Assignment 4 Report: Line-based Extended Kalman Filter for Robot Localization

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1 Introduction

This report details my solution to the tasks outlined in Assignment 4, where I implemented and validated the components of a Line-based Extended Kalman Filter (EKF) for robot localization. The assignment involved tasks ranging from state prediction to state update, measurement association, and full incremental localization in simulation.

2 Task 1: Transition Function

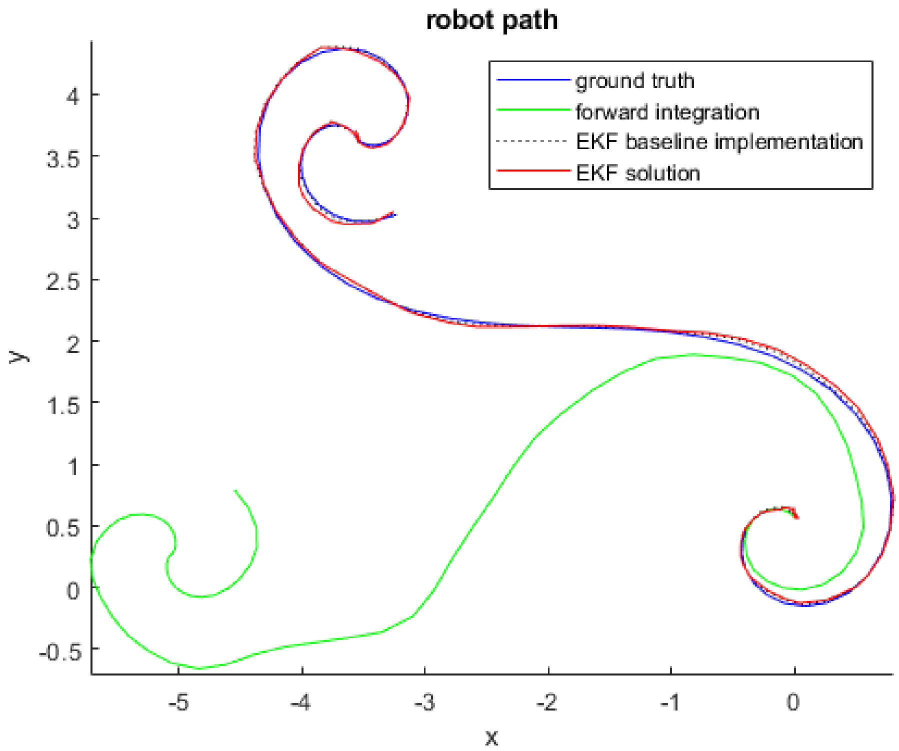
The first task was to implement the `transitionFunction`, which predicts the robot's state at the next time step based on the current state, control inputs, and the robot's differential drive motion model.

Implementation

I computed the predicted state f using the motion model equations. I also derived the Jacobians F_x and F_u to model how the state changes with respect to the current state and control inputs. The function was validated using `validateTransitionFunction`, which confirmed its correctness.

Validation

After validation, I observed a plotted robot path, where the forward integration of control inputs accurately depicted the robot's trajectory. This demonstrated that the transition function was working as intended.



figureRobot Path for Transition Function Validation

3 Task 2: Measurement Function

In this task, I implemented the `measurementFunction`, which computes the predicted measurement of a map feature as observed by the robot. It also calculates the Jacobian with respect to the state.

Implementation

The measurement function transforms lines from the map's world frame to the robot's body frame. I derived the Jacobian H_x to model the relationship between the measurement and the robot's state. The function includes a normalization step to ensure consistency in line representation.

Validation

The function was validated using `validateMeasurementFunction`, and the results confirmed the correctness of the implementation.

4 Task 3: Measurement Association

This task required implementing `associateMeasurements`, which associates the robot's observations with map features using the Mahalanobis distance.

Implementation

I evaluated the Mahalanobis distances between measurements and map features, then matched each measurement to the nearest map feature within a validation gate. The innovations, Jacobians, and covariances were computed for use in the EKF update step.

Validation

The function was validated with `validateAssociations`, which confirmed that the associations were computed correctly.

5 Task 4: Filter Step

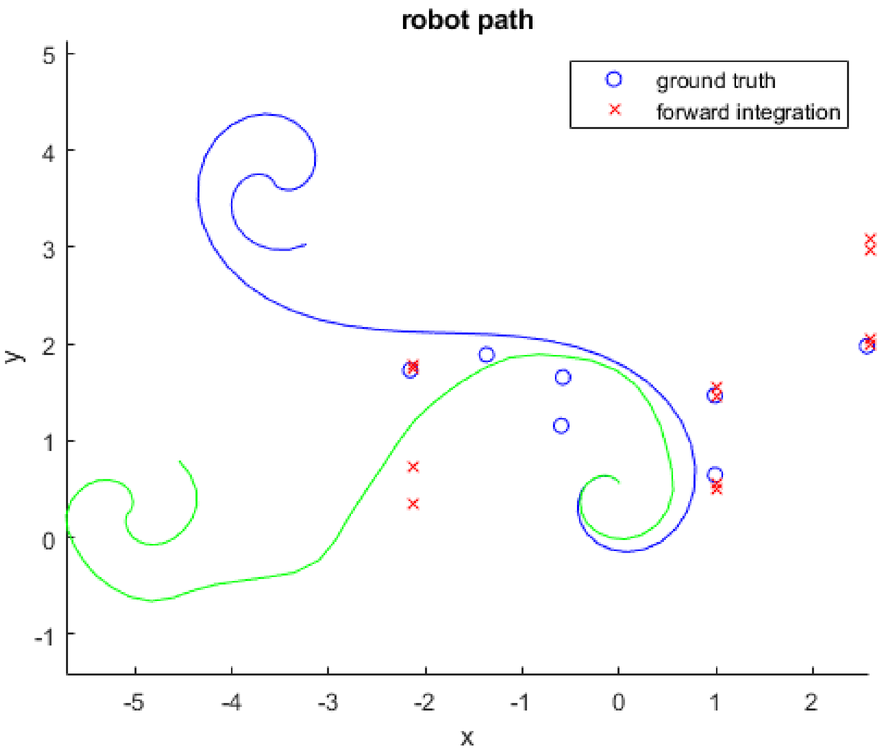
The `filterStep` function implements the EKF update step, combining state prediction, measurement association, and state correction.

Implementation

I used the previously implemented `transitionFunction` for state propagation and `associateMeasurements` for measurement association. The innovation covariance matrix S, Kalman gain K, and updated state and covariance were calculated based on the EKF equations.

Validation

The function was validated using `validateFilter`. The EKF solution closely followed the ground truth, as shown in the plot of the robot's path.



figureRobot Path Comparing EKF Solution, Ground Truth, and Forward Integration

6 Task 5: Incremental Localization

In this task, I combined all components to implement `incrementalLocalization`, which processes laser scan data and control inputs to estimate the robot's pose incrementally.

Implementation

I extracted lines from the laser scan using `extractLinesPolar`, transformed them into predicted measurements using `measurementFunction`, and updated the robot's pose using `filterStep`. I also added a visualization of the measured and predicted lines.

Simulation Results

I tested the implementation in the CoppeliaSim simulator using the provided `vrepSimulation` script. The robot moved correctly, and the EKF successfully localized the robot based on the laser scan and map data.

figureComparison of Measured and Predicted Lines

7 Conclusion

Through systematic implementation and validation of each task, I successfully implemented the EKF-based localization system. The final simulation in CoppeliaSim demonstrated the accuracy and robustness of the system. This assignment enhanced my understanding of Kalman filtering, measurement association, and real-world robot localization.