Navigation of a UAV Utilizing a Created Map and Physical Markers

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Abstract

Research and use of drones are constantly increasing as the world moves towards a more automated nature. A need for GPS-less travel and navigation is becoming a focus due to how common GPS can become unavailable either due to environmental reasons or purposeful jamming. This paper proposes a method of GPS-less homing by identifying a ”home base” marker as the drone takes off, and then after flying around the drone will return to the marker using monocular SLAM. This project is completed using the ROS framework and the AR. Drone 2.0 for programming and testing.

1 Introduction

Unmanned Aerial Vehicles (**UAVs**) continue to be a very popular topic for research and development with many applications including military use, delivery and transport, and environmental surveying. The most obvious way of localizing a drones environment and to provide directions and information about the environment it is flying in is the use of a Global Positioning System (**GPS**). However, due to various environmental effects and hazards as well as direct human interaction GPS signals can be lost and jammed. As a result, a current hot topic issue in UAV research is trying to figure out how to localize and have a drone home in on a target without the use of a GPS or a human controller.

One study of using GPS for navigation was important even if the focus of this project is on GPS-less homing. Santana et al. [2015] provided important general information of the AR. Drone, the drone we will be using for our study. This introductory knowledge and overview of the AR. Drone was useful when figuring out what hardware to use for this project. It also provided the idea of using a Kalman Filter to smooth given data and to provide better state estimation.

The Robot Operating System (**ROS**) is an open-source framework primarily for developing robot control programs. ROS allows the use of more than 2000 packages as well as multi-platform support. Packages include better autonomous control of the drone, as well as baselines for Simultaneous Localization and Mapping or **SLAM** that this project can use and expand upon to suit specific needs. With these benefits in mind, this project will be developed using the ROS framework for controlling specifically the AR. Drone 2.0.

The AR. Drone 2.0 was determined to be a good choice due its affordability, and established connection to the ROS framework. Many useful packages specifically for the AR Drone 2.0 in ROS exist and will be used. Some limitations of the AR Drone 2.0 include a short flight time and small payload capabilities. With this in mind, the project will focus on using the front camera and vertical camera located under the drone for SLAM. The onboard sensors of the drone will be used for the purposes of orienting itself in the environment and will be used to give data to the Extended Kalman Filter in order to provide better control in drone movement towards a marker.

1.1 Problem Description

GPS Systems are subject to numerous ways of becoming less effective or even unusable. The official GPS.gov website states that the common causes of the degradation of GPS positioning accuracy include satellite signal blockage due to buildings, trees, etc., indoor or underground use, and reflected signals off of walls (multipath). Other causes include solar storms, satellite maintenance and different types of jamming. (Insert citation of article) categorizes jamming technology in different ways, but primarily the devices are grouped as Jammers and Spoofers. Jammers transmit a spurious signal in order to cause interference and block navigation signals. Spoofers generate a mockery of an original signal for the purpose of misleading users or providing the user with incorrect navigation. Work by the United States government is being made to improve GPS capabilities and to provide better resistance against losing signal or picking up jamming signals. Regardless, jamming will continue to be a method for interrupting GPS signals. Either for military use or civilian use, expansive range or close-range, jammers are becoming more common and cheap as technology advances. Despite the use of jammers being outlawed in the United States of America, virtually anyone today has the capability of using a jammer by simply ordering a basic civilian jammer online, having it delivered, and simply giving it power through their car or other means. As a result of the current and growing prevalence of jamming technology, work must be done to either combat GPS jamming or to find a way to avoid the possibility of it altogether.

With all of this in mind, there is a great need for drone navigation that does not rely on GPS technology so that it can work in environments suitable for GPS but also environments where GPS can be disabled, blocked, or jammed. More specifically, the problem this project will try to solve is developing a system for GPS-less homing and navigation in the event that GPS is unusable either due to environmental or human-interaction changes. Many different methods of GPS-less travel and navigation will be discussed in the next section. This project will propose a method of identifying a marker when the drone takes off, saving this as a home base position that the drone can return to after it spends time traveling. The drone will save this home base along with its surroundings using SLAM and the drones monocular camera. After this, the drone travels away from the home base and performs a mission of various irrelevant movements while using SLAM and the monocular camera to localize itself. When the drone is ready, the drone will autonomously return to its home base using the map it has been creating. With this system, a drone would be able to take-off, travel around in an unknown environment, and come back to its take-off location without any use of a GPS system. Research has been done on SLAM navigation with drones, as well as identification and homing of a marker within a drones vision. This project will combine both to create a full flight experience of take-off and saving a home base marker, travel and localization of the drone, and finally return back to a saved home base.

1.2 Review of Literature

Much work and many different methods have been studied in trying to figure out a way to solve this non-GPS navigational issue. Benzemrane et al. [2009] uses just Inertial Measurement Unit (**IMU**) sensors to gather orientation, angular velocities and acceleration of the drone to observe and estimate the linear velocity of the drone. This work is said to be used later to improve tracking and stabilization of the drone, which are important aspects of navigation without the use of a GPS. Another similar approach is Vlez et al. [2015] in which the authors used a Proportional, Integral, Derivative (**PID**) controller and a position estimator and after localizing itself in the environment it would calculate a trajectory path to a waypoint for the drone to follow using cubic polynomial functions and Bézier curves. Another study is Lugo and Zeil [2013] in which a microcontroller is used for position estimation, path planning and control after receiving position information. This allowed the drone to travel predetermined shapes or given waypoints autonomously. The three mentioned studies focus on the sensors related to the drones control itself to orient itself in an environment and correct its movements to follow a given path. Using the AR. Drone 2.0s PID controller will be required for when the drone needs to return back it its home base. A waypoint navigation will be used for this project (returning back to home base after traveling around), so a PID controller will be needed to assure that the drone approaches the waypoint successfully and efficiently.

The use of Inertial Navigation System (**INS**) and Light Detection and Ranging (**LiDAR**) sensors for an alternative navigation method is possible with the help of an inertial sensor which only relies on gravity and platform dynamics. Such a sensor is recommended by Miller et al. [2010] for GPS-less travel because inertial sensors cannot be jammed. The only problem one has to worry about is handling errors of the inertial sensors as time goes on. This project will use inertial sensors of the drone to acquire basic information such as altitude and angular velocity, which we can then use to gather more complex information such as linear velocity. Creating a 3D map is possible using a 2D LiDAR as referenced by Mohta et al. [2018]. Mounting a 2D LiDAR on a free rotational axis of a gimbal allows the 2D LiDAR to tilt around to capture a 3D map. One of the problems with the sensor is the orientation pointing downward jumps in measurement when the robot goes over obstacles as referenced by Mohta et al. [2018]. To take care of these jumps, an Unscented Kalman Filter (UKF) maintains an internal floor level as the reference level. While LiDAR is useful for creating 3D maps and has potential, the AR. Drone 2.0 cannot reasonably fly with a LiDAR sensor attached to it due to the AR. Drones small payload capabilities.

In terms of finding a specific target or landing zone to home to, the majority of work is done purely visually, which the project will incorporate for saving a home base location. Nguyen et al. [2014] proposes a vision-based 3D navigation technique for UAV deriving from Funnel Lane theory which allows the drone to navigate indoors. This method for visual-homing on a feature is possible through creating fixed point funnels where if the drone is inside a funnel, it can move straight to be closer to the target. With multiple funnels, calculations are made to create a optimal funnel lane that is overlapping all lanes. This is what the drone will make effort to stay inside and move forward, creating an effective system for indoor navigation. While this research allows for good navigation, it goes off of what the drone sees in its camera. Our project will require navigation to its home base even if it not currently in view of the drones camera.

One of the most popular techniques is the use of Simultaneous Localization and Mapping, or SLAM, to localize a drone in an unknown environment. Huang et al. [2008], Stephan et al. [2011], Qader and Fayez [2018], Cheng and Liu [2015] study either improving analyzing the method itself (Huang et al. [2008]) or using SLAM to navigate an environment towards a waypoint using a two-wheeled robot in the case of Qader and Fayez [2018] or a UAV in the case of Stephan et al. [2011] and Cheng and Liu [2015]. This research and concept is extremely interesting and advancements can be made to apply it to a full flight experience where the landing pad is a marker that the drone will log or take note of during take off and will return to using the drones created map. This project will use SLAM in order for the drone to localize itself in an environment and to take note of and log a home base marker that the drone will use for take-off. After traveling, the drone will then use the map to return to its home base marker.

One article used global mapping in their navigational methods, Scaramuzza et al. [2014], but because maintenance of global consistency is a problem as stated by Mohta et al. [2018], this project will create and use a local map for planning flight instead of a global one. Utilizing a local map helps the planner tolerate drifts in the state estimation as stated by Mohta et al. [2018]. This study by Mohta et al. [2018] also provided an issue to keep in mind, that floors are an issue when using camera images. Smooth textureless floors in particular become hard to detect which causes the UAV to pick up few images in a relatively flat environment such as a warehouse. This could present problems, but this project will have a clearly identifiable home base marker which the drone will be able to recognize. This project also does not take into account object avoidance, so whatever the drone travels and logs in its map should be considered safe for travel for a return home as the drone does not have to worry about possible obstacles.

While out of the scope of this project, studying was done for the landing of the drone. Papers done on using physical markers for a drones camera to identify and land on the marker are considered for possible integration with the returning home aspect of the project. Sani and Karimian [2017], Polvara et al. [2017], Zhao and Jiang [2016] use physical markers and the drones camera to identify the marker and autonomously land itself upon the marker using Proportional Integrative Derivative (PID) controllers while using Kalman Filter on inertial sensors or IMU sensors to estimate errors and adjust accordingly. This project would like to combine both the use of visual mapping to hold a map of the area it travels as well physical marker identification in order for the drone to have a physical landing zone that the drone can save/log when it takes off and travel back to when the mission is done.

For sensing unknown environmental structure with sufficient accuracy and low latency the estimate for the position and velocity has to be available. By combining measurement between laser scans, visual data, and the IMU, the authors Abraham et al. [2011] were able to obtain accurate estimates of the vehicles various states to use for control of the drone. The development of a very accurate and robust high-speed laser scan-matching algorithm was made to allow the user to compute the relative position estimates with enough accuracy and low enough delay for control. To accomplish this, the researchers had to analyze the difference between the ground robot and the air robot for autonomous flight in GPS-denied areas. While environmental/obstacle avoidance is not within the scope of this project, Abraham et al. [2011] still provides relevant information on getting a drone's various states using IMU readings. It also shows that it is possible for SLAM to work by sending data to a data fusion Extended Kalman Filter to correct drifts in relative position estimates. For navigational control, this use of Extended Kalman Filter will be considered in this project as the drone needs error-handling as it travels back to its home base location.

The process in which the Extended Kalman Filters were being used by Miller et al. [2010] is that the visual feature location was estimated using a Harris Corner Detector. Inertial measurements were used to predict and observe the selected feature locations. Then, inertial measurements were compared with an observed location to bound the INS drift. The Extended Kalman Filter corrected the errors that were made by inertial sensors biases. This process was conducted to operate a vision-aided navigation system on a UAV without GPS. Projects using an Extended Kalman Filter relating to drone navigation was needed due to the project wanting to use such a system due to its effectiveness. An Extended Kalman Filter will be used for the return home portion of the project as the drone needs error handling to assure the drone is correctly following the path towards the home base marker. An Extended Kalman Filter can take information about its current readings and use that to give weights on how much to trust the estimated positions, a loop that essentially works to control a drones movement.

Other similar research in the area include Kartik et al. [2017] which provides a way for UAV drones to safely move around a 3D environment with obstacles at great speed. This is more about path planning and obstacle avoidance, which is out of the scope of this current project. Lastly, a very similar research proposal is Bender et al. [2017] where by combining camera images, inertial data, and GPS data to create a metric map that the drone can use to go back to its home position should the GPS be compromised. This research project allows a drone to arrive back home using the crafted map and even explore unvisited areas for the purposes of finding the shortest and most effective way back. This papers idea of returning back home using a crafted map is precisely the method of this project, without the added challenge of not utilizing GPS data whatsoever. This project intends to expand on this paper in a sense to a full system of travel where SLAM is used to record the landing zone, produce a map, and fly while localizing itself in the environment without the use of GPS data. Then when it is time to go home, the drone will use the created map to fly home effectively.

2 Body

3 Conclusion

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