Tracking People for a mmWave-based Interactive Game

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1. Environment

Figure 1. Transparent windows installed in Rotterdam The Hague Airport. Currently, their primary utility is glare control and information dissemination. Image courtesy of VideowindoW [1].

2. Interactive Video Games

Current Tracking Systems

- Vision-based – privacy invasion and strict lighting
- Wearables – inconvenient and impractical in public space

Alternative Solution

Frequency-Modulated Continuous Wave (FMCW) radars work in the millimeter wave (mmWave) range. They, unlike wearables, require no sensors attached to the users. In addition, processing point clouds do not reveal sensitive information as illustrated in Figure 2.

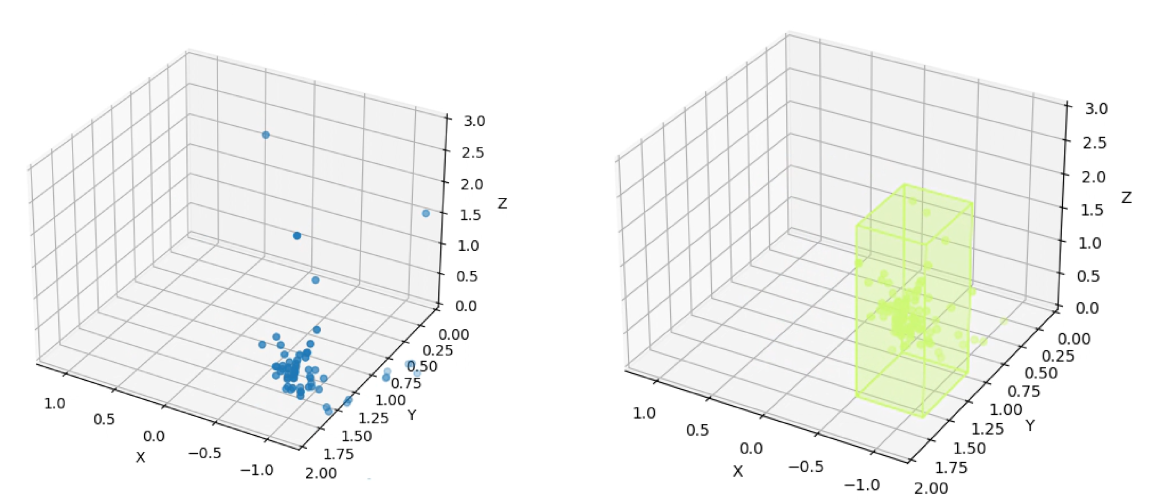

Figure 2. Data sampled from a single dynamic target in front of an FMCW radar, placed at the origin. A raw point cloud (left), and clustered points with the corresponding bounding box (right).

Our Research Question

How to track people in real-time for the interactive video game Breakout using mmWave radar?

3. Challenges

Noise in Static Target Tracking

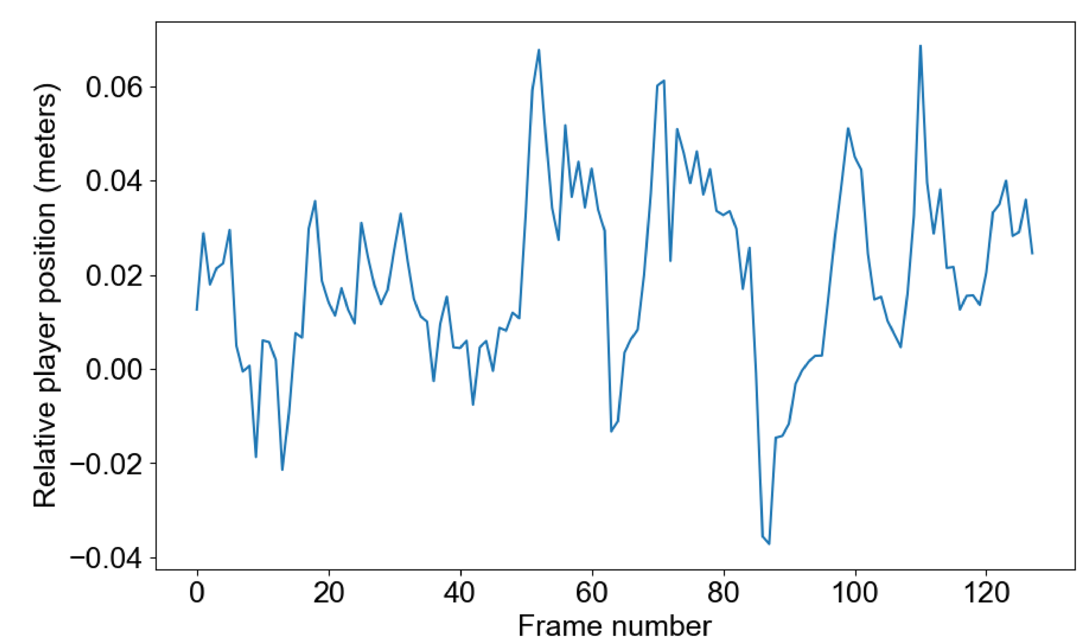

Figure 3. Tracking a stationary target, positioned right in front of the radar. The relative player position is measured in a single-dimension, perpendicular to the radar-to-player direction vector.

Snappy Movement due to Refresh Rates Mismatch

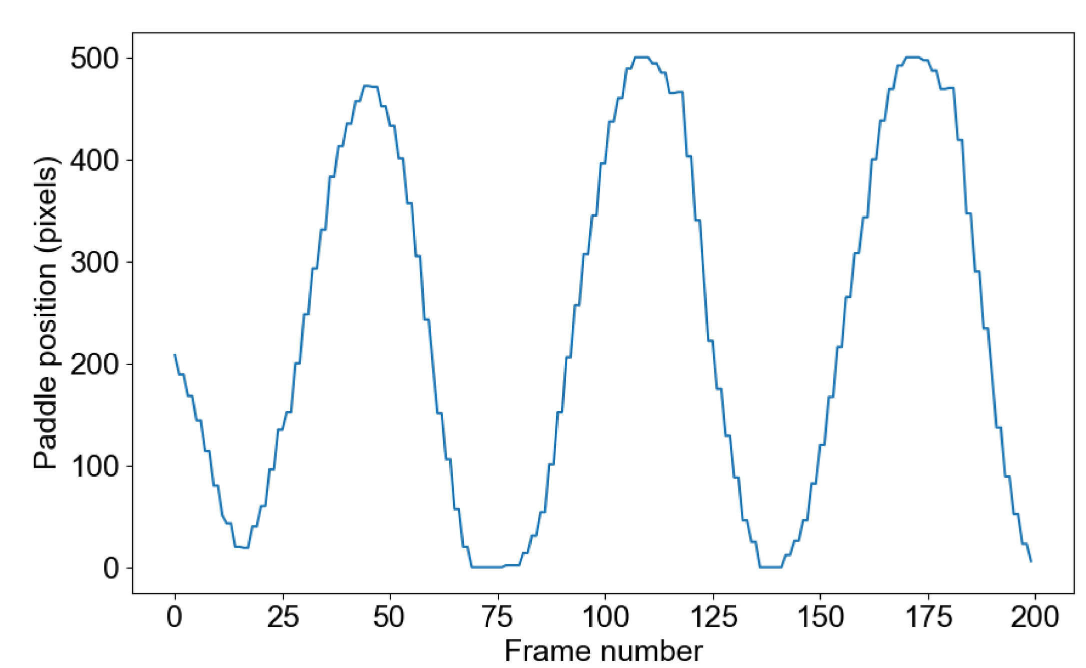

Figure 4. The paddle position at every frame. The radar generates a point cloud every 100 ms, whereas the game screen is updated every 50 ms. A reconstruction using the current player's position updates the paddle every 100 ms, resulting in snappy movement.

4. Methodology

Noise in Static Target Tracking

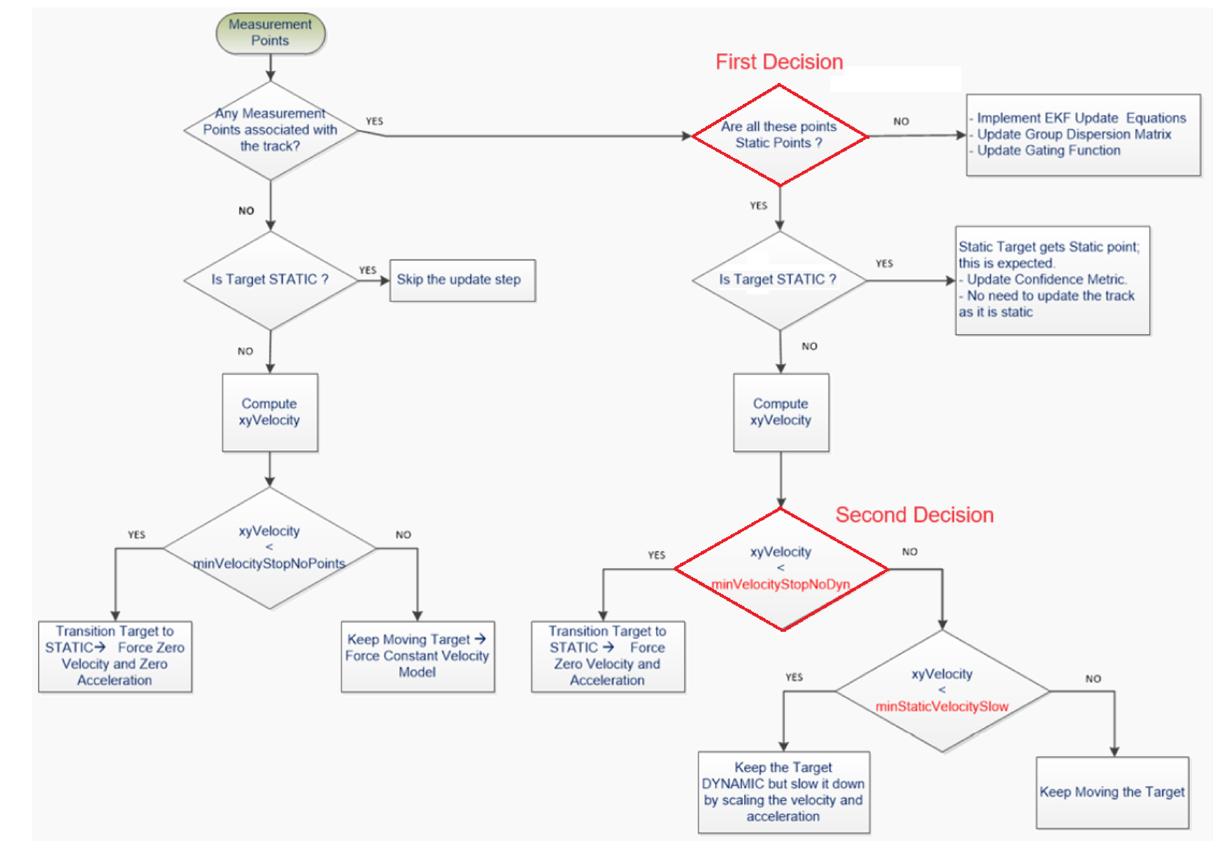

Figure 5. Flow Diagram: Tracker Update Steps. The decision points examined are in red. Image courtesy of Texas Instruments [2].

Snappy Movement due to Refresh Rates Mismatch

To decrease the lag, the system should support a higher refresh rate, and displace the paddle between measurement frames. We consider two techniques.

Interpolation

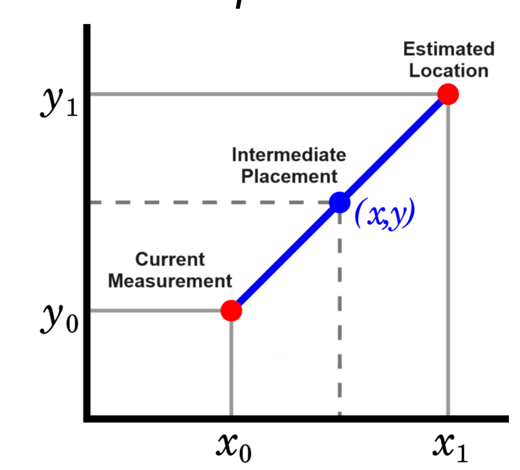

Figure 6. Simplified diagram illustrating interpolation between two measurement frames – the paddle is partially displaced.

Moving Average

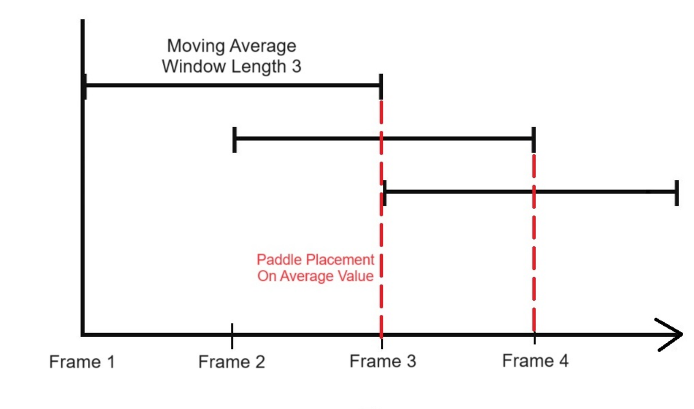

Figure 7. Simplified diagram illustrating moving average in between two frames. The paddle is placed on the location determined by averaging the three most current locations.

5. Findings

Noise in Static Target Tracking

The baseline achieves 4.52 cm standard deviation on the static target, whereas the extended version achieves 3.02 cm standard deviation. The extended system accurately follows a target in motion, as illustrated in Figure 8b. It also achieves notable improvement in stabilising a target track once it temporarily stops.

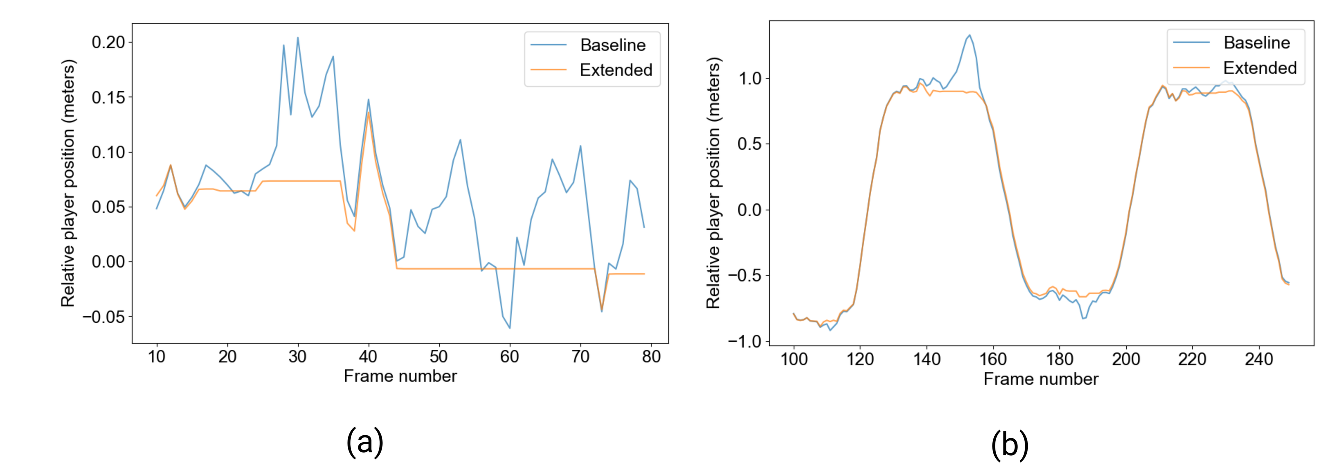

Figure 8. Comparison between the baseline and extended algorithm in static (a) and dynamic target tracking (b).

Snappy Movement due to Refresh Rates Mismatch

Interpolation

Assumes an accurate estimator, but the Kalman filter does not accurately capture the target speed and performs poorly. The paddle is displaced by 0.97 pixels between measurements.

Moving Average

Allows a higher refresh rate, but introduces a response delay. Figure 9 compares the baseline and two window lengths W_l, showing that a larger window increases delay. With $W_l = 3$, the delay is at most 100 ms, and with $W_l = 15$ – at most 700 ms.

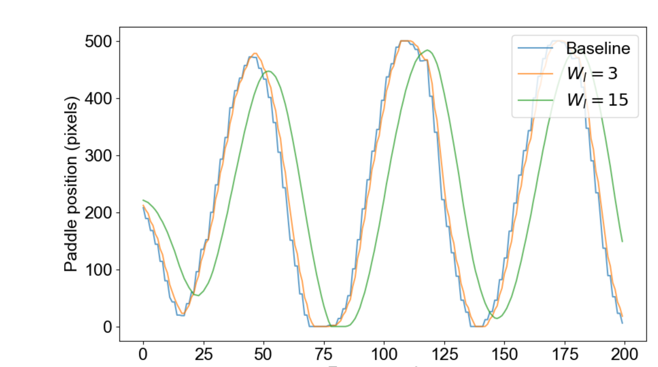

Figure 9. Comparison between paddle position over time using two moving window lengths W_l and the baseline.

6. Conclusions

- A state transition module processing the point count and their velocities improves system accuracy, reducing the standard deviation in tracking a static target by 33%.
- Moving Average shows superior improvement in paddle movement compared to Interpolation, due to an inaccurate Kalman filter estimator.

7. Limitations

- The experiments are conducted in a small room with less dynamic objects and closer distances.
- Only one person interacted with the system, which does not represent various movement patterns.

References

[1] "Videowindow." https://www.videowindow.eu (accessed Jun. 21, 2024).

[2] "People Tracking," May 2023. https://dev.ti.com/tirex/explore/node?node=A__AAA1qiZfNyuf6Vuc4GJbiQ__radar_toolbox__1AslXXD__LATEST (accessed Jun. 16, 2024).

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