Comparison: Consumer and Scientific Grade Motion Tracking Systems

A Comparison of HTC Vive Pro and WorldViz PPT-N motion tracking
for Virtual Reality applications

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Consumer virtual reality systems have become readily available at low prices in recent years, leading more and more scientific researchers to conduct experimental studies with such consumer systems. Technological advances along the parameters of visual resolution and field-of-view, sensor integration, component miniaturization, weight and wearing comfort have been enormous.

Since many scientific studies involving virtual reality aim at investigating human motion based on visual stimuli, it is obvious that accurate and consistent recording of 3D motion data is critical for relevant research study outcomes. This white paper aims at providing scientific researchers with information on how the choice of a consumer VR motion tracking system versus a scientific grade motion tracking solution could impact their research data collection and study outcomes.

To shed light on how these systems perform against each other, this white paper presents a side-by-side investigation of the performance of a consumer motion tracking system against the performance of a standalone scientific grade motion tracking system. For the purpose of simplicity, only one representative system of each, the consumer and the professional motion tracking system group, was chosen: namely the HTC Vive Pro integrated consumer motion tracking system and the WorldViz PPT-N standalone professional motion tracking solution.

Methodology and Results

The HTC VIVE Pro system was tested with a setup of 4 Lighthouse Sensors in a 5m by 5m space, for a ‘static’ use case, i.e. each measurement was taken while the HMD was held static.

The PPT-N system was matched in size with a 4 sensor setup and the same measurements were taken for comparison.

Experiment Preparation - Measurement Setup

This section describes in detail how the area for measurement was set up to ensure comparable measurements throughout. A focus was put on the ability to repeat any measurement at the exact same location, height, and head pitch. All measurements presented in this white paper were taken with the below setup.

1. Using laser lines and high accuracy laser measure tools the corners of a 5 x 5 meter square were taped to the floor. In the center of the square a 4 x 4 meter grid of measurement points every 1m was added. In addition to the measurement points two parallel lines were added to be able to place a tripod accurately over the measurement points (see 2). See figure 1 for reference of the grid setup.

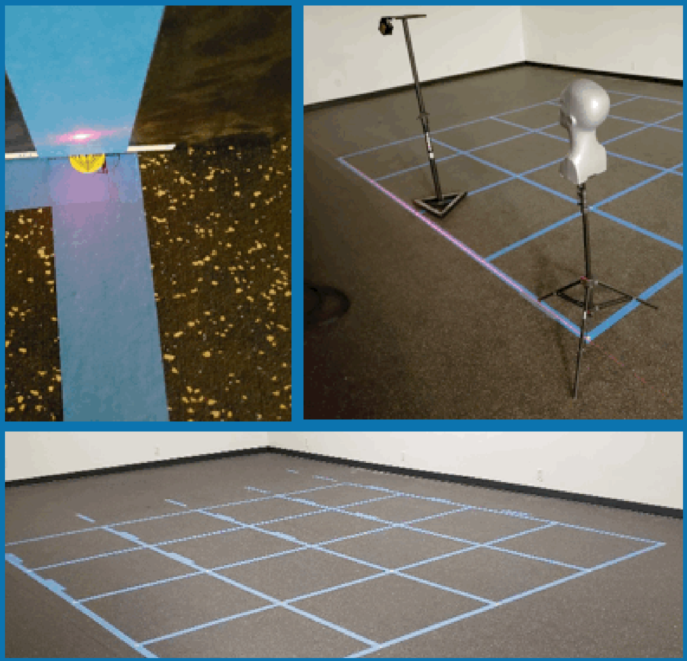


Figure 1

2. The legs of a tri-pod were clamped down so that the feed could neither be spread nor compressed. A string with a plumb was attached to the bottom of the center pipe of the tripod so that the tripod could be placed accurately over the measurement points. See figure 2 for reference

Figure 2

Experiment Preparation - Measurement Setup

3. A Vive pro headset was securely attached to a mannequin head that was screwed onto the top of the tripod. See figure 3 for reference.

Figure 3

4. Four additional tripods were placed into the four corner marks of the 5 x 5 meter square. Using ultra clamps 4 Vive Base Stations 2.0 were attached to the tripods at about 2.25 m. Four PPT-N sensors were added to the top of each tripod. Both the base stations and the PPT-N sensors were angled so that the headset could be tracked both at a height of about 1.8 m and 1.2 m height. See figure 4 for reference.

Figure 4

Experiment Preparation - Measurement Setup

5. The Vive Pro headset was placed in the center of the 5m x 5m tracking area. With the controllers 1m left and right of the headset, the room setup within the HTC Vive software was performed. This method was chosen since some online comments suggest that the distance between controllers and headset during calibration may have an impact on the virtual ground plane of the HTC Vive which, since it was not in the scope of this experiment, was not investigated further.

6. The x, y, z, yaw, pitch, roll data of the headset were recorded for each measurement point along the grid by moving the tripod from one location to the next, first at 1.8 m height and then again at 1.2 m height

7. The PPT sensors were calibrated by placing the calibration rig in the center of the tracking area.

8. With the PPT-Eyes tracker mounted on top of the HTC Vive Pro headset the PPT tracking data for each location and at both heights were recorded in the same was as described in point 6.

Results - Measurement Outcome

This section outlines the results of the measurements taken as described in the previous section. The coordinate system used for plotting the data assumes a Y = up orientation, i.e. from an HMD user perspective +X is to the right, +Z points forward.
Blue = Vive data Orange = PPT data

Magnitude of Error

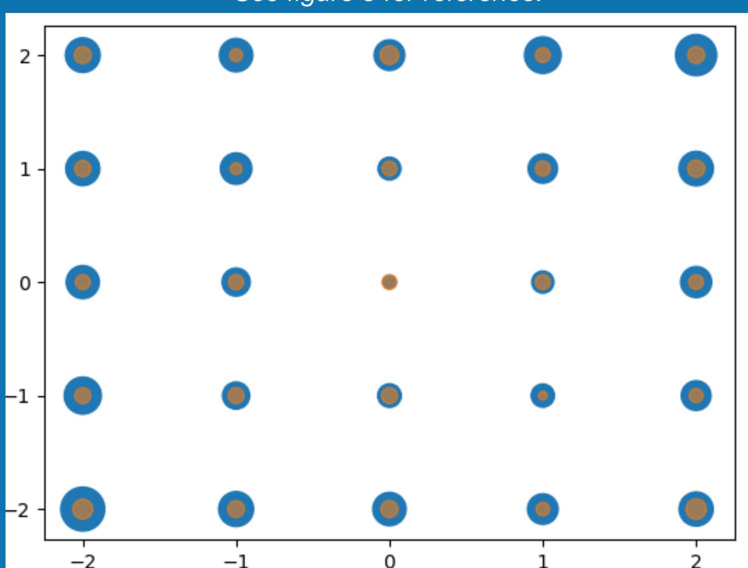
The first two plots show the total magnitude of the error at each of the 25 locations as size of the of the bubbles.

At waist height (Y = 1.2 m):

The absolute error for the HTC Vive Pro increases with the distance of the measurement points from the origin with a maximum error vector length of 51.1 mm with a median length of 25.99 mm.

For the PPT-N measurements the maximum error vector length was 11.1 mm with a mean length of 5.98 mm.

See figure 5 for reference.

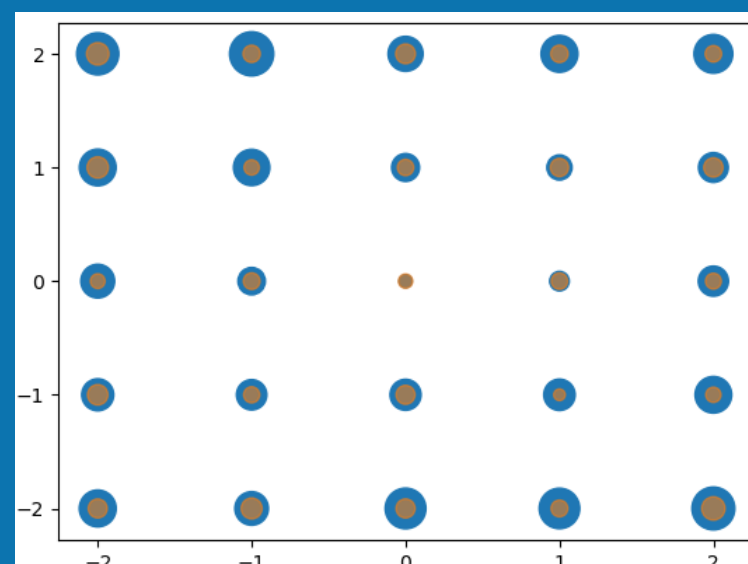


At head height (Y = 1.8 m):

The same observation as described above was made with a maximum error vector length of 51.1 mm and a median of 29.9 mm for the HTC Vive Pro.

For PPT-N the max was 14 mm and the median 7.8 mm.

See figure 6 for reference.



**It should be noted that the increase of the error with increasing distance from the origin is higher for the HTC Vive Pro tracking which can be seen in the following plots.*

Direction of Error

The following set of plots is showing the same data from different angles, plotting the direction of error between measured points from the physical location at waist height (Y = 1.2 m).

In the side view one can see how the X-Z-plane of the HTC Vive Pro measurements is slanted (error in Y direction). This results in a total height (Y) difference of 60 mm between opposite corners of the tracking area. See figure 7 for reference.

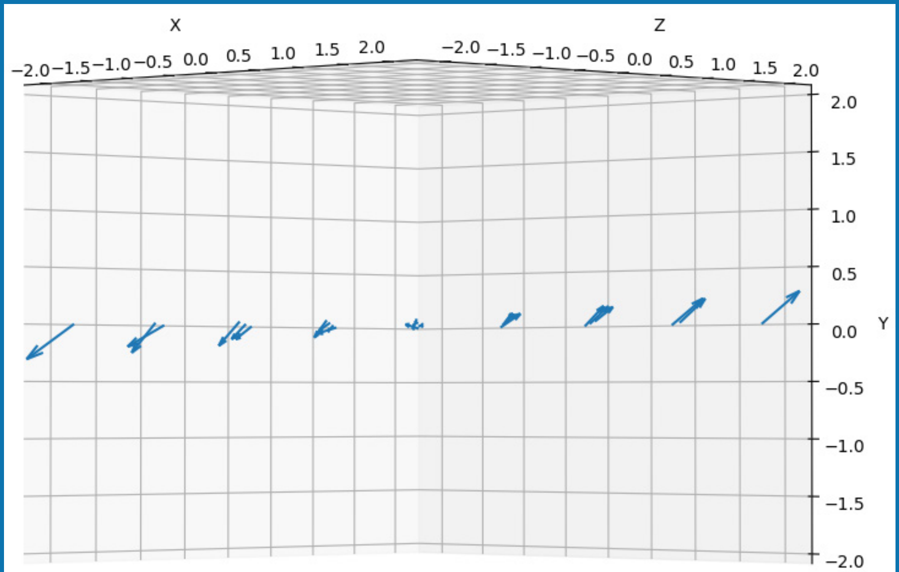


Figure 7

No such correlation between the Y error of the different measurement points was present in the PPT data. See figure 8 for reference.

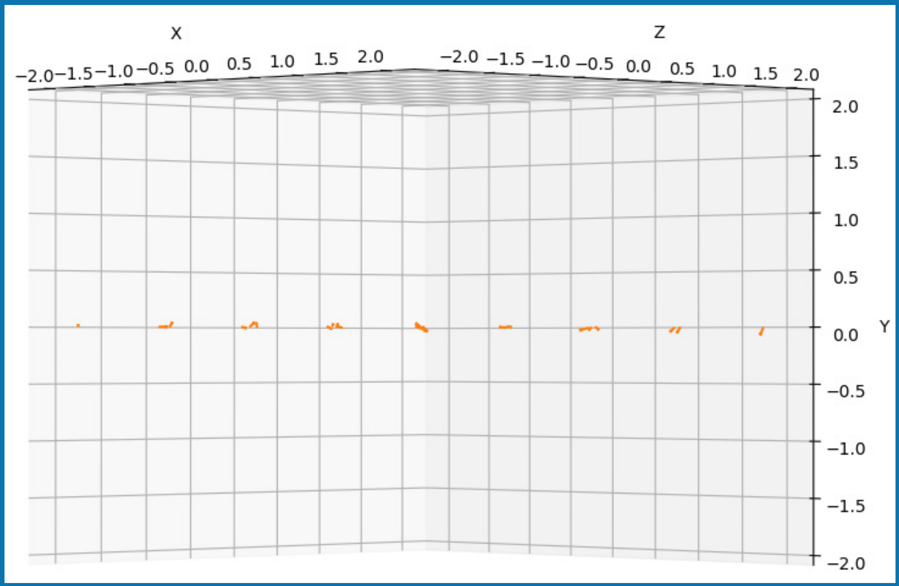


Figure 8

Looking at the error in X and Z direction, the largest errors are again at the measurement points furthest from the origin.

In the quadrant Q1 (decreasing X, increasing Z) the error seems to increase with the distance from the origin in the direction of positive X and negative Z. In the opposite quadrant Q4 (increasing X, decreasing Z) the error seems to increase in the opposite direction (negative X and positive Z) with the distance from the origin. In Q2 (increasing X, increasing Z) the magnitude of the error increases in positive X and positive Z direction while in Q3 it again increases in the opposite direction (negative X and negative Z). In simple terms, the error vectors in Q1 and Q4 point towards the origin and in Q2 and Q3 away from it.

This results in a total error difference between opposite corners of 93.3 mm with the HTC Vive Pro Lighthouse tracking.

No such correlation could be found in the PPT errors and the max difference between error values is only 18.6 mm. See figure 10 for reference.

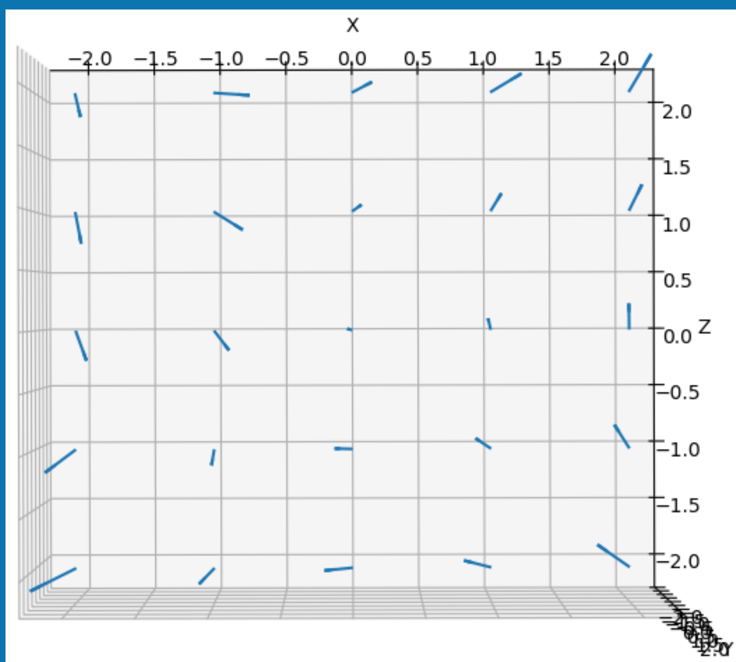


Figure 9

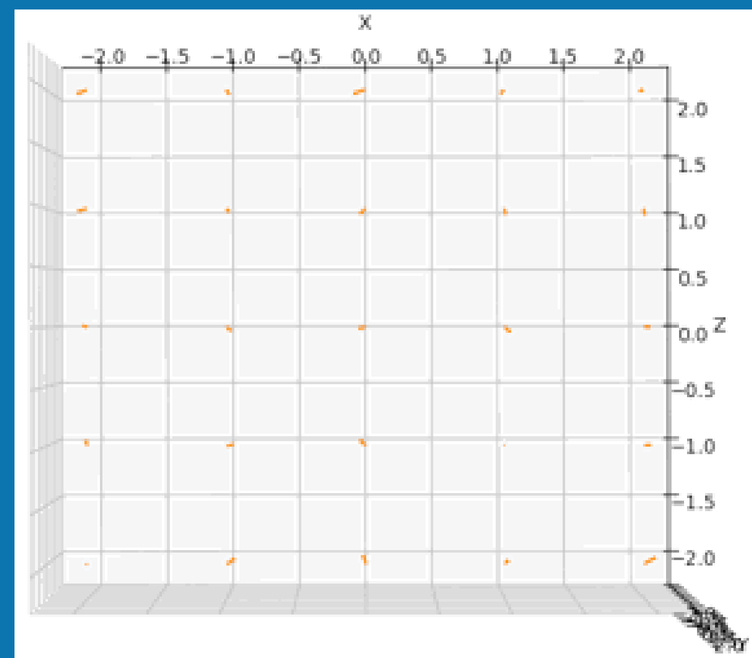


Figure 10

The following plots show the same measurements as above but at head height (Y = 1.8 m). Here, the error direction plots show a similar pattern as compared to waist height, although along different axis. This might be due to a restart of the system between the two recordings of the measurement data.

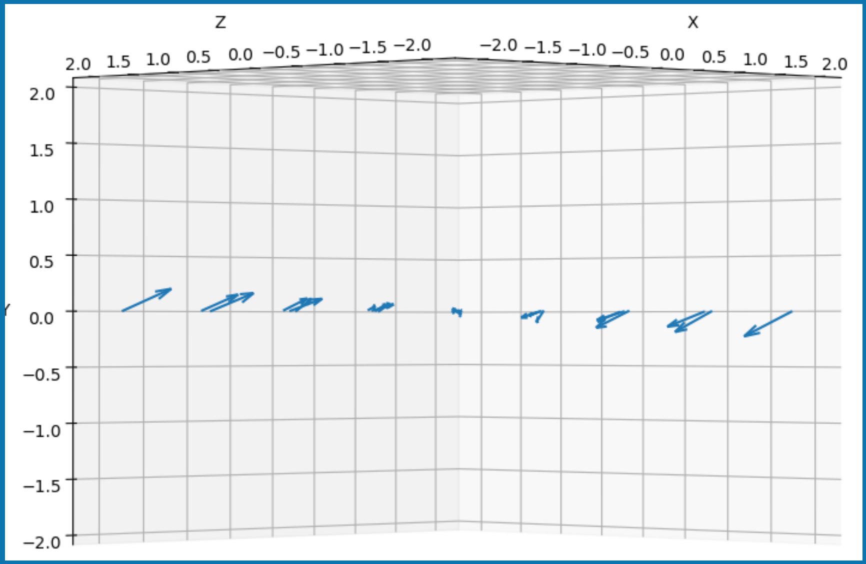


Figure 11

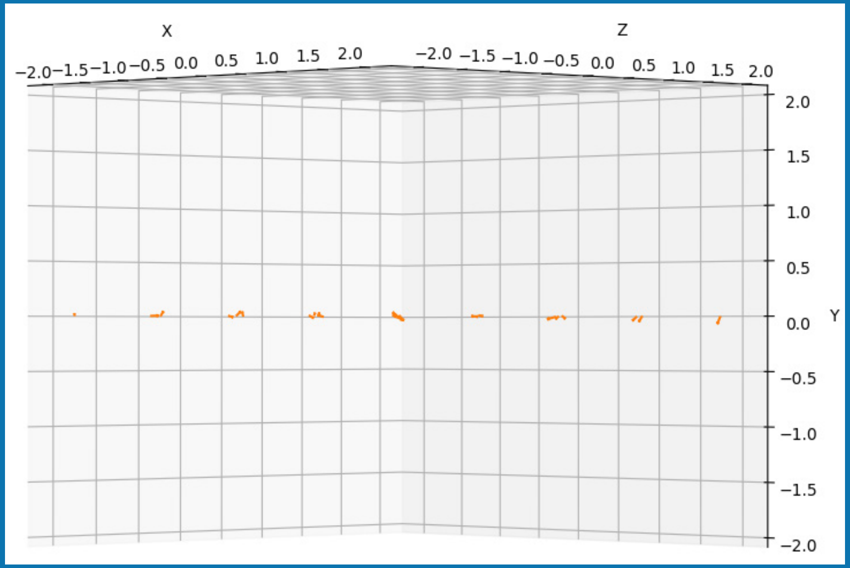


Figure 12

Similarly to the observation at waist height the difference between the error at opposite corners is 96.6 mm for the HTC Vive Pro Lighthouse tracking.

The max difference between opposite error values in the PPT data is 27.3 mm

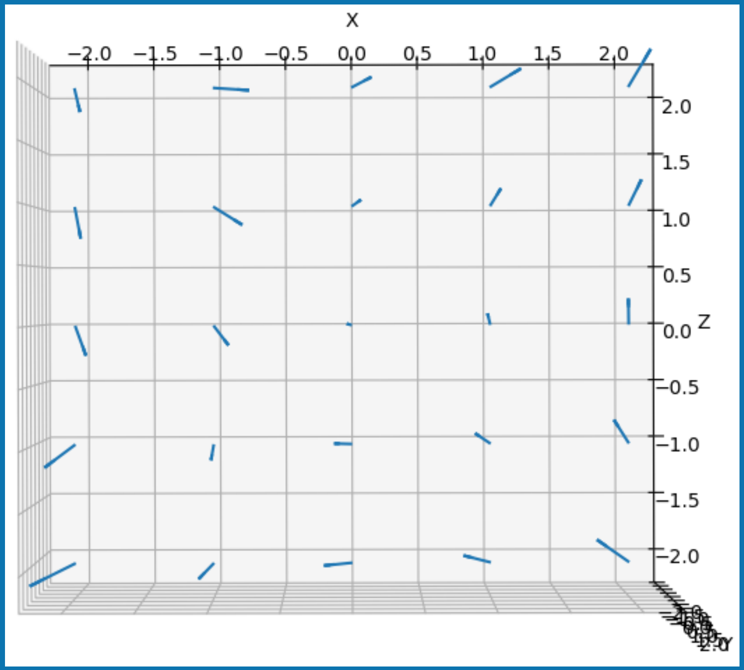


Figure 13

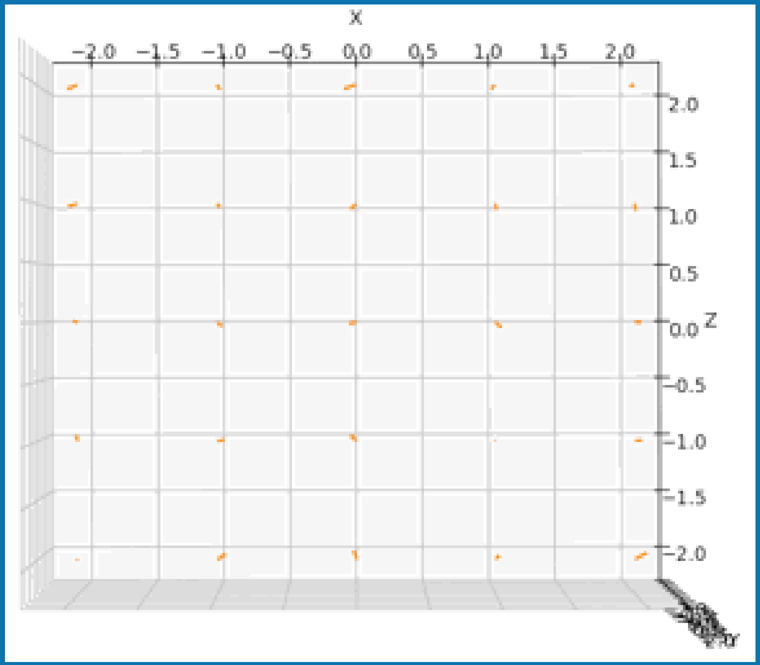


Figure 14

Conclusion

Looking at the magnitude of the error the data shows that the HTC Vive Pro Lighthouse tracking system error is about four times larger than PPT tracking, varying in height significantly.

In a given virtual environment, physical movement from one corner of the motion tracking area to another with HTC Vive Pro results in significant height difference of up to 60 mm across a 4 m by 4 m tracking area in the corresponding virtual environment.

With the HTC Vive Pro, the error magnitude as well as the direction of the error are not consistently within the same range or location. This means that once tracking is lost (i.e., when the system is turned off), the errors might manifest in a different location and at a different magnitude. Subsequently, there is no reliable way to compensate for the issue within a given VR software programmatically.

Professional systems like the WorldViz PPT-N system can correct for such errors, keeping data noise to a minimum.

Scientific Literature with similar results:
[1] D. C. Niehorster, L. Li, and M. Lappe. The Accuracy and Precision of Position and Orientation Tracking in the HTC Vive Virtual Reality System for Scientific Research. I Perception, 8(3):2041669517708205, 2017.