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Study On The Dead Reckoning Of Land Vehicles In A Distributed Interactive Simulation Environment

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INSTITUTE FOR SIMULATION AND TRAINING

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STUDY ON THE DEAD RECKONING OF LAND VEHICLES IN A DISTRIBUTED INTERACTIVE SIMULATION ENVIRONMENT

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Abstract

This report is the result of an effort to study the dead-reckoning of a military tank in a DIS environment. Four dead-reckoning equations (zero, first, second and third order) are used for position dead reckoning; and three dead-reckoning equations (zero, first, and second order) are used for orientation dead reckoning. Dead reckoning for position only, for orientation only, and for both position and orientation are studied. The results are plotted as PDU/sec vs. threshold and RMS error vs. threshold to represent the network load and accuracy, respectively. The effects of turret dead reckoning are also studied.

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List of Figures

1 Introduction

This report is the result of an effort to study the dead-reckoning of a military tank in a DIS environment. The dead-reckoning equations used in this study are

Zero-order equation:

$$x_i = x_0 \tag{1}$$

First-order equation:

$$x_i = x_0 + v_0 ih \tag{2}$$

Second-order equation:

$$x_i = x_0 + v_0 ih + a_0 (ih)^2/2 \tag{3}$$

Third-order equation:

$$\begin{aligned} x_i &= x_0 + v_0 \left[ih - \frac{(ih)^3}{3\Delta t_{-1}^2} \right] + v_{-1} \frac{(ih)^3}{3\Delta t_{-1}^2} \\ &+ a_0 \left[\frac{(ih)^2}{2} + \frac{(ih)^3}{3\Delta t_{-1}} \right] \end{aligned} \tag{4}$$

where x_i is the dead-reckoning x (position) at time $t_i = t_0 + ih$, $i = 1, 2, ...$, which counts the dead-reckoning time steps from the update time, x_0, v_0, and a_0 are the x, $\dot{x}$ (velocity), and $\ddot{x}$ (acceleration), respectively, at time t_0, and v_{-1} is the $\dot{x}$ at t_{-1}, the last update time.

The equations used for position dead-reckoning are zero order to third order, for orientation are zero order to second order. The tank has two articulation parts: turret and gun. They will use the dead-reckoning equations of orders zero and one.

The performance of the dead-reckoning equations are shown in figures. There are two type of figures in this report. The first one is PDU/sec vs. threshold, which represents the network traffic. The second one is RMS error vs. threshold, which represents the accuracy.

A 139.7-second sample trajectory is generated by a three-dimensional tank simulation program. The data rate of the sample trajectory is 10 Hz. The trajectory in the horizontal plane is shown in Figure 1.

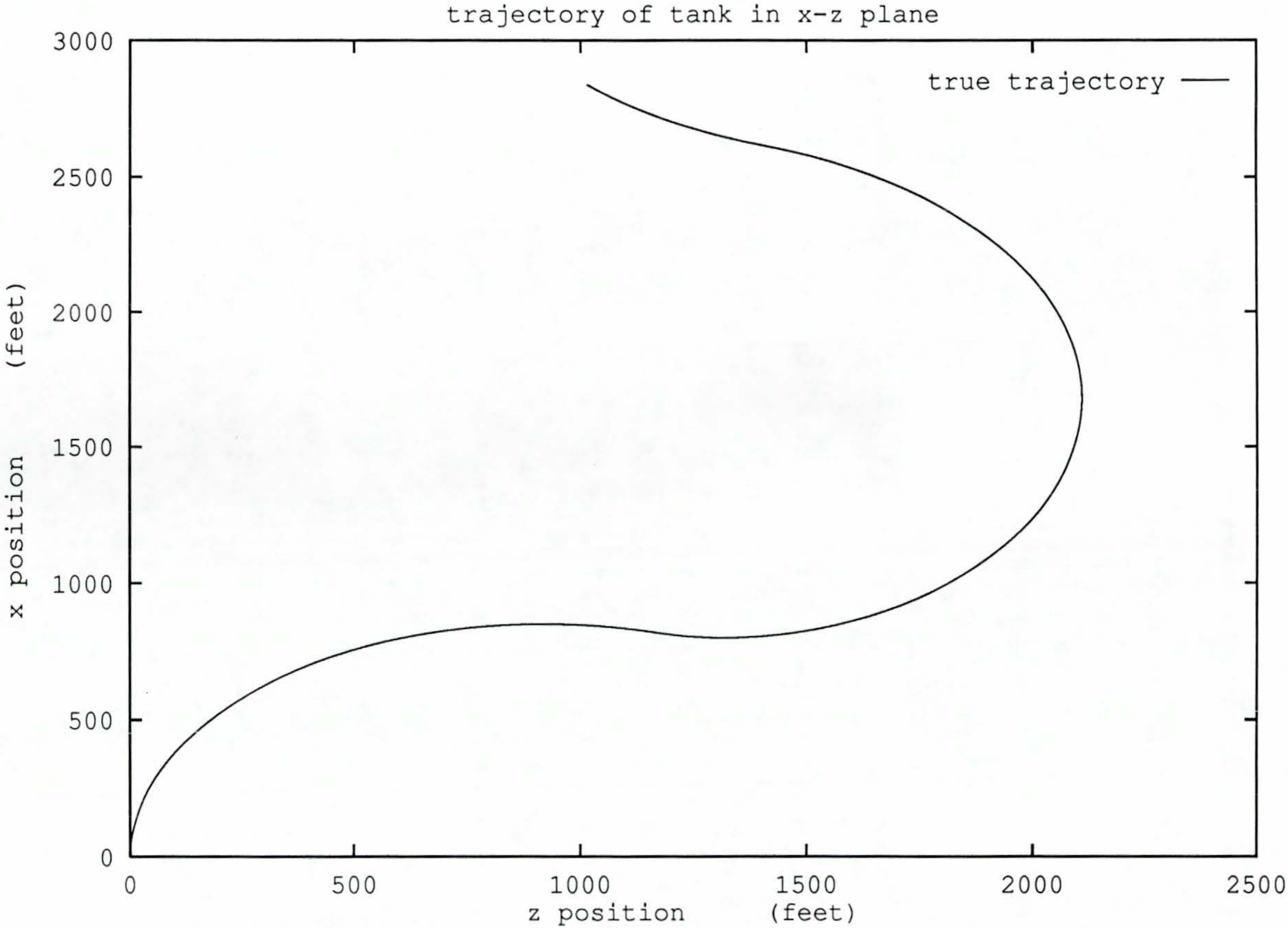

Figure 1: Sample tank trajectory.

2 Network Load and Accuracy

The network load is measured by the average PDU rate. The dead-reckoning equations listed in the previous section are applied to this trajectory. The total number of PDUs is recorded for each case. Then, the average PDU rate (PDU/sec) is calculated and plotted against thresholds. Since the trajectory data rate is 10 Hz, the maximum PDU rate is 10 PDU/sec. For large thresholds, the position error may not exceed the threshold in 5 seconds. In this case, a PDU is sent at the fifth second. Hence the theoretical lowest PDU rate is 0.2 PDU/sec. However, since the total time of the trajectory, 139.7 seconds, is not an integer multiple of five. The actual PDU rate may be a little lower than 0.2 PDU/sec.

In general, higher order dead reckoning equations generate lower PDU rates. That is because higher order equations give better approximation of the trajectory. However, higher order equations need more computation time. This study can find out what are the differences in PDU rate for equations of different order.

Larger thresholds usually generate lower PDU rates. There are a few exceptions. The reasons will be discussed later. Large threshold means poor accuracy. The results in this section can show the relationship between PDU rate and threshold.

The accuracy is measured by root-mean-squared (RMS) error. The smaller the RMS error the better the accuracy. The RMS error is obtained by comparing the dead-reckoning trajectory and true trajectory point by point, recording the difference at each point, and using the RMS formula:

$$\text{RMS error} = \left\{ \frac{1}{\text{No. of point}} \sum (\text{error at each point})^2 \right\}^{1/2} \qquad (5)$$

The parameter that effects accuracy most is the threshold. The smaller the threshold the better the accuracy. However, small threshold also means high PDU rate. How to decide the right threshold depends on the application.

3 Position Dead Reckoning

The position dead reckoning is first studied. In this case, PDUs are sent only when the position error is over the threshold. The orientation dead reckoning does not generate PDUs. The results are shown in Figure 2, 3, and 4.

Figure 2 shows that there is a big difference in PDU rates between the zero-order and first-order dead-reckoning equations, while the differences among first, second, and third-order equations are not as large. Figure 3 shows only the first, second, and third-order dead-reckoning equations. There is almost no difference in PDU rates between the second and third-order equation. When the threshold is greater than 8 feet, the dead reckoning trajectories will not have errors exceed the threshold, and PDUs will be sent every five seconds.

Figure 4 shows the RMS error vs. threshold for equations of different orders. In general, the higher the order of the equation, the smaller the error. However, from the figure, the zero-order equation has the lowest RMS errors at very low thresholds. The reason is that at a very low threshold, the dead reckoning trajectory is updated very often, hence, the error is small. The accuracy of the second and third-order equations are about the same.

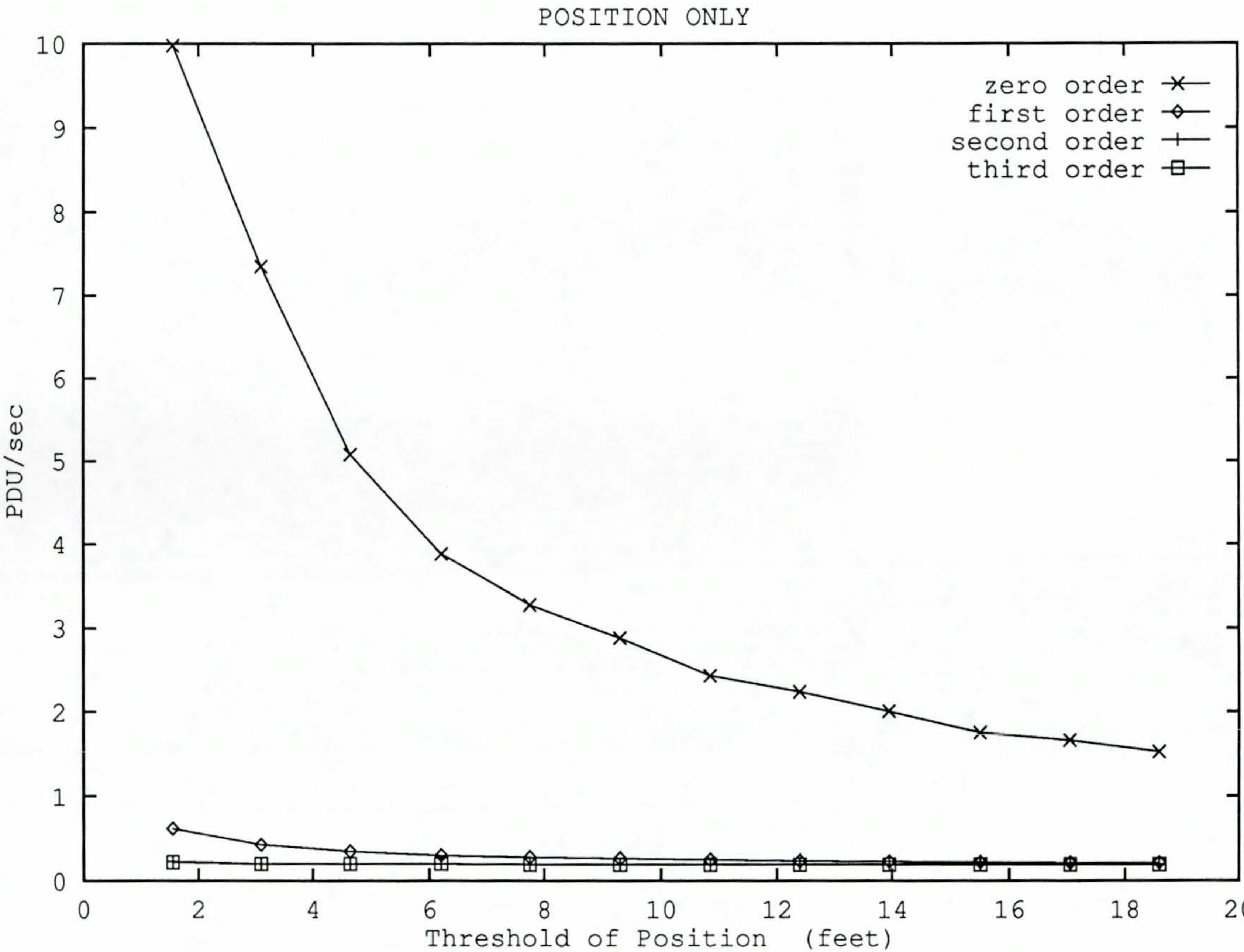

Figure 2: PDU rate of zero to third order dead reckoning on position only.

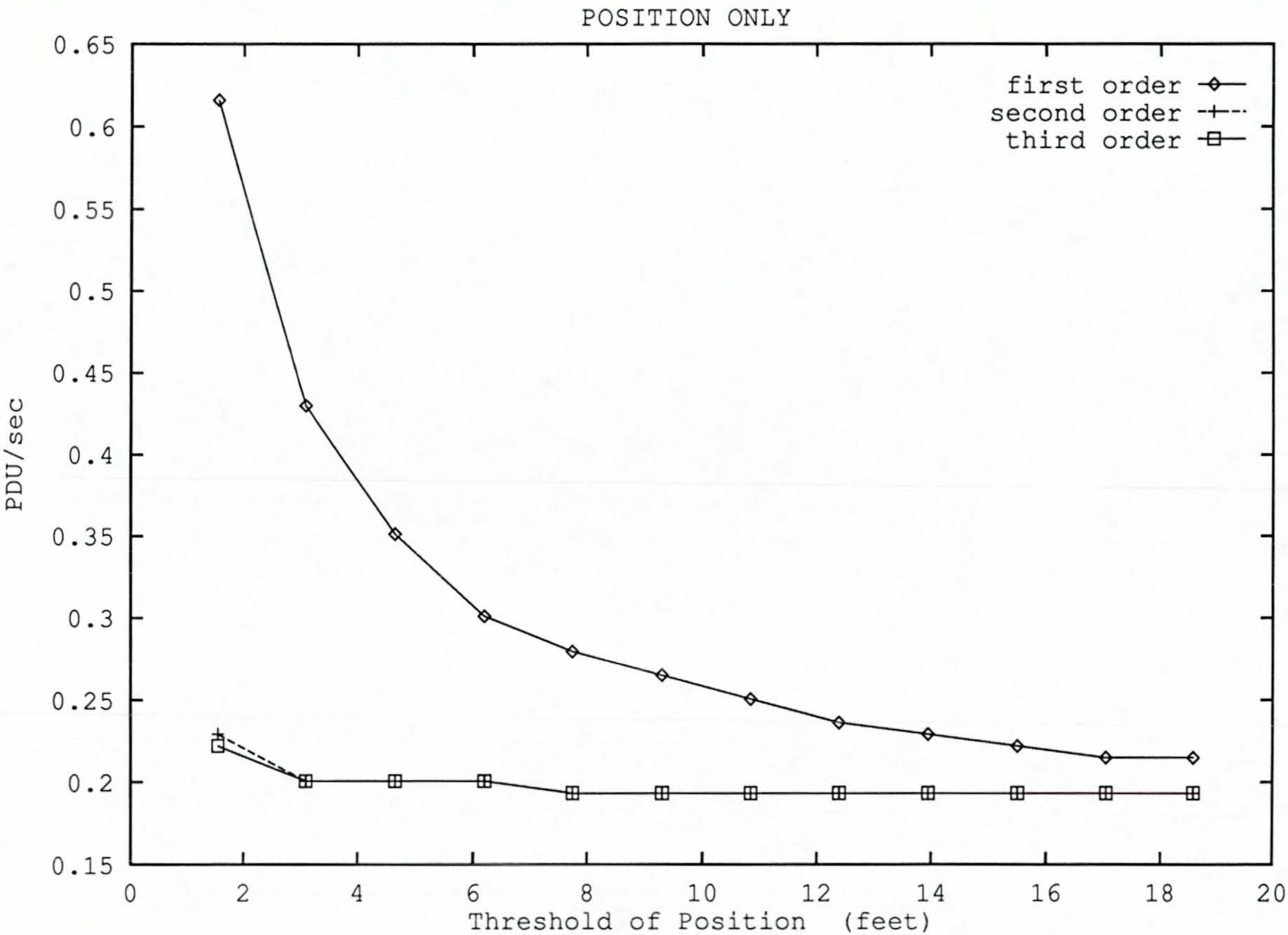

Figure 3: PDU rate of first, second, and third order dead reckoning on position only.

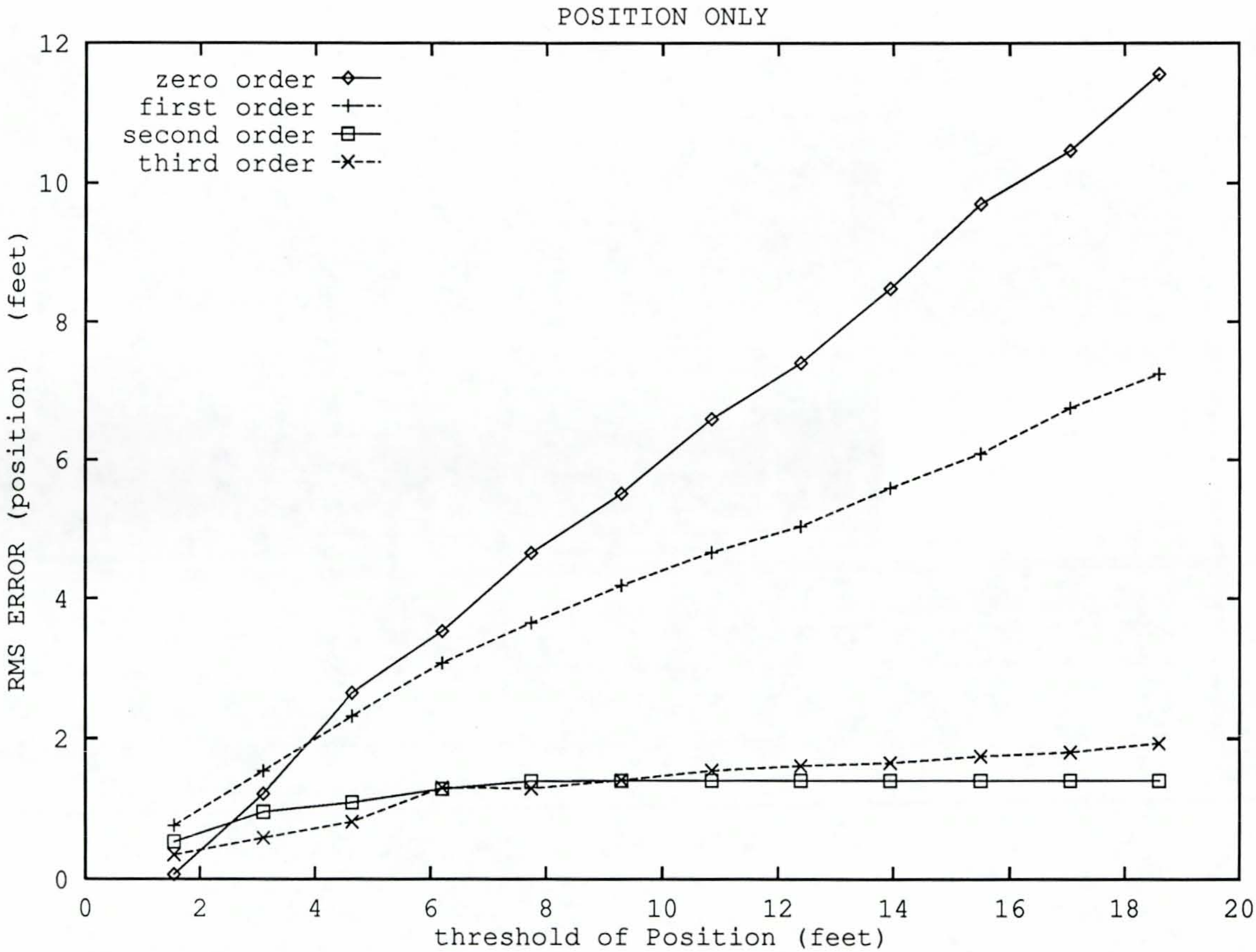

Figure 4: RMS error of first order dead reckoning on position only.

4 Orientation Dead Reckoning

In this case, PDUs are sent only when the orientation error is over the threshold. The position dead reckoning does not generate PDUs. The results are shown in Figure 5, 6, and 7.

Figure 5 shows the zero-order equation has higher PDU rates in the low threshold region than both first and second-order equations. Figure 6 shows there is not much difference in PDU rates for first and second-order equations. At the low threshold region, the second-order equation even has higher PDU rates than the first-order equation. The reason is that the angular acceleration is not available for dead reckoning. An extrapolation method must be used to calculate the angular accleration which is needed in a second-order equation. The extrapolation procedure may cause error in the second-order equation resulting in a higher PDU rate than the first-order equation at low threshold.

Figure 7 shows the RMS error vs. threshold for equations of different orders. In this case, a very low threshold was not used. Hence, the zero-order equation generates the largest errors as expected. The first and second-order equations generate about the same levels of errors with the second-order equation slightly higher. The reason is explained before.

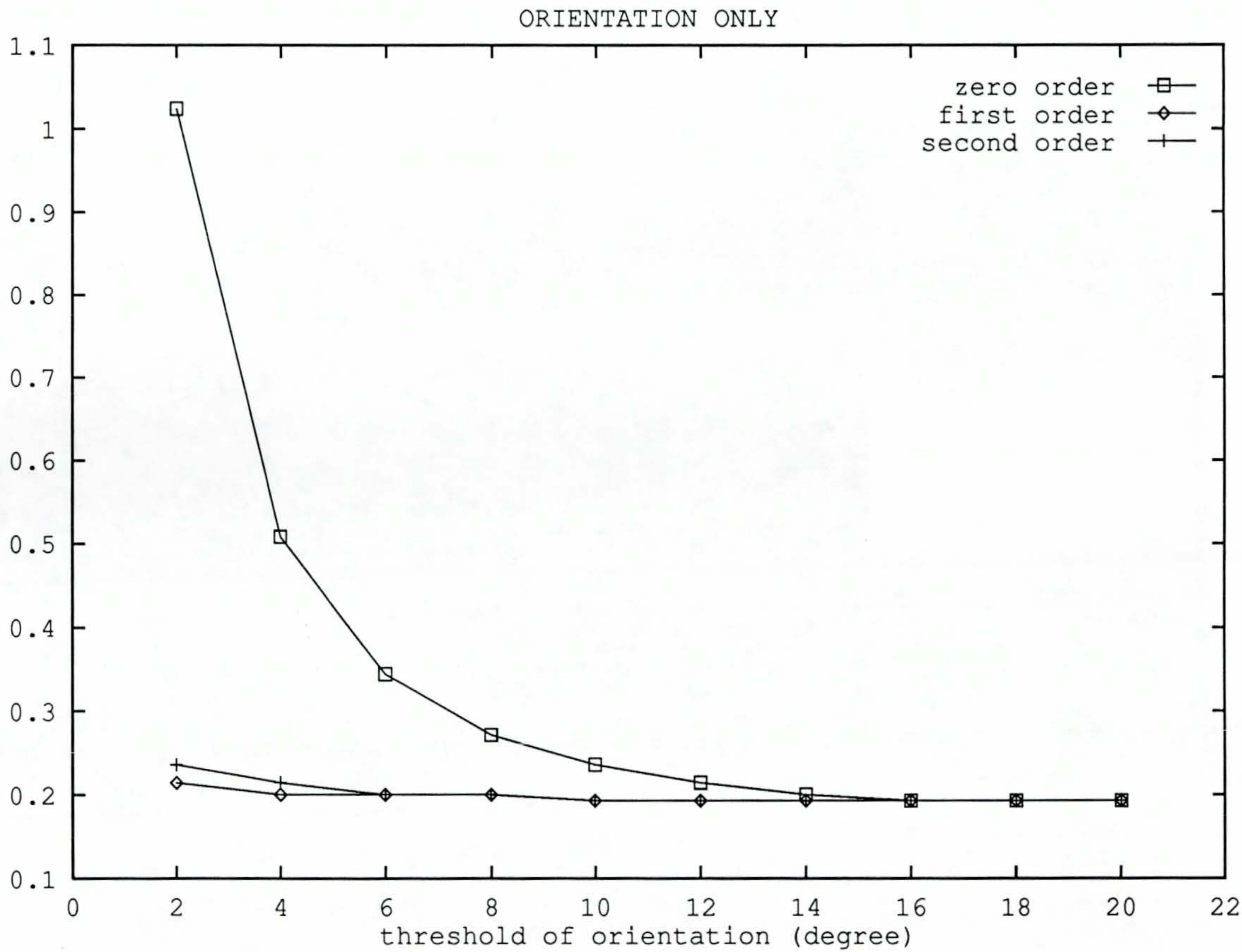

Figure 5: PDU rate of zero, first and second-order dead reckoning on orientation only.

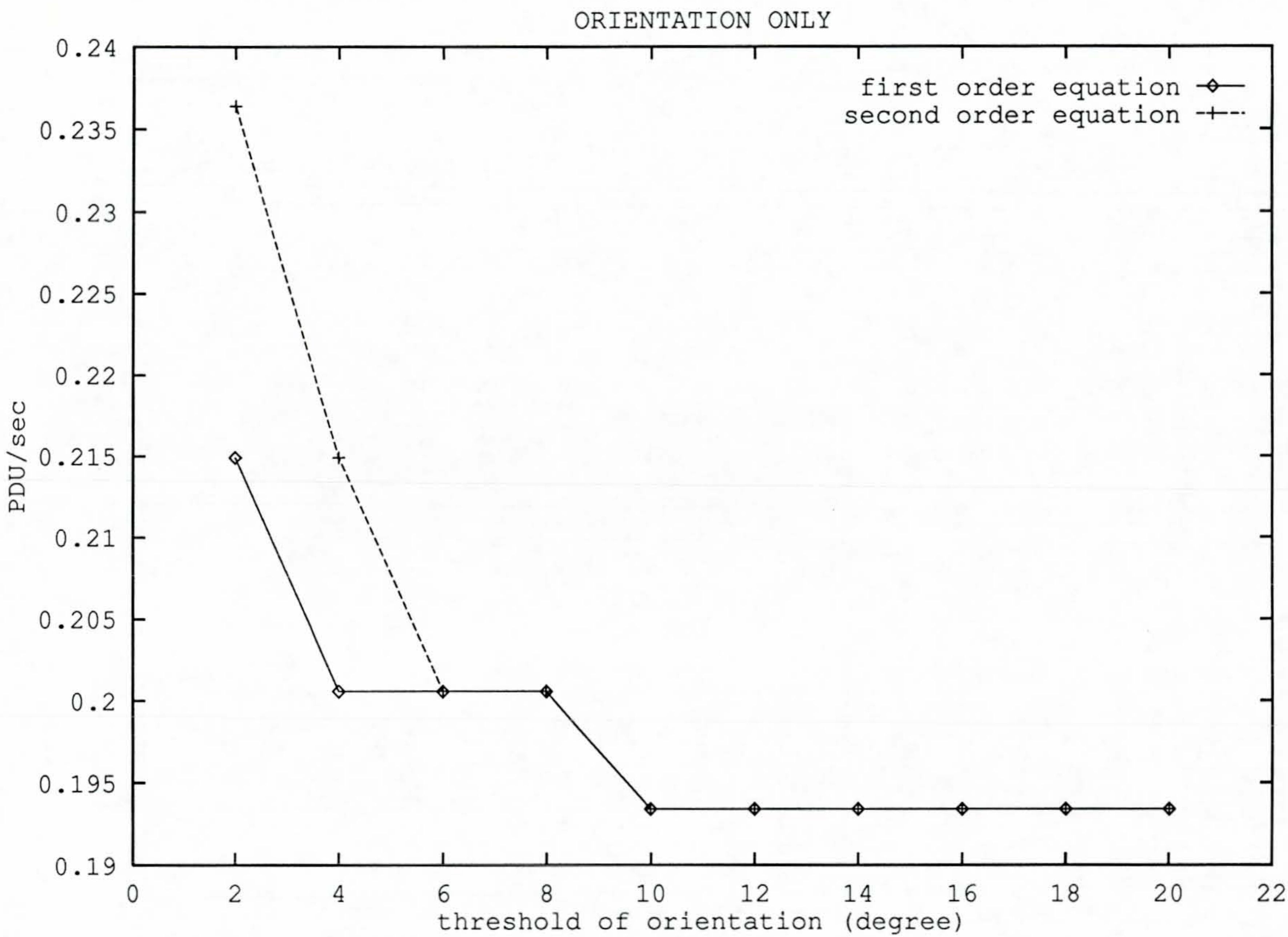

Figure 6: PDU rate of first and second-order dead reckoning on orientation only.

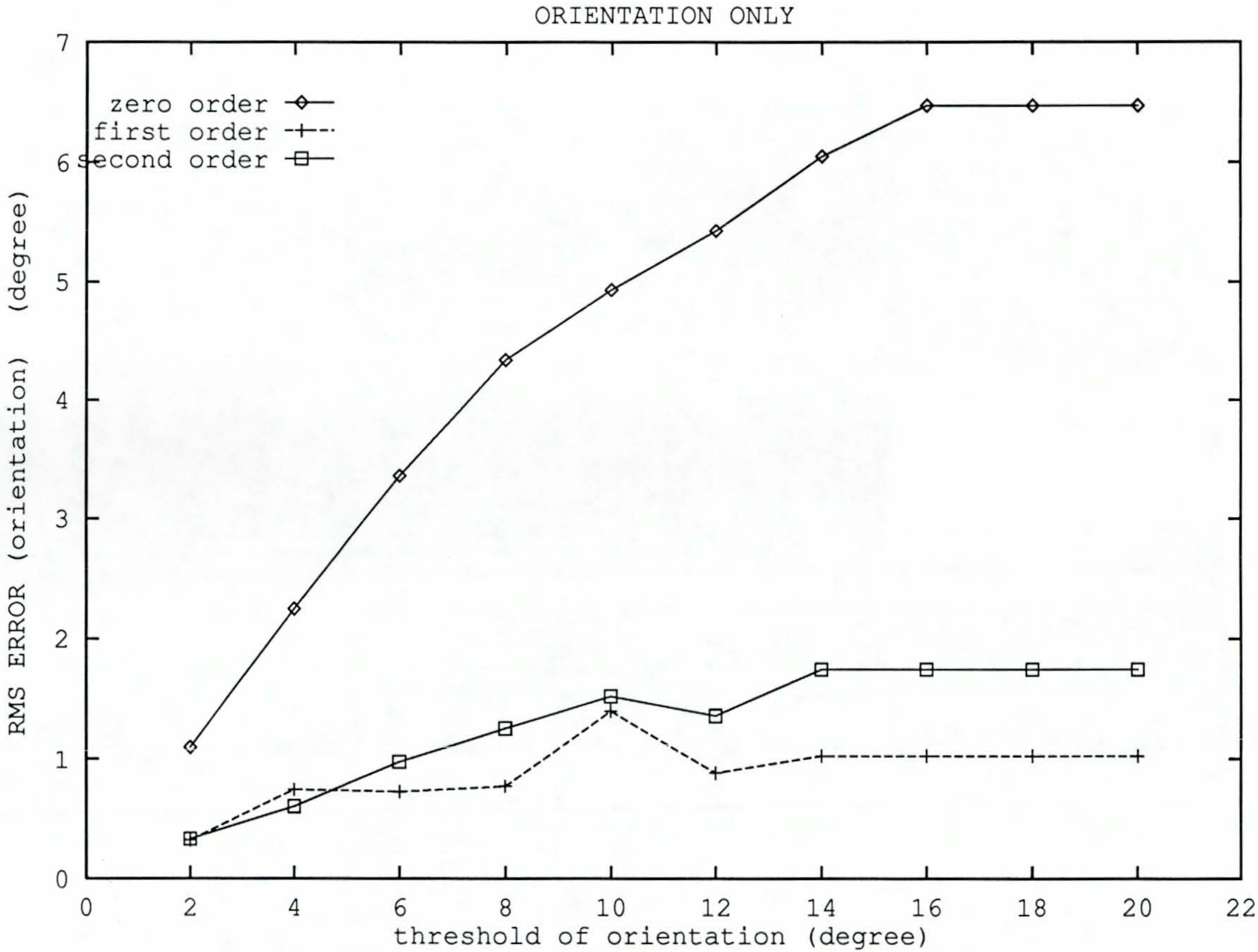

Figure 7: RMS error of first order dead reckoning on orientation only.

5 Dead Reckoning on both Position and Orientation

In this case, PDUs are sent when either the position or orientation error is over the threshold. The results are shown in Figure 8, 9, 10 and 11.

Figure 8 shows PDU rate vs. position threshold at different orientation thresholds for zero-order dead-reckoning equation. The curves level off at high threshold, indicating that the updates are mainly due to orientation dead reckoning. Figure 9 shows the results of the first-order dead-reckoning equation. In this case, the updates are mainly due to position dead reckoning.

Figure 10 shows position RMS error vs. position threshold at different orientation thresholds. Since the updates are dominated by the position dead reckoning, the RMS errors are almost independent of orientation threshold.

Figure 11 shows orientation RMS error vs. orientation threshold at different position thresholds. Where the curves level off, the orientation dead reckoning is not generating PDUs and the RMS errors are independent of the orientation threshold.

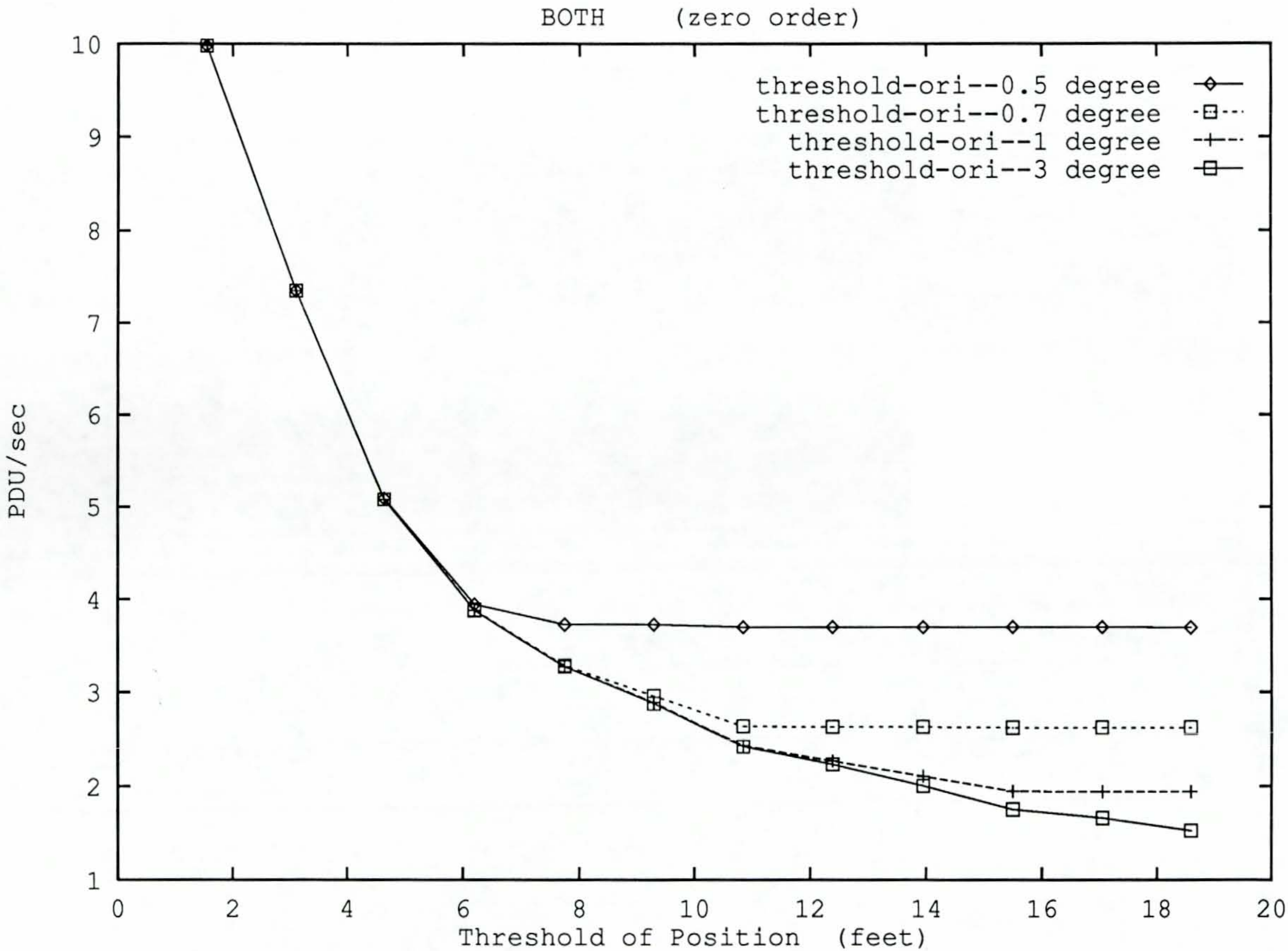

Figure 8: PDU rate of zero-order dead reckoning on both position and orientation.

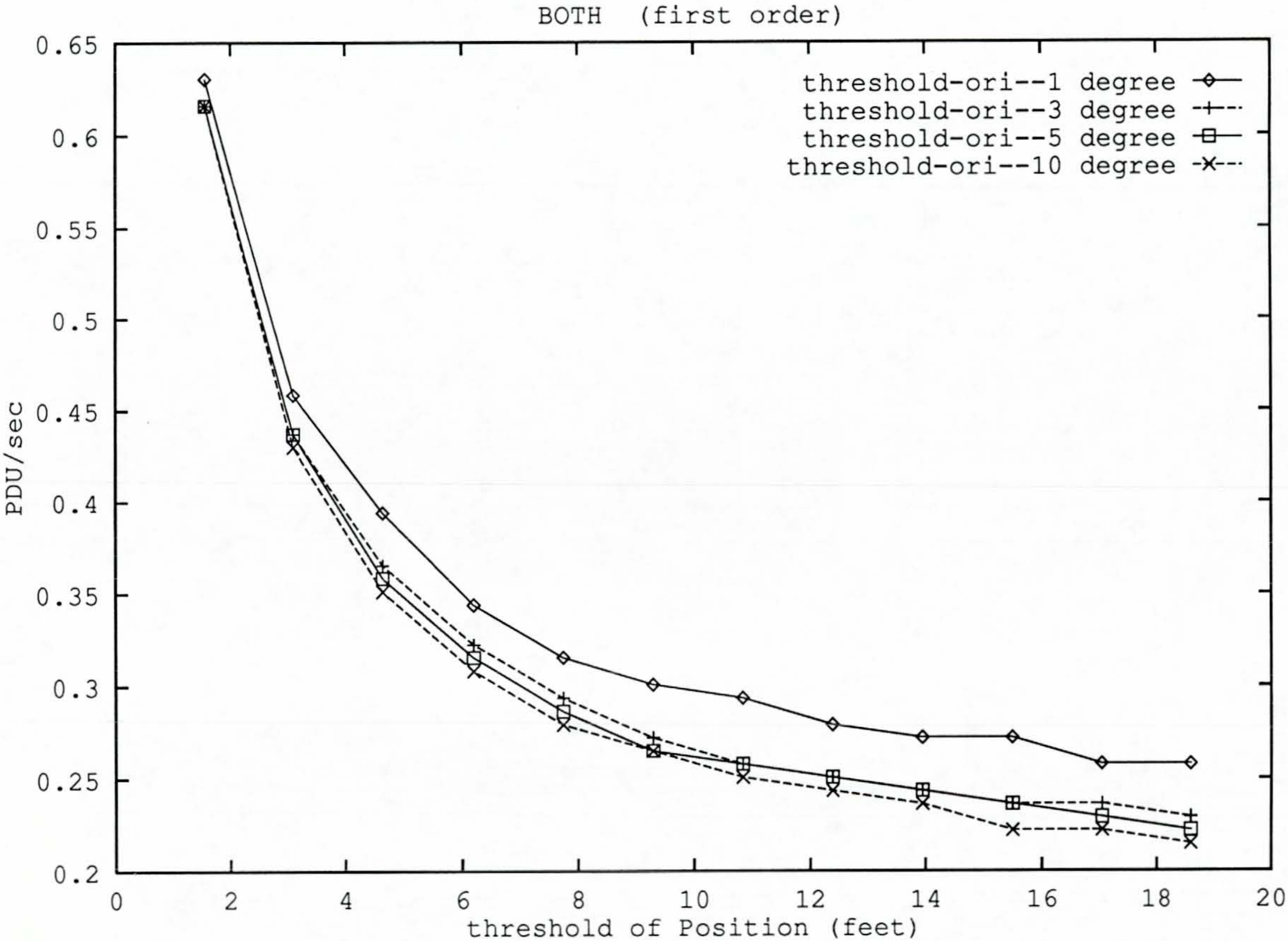

Figure 9: PDU rate of first-order dead reckoning on both position and orientation.

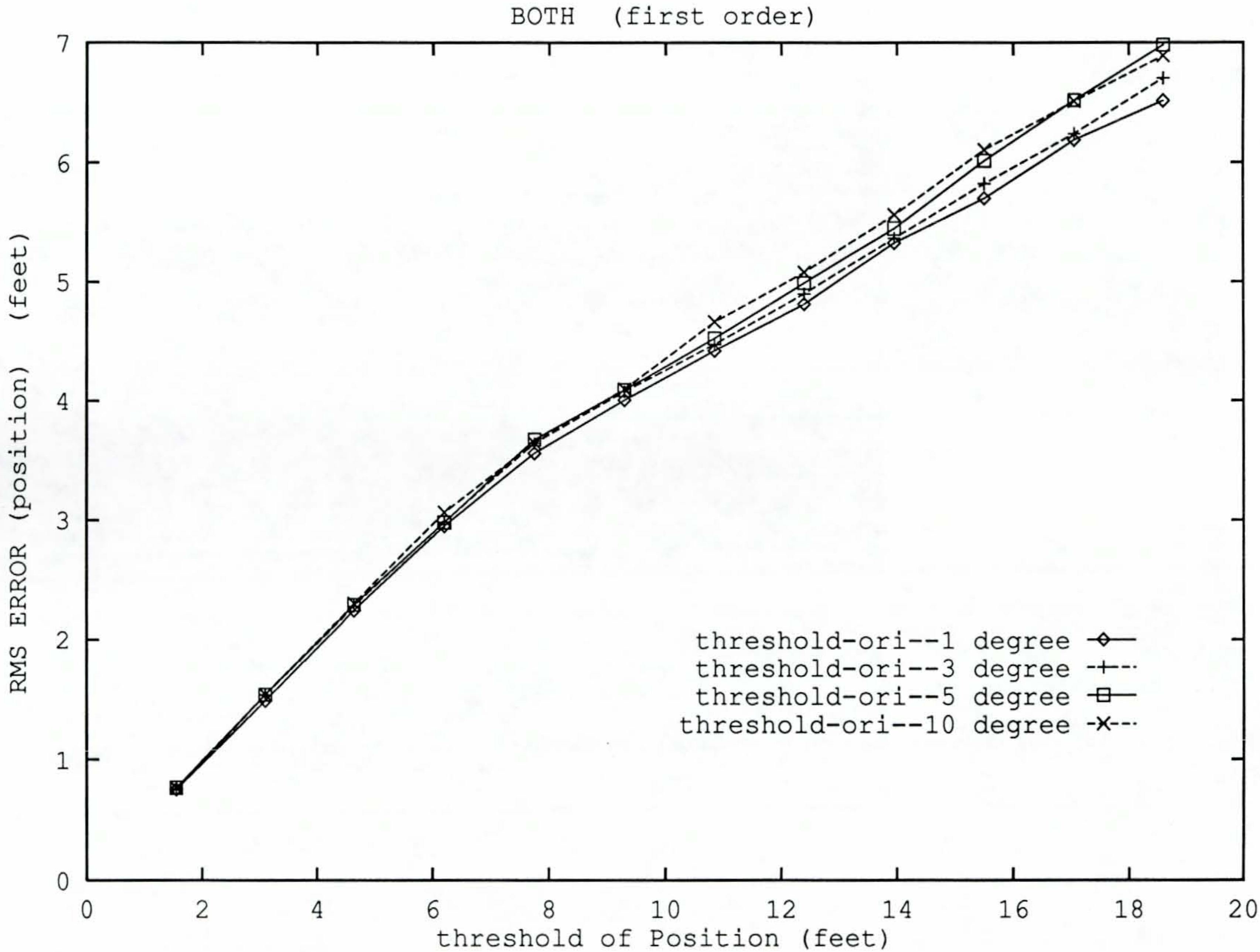

Figure 10: Position RMS error of first-order dead reckoning on both position and orientation.

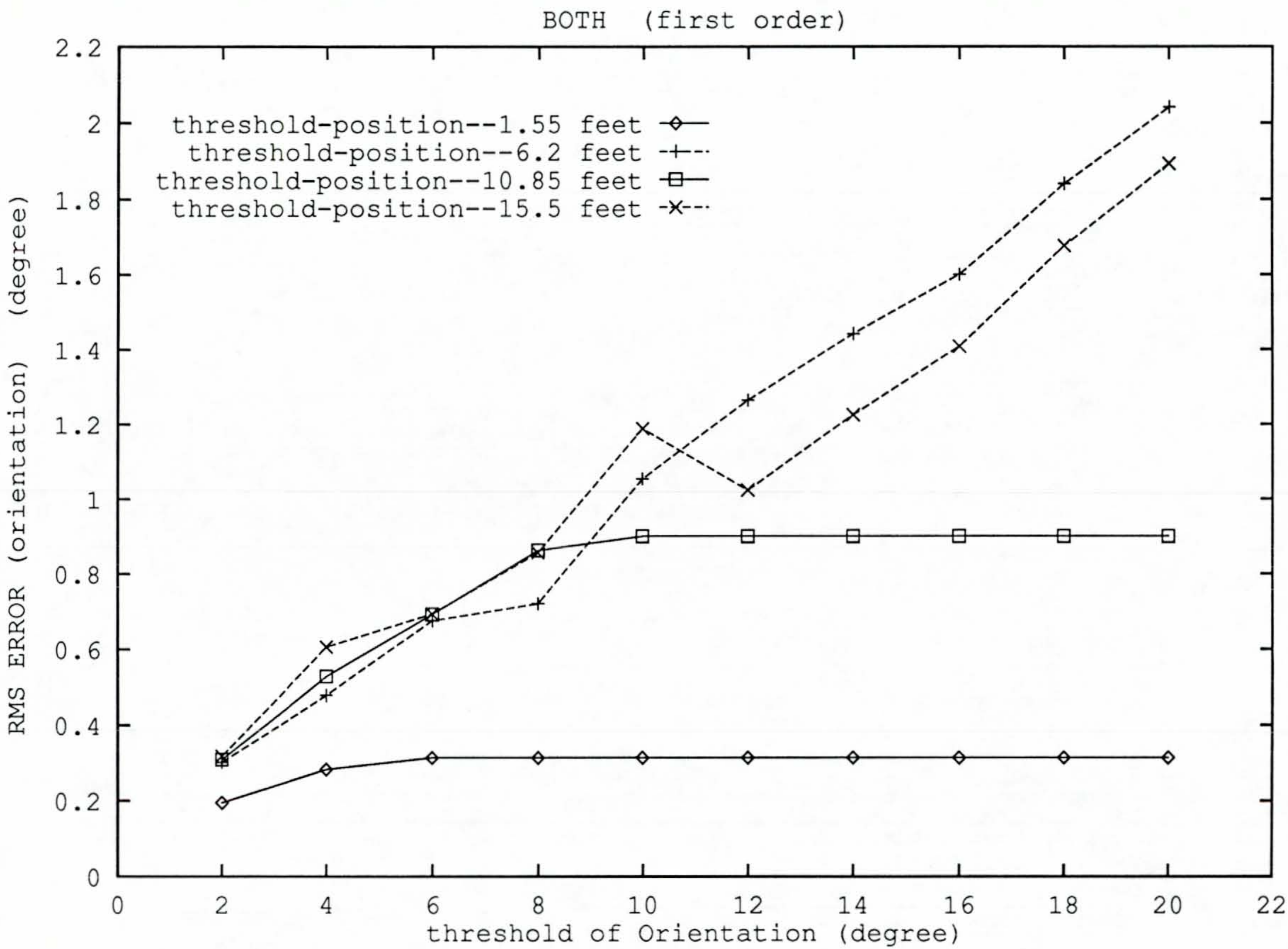

Figure 11: Orientation RMS error of first-order dead reckoning on both position and orientation.

6 Effect of Turret

Turret is an articulated part of the tank. Its information is also sent in the entity state PDU. In some cases, we also need to dead-reckon the turret. To study the effect of turret on PDU rate and RMS error, the rotation of the turret is assumed in a way that the gun is always pointing to a point with coordinates x = 4,000 feet and z = 8,000 feet. The results are shown in Figure 12, 13, 14, and 15.

Figure 12 represents the same variables and parameters as Figure 8, except that the dead reckoning of the turret also generates PDUs. The threshold of the turret dead reckoning is 1 degree. Comparing Figure 12 and Figure 8, we see they are almost identical except the high position threshold and high orientation threshold region. In that region, some updates maybe triggered by the turret dead reckoning. Similar conclusion can be drawn from comparing Figure 13 with Figure 9 except in the high position threshold and high orientation threshold region.

Figure 14 shows the RMS errors of position with the turret dead reckoning. Comparing with Figure 10, the effect of turret dead reckoning on position RMS error is minimum.

Figure 15 shows the RMS errors of orientation with the turret dead reckoning on. Comparing with Figure 11, the effect of turret dead reckoning on position RMS error is more significant.

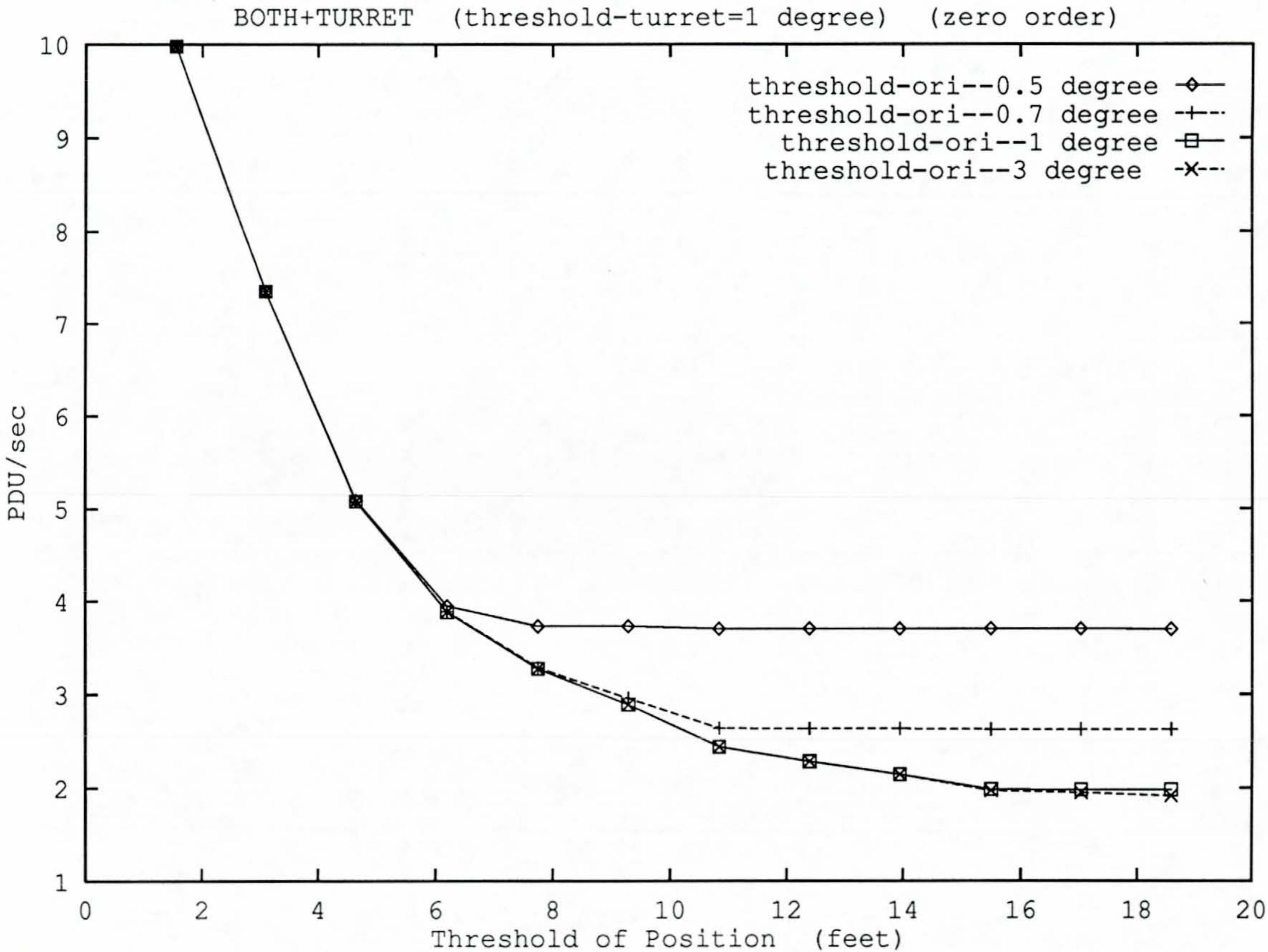

Figure 12: Effect of turret on PDU rate of zero-order dead reckoning.

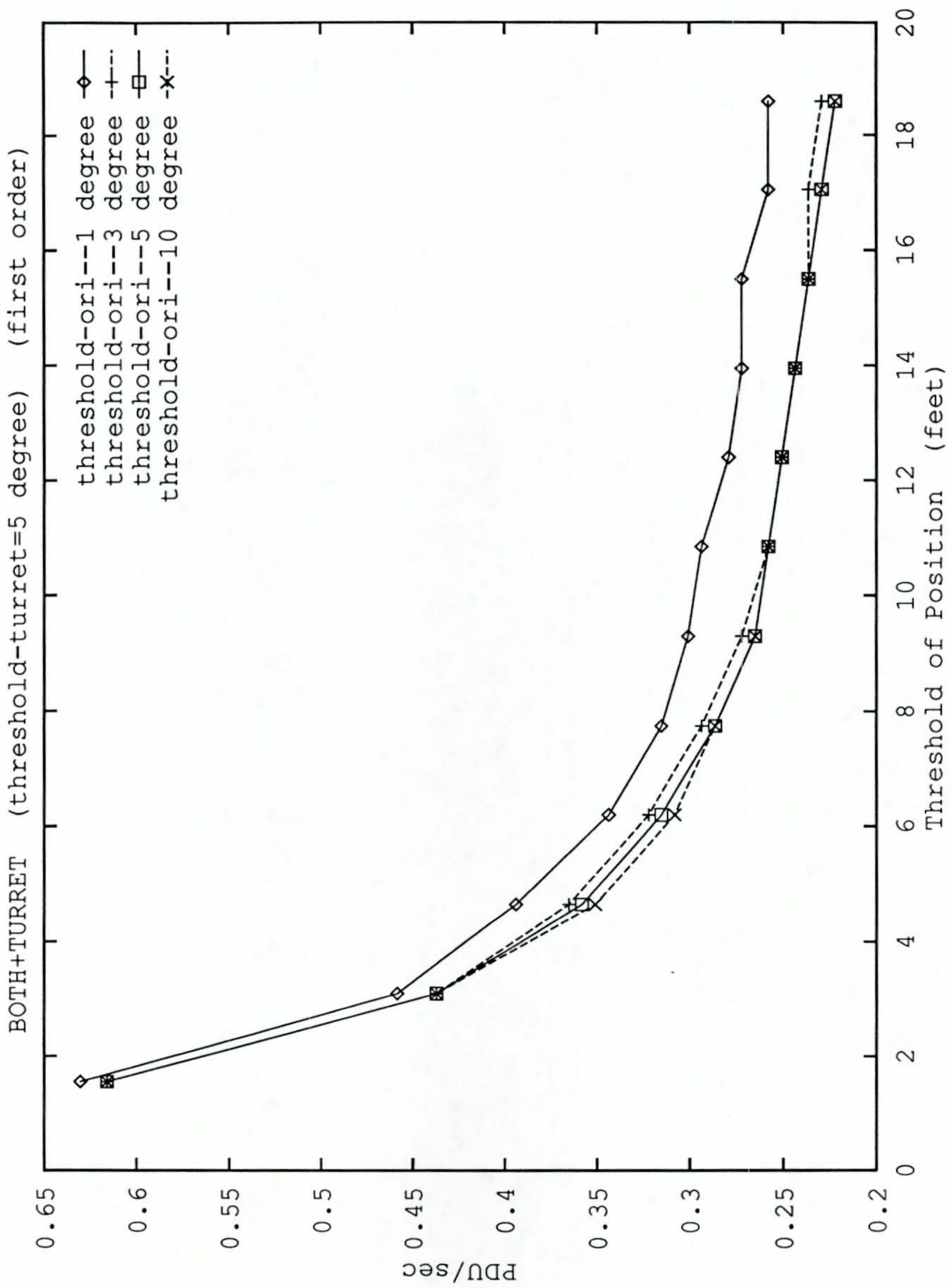

Figure 13: Effect of turret on PDU rate of first-order dead reckoning.

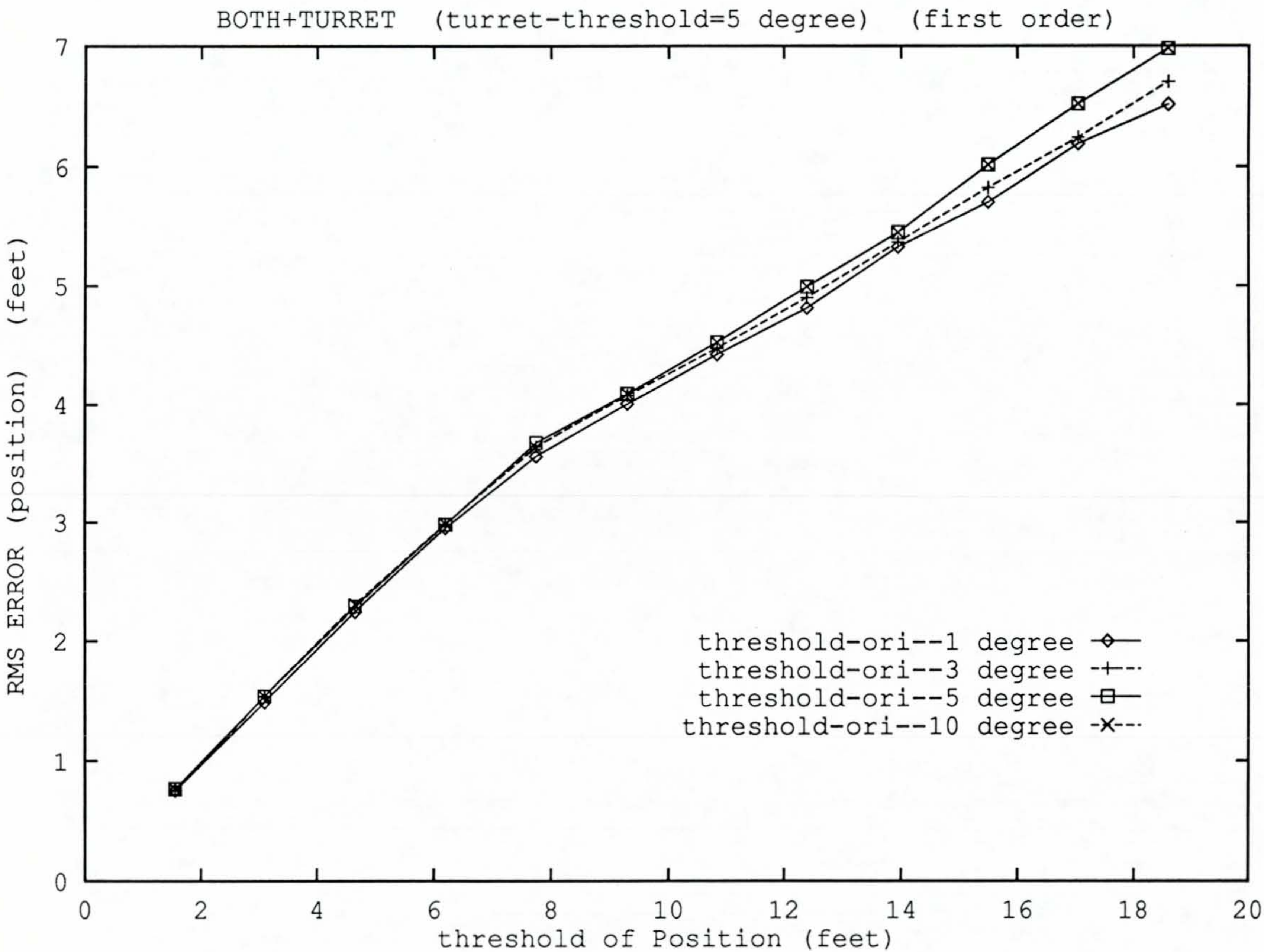

Figure 14: Effect of turret on position RMS error of first-order dead reckoning.

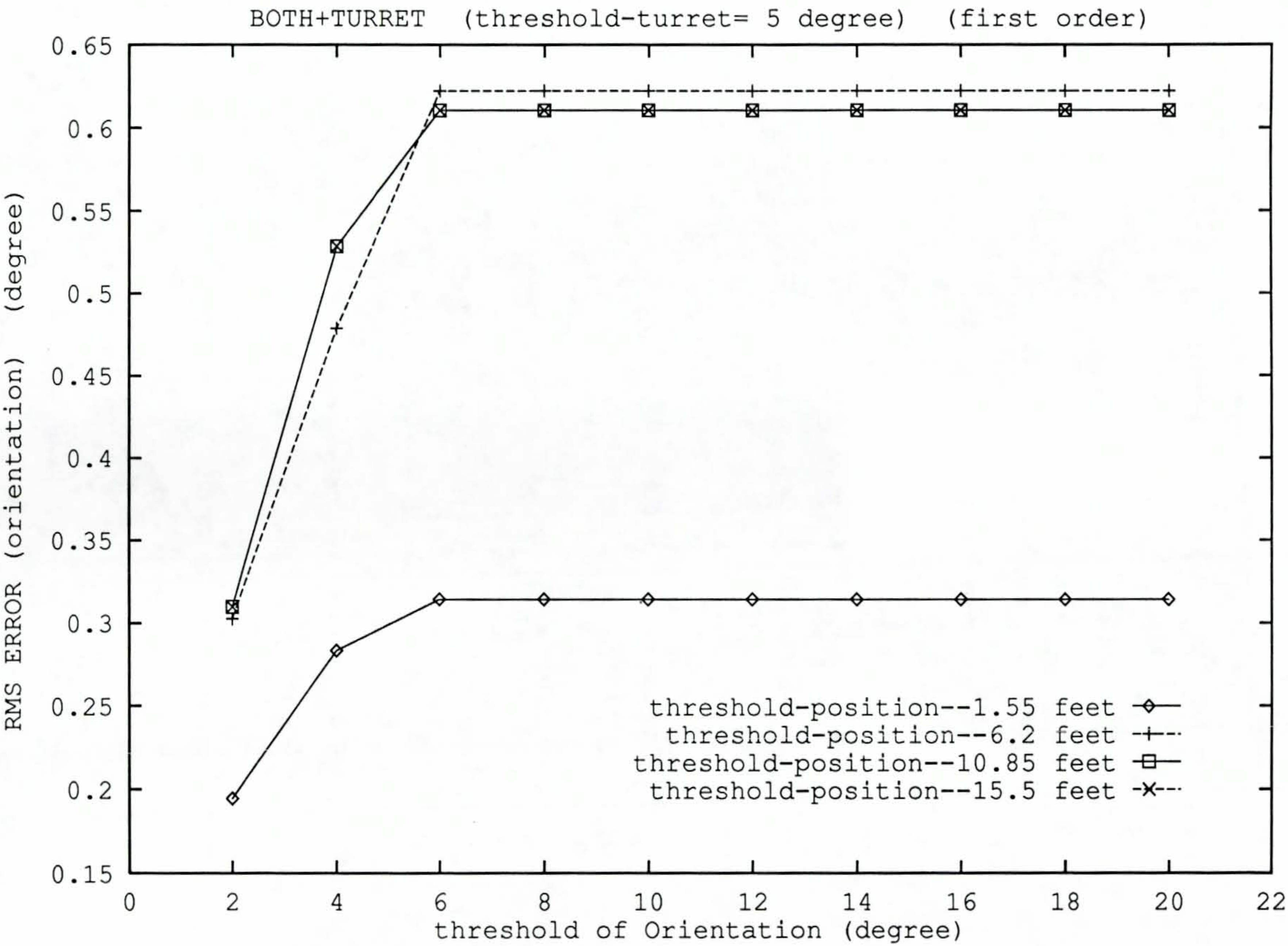

Figure 15: Effect of turret on orientation RMS error of first-order dead reckoning.

7 Conclusion

The followings are the summary of the results shown in the previous sections:

1. In position dead reckoning, there is a big difference in PDU rates between the zero-order and first-order dead-reckoning equations, while the differences among first, second, and third-order equations are not as large.

2. In position dead reckoning, the higher the order of the equation, the smaller the error. However, when the threshold is small, the differences in RMS error are not very obvious.

3. In orientation dead reckoning, the zero-order equation generates higher PDU rates in the low threshold region than both first and second-order equations. There is not much difference in PDU rates for first and second-order equations.

4. In orientation dead reckoning, the zero-order equation has higher errors than the first and second-order equations, unless in the very low threshold region.

5. If the articulation parts, turret and gun, need dead reckoning, the PDU rate will increase a little bit. Usually it is not a factor in the decision of which equations to use.

From the above summary, the following conclusions can be drawn:

1. Error analysis can be used to decide the thresholds used in dead reckoning.

2. The combination of first-order equation for both position and orientation dead reckoning is recommended.

3. Sometimes zero-order equation for orientation dead reckoning can also meet the accuracy requirement. In that case, PDU rates are used to decide whether the zero-order equation can be used or not.