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LOCALIZATION OF A QUADCOPTER IN AN UNKNOWN ENVIRONMENT USING MAGNETIC ANOMALY OF EARTH

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Abstract

The topic of navigation in GPS denied environment still faces lot of challenges. Active research has been going on to improve navigation in this uncharted terrain. Robust localization techniques are essential to ensure accurate navigation and situational awareness, particularly for autonomous systems, robotics, and drones operating in areas without reliable GPS signals. Few existing techniques that exist often rely on a combination of alternative sensors and algorithms to estimate position accurately. Common approaches include the use of LiDAR and visual-inertial odometry (VIO), which combine camera-based visual data with inertial measurements to track movement and estimate location. Simultaneous Localization and Mapping (SLAM) algorithms are also widely used; they enable systems to build and update a map of the environment while concurrently estimating their position within it. Additionally, technologies like magnetic field mapping, Wi-Fi signal fingerprinting, and ultra-wideband (UWB) systems offer solutions for localization by leveraging environmental cues and infrastructure when GPS is unavailable. By fusing data from multiple sources, these techniques improve resilience and adaptability in dynamic, cluttered, or low-visibility settings, making localization in GPS-denied environments more reliable and robust. In this paper a simulation of a quadcopter moving in a circular trajectory is made in MATLAB, a EKF and a PF is developed for state estimation and the results are compared for better accuracy.
Keywords: Navigation, Localization, Global Positioning System (GPS), Internal Measurement Unit (IMU), Maximum Likelihood(ML), Extended Kalman Filter (EKF)

I. 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 such as SLAM, vision aided navigation, magnetic anomaly of earth, star tracking, gravity gradiometers, etc. SLAM is a localization technique in which the robot creates a map of the surrounding and keeps updating it with every feedback it gets from the onboard sensors. For this project we are focusing solely on using combination of IMU and magnetic anomaly of earth for localization of a quadcopter. A magnetic anomaly map of Kentucky Tennessee [15] was downloaded from the web and is used as reference for this project. A detailed map analysis is done to understand the quality of the data. During the analysis a significant problem came to light because of the absence of magnetic data when the quadcopter travels off the map. To avoid this situation a trajectory is being given so that the quadcopter stays on the map for the entirety of the test. For cases where the quadcopter travels to a place with no available data, an average of the surrounding magnetic data is being calculated and used as a rough estimate. Another problem that was faced during this research is the repetitiveness of the magnetic data over a span of distance. To overcome this two different EKF SLAM techniques i.e. Kalman filter SLAM and Particle filter SLAM was implemented and compared.

II. LITERATURE SURVEY

There are several techniques that have been developed over the years for localization and navigation in GPS denied environments. Few techniques are as using Bayesian filters like Kalman filters, particle filters, SLAM techniques equipped with AI and Camera feedback, Star tracking, etc. Using magnetic data of earth is one of the unique techniques that has been recently in talks to use a navigation tool to position an aircraft. One of the challenges with this method is that magnetic data has lot of repetitive data and the change in the magnetic value is quite small over long distances. There are ways though which the shortcomings of this method can be handled which will be discussed in the methodology section.

III. METHODOLOGY

A magnetic anomaly map of Tennessee -Kentucky [15] is taken from the internet. A detailed map analysis is done to decide which filter is appropriate for the given map. There are 3 different types of statistical methods that can be used for Bayesian filters which are ML, ABL, MLR. For this research ML technique is chosen. A kinematic model of a quadcopter is derived in MATLAB SIMULINK using dead reckoning method. By choosing appropriate inputs to the model, the quadcopter is made to travel along a circular path. A magnetic anomaly map of Tennessee-Kentucky shown in (Fig-1) which was obtained from [3]. A EKF and particle filter was developed for the means of localization for this project. The IMU data was used to predict the position of the quadcopter. For simulation purposes, the magnetometer sensor value is substituted for the magnetic value on the map with a calculated noise. This magnetic data is then used to give a position update. This position data is passed on to the particle filter. ML state estimation technique gives a probability of the position on the magnetic map for each magnetometer reading. The points with maximum likelihood are passed to the particle filter for the update step. State estimation and Localization techniques are the key features of this project.

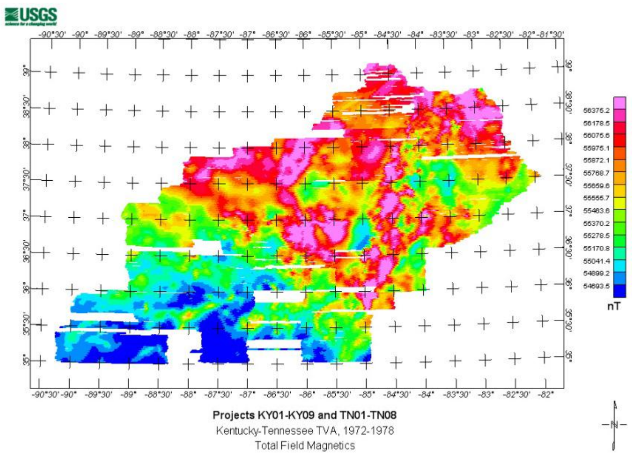

Figure 1: **Magnetic Anomaly Map Tennessee-Kentucky [15]**

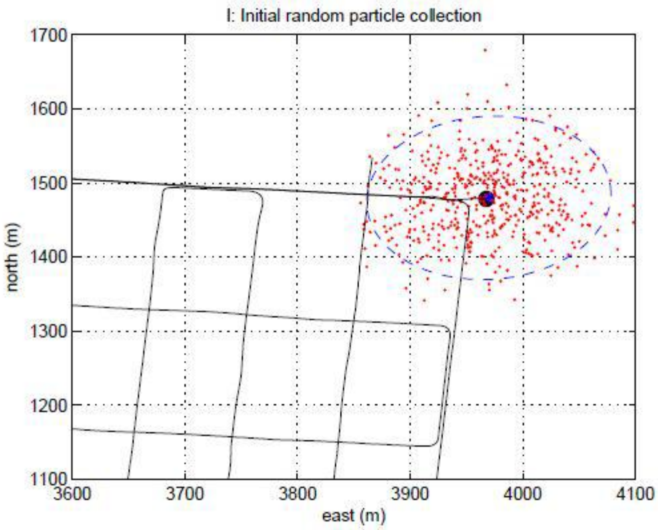

Figure 2: Particle Filter SLAM

IV. RESULTS

The simulation of the estimated states showed that the EKF SLAM had significantly more error as comparted to the Particle filter which added up over time leading to incorrect results Absence of any available landmarks also makes EKF not favorable in this scenario. The particle filter showed a promising result with an error margin for 3km to 5 km. Although there are situations where particles fail to provide accurate result i.e where there is absolutely no change in magnetic data which can be overcome by adding suitable landmarks in the maps. Following is the result obtained with both EKF and Particle SLAM for a circular trajectory.

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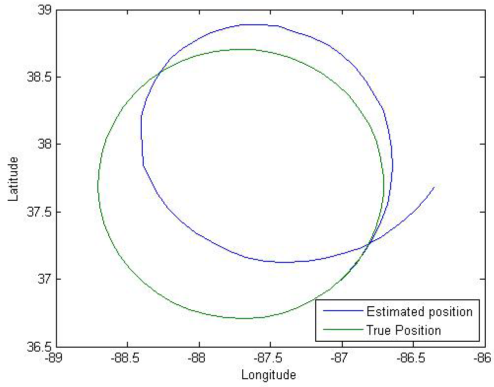

FIGURE 3: EKF SLAM Estimation

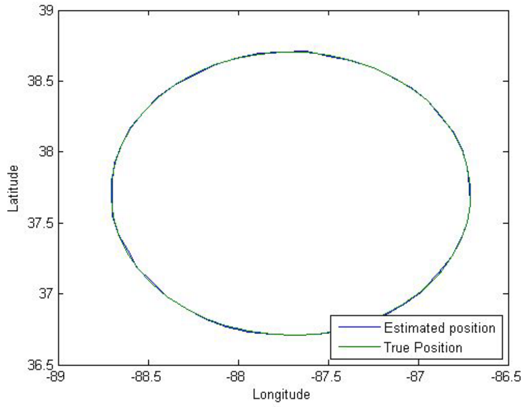

FIGURE 5: Particle Filter SLAM Estimation

V. CONCLUSION

The result of this project shows that magnetic navigation has a good potential to be a substitute for GPS navigation when unavailable. This project was tested with different trajectories and the best results were found with a straight line. There is a scope of improvement for various other trajectories. This technique could be extended to other unmanned vehicles. Doing Sanity checks after regular intervals of time can improve the quality of the output and help in avoiding steady state error. The future scope of this project is to develop and introduce landmarks that can act as point of reference in the simultaneous EKF algorithm. Sensor fusion is another way which can help in getting more refined state estimation which could comprise of using radio sensors/ultrasonic sensors for ranging and implementing cooperative localization between different vehicles.

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