3D Marker Tracking Cameras on Low-Cost Embedded Platforms

EECS 452: Digital Signal Processing Design Lab – Winter 2024
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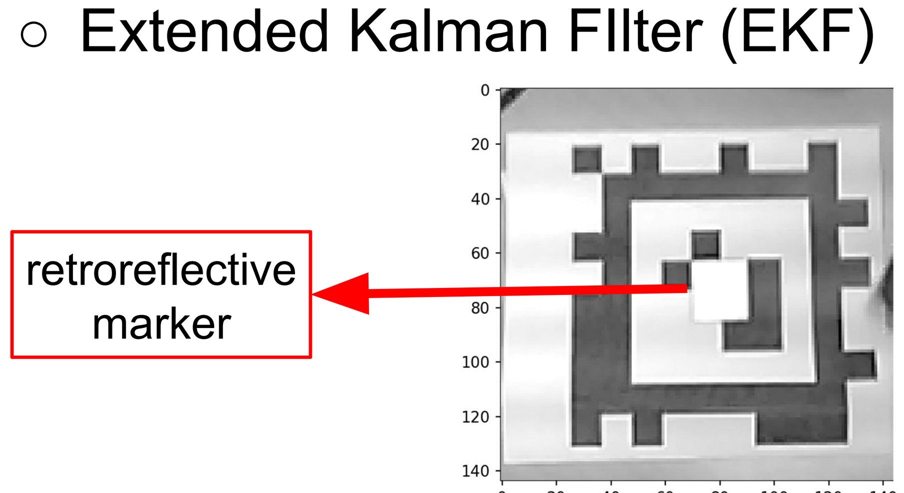
Motivation

The core goal of our project is to implement a low-cost embedded motion capture system that can accurately localize and track points in space, while running efficiently on easily-accessible hardware. This technology allows small game studios, independent filmmakers, and researchers to effectively localize points on objects at low cost.

Methods

- Image Processing
  - Detect retroreflective marker
  - Detection aggregation
  - Windowing
- Wireless Communication
  - UDP packets
    - Windowed image
    - Timestamp
    - Camera ID
- 3D Marker Localization
  - April Tag Detection (48h12 custom tag family with no center)
  - Extended Kalman FIlter (EKF)

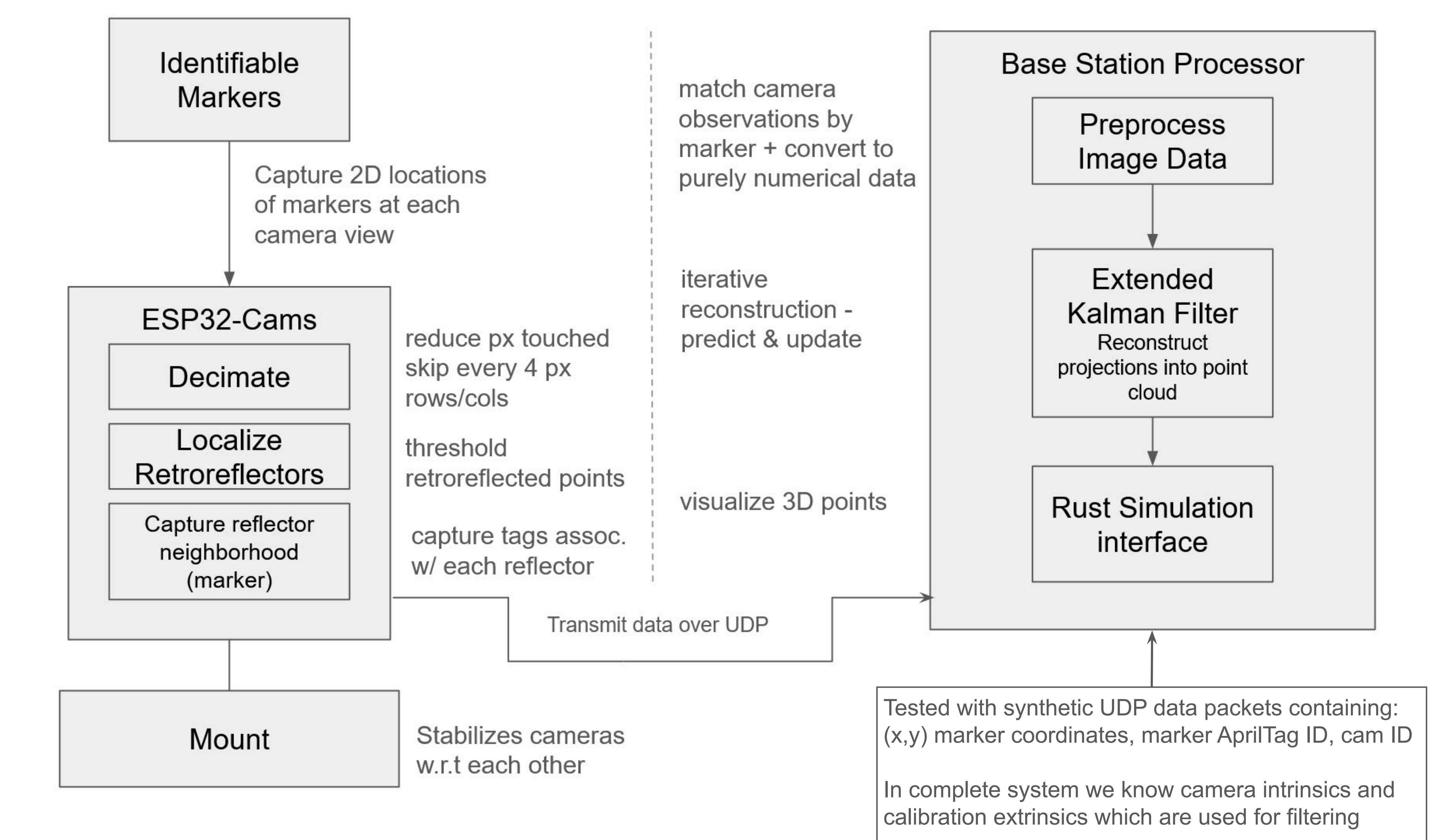


Windowed Tag Detection

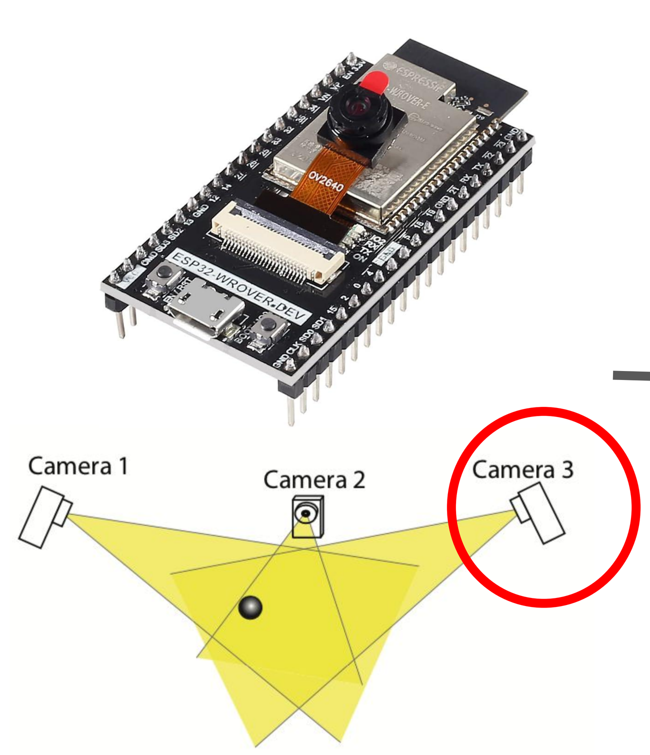
Challenges

- Accuracy of marker identification
  - Camera Extrinsics
  - Intermittent marker visibility through time
- Computational constraints of the ESP32-Cam

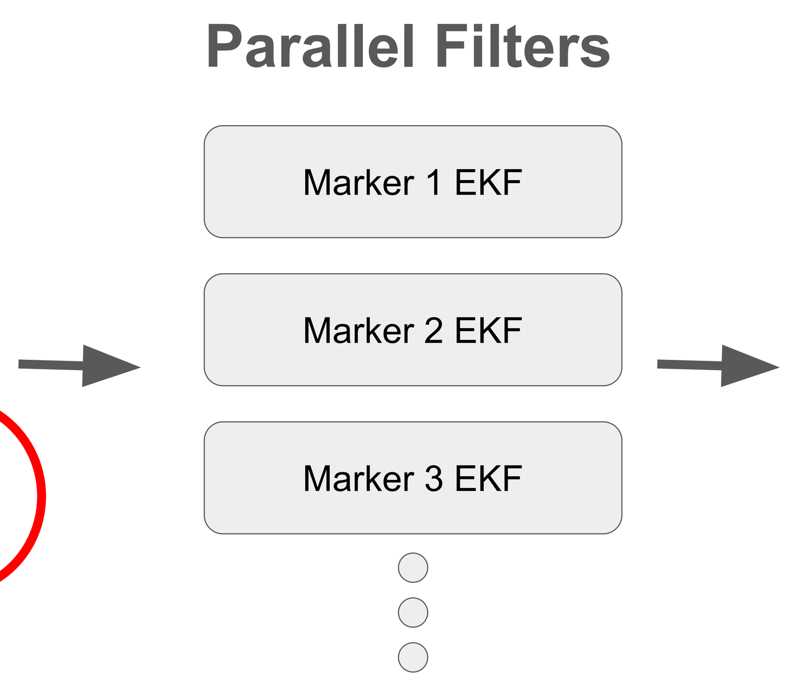
System Architecture



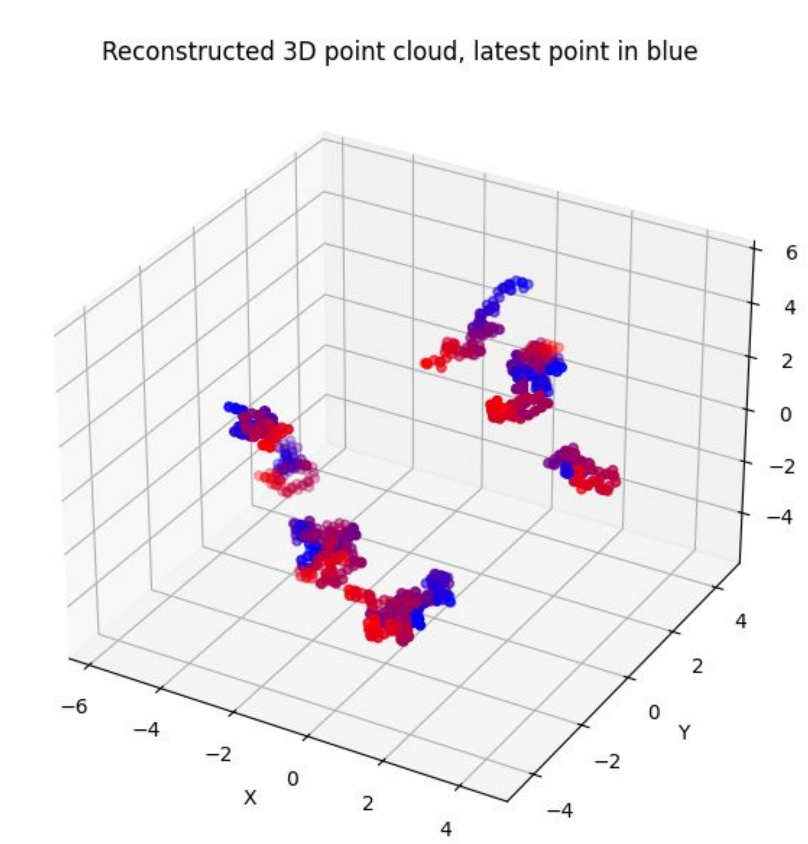
Reconstruction Algorithm



ESP32-Cam and Experimental Diagram



EKF Filter Bank

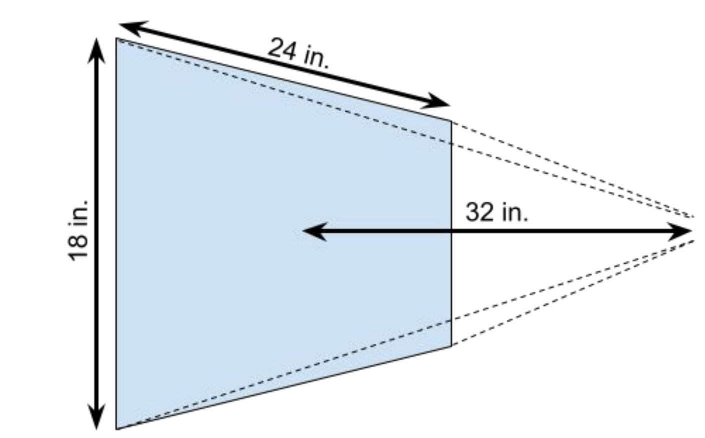


Reconstructed Points

1. Label measurement with marker ID according to April Tag detection
2. Initialize state vector (center point of the marker in 2D), covariance matrix, measurement noise covariance matrix
3. Linearize state measurement model for the given camera
4. Update state and covariance using the Kalman gain and difference between measurement of currently predicted state and new measurement
5. Iterate step 4 for measurements across cameras and time

Results

We found that our 3D marker tracking system is constrained by memory and processing speeds of the ESP32-Cam. This limited our image resolution and thus the area of detection.



Area of Detection

Without JPEG encoding, the ESP32-CAM only supports up to VGA (320x240). Accessing the image buffer within PSRAM is also slower than SRAM. Additionally, we experimented with sending the image over serial, but it was much slower than UDP.

# Tags	Average Frame Rate
1	100 FPS
2	70 FPS
3	50 FPS

Detection and Transmission Performance under Variable Load

We compared performance and accuracy of EKF versus UKF. Because EKF uses analytic linearization, it is faster. However, we expect UKF to be more accurate on the synthetic data.

Acknowledgements

Low-Cost, High-Accuracy Marker Localization by Stancic et al.

AprilTag2: Efficient and robust fiducial detection by Wang & Olson