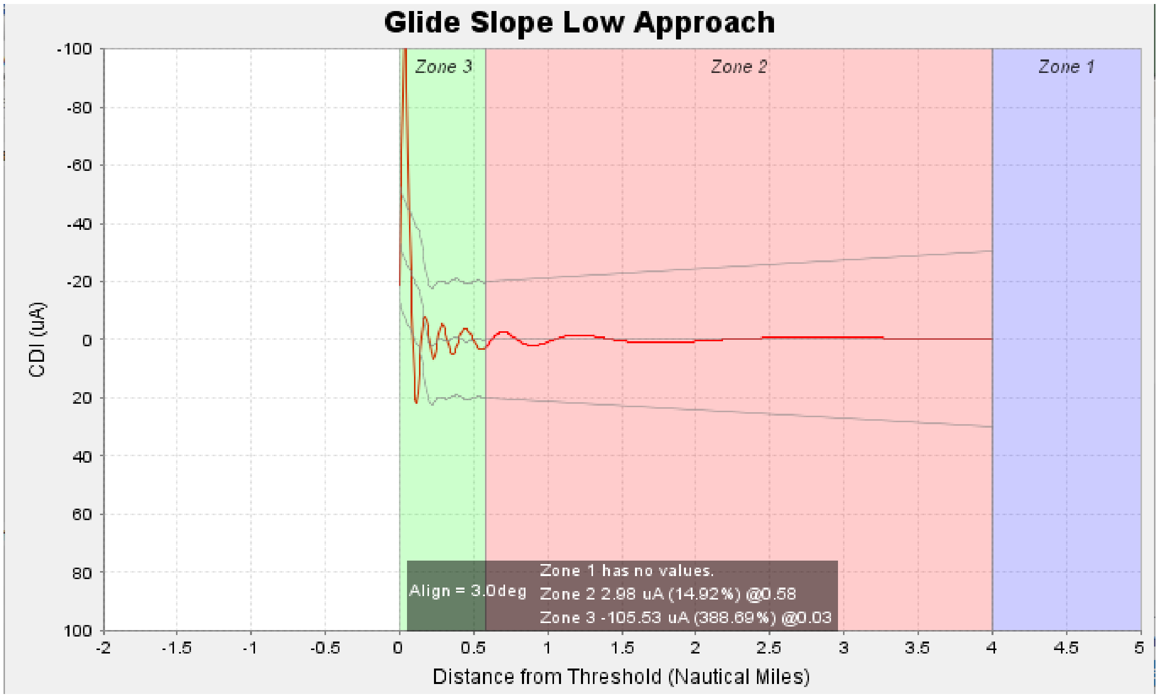
0.0000200 Stop

0.0000010 Inc

Figure 6: Ideal Glideslope Pattern

Glideslope Pattern Perturbed by Scatterer

A Boeing 777-200 was inserted into the scene, 500 feet in front of the glideslope, and 250 towards the runway. This introduced the structure deviation depicted in Figure 7. Figure 8 shows the perturbed signal; notice how much rougher the lower "planes" of the pattern are compared to Figure 6.



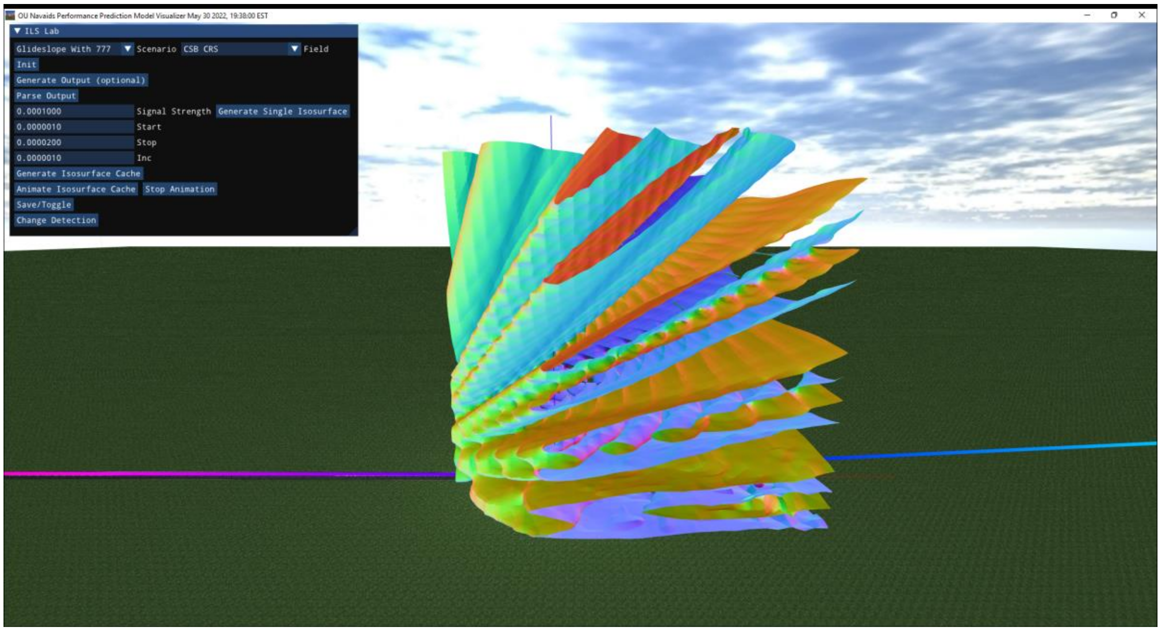
Align = 3.0deg

Zone 1 has no values.

Zone 2 2.98 uA (14.92%) @0.58

Zone 3 -105.53 uA (388.69%) @0.03

Figure 7: Structure Error in Glideslope Introduced by Scatterer

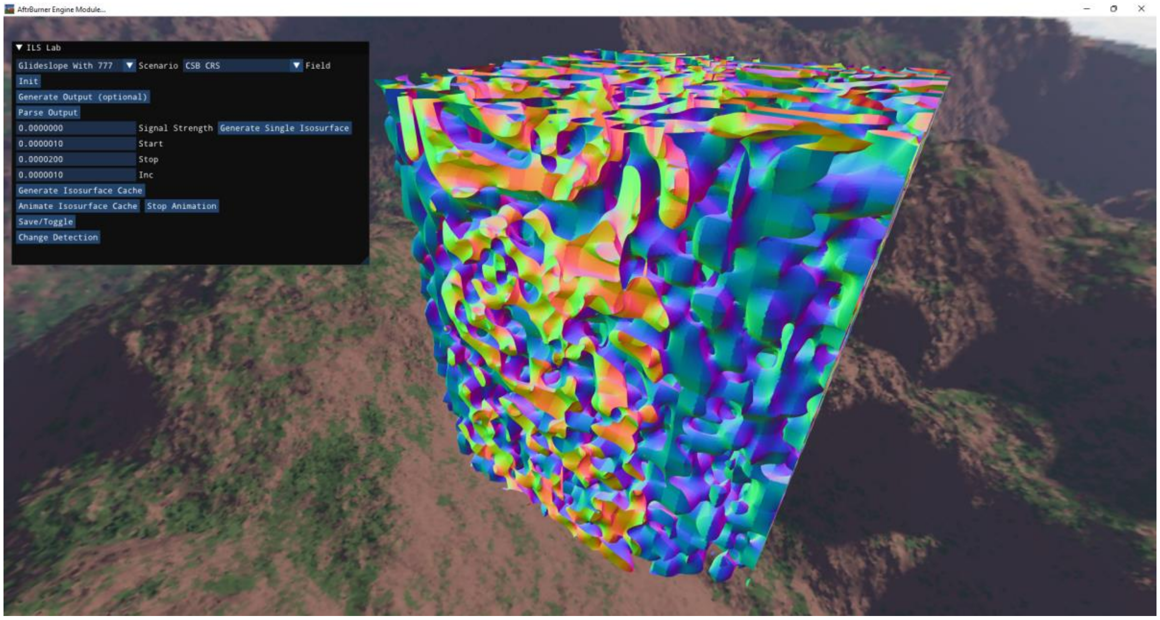


Glideslope With 777 ▼ Scenario CSB CRS ▼ Field
0.0001000 Signal Strength
0.0000010 Start
0.0000200 Stop
0.0000010 Inc

Figure 8: Perturbed Glideslope Pattern (Compare to Figure 6: Ideal Glideslope PatternFigure 6)

Change in Glideslope Pattern – Average

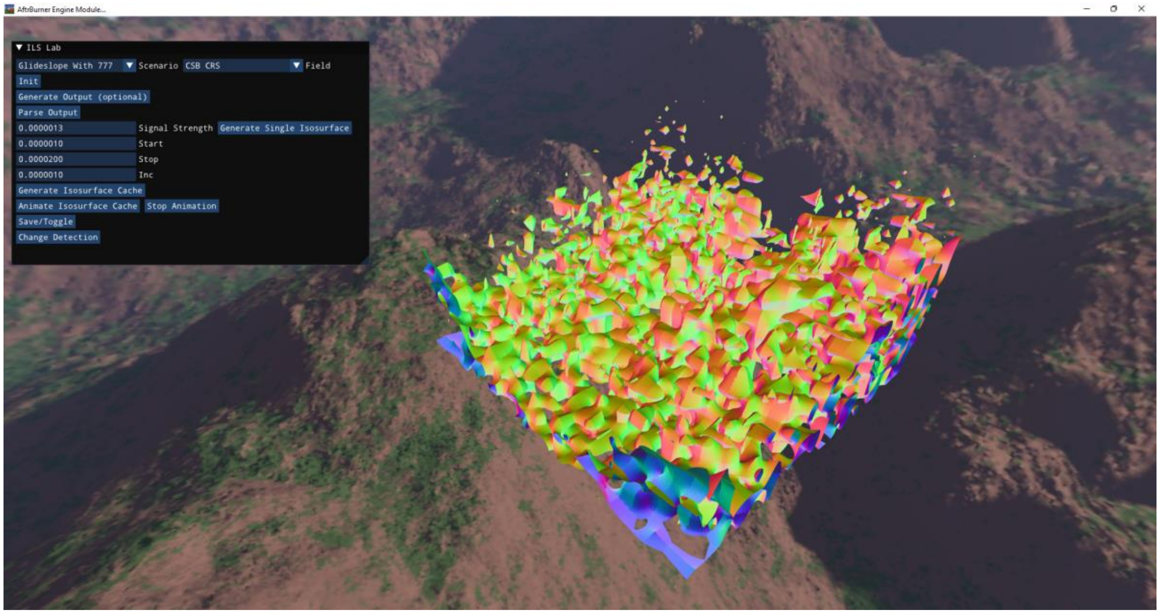
The idea behind the change detection is simple. The difference between a perturbed field and an ideal field, is also a field which can be sampled and visualized. The first change detection method we attempted was to find the iso-surface of the average value of the differences between the perturbed field and the ideal field. However, since the fields can either increase or decrease, the average difference was very near zero, which could be found in many regions of the field creating a visually interesting, but entirely unhelpful iso-surface.



Glideslope With 777 ▼ Scenario CSB CRS ▼ Field
0.0000000 Signal Strength
0.0000010 Start
0.0000200 Stop
0.0000010 Inc

Figure 9: Average Value Change Detection Iso-Surface

The next attempt was to take the absolute values of all of the differences in the fields, and again visualize the iso-surface of the average. This visualization was slightly more useful. As one would expect, regions near the ground were more active.



Glideslope With 777 Scenario CSB CRS Field

0.0000013 Signal Strength

0.0000010 Start

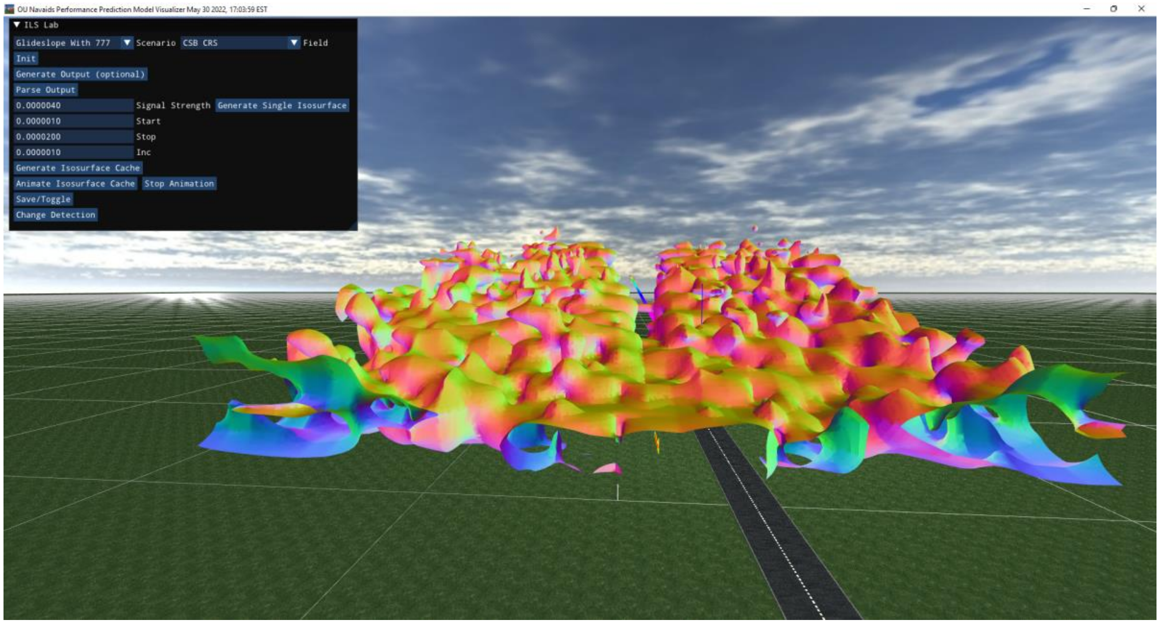
0.0000200 Stop

0.0000010 Inc

Figure 10: Average Value Change Detection Iso-Surface, using Absolute Values

Change in Glideslope Pattern – 90th Percentile

The next insight was that we do not necessarily care about the average or median case, we are about the extremes. Therefore, we sorted all of the values in the grid and found the 90th percentile value and visualized that iso-surface. Again, we get a surface near the ground, with much less noise.



Glideslope With 777 Scenario CSB CRS Field

0.0000040 Signal Strength

0.0000010 Start

0.0000200 Stop

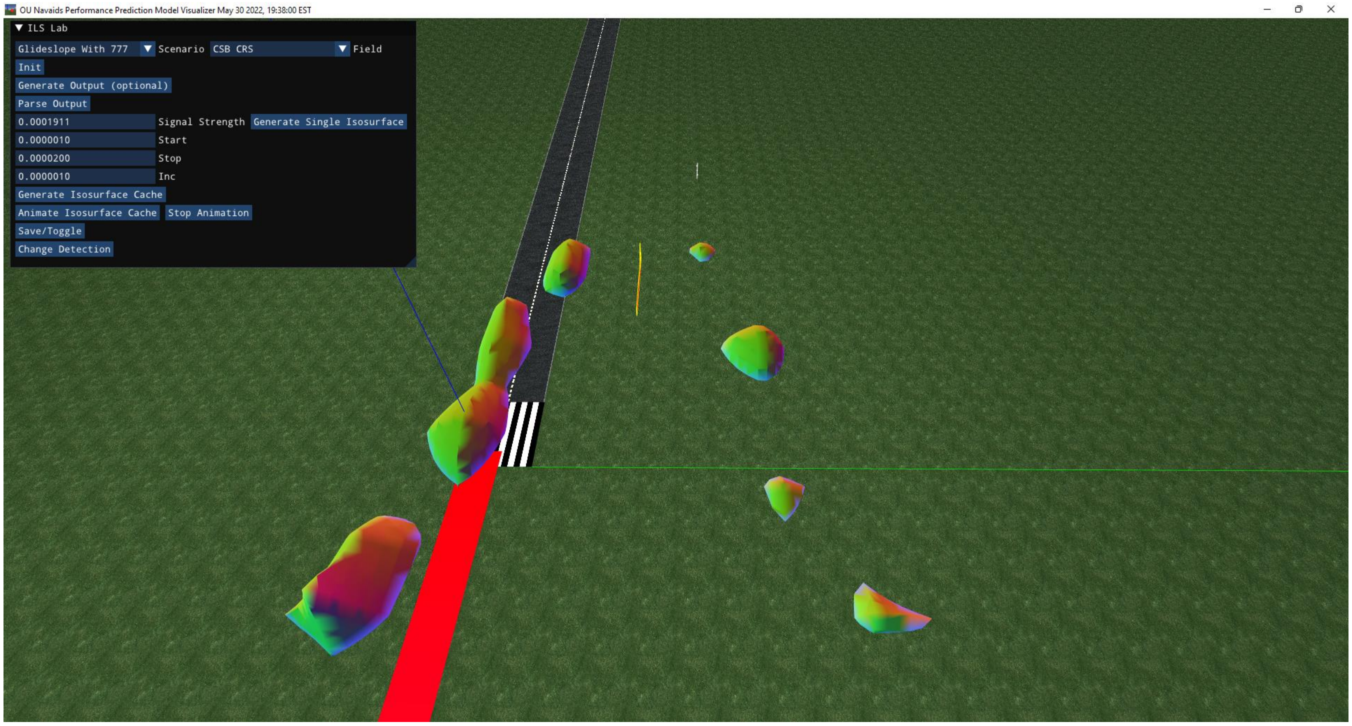
0.0000010 Inc

Figure 11: 90th Percentile Change Detectino Iso-Surface

Change in Glideslope Pattern – 90 Percent of Maximum

Our final attempt was the visualization of the 90% of maximum value iso-surface, instead of the 90th percentile value. This particular dataset included an abundance of zeros, so the 90th percentile value was significantly lower than the 90% of maximum value. Here you can see there is much less iso-surface, some of which, aligns very well with the inspection flight path.

As discussed in [1], our tool supports animations over a range of iso-surfaces. One useful strategy may be to find the 90% of maximum value iso-surface and animate over nearby values.



Glideslope With 777 Scenario
CSB CRS Field
0.0001911 Signal Strength
0.0000010 Start
0.0000200 Stop
0.0000010 Inc

Figure 12: 90% of Maximum Value Change Detection Iso-Surface

CONCLUSIONS

We have demonstrated that it is possible to visualization the antenna pattern, including multipath error, in a 3D visualization tool tightly coupled with the OUNPPM software. Our initial attempts at change detection in the patterns were successful, but utility is still unclear.

RECOMMENDATIONS

We are seeking input from others in the field about how these antenna patterns might be of use to the community at large.

FUTURE WORK

There are a few obvious next steps for this new feature.

Firstly, in addition to the ILS systems, OUNPPM can model VOR systems, and therefore a similar approach should be able to be applied to their fields and multipath.

Secondly, we can return from the wide area visualization back to the inspection flight paths. Change in signal on the flightpath is the relevant portion of the signal, so visualizations strictly in that area may be more useful.

Thirdly, derived values like the CDI should also be able to be calculated, and iso-surfaces of, for instance, some percentage of tolerance could be visualized.

Fourthly, the process is not fully automated yet, but new scenarios can be executed fairly quickly. We hope to have full automation complete and integrated into a future publicly released version of OUNPPM soon.

Fifthly, the process can be further optimized. We use a naïve implementation of marching cubes. A more modern approach like Flying Edge [5] could be integrated, or a GPU accelerated option may be possible. Similarly, we are using a fixed size voxel grid at the moment; some sort of iteratively deepening implementation could be used to render something quickly and refine.

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