Robust Localization Techniques for Autonomous Systems in GPS-Denied Environments

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Abstract
Navigation is an essential part of our everyday life. One of the most used and reliable techniques used for localization is GPS. Few examples where GPA plays a major role are in navigation of autonomous vehicles such as drones, underwater vehicles, and mobile robots. As GPS works correctly in most scenarios there are situations where GPS data can't be reliable,for example cities with high rise building, underwater exploration, indoors,etc. In this paper we will discuss different robust localization techniques designed for autonomous systems where GPS data is unavailable.

Keywords: Navigation, Localization, Visual Odometry, Simultaneous Localization and Mapping, sensor fusion, machine learning

Introduction

Geographic Positioning System (GPS) is one of the means that is widely used to locate and provide navigation assistance on earth. But GPS signals are often unreliable in underwater, underground and places with tall buildings. The standard way is to use a combination of Inertial Measurement Unit (IMU) and GPS for positioning. IMU data is used to predict the upcoming states and GPS data is used to update the position. For GPS deficient places, various other techniques are used as an alternative andwill be discussed in this paper. Different challenges faced in GPS denied environments are as follows: -

1. Drift and noise posing problems of sensor limitations.
2. Dynamic data can because discrepancy in sensor data

Methodology

Different localization techniques that can be used are as follows: -

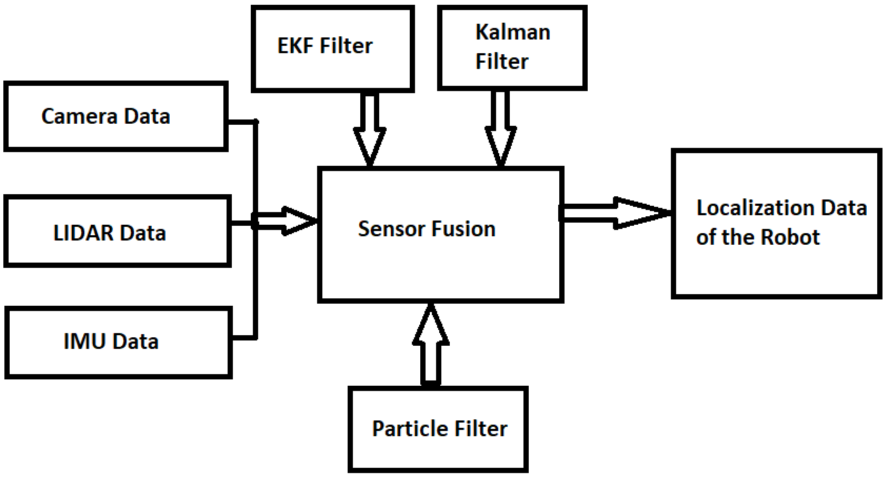
1. Simultaneous Localization and Mapping (SLAM): - SLAM is an algorithm that enables vehicles to build a map without any initial data and simultaneously localize itself. There are different ways SLAM can be implemented as mentioned below: -

- Visual SLAM: - This algorithm uses a camera onboard the robot to build the map and localize itself with the camera feedback. Few limitations to these techniques present themselves in foggy or dynamic environments.
- LIDAR SLAM: - In this localization technique, a robot uses data received from onboard LIDAR sensors to build a map. One of the limitations of this method is that the computational costs are very high.

2. Inertial Navigation Systems (INS): - In this technique a gyroscope and a accelerometer is used to determine the location using motion dynamics. One of the limitations of this technique is that the error gets accumulated over time which can lead to incorrect data.
3. Sensor Fusion: - This method integrates output from different sensors to build a map. The most popular sensor fusion techniques are as follows: -

- Kalman Filter (KF): - This method is reliable in case of linear systems.

- Extended Kalman filter: - These filters are good for linear systems with different estimates.
- Particle filter: - These are best technique to be used in cases of nonlinear systems and non-Gaussiansystems.



4. Machine Learning for Localization: - This ML technique works by learning patterns from sensor data and updating the dynamic map as the robot learns and moves.
5. Using Magnetic data of earth to localize by implementing different sensor fusion techniques.

Future Scope

Research continues to focus on improving localization robustness through:

- Resilient SLAM algorithms: Adaptive to dynamic and feature-sparse environments.
- Advanced sensor fusion frameworks: Incorporating machine learning for real-time optimization.
- Collaborative multi-agent systems: Enhancing collective situational awareness.
- Quantum localization techniques: Potentially revolutionizing precision through quantum sensor technologies.

Conclusion

Robust localization in GPS-denied environments remains a critical challenge for autonomous systems. By leveraging advancements in SLAM, visual odometry, inertial navigation, and sensor fusion, these systems can achieve high accuracy and reliability. Continued research and integration of machine learning techniques will further enhance the capabilities of autonomous systems, opening new possibilities for operations in complex and challenging environments.

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