Improving Walking Distance Estimation with Anomaly Detection Support

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***Abstract*—This study aims to improve the accuracy of walking distance estimations by using anomaly detection in anchor-based range measurements. Anomalous moments were identified in preprocessed data using a Kalman filter and the Chi-Square method based on the Mahalanobis distance. Walking distance during these moments was analyzed separately. The results show that the anomaly-supported approach improves the accuracy of distance estimation by reducing measurement errors.**

I. Introduction

Anchor-based distance measurements are widely used in applications such as indoor positioning, motion analysis, and walking distance estimation. However, measurement errors and anomalies can significantly degrade the accuracy of these calculations. In this study, anomaly detection was performed using a Kalman filter and Chi-Square statistics, and how walking distance estimations can be improved during anomalous periods was investigated. Additionally, LMS and KF-LMS methods were compared for walking path estimation.

II. Anomaly Detection: Kalman Filter and Chi-Square Method

A. Data Preparation and Filtering

Initially, anchor distance data collected under normal conditions was analyzed. To reduce sensor noise, a 1D Kalman filter was applied separately to each anchor measurement. During this filtering process:

- Previous estimates and error covariance were updated.
- Kalman gain was calculated.
- The predicted value was updated with new measurements.

B. Calculation of Chi-Square Scores

After applying the Kalman filter, sequential differences of the resulting data were calculated. The mean vector and covariance matrix were derived from these differences. Using this statistical summary, chi-square scores based on Mahalanobis distance were calculated as follows:

$$\chi^2 = (x-\mu)^T \Sigma^{-1} (x-\mu)$$

Scores exceeding a defined threshold were marked as anomalies. Movement during these periods was considered anomalous.

C. Movement Estimation During Anomalies

The amount of movement during the identified anomaly periods was calculated by summing the L2 norms of the difference vectors. This approach allowed us to determine the total walking distance occurring during anomalous periods.

III. Advanced Position Tracking and Anomaly Analysis

A. Position Estimation Methods

The distance measurements obtained from the anchors were processed using the following methods:

- **LMS:** Instantaneous position estimation using the Least Mean Squares method.
- **KF-LMS:** LMS results were improved using the Kalman filter.

B. Example 1: First Test Scenario

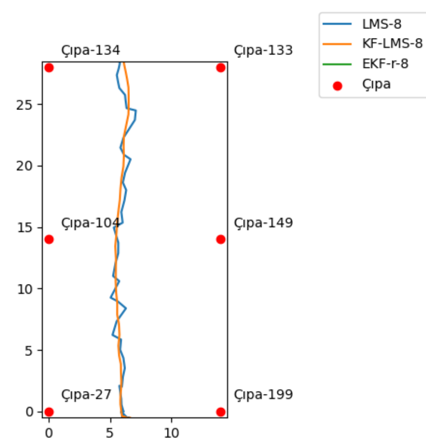


Fig. 1: Walking paths predicted using LMS and KF-LMS methods

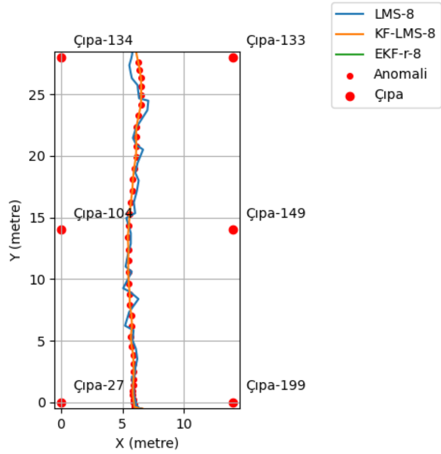


Fig. 2: Walking path with anomaly detections marked

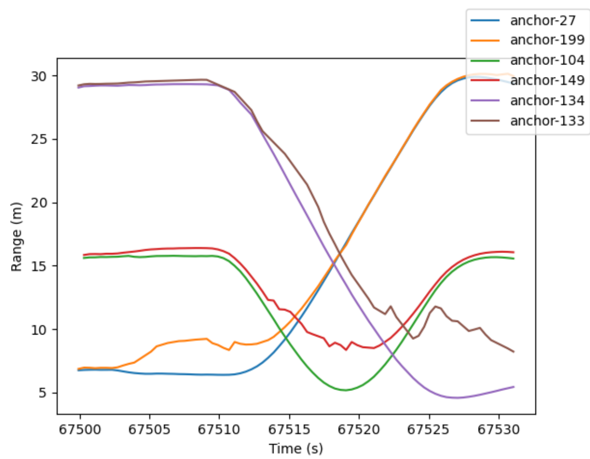


Fig. 3: Raw distance measurements

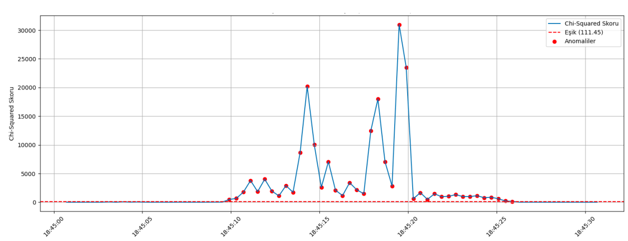
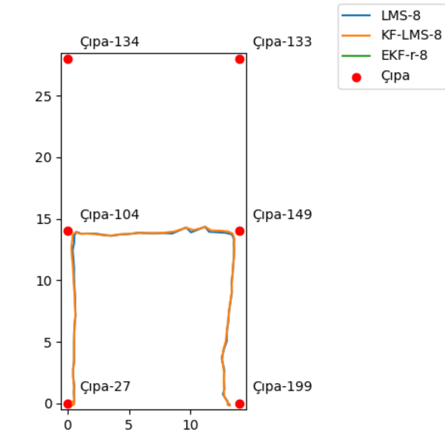


Fig. 4: Chi-Square threshold

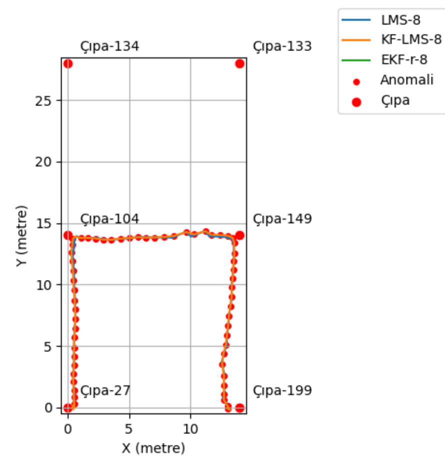
TABLE I: Estimated Total Walking Distance by Method (Example 1)

Method	Total Distance (m)
LMS	43.00
KF - LMS	33.64
Anomaly	27.73
Ground Truth	28.00

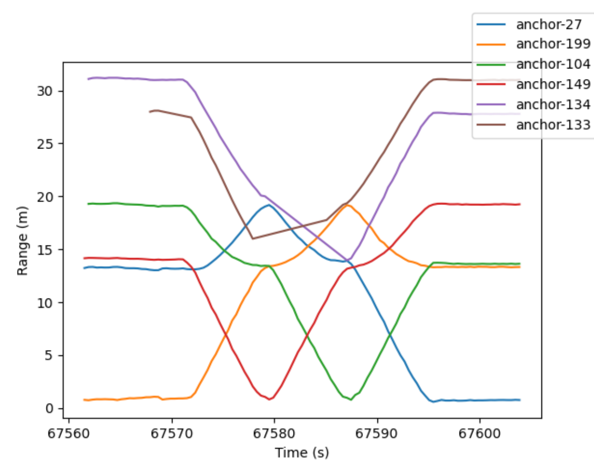
C. Example 2: Alternative Test Scenario



(a) Predicted walking paths



(b) Anomaly indications



(c) Raw distance measurements

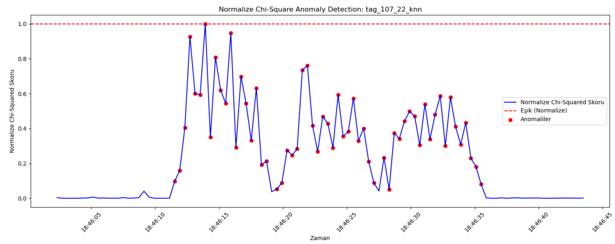


Fig. 6: Chi-Square threshold

TABLE II: Estimated Total Walking Distance by Method (Example 2)

Method	Total Distance (m)
LMS	42.57
KF - LMS	42.33
Anomaly	40.73
Ground Truth	**41.00**

D. *Trajectory and Path Length Calculation During Anomalies*

The walking paths from each method were compared graphically, and total path lengths were computed using the following formula:

$$\text{Path Length} = \sum_{i=1}^{n-1} ||\mathbf{x}_{i+1} - \mathbf{x}_i||$$

Additionally, in this study, where movement is evaluated as an indicator of anomaly, the walking distance during anomaly periods was calculated using the KF-LMS method:

$$\text{Anomaly Distance} = \sum_{i=1}^{n-1} ||\mathbf{x}_{i+1}^{anomaly} - \mathbf{x}_i^{anomaly}||$$

This analysis demonstrates that movement increases during anomalies and that this can be quantitatively evaluated based on total walking distance.

IV. Results and Evaluation

- While the LMS method produced the longest walking path, the Kalman filter-based methods offered more stable and smooth predictions.
- With Chi-Square-based anomaly detection, walking distance during anomalies was calculated accurately, and measurement errors during those periods were reduced.

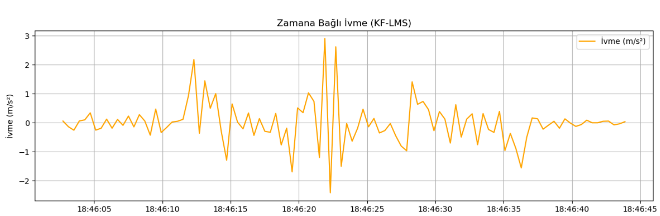


Fig. 7: Speed over time (Example 2)

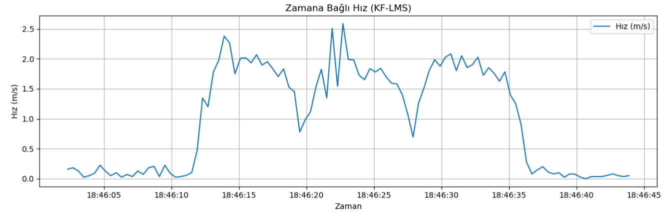


Fig. 8: Acceleration over time (Example 2)

Note: The selection of the threshold and the Q and R values used in positioning significantly affect the shape of the walking path and the estimation results. The threshold was kept low due to small vibrations caused by hand movements, as the normal data was collected while the person was standing still.

Currently to be optimized: Q, R values and threshold selection.

References