High-Precision Indoor Localization Using the Extended Kalman Filter Approach

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ABSTRACT

Indoor positioning and navigation have emerged as critical areas of research due to the limitations of GPS in enclosed environments. This study presents an innovative approach to high-precision indoor localization by employing the Extended Kalman Filter (EKF). Unlike traditional methods that often suffer from noise and multi-path effects, the EKF methodology accounts for nonlinearities and offers a recursive solution to estimate the state of dynamic systems. We deployed a sensor on a mobile robot that needs to move in an indoor environment while there is a moving obstacle that is moving around. Our findings demonstrate a significant accuracy in locating the obstacle while maneuvering inside the environment.

Keywords: Extended Kalman Filter, estimation strategies, target tracking, mobile robot

1. INTRODUCTION

Indoor localization has become a prominent area of research due to the scarcity of accurate yet cost-effective sensors. Consequently, numerous efforts have been made to enhance accuracy by leveraging filters, particularly predictor-corrector filters. These filters encompass both optimal and robust variants, with the Extended Kalman Filter (EKF) standing out as a well-established example of the former, showcasing effectiveness and precision across various applications.

In this study, a mobile robot is outfitted with sensors to measure distance and angle relative to a target. The robot is tasked with navigating within an indoor environment while evading a moving obstacle. Sensors capture the distance and angle of the target in relation to the robot, while additional sensors track the robot's position within the environment. The objective of the filter is to accurately estimate the locations of both the robot and the obstacle within the environment, compensating for the use of low-cost sensors with reliable accuracy.

The remainder of the paper is structured into four sections. Two sections provide a summary of the EKF algorithm and the model under examination, while the other two sections delve into the discussion of results and their conclusion.

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2. THE EXTENDED KALMAN FILTER

The EKF algorithm can be summarized as follows:

$$\mathit{Initialize}\ \hat{\mathbf{x}}_{o_{0|0}}, \hat{\mathbf{x}}_{0|0}$$
$$\hat{\mathbf{x}}_{o_{k|k-1}} = \mathbf{A}\hat{\mathbf{x}}_{o_{k-1|k-1}}$$
$$\hat{\mathbf{z}}_{o_{k|k-1}} = \hat{\mathbf{x}}_{o_{k|k-1}}$$
$$\mathbf{P}_{o_{k|k-1}} = \mathbf{A}\mathbf{P}_{o_{k-1|k-1}}\mathbf{A}^{\mathbf{T}} + \mathbf{Q}_o$$

$$e_{z_{o_{k|k-1}}} = \mathbf{z}_{o_k} - \hat{\mathbf{z}}_{o_{k|k-1}}$$
$$\mathbf{K}_{o_k} = \mathbf{P}_{o_{k|k-1}}\mathbf{H}_o^T\left(\mathbf{H}_o\mathbf{P}_{o_{k|k-1}}\mathbf{H}_o^T + \mathbf{R}_o\right)^{-1},$$
$$\hat{\mathbf{x}}_{o_{k|k}} = \hat{\mathbf{x}}_{o_{k|k-1}} + \mathbf{K}_{o_k}\left(e_{z_{o_{k|k-1}}}\right)$$
$$\mathbf{P}_{o_{k|k}} = \left(\mathbf{I} - \mathbf{K}_{o_k}\mathbf{H}_o\right)\mathbf{P}_{o_{k|k-1}}$$

Then

$$\hat{\mathbf{x}}_{k|k-1} = \mathbf{A}\hat{\mathbf{x}}_{k|k-1} + \mathbf{A}\hat{\mathbf{x}}_{o_{k-1|k-1}} - \hat{\mathbf{x}}_{o_{k|k}}$$
$$\hat{\mathbf{z}}_{k|k-1} = \mathbf{h}\left(\hat{\mathbf{x}}_{k|k-1}\right)$$
$$e_{z_{k|k-1}} = \mathbf{z}_k - \hat{\mathbf{z}}_{k|k-1}$$
$$\mathbf{P}_{k|k-1} = \mathbf{A}\mathbf{P}_{k-1|k-1}\mathbf{A}^{\mathbf{T}} + \mathbf{Q}$$
$$\mathbf{K}_k = \mathbf{P}_{k|k-1}\mathbf{H}_k^T\left(\mathbf{H}_k\mathbf{P}_{k|k-1}\mathbf{H}_k^T + \mathbf{R}_k\right)^{-1},$$
$$\mathbf{H}_k = \frac{\partial \mathbf{h}}{\partial \hat{\mathbf{x}}_{k|k-1}}$$
$$\hat{\mathbf{x}}_{k|k} = \hat{\mathbf{x}}_{k|k-1} + \mathbf{K}_k\left(e_{z_{k|k-1}}\right)$$
$$\mathbf{P}_{k|k} = (\mathbf{I} - \mathbf{K}_k\,\mathbf{H})\mathbf{P}_{k|k-1}$$

Where the state and measurement vectors are defined as $\mathbf{x}$ and $\boldsymbol{z}$, respectively. k represents the time step, while $k|k-1$ and $k|k$ represent the a priori, and the a posteriori values, respectively. **A,** $\mathbf{H}, \mathbf{P}$ and **K** are the state, measurement, covariance and correction matrices, respectively. The error vector is e, while $\hat{a}$ is the estimate of a. $\mathbf{Q}$ and $\mathbf{R}$ are the system and measurement covariance matrices.

3. UAV/TARGET TRACKING MODEL

The system can be summarized as follows [97]:

$$\begin{bmatrix}\mathbf{x}_{o_k}\\ \mathbf{x}_{t_k}\\ \mathbf{x}_k\end{bmatrix} = \begin{bmatrix}\mathbf{A} & \mathbf{0}\\ \mathbf{A} & \mathbf{0}\\ \mathbf{I} & -\mathbf{I}\end{bmatrix}\begin{bmatrix}\mathbf{x}_{o_{k-1}}\\ \mathbf{x}_{t_{k-1}}\\ \mathbf{x}_{k-1}\end{bmatrix} + \begin{bmatrix}\mathbf{w}_{o_{k-1}}\\ \mathbf{w}_{t_{k-1}}\\ 0\end{bmatrix}$$

$$\mathbf{z}_k = \begin{bmatrix} \mathbf{H}\mathbf{x}_{o_k} \\ \mathbf{h}(\mathbf{x}_k) \end{bmatrix}^T + \mathbf{v}_k$$

Where $\mathbf{w}$ and $\boldsymbol{v}$ are the system and measurement noise vectors, respectively. The required paths for both robot and obstacle are shown in figure 1.

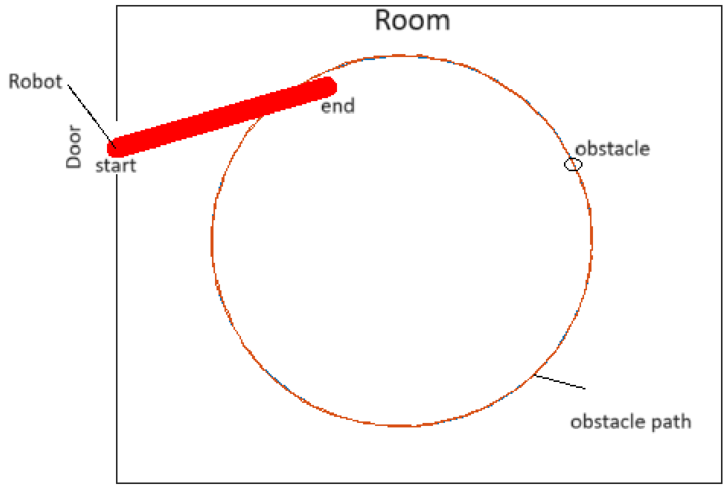

Figure 1. Robot and obstacle trajectories in the environment

4. SIMULATION RESULTS

We utilized the algorithm outlined in Section 2 to derive the locations of the robot and the obstacle as described in Section 3. The results are presented in Figure 2 and Table 1. The maximum absolute error (MAE) and the root mean squared error (RMSE) for the errors were determined to be less than 1.61 cm and less than 0.88 cm, respectively.

These errors accounted for less than 1.7% of the maximum absolute value. This demonstrates that the Extended Kalman Filter (EKF) was a suitable choice for accurately estimating the locations of the robot and obstacle within an indoor environment.

Table 1. RMSE and MAE for the results.

	$RMSE$		MAE	
	$Target$	$Observer$	$Target$	$Observer$
x	0.8415	0.0091	1.6833	0.0283
y	0.8764	0.0093	1.8979	0.0312
V_x	0.0134	0.0091	0.0405	0.0270
V_y	0.0145	0.0087	0.0462	0.0255

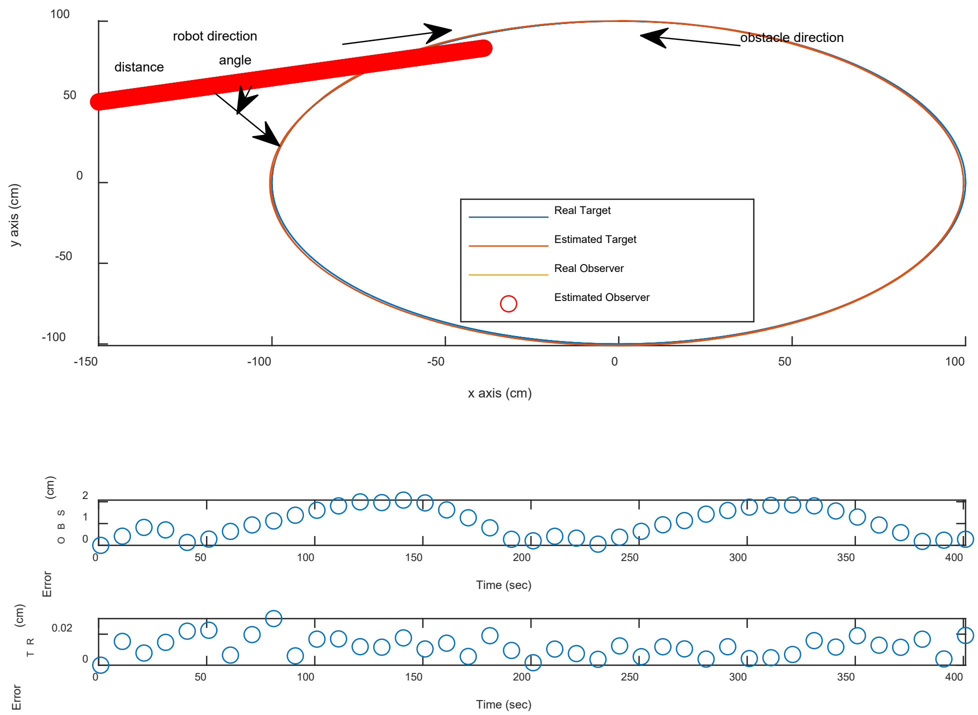

Figure 2. The trajectories of the observer and the target, and their relative errors.

5. CONCLUSIONS AND FUTURE WORK

In this paper, the Extended Kalman Filter (EKF) was employed to precisely estimate the location of a robot navigating within an indoor environment, while an obstacle moved in circular paths within the same environment. Furthermore, it accurately estimated the target's location. The results underscore the effectiveness and precision of the EKF in such application scenarios.

For future endeavors, an experimental setup will be employed to validate the simulated results.

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