Sub-Terranean Navigation Challenge

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***Abstract*—This document provides a 6-page IEEE conference-style template for your final project report. Your challenge is to estimate 2D position (x, y) and orientation (yaw) of a robot in a motion capture arena without GPS. You must fuse data from IMUs and Time-of-Flight (ToF) distance sensors while dealing with potential sensor noise and environmental anomalies (e.g., walls with holes). Present your sensor fusion method, experimental results, and analysis of performance versus ground truth.**

***Index Terms*—Sensor fusion, Time-of-Flight, Inertial measurement, State estimation, Robotics**

I. Introduction

This final project simulates a "Sub-Terranean Navigation Challenge," wherein a wheeled robot must navigate without GPS inside a confined arena. Your team is required to design an estimation algorithm for real-time tracking of the robot's 2D position and yaw. You will fuse data from:

- An STM Nucleo IKS02A1 board (accelerometers, gyroscope, magnetometer)
- X-NUCLEO-53L1A1 ToF sensors (one forward-facing, two sideways)

Ground truth will be captured via a motion capture system, and your estimator will be evaluated against it.

Use this template to structure your 6-page (maximum) report. References may exceed the page limit (i.e., total of $6 + n$ pages). Section III details what should appear in your methodology, while Section IV outlines experiments and results. Maintain IEEE formatting and numbering conventions.

II. Background & Related Work

Briefly review sensor fusion for robotics, highlighting relevant techniques such as:

- **Extended Kalman Filter (EKF)** or **Unscented Kalman Filter (UKF)**
- **Complementary filters** for combining low/high-frequency sensor data
- **Particle filters** (if applicable)

Discuss prior implementations of inertial and distance sensor fusion in robotics literature, referencing works that influenced your approach.

If you have funding acknowledgments, include them here.

III. Methodology

Here, describe your overall design. You might separate the explanation into subsections:

A. System Model

Clearly define your state vector, e.g.,

$$\mathbf{x} = [\,x,\, y,\, \theta,\, \dot{x},\, \dot{y}, \dots]^\top.$$

Include any relevant equations of motion and measurement models:

$$\mathbf{x}_{k+1} = f(\mathbf{x}_k, \mathbf{u}_k) + \mathbf{w}_k, \tag{1}$$

$$\mathbf{z}_k = h(\mathbf{x}_k) + \mathbf{v}_k, \tag{2}$$

where $\mathbf{w}_k$ and $\mathbf{v}_k$ represent process and measurement noise, respectively. Explain how accelerometers, gyroscopes, magnetometers, and ToF data feed into the equations.

B. Sensor Fusion Algorithm

If you chose an Extended Kalman Filter (EKF), detail its prediction and update steps. Discuss any calibration steps (e.g., bias removal, sensor alignment). Include equations or references for matrix definitions (Jacobian, covariance, etc.). For instance:

$$\mathbf{K}_k = \mathbf{P}_{k|k-1}\,\mathbf{H}_k^\top \big(\mathbf{H}_k\,\mathbf{P}_{k|k-1}\,\mathbf{H}_k^\top + \mathbf{R}_k\big)^{-1}.$$

C. Implementation Details

State how data is read in from the provided datasets (e.g., sampling rate, time synchronization, outlier handling). If you are handling real-time streams, discuss your approach for concurrency or sensor timing.

IV. Experiments & Results

A. Experimental Setup

Summarize the provided *training* and *testing* datasets:

- Straight-line dataset (Task 1)
- Circuit driving dataset (Task 2)

Include any parameter choices (e.g., noise covariances, filter tuning).

B. Quantitative Results

Compare estimated position/orientation with ground-truth motion capture. Present tables or plots illustrating error metrics (RMSE, final position error, etc.). An example table:

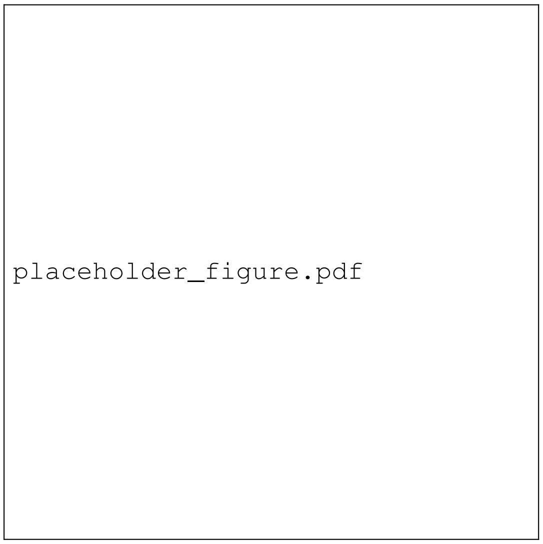

Fig. 1. Placeholder for your system diagram or sensor layout.

TABLE I
SAMPLE ACCURACY METRICS

Dataset	**RMSE**	**Max Error**
Straight-line	0.10 m	0.15 m
Circuit	0.15 m	0.25 m

C. Qualitative Observations

Show trajectory plots and discuss how well your estimator stayed aligned with ground truth, especially when encountering sensor anomalies.

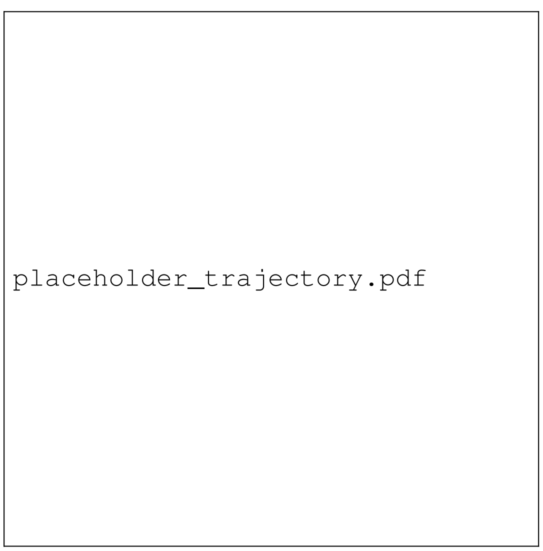

Fig. 2. Placeholder for a trajectory comparison figure. Plot both the estimated path and the ground truth.

V. DISCUSSION

Reflect on how sensor noise or wall holes affected ToF readings and how you mitigated that (e.g., outlier rejection). Highlight strengths (e.g., robust to certain disturbances) and weaknesses (e.g., magnetometer drift in certain arenas). Address possible improvements if you had more time or resources (advanced filters, additional sensors, etc.).

VI. CONCLUSION & FUTURE WORK

Conclude with a concise summary of:

- Your overall approach to sensor fusion
- Main results achieved
- Key lessons learned

Suggest how others might expand upon or improve your methods in subsequent projects.

ACKNOWLEDGMENTS

If you wish, acknowledge team members, course instructors, or any funding sources here.

REFERENCES

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