Design and Performance Evaluation on Ultra-Wideband Time-Of-Arrival 3D Tracking System

Jianjun (David) Ni, Dickey Arndt, Phong Ngo, John Dusl

Abstract

A three-dimensional (3D) Ultra-Wideband (UWB) Time--of-Arrival (TOA) tracking system has been studied at NASA Johnson Space Center (JSC) to provide the tracking capability inside the International Space Station (ISS) modules for various applications. One of applications is to locate and report the location where crew experienced possible high level of carbon-dioxide and felt upset. In order to accurately locate those places in a multipath intensive environment like ISS modules, it requires a robust real-time location system (RTLS) which can provide the required accuracy and update rate. A 3D UWB TOA tracking system with two-way ranging has been proposed and studied. The designed system will be tested in the Wireless Habitat Testbed which simulates the ISS module environment. In this presentation, we discuss the 3D TOA tracking algorithm and the performance evaluation based on different tracking baseline configurations. The simulation results show that two configurations of the tracking baseline are feasible. With 100 picoseconds standard deviation (STD) of TOA estimates, the average tracking error 0.2392 feet (about 7 centimeters) can be achieved for configuration "Twisted Rectangle" while the average tracking error 0.9183 feet (about 28 centimeters) can be achieved for configuration "Slightly-Twisted Top Rectangle". The tracking accuracy can be further improved with the improvement of the STD of TOA estimates. With 10 picoseconds STD of TOA estimates, the average tracking error 0.0239 feet (less than 1 centimeter) can be achieved for configuration "Twisted Rectangle".

References

[1]. R. Barton, et al; "Performance Capabilities of Long-Range UWB-IR TDOA Localization Systems", EURASIP Journal on Advances in Signal Processing, Volume 2008, Article ID 236791, 17 pages.
[2]. "Data Sheet of PulsON 400 RCM", Time Domain Corporation, March 2011.
[3]. J. Ni; "Performance Evaluation on the Least Square Solution to the Ultra-Wideband Time-Of-Arrival Tracking", 2011.

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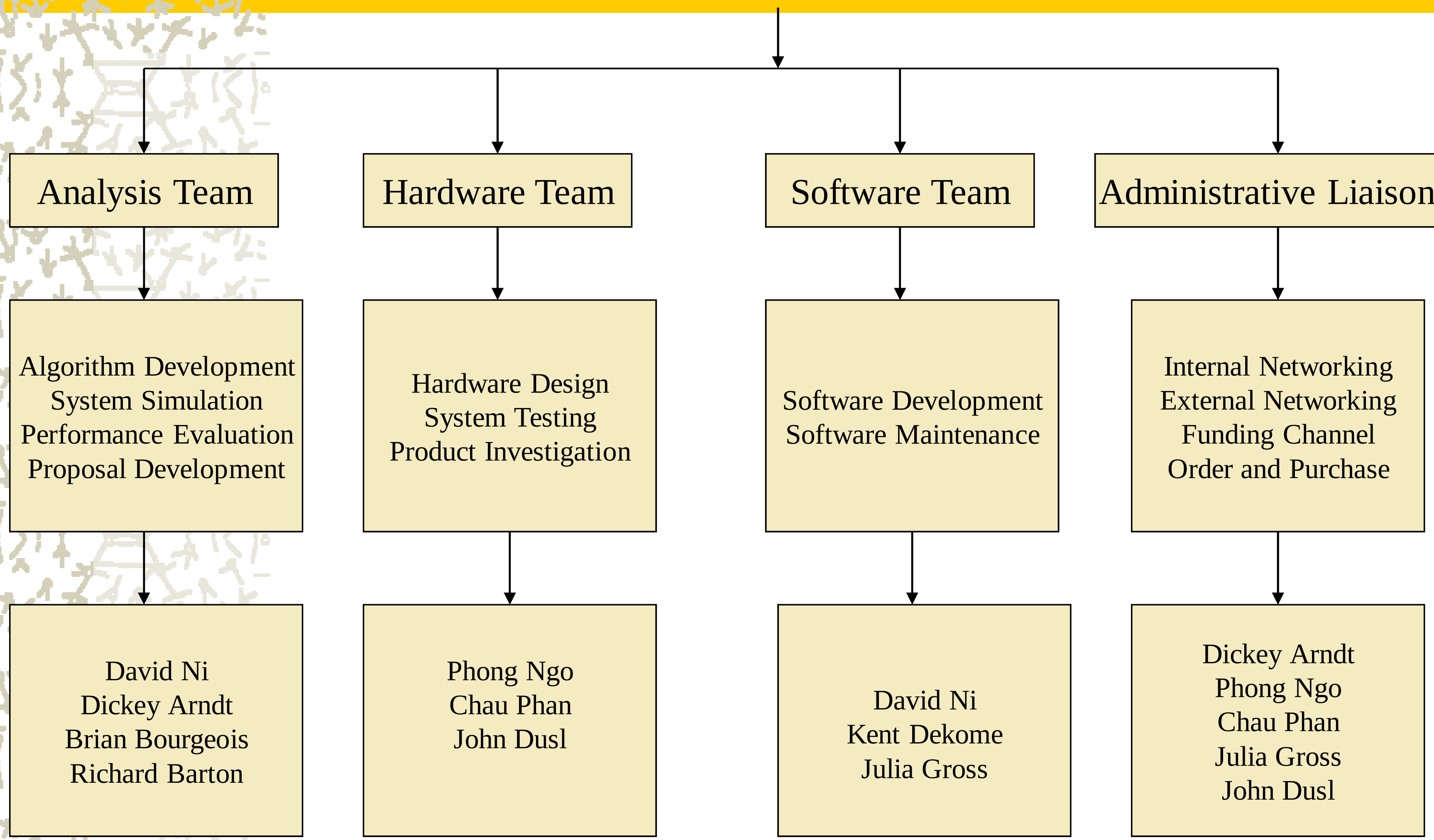
JSC Today - Quote of the Day

- “ No one can whistle a symphony. It takes a whole orchestra to play it.”

  -- H.E. Luccock

UWB Systems Group
(A Functional Team Architecture)

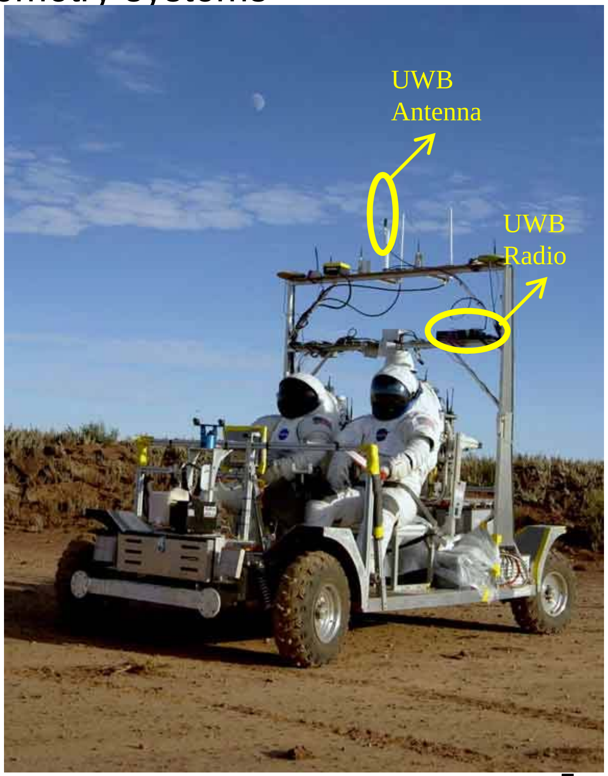


Outline

- UWB Technology Development at JSC
- Motivation of Work
- UWB Fine Time Resolution
- TOA Tracking Methodology and Algorithm
- TOA Simulation Results
- Summary
- Future Work

UWB AOA Long Range Tracking

- UWB AOA long range tracking with the SCOUT vehicle at the Meteor Crater, Arizona in 2005 and 2006
- Excellent tracking performance with less than 1% error at ranges up to 4000 ft
- No RF interference with on-board GPS, video, audio, and telemetry systems



UWB TDOA High Resolution Tracking for 2D Docking Mechanism

- Use Time Difference of Arrival (TDOA) technique to provide sub-inch tracking resolution
- Two tracking points on target to accurately guide the target into its docking station

UWB TDOA 3D High Resolution Tracking for Robotic Control

- UWB TDOA 3D tracking at Honeywell's Moonyard Facility
- Real-time trajectory can be displayed and recorded
- Tracking accuracy within1 inch in the xy plane and within 2 inches in the z direction
- Tracking data are passed to the robotic control system

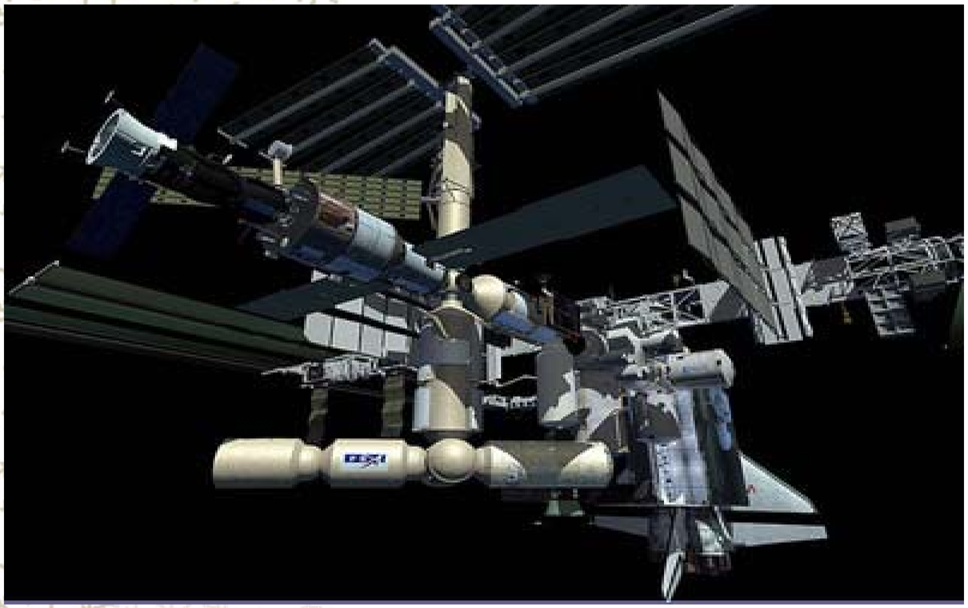
UWB Relative Navigation – Vehicle Following

- The UWB TDOA tracking system at the following vehicle can track the leading vehicle in a real time with a update rate of 1 hertz (Hz) by running the experimental code.
- It is anticipated that the update rate can be improved greater than 5 Hz with immigrants to the application code.

Following Vehicle

Leading Vehicle

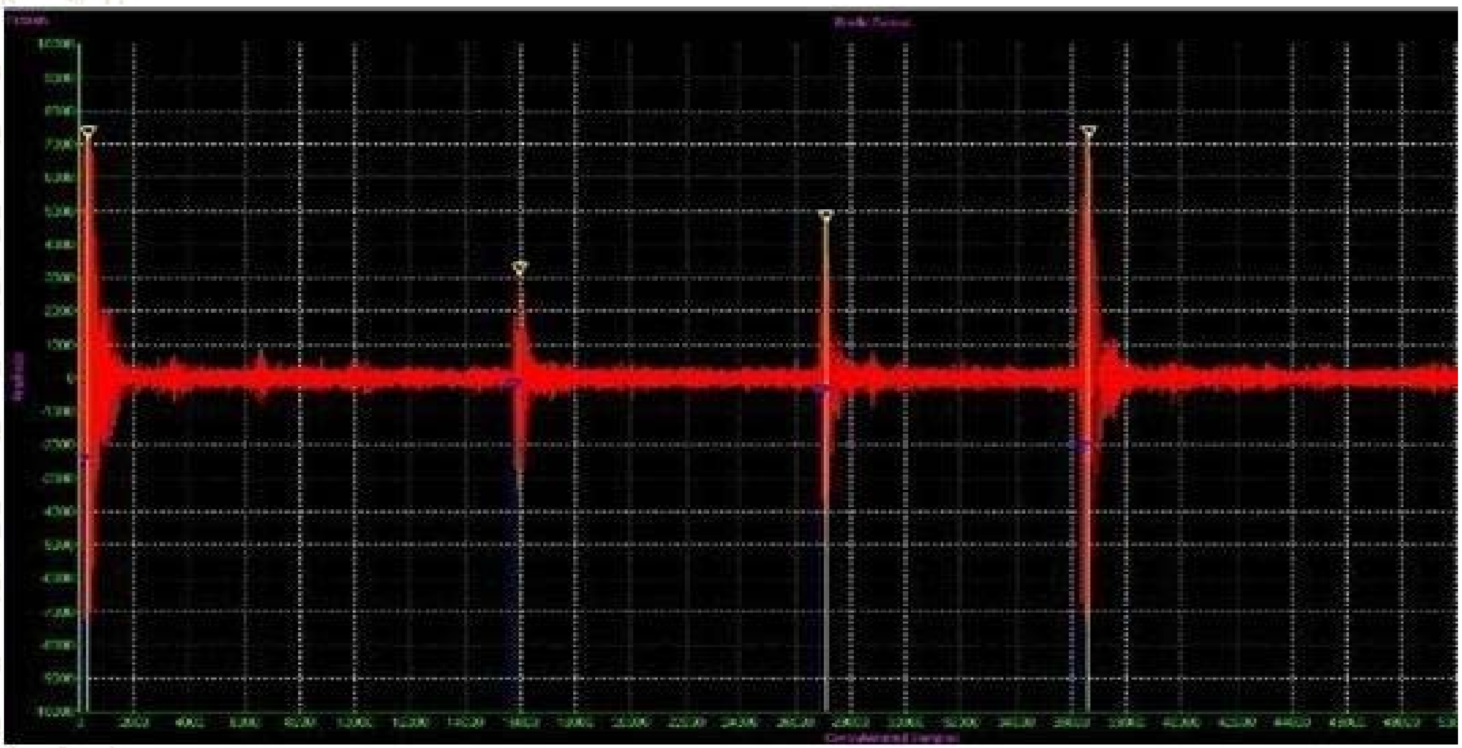
Motivation of Work



- The system is being designed to provide the tracking capability inside the International Space Station (ISS) modules for various applications. One of applications is to locate and report the location where crew experienced possible high level of carbon-dioxide and felt upset.
- In order to accurately locate those places in a multipath intensive environment like ISS modules, it requires a robust real-time location system (RTLS) which can provide the required accuracy and update rate. The designed system will be tested in the Wireless Habitat Testbed (WHT) which simulates the ISS module environment.

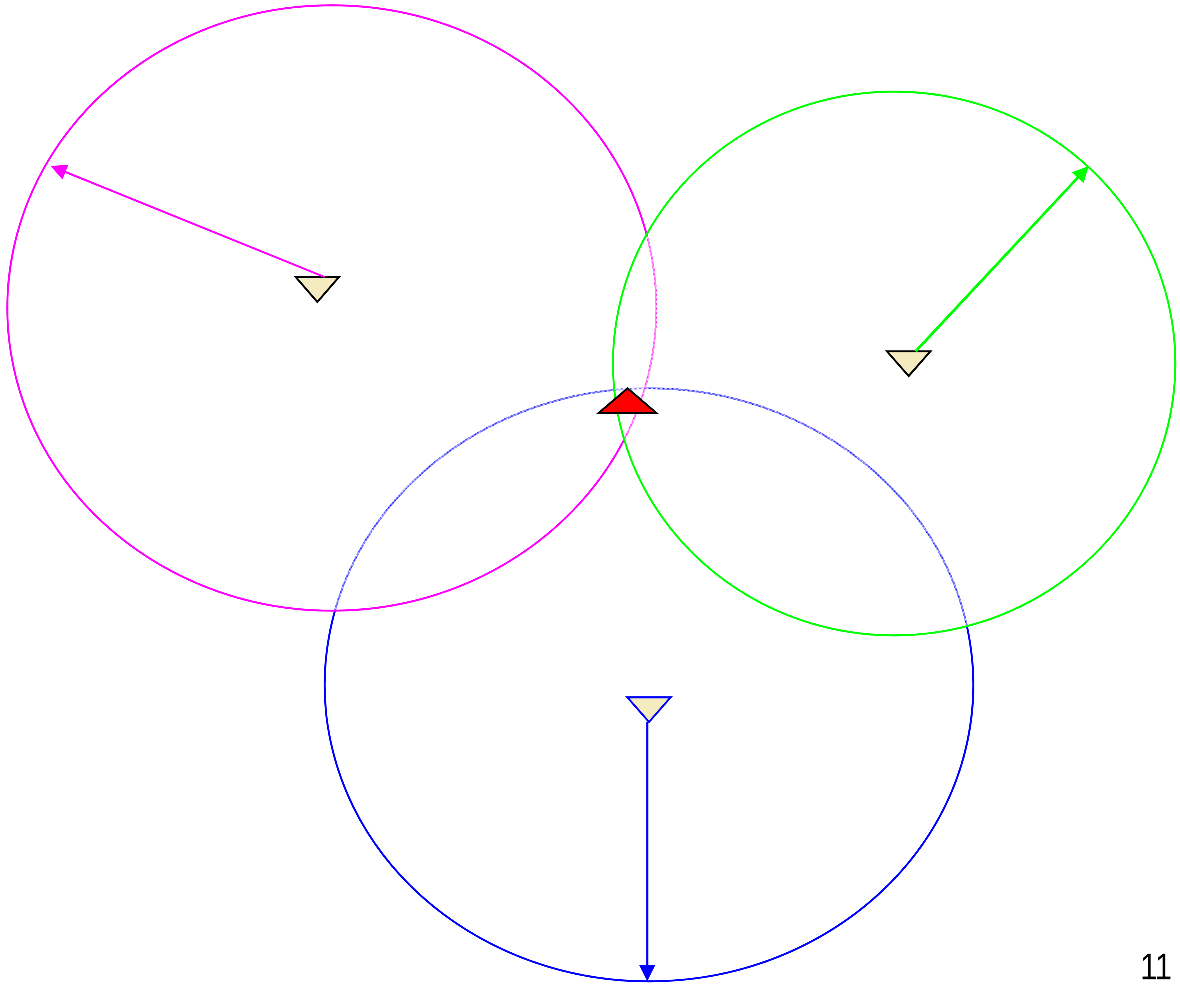
Why UWB?

- Immunity to interference from narrow band RF systems due to ultra-wide bandwidth
- Low impact on other RF systems due to extremely low power spectral densities
- Capable of precise tracking due to sub-nanosecond time resolution
- Robust performance in multipath environments



Time of Arrival (TOA)

(2D Illustration)



Linear TOA Equations (3D)

$$\mathbf{Gp} = \mathbf{h}$$

$$\mathbf{G} = \begin{bmatrix} x_2 - x_1 & y_2 - y_1 & z_2 - z_1 \\ x_3 - x_1 & y_3 - y_1 & z_3 - z_1 \\ x_4 - x_1 & y_4 - y_1 & z_4 - z_1 \end{bmatrix}, \ \mathrm{p} = \begin{bmatrix} x \\ y \\ z \end{bmatrix},$$

$$\mathrm{h} = \frac{1}{2}\begin{bmatrix} {x_2}^2 + {y_2}^2 + z_2^2 - c^2 t_2^2 - ({x_1}^2 + {y_1}^2 + z_1^2 - c^2 t_1^2) \\ {x_3}^2 + {y_3}^2 + z_3^2 - c^2 t_3^2 - ({x_1}^2 + {y_1}^2 + z_1^2 - c^2 t_1^2) \\ {x_4}^2 + {y_4}^2 + z_4^2 - c^2 t_4^2 - ({x_1}^2 + {y_1}^2 + z_1^2 - c^2 t_1^2) \end{bmatrix}.$$

Least Square Solution to TOA Equations

- In the presence of TOA measurement errors, the target radio location can be estimated using the standard least square solution

$$\hat{\mathbf{p}} = \arg\min(\mathbf{G}\hat{\mathbf{p}} - \mathbf{h})^T(\mathbf{G}\hat{\mathbf{p}} - \mathbf{h})$$
$$= (\mathbf{G}^T\mathbf{G})^{-1}\mathbf{G}^T\mathbf{h}.$$

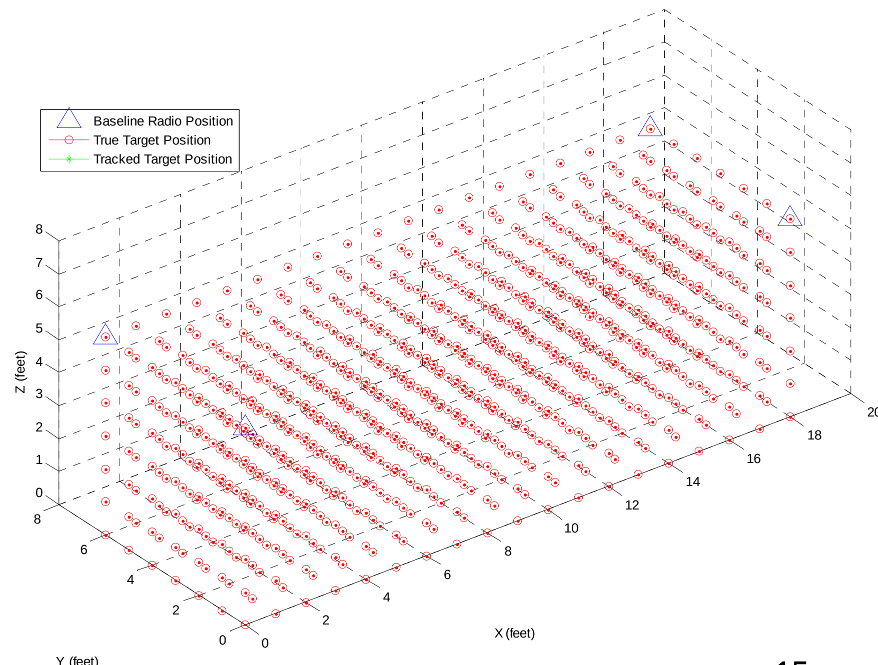
Tracking Hardware

- P400 RCM (Ranging and Communication Module) from Time Domain Corporation
  - RF transmissions from 3.1GHz to 5.3 GHz, with center at 4.3 GHz
  - RF emissions compliant with FCC limits
  - Each unit is a full transceiver
  - High precision ranging with industry-leading update rate
  - Typical range accuracy LOS: 3.5 cm
  - Range Update Rate: 40 Hz to 3.5 Hz
  - Max Distance (FCC Part 15 0dB Antennas, Free space): 88m, 125m, 177m, 250m, 354m (standard)

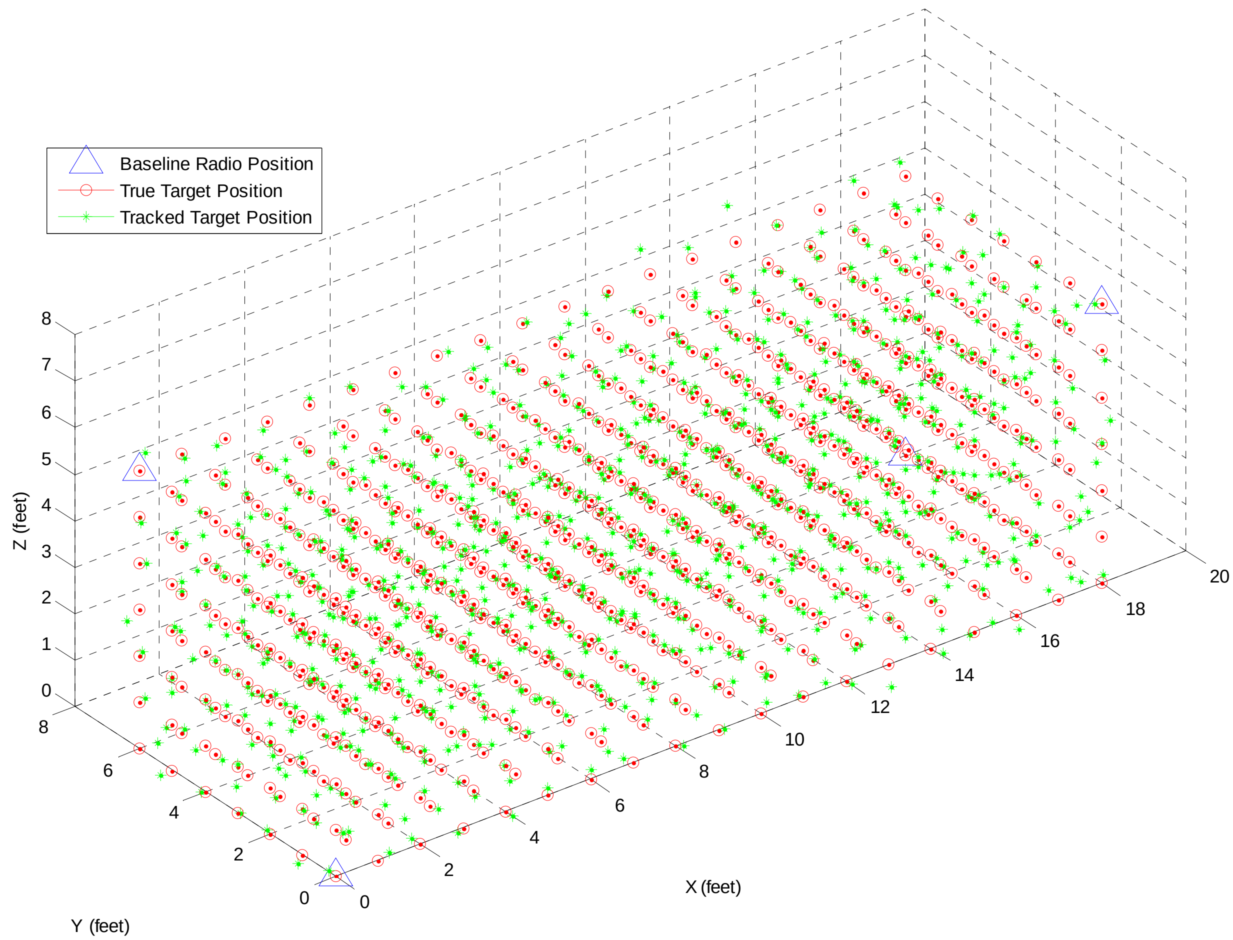
- Currently UWB System Group owns two units

Simulation Set-Up

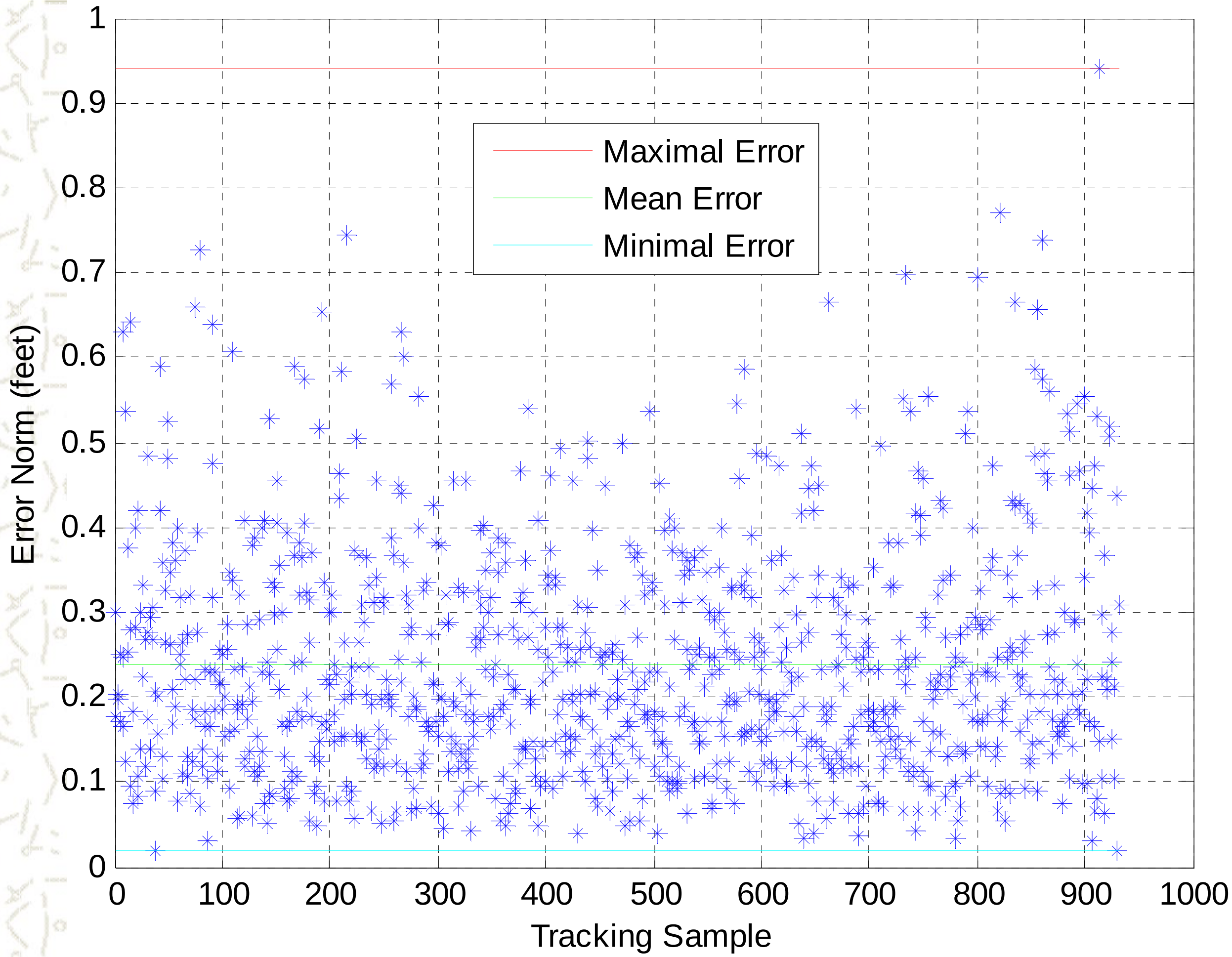
- Within WHT, an rectangular cuboid with dimension 18 feet (L) x 6 feet (D) x 6 feet (H) is defined as the available tracking space where about 931 test points are set one foot apart. The standard deviation (STD) of TOA estimates 100 picoseconds is used in these simulations.



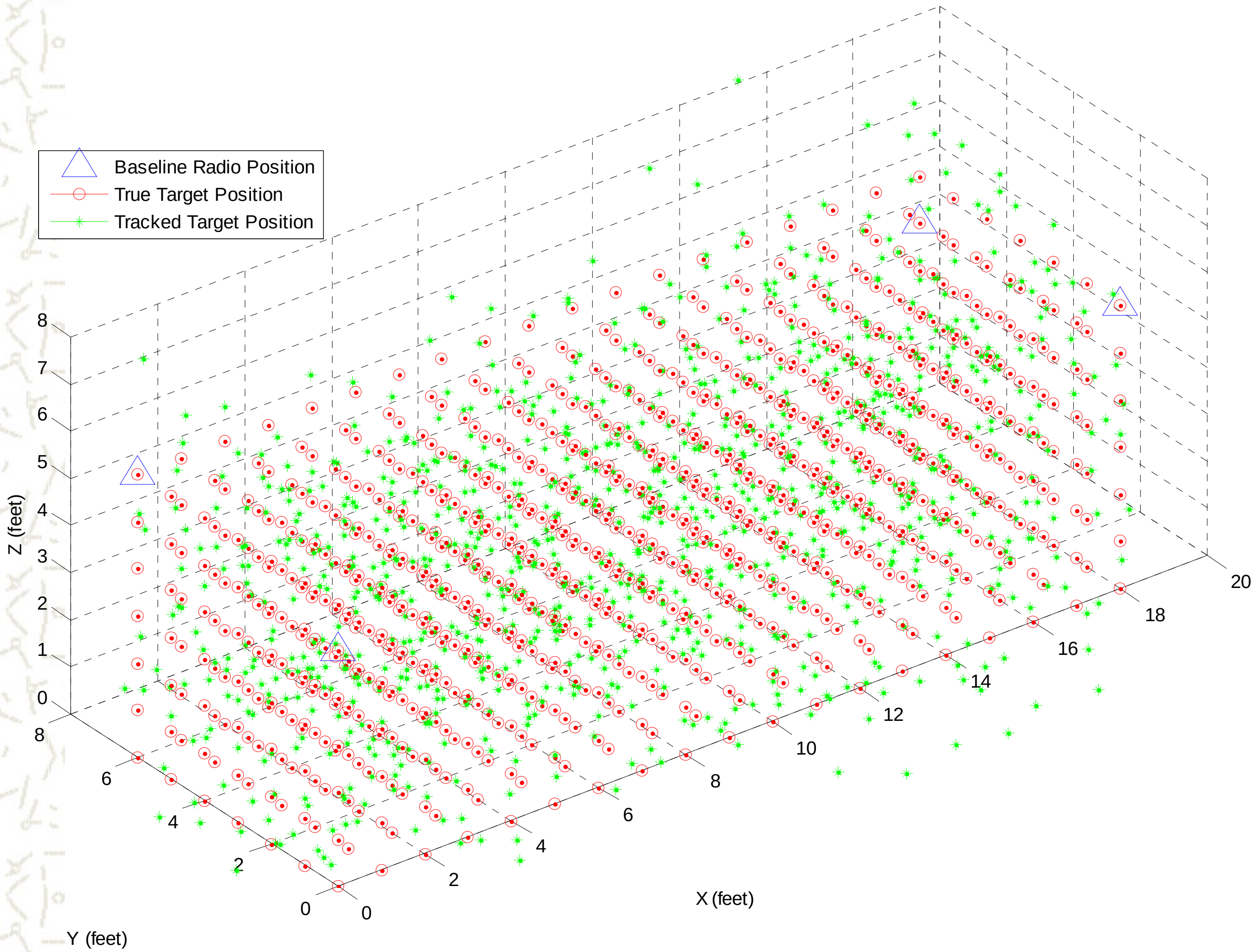
Simulation Results for Configuration "Twisted Rectangle"



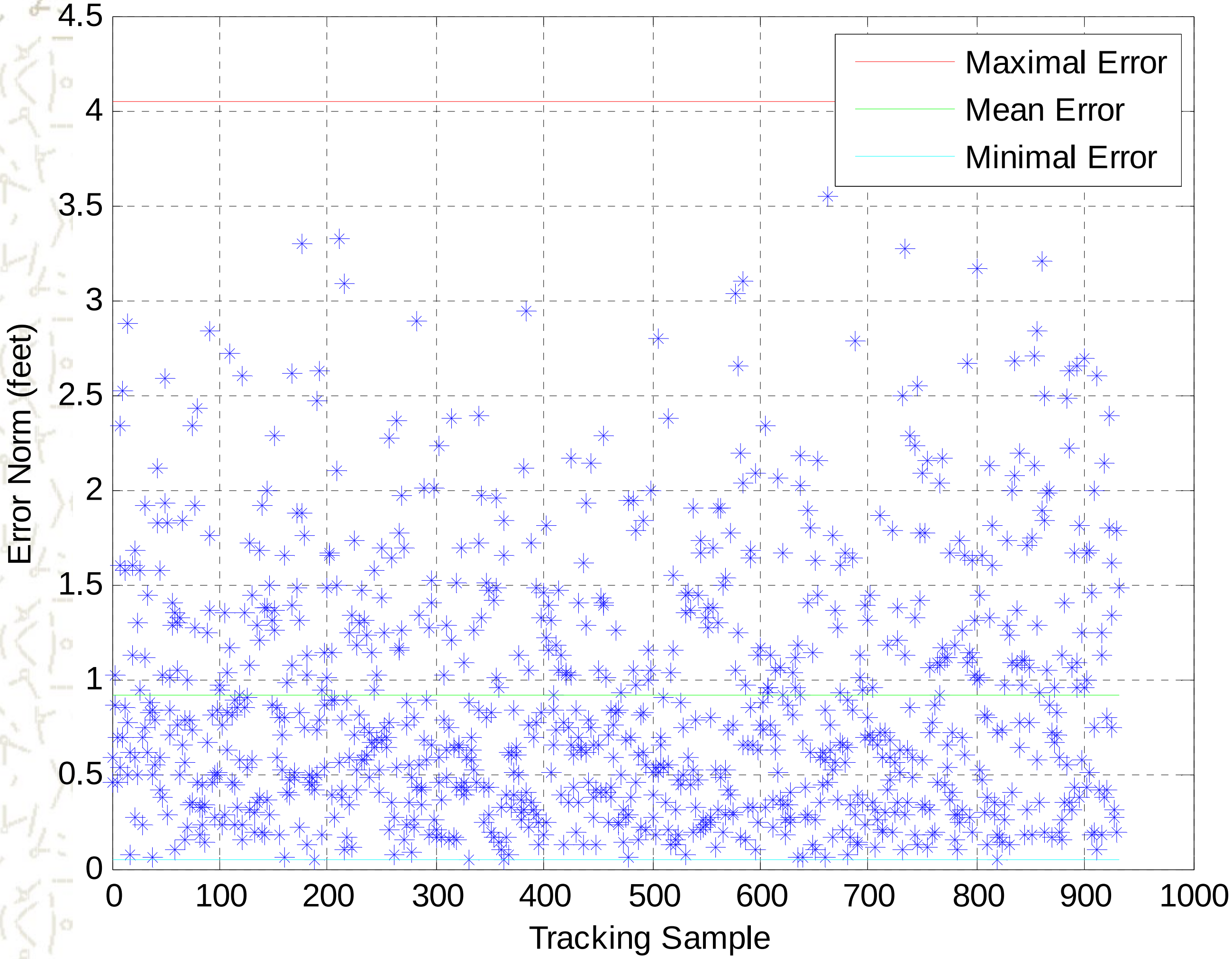
Tracking Error Analysis for “Twisted Rectangle” (average error = 0.2392 feet, STD = 0.1373 feet)



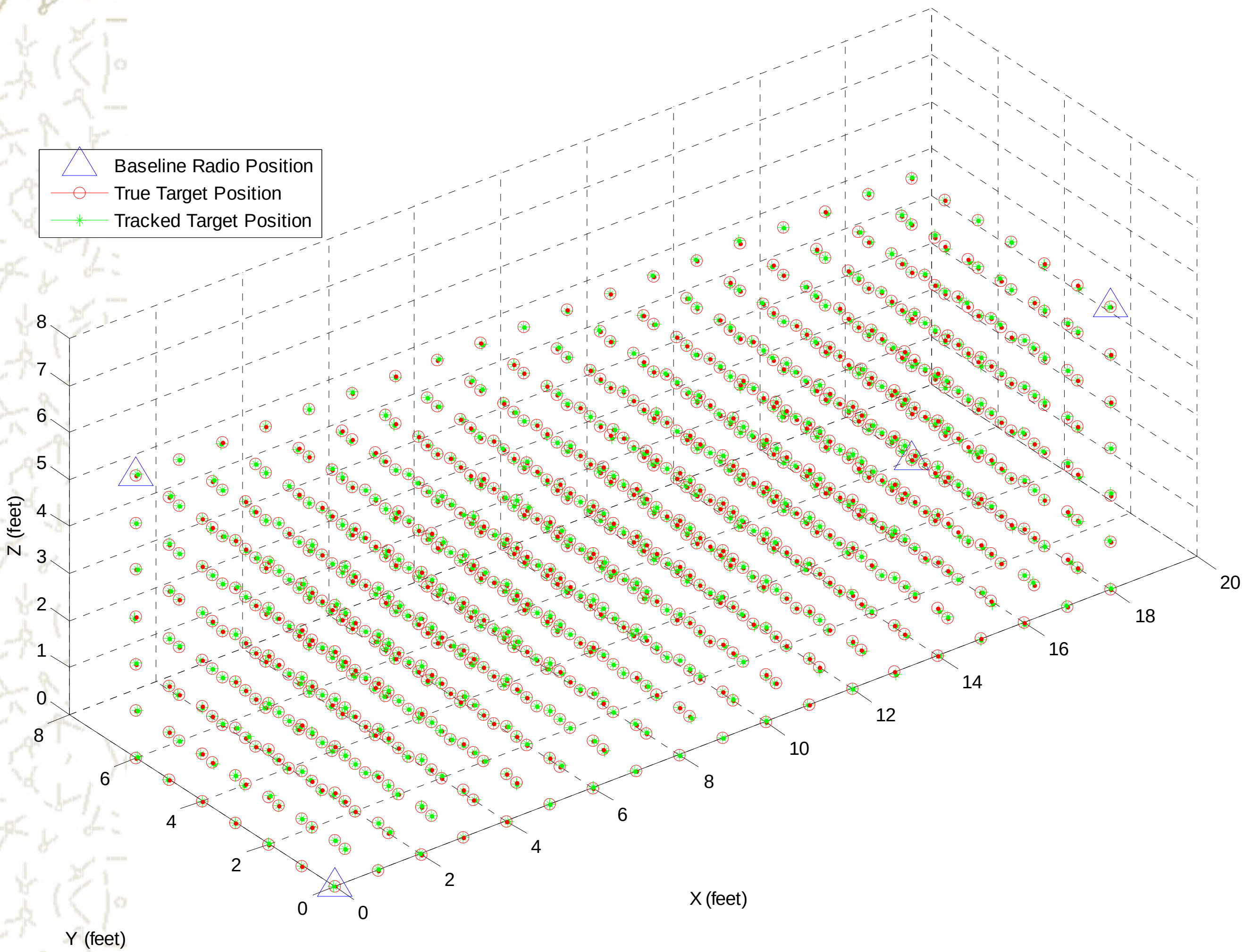
Simulation Results for Configuration "Slightly-Twisted Top Rectangle"



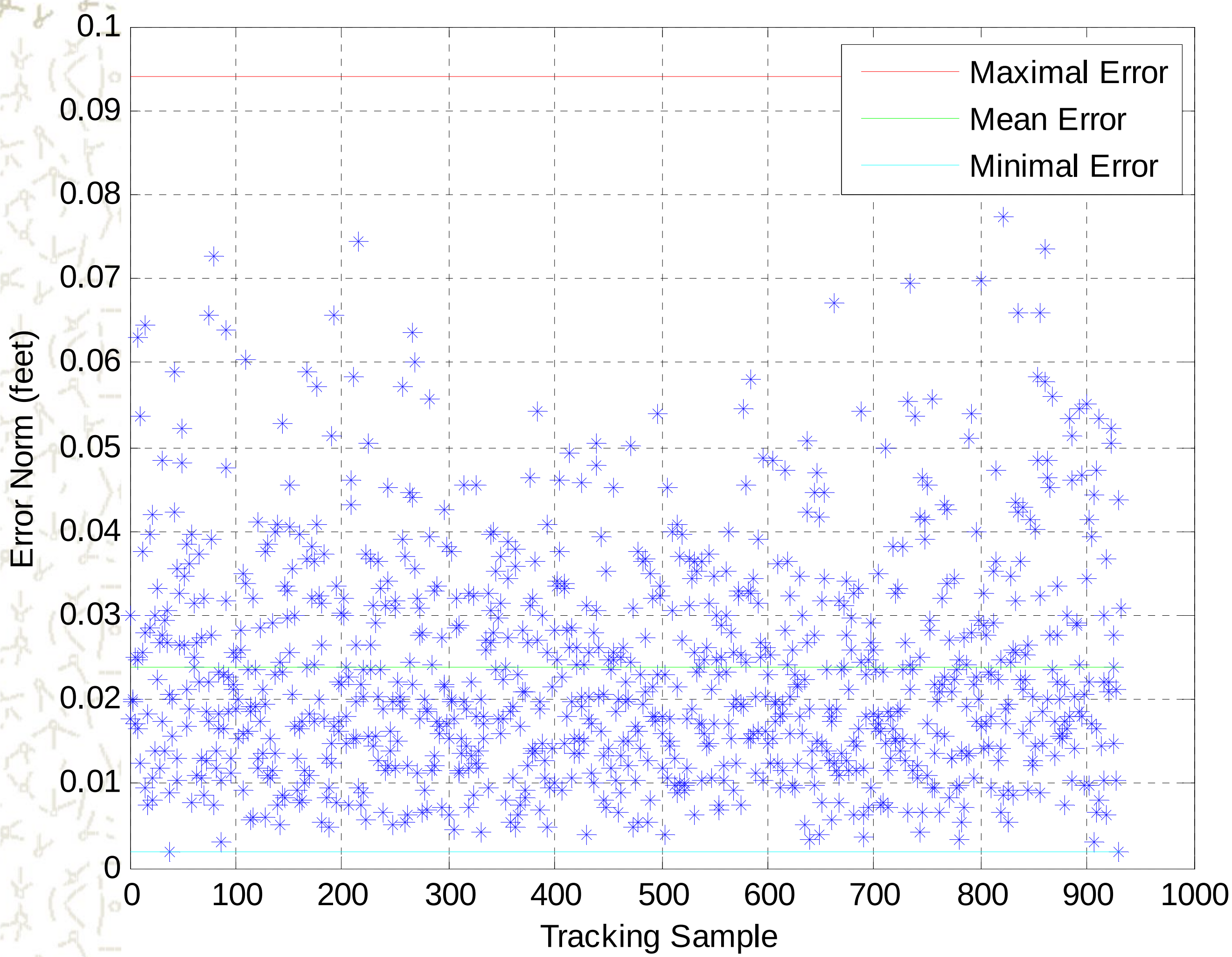
Tracking Error Analysis for “Slightly-Twisted Top Rectangle” (average error = 0.9183 feet, STD = 0.6927 feet)



Simulation Results for Configuration “Twisted Rectangle” with 10 ps TOA_STD



Tracking Error Analysis for "Twisted Rectangle" with 10 ps TOA_STD (average error = 0.0239 feet, STD = 0.0137 feet)



Summary and Future Work

- A tracking performance evaluation has been conducted for the UWB TOA 3D Tracking System in the Wireless Habitat Testbed through simulation. The results show that two configurations of the tracking baseline are feasible to achieve the fine tracking accuracy.
- Future work includes acquiring three more P400 RCM units to conduct 3D tracking tests with chosen baseline configuration and develop signal processing techniques to refine the TOA estimates so that the tracking accuracy can be further improved.