3D Motion-Tracking PET Prototype

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Path to a “RoomPET”

- Interest in brain PET
- Fully functional patient

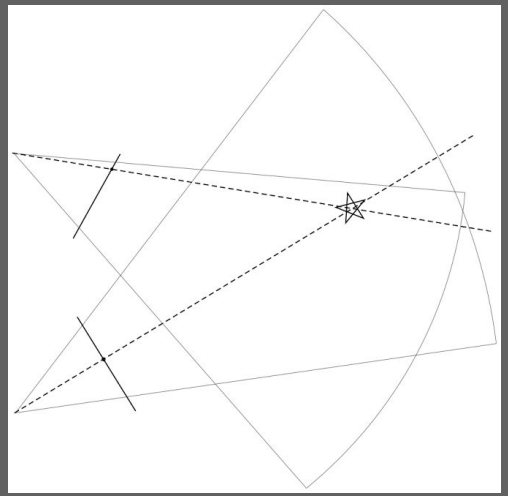
1D Motion-Tracking Prototype

Goals:

- Determine suitability of a vision system for the RoomPET project.
- Understand to what precision the position of the detector and target can be known during motion

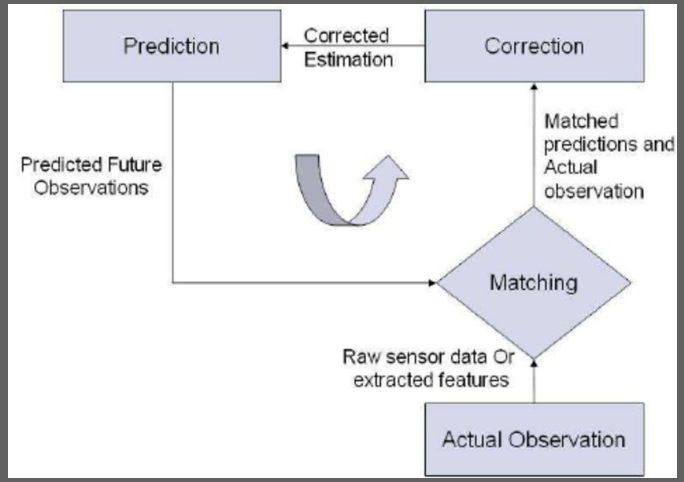
Camera Tracking Theory and Fundamentals

From Triangulation to Image Disparity



Challenge: Limited angular coverage due to position

Kalman Filtering

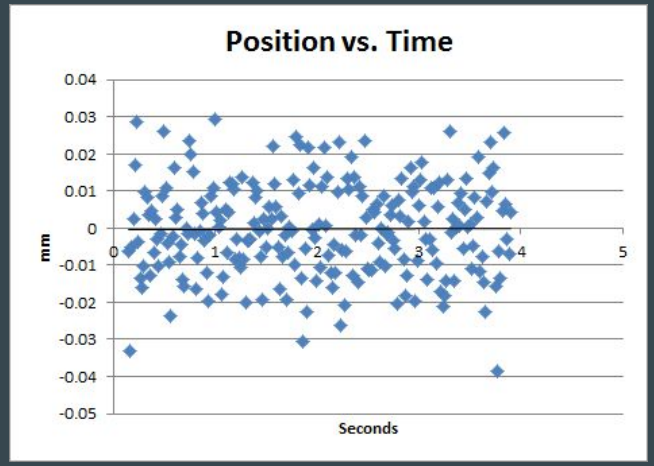


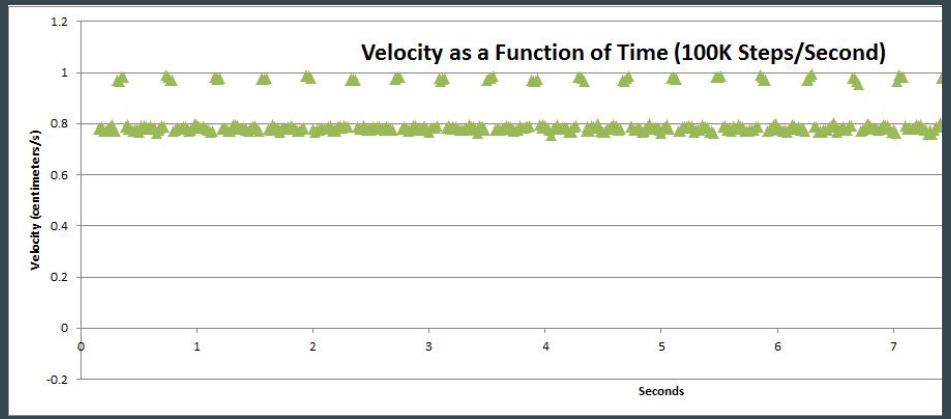
Challenge: Insufficient sampling due to motion

Error Identification

Types of Error Identified:

- Mechanical Errors
- Kalman Filter Induced Errors
- Random Errors
- Scale Error
- Offset Error





Goal: Understand relationship between error and tracking motion to produce certainty-level

Methods

1. Vision System Calibration

2. Isolation of Movement to Single Axis

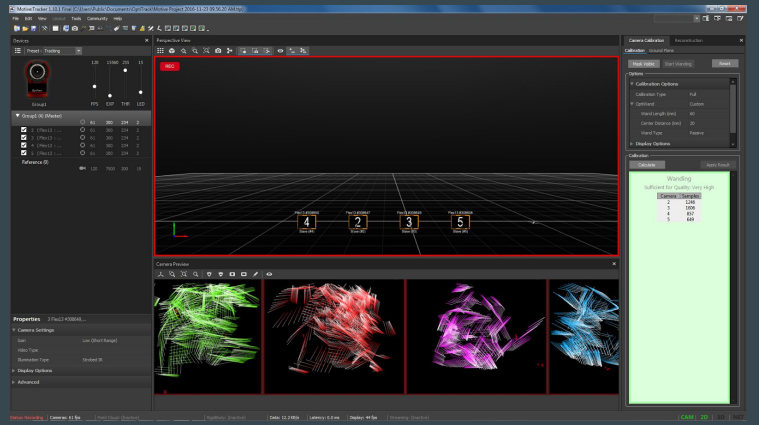
3. Computation of Real-Time Values

4. Validation of System Control

5. Statistical Analysis of System Performance

- Space-dependent metrics
- Time-dependent metrics
- Velocity-dependent metrics

1)



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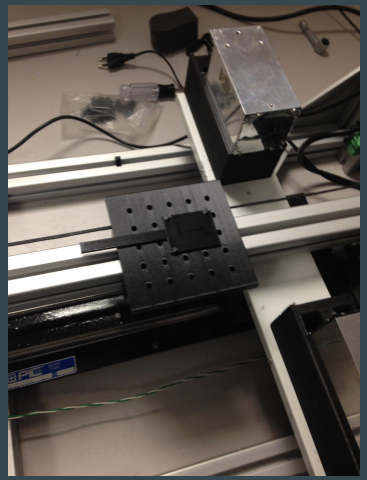
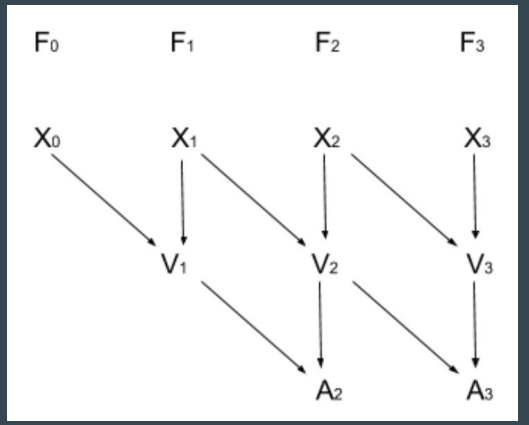




3)

Goal: Understand relationship between error and tracking motion

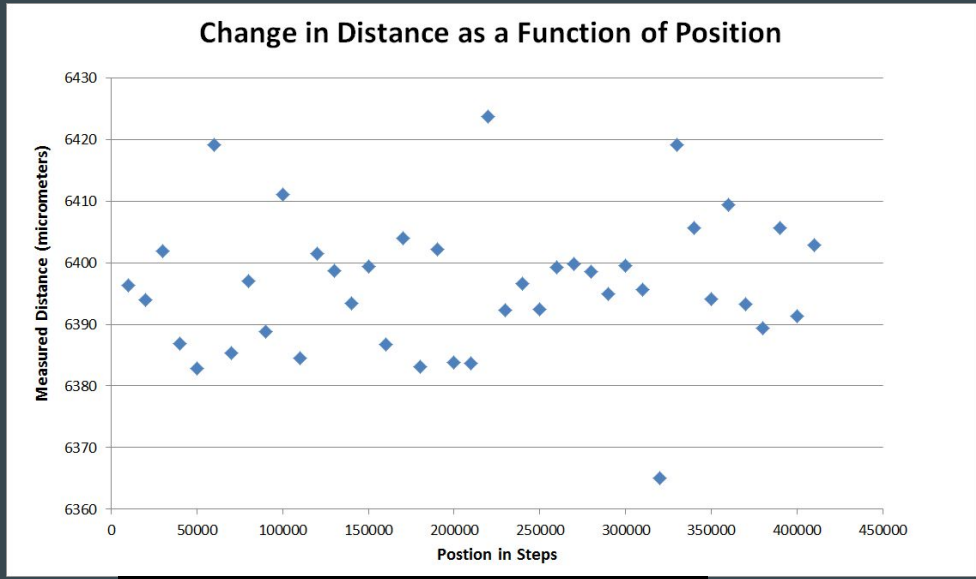
Validation of System Control

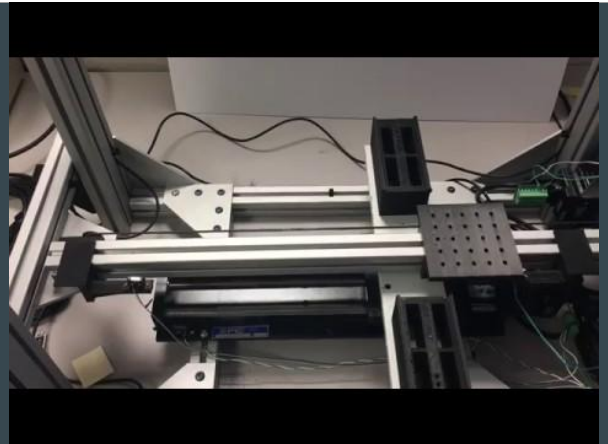
Method: Move stage at uniform increments of 10,000 steps along the track and acquire 7,000 samples at each position.

Analysis: Compute mean positions and distances between consecutive positions.

Results: Random error distribution with offset of 45 μm and std. of 10.49 μm. Largest error is under 100 μm.

Conclusion: The overall system performs in an accurate and dependable manner.





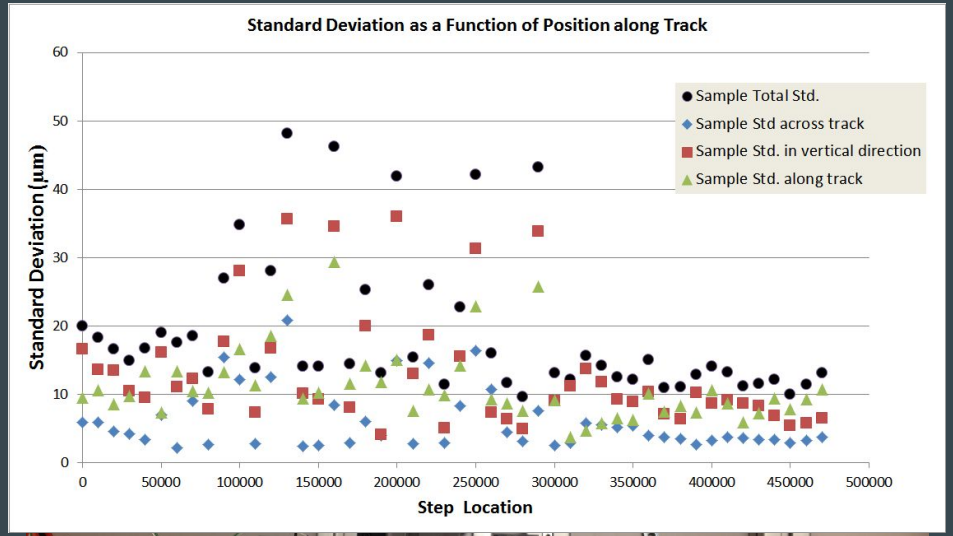
Spatially-Dependent Performance

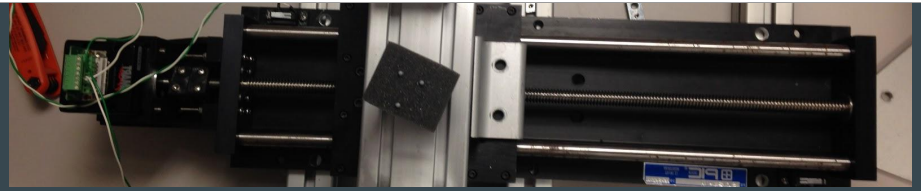
Method: Move stage at uniform increments of 5 mm along the track and acquire 7,000 samples at each position.

Analysis: Calculate total and coordinate standard deviation at each position.

Results: Vertical measurements contributed the most error. Coordinate positional standard deviation increases with distance away from all cameras.

Conclusions: Geometry of camera set-up affects confidence level of each coordinate.
Distance-dependent performance may prove problematic with an increased system size.





Time-Dependent Performance

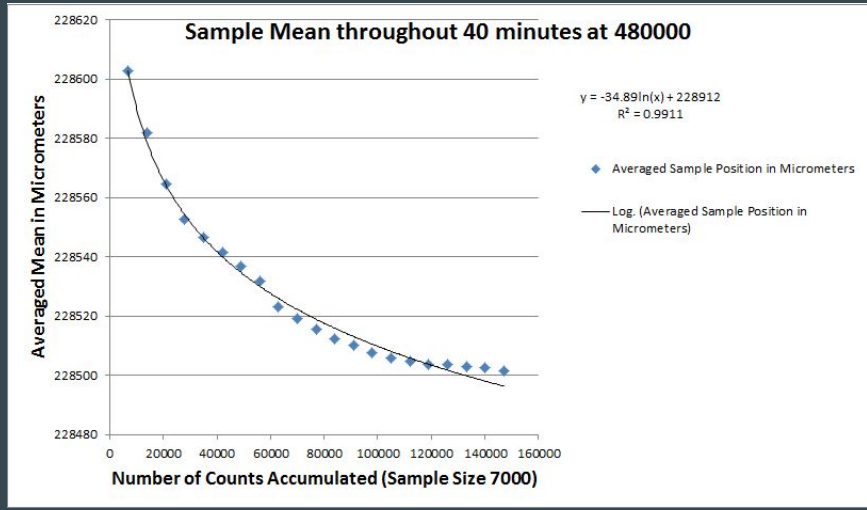
Method 1: Track stationary position of stage over 40 minutes. Compute 10 frame sample average positions.

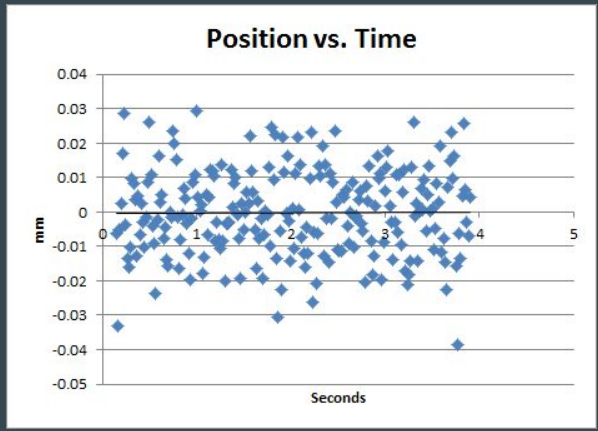
Method 2: Track stationary position of stage over 4 seconds without averaging.

Analysis: Plot positional data as a function of time.

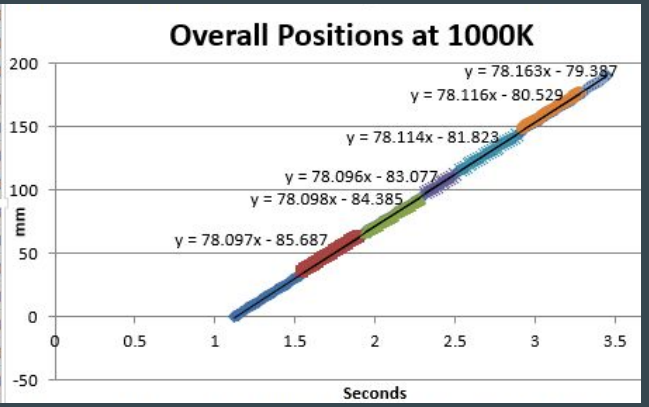
Results: In the long run, a shifting average changes by 300 μm overall. The change follows a logarithmic trend. In the short run, the reported position has less than a 1 μm standard deviation.

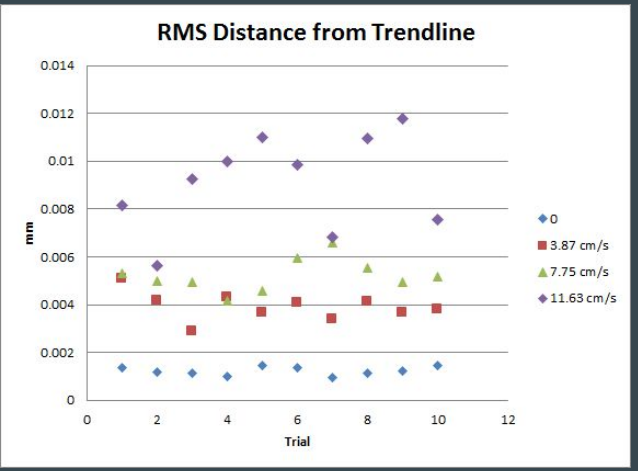
Conclusion: Shifting averages overtime cause a discrepancy in reporting the absolute position. An additional fiducial reference is necessary.





Velocity-Dependent Performance





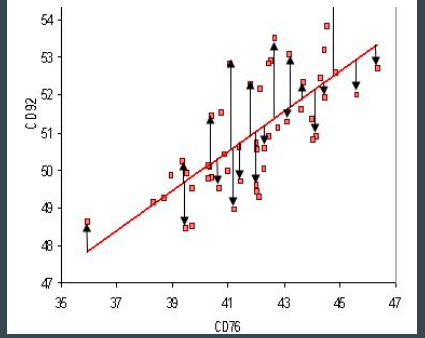
Method: Measure position of stage as it moves at constant velocity. Filter out mechanical errors and identify 'well-behaved' segments of data.

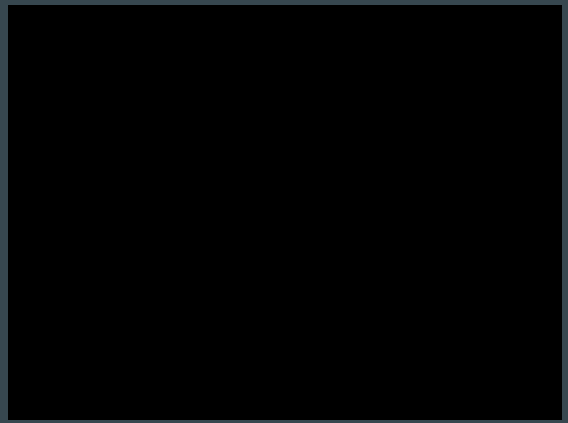
Analysis: Fit the positional data to linear trendlines. Compute RMS error between trendline positions and actual positions. Repeat this process for 10 segments at 3 velocities (3.7 cm/s, 7.4 cm/s, 11.1 cm/s)

Result: Higher velocities produce slightly higher RMS errors in positional data. All RMS errors were under 15 μm and well within the needed precision.

Conclusion: Velocity has minimal effect on performance at velocities under 12 cm/s. .

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n}}$$

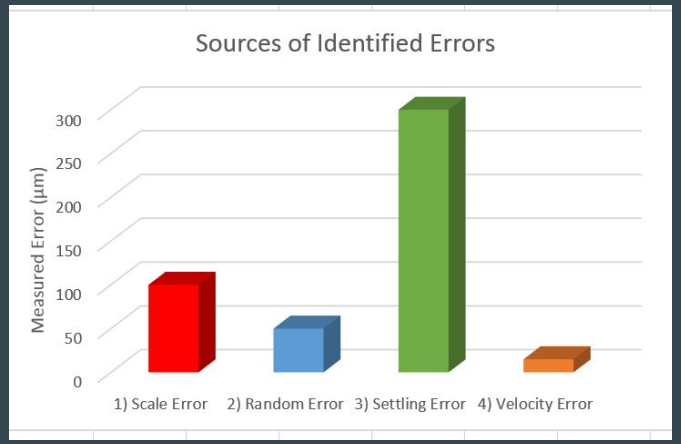




Discussion

Types of Error Identified:

1. **S**cale Error - Spatially dependent
2. Random Error - Vision system dependent
3. Settling Effect - Time dependent
4. Kalman Filtering Error - Velocity Dependent
5. Mechanical Error - System Dependent



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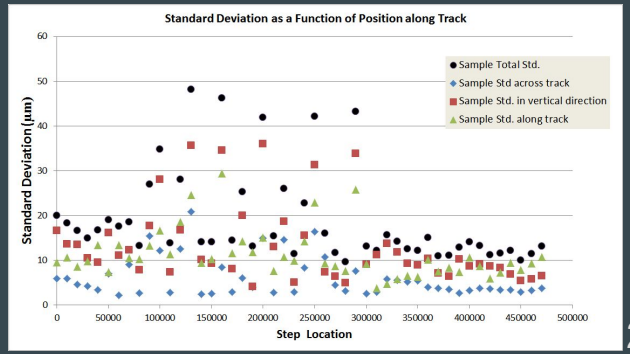

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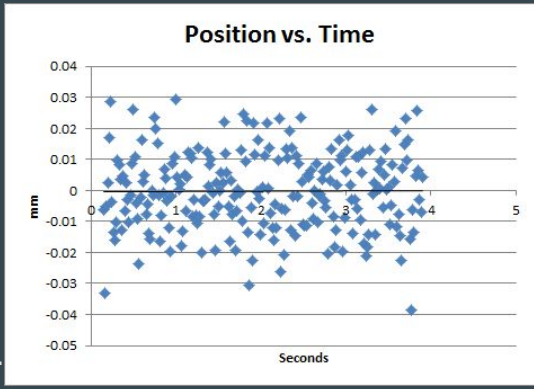

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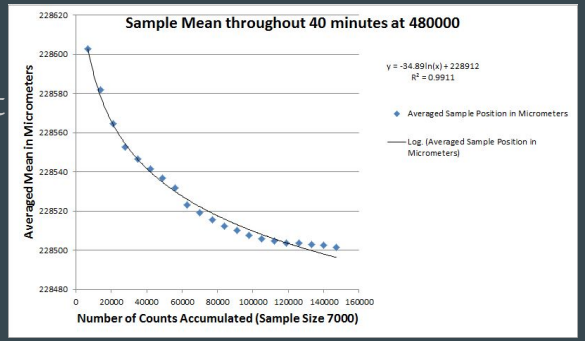

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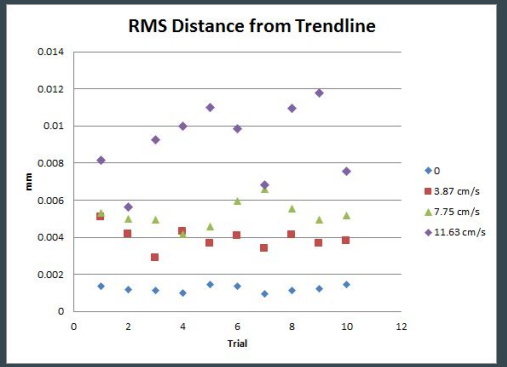

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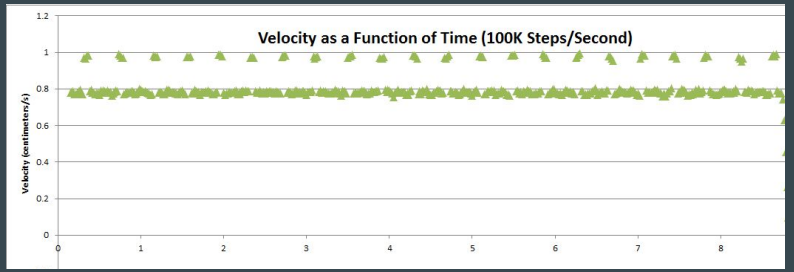
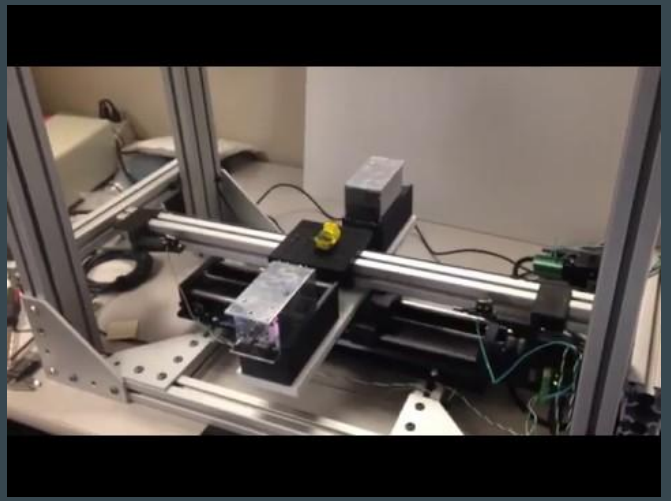


Conclusions

Future Implications:

- Angular Coverage dependency for camera set-up
- Strong tracking performance at low velocities
- Settling Effect calls for fiducial reference.
- Proof of Principle for RoomPET Vision System
- Future Tracking System Performance Protocol



Acknowledgements

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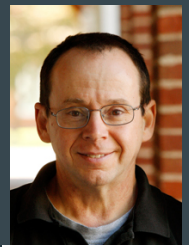

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Dr. Mark Smith

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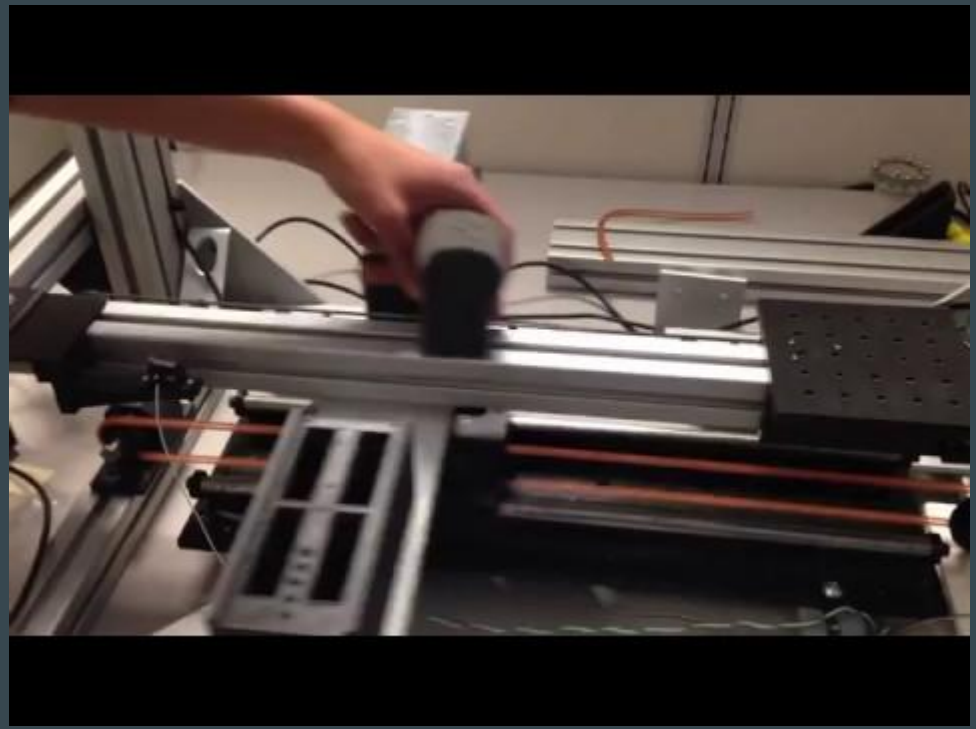
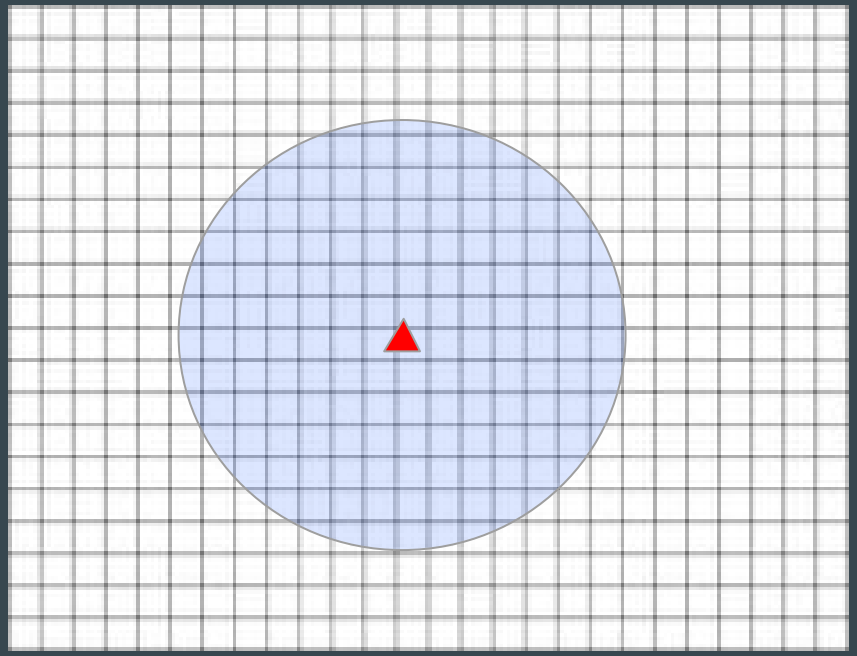
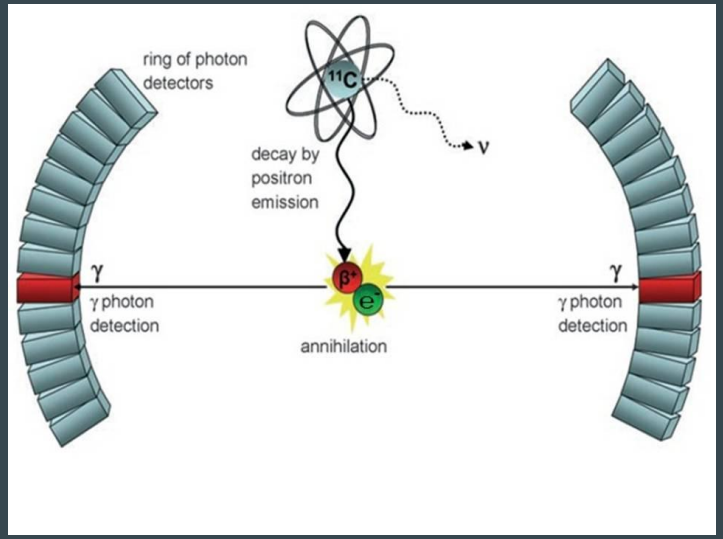


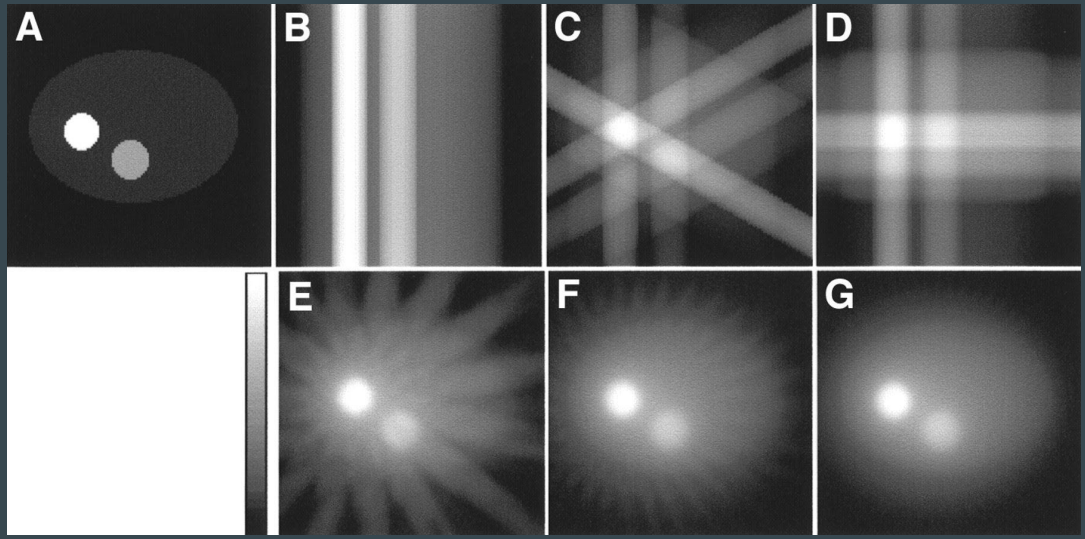
Granularity

- Retroreflectors cover multiple pixels
- Centroid of retroreflector sphere calculated by the spread across the pixels.
- Granularity no longer limits precision



PET Imaging Fundamentals





IR Tracking System Applications