Unmanned Autonomous Aerial Navigation in GPS-Denied Environments

Noshin Habib[1], Angel Flores-Abad[1], Josué Martínez-Martínez[2], Diego A. Aponte-Roa[2], Albert A. Espinoza[2]
[1] University of Texas at El Paso, USA, nrhabib@miners.utep.edu, afloresabad@utep.edu
[2] Universidad Ana G. Méndez – Gurabo, Puerto Rico, jmartinez718@email.uagm.edu, aponted1@uagm.edu, espinozaa1@uagm.edu

Abstract*– This work focuses on enhancing existing technology to support unmanned aerial vehicle navigation for the inspection of power plants. These inspections are a vital component of a power plant's capability to function but can be costly and dangerous to do by humans. Therefore, it has been proposed to utilize a small, unmanned quadcopter integrated with autonomous navigation by using an alternate signal in place of GPS. The quadcopter can gain the ability to navigate to desired coordinates without the need for GPS, which can often be unavailable within these structures. The UAV uses an optical flow sensor to determine the ground velocity and x-y position, and sonar for measuring the altitude. Using ROS and MAVLink, the communication can be modified to use "fake GPS" data, instead of the actual GPS signal, to be published in the appropriate ROS topics to avoid GPS failures. The optical flow and fake GPS are filtered by an Extended Kalman Filter to get a better position estimation during navigation. Through this process, autonomous flight was successfully achieved without GPS.

***Keywords*— UAV, Fake GPS, Power Plant Inspection, Robotics.**

I. Introduction

To maintain the safety and efficiency of power plant operation, inspection of these facilities is a crucial process. However, these plants have areas that are difficult to inspect by humans due to limited space between structures or harmful chemicals that may negatively affect the inspector [1]. Inspection of industrial systems also involves the risk of damage and high cost due to the outage of the facilities during the inspection procedure [2]. In addition to these risks, human inspection requires increased time and resources, with added risk of human error. External tracking systems such as Vicon and Opti track [3] can provide position and attitude measurements exceeding 100 Hz. However, this work will focus on scenarios where such external system is not available, nor is GPS.

Recently, active vision was proposed for autonomous flight in similar environments [4]. A texture on the scene would be carried on-board by a pattern generator. One such example that has been explored is the Iterative Closest Point algorithm (ICP), in which the scene and motion can be recovered on-line. However, this method requires sufficient 3D structure constraining the approximations. Also, the scene needs to be near the sensor and ambient light may reduce the quality of the projected texture.

To reduce the risks and consider the limitations, it has been proposed to perform inspections using an Unmanned Aerial Vehicle (UAV) that is autonomous and capable of recognizing any damages that occur within the power plant.

To accomplish this, the UAV uses an optical flow sensor to determine the ground velocity and x-y position, and sonar for measuring the altitude. Additionally, the UAV has the PX4 Firmware that uses a uORB Message Bus to communicate with the drivers and flight control topics. Using ROS and MAVLink, the communication can be modified to use "fake GPS" data, rather than the actual GPS signals, to be published in the appropriate topics to avoid GPS failures. The optical flow and fake GPS are filtered by an Extended Kalman Filter to get a better position estimation in the navigation [5].

II. Methodology

To begin the process for autonomous flight, different Unmanned Air Vehicle (UAV) setups are considered to see if there is one that has a low-budget yet efficient system that allows for autonomous flight missions in GPS-denied environments. The two setups that were explored were the Qualcomm Snapdragon Flight Starter Kit and the Intel Aero Ready-to-Fly (RTF) Drone. The Intel Aero RTF was chosen due to the fast-tracked SLAM development that the drone would provide straight out of the box. In order to select low-budget components, different missions were simulated utilizing different firmware to identify the components that are required when GPS is not available. After analysing the simulations, goals for the mission were established. Then, communication was established with the UAV components using MAVLink and the Robotic Operating System (ROS). This communication and the PX4 Firmware that was chosen allowed the Extended Kalman Filter parameters to be altered for the purposes of filtering the data that is transmitted in substitution of the GPS data. Then, outdoor tests were conducted using this build to validate the GPS-denied system.

III. Technological Components

A. Drone Selection

The Intel aero Ready-to-Fly drone, shown in Fig. 1, was selected, because it offers a low-budget system that is equipped with an Intel-powered computing system. It also offers a full Intel RealSense system with prebuilt setup with an integrated flight controller, co-processor, and field programmable gate array (FPGA) based peripheral bus [6]. Additional components required for the drone were greatly reduced, allowing for an easy setup process. This also meant fast track development on Simultaneous Localization and Mapping (SLAM) with autonomous navigation and flight-testing was capable right out of the box [7]. An important feature that led to the selection of this drone is the secured remote login in case that something

Digital Object Identifier (DOI):
http://dx.doi.org/10.18687/LACCEI2020.1.1.349
ISBN: 978-958-52071-4-1 ISSN: 2414-6390

must be changed in the computer. It uses OpenSSH, a connectivity tool for remote login, with Secured Socket Shell (SSH) cryptographic network protocol. Additionally, if the IP of the host computer used to send commands to the drone is not saved in the MAVLink router configuration file, the UAV will not allow communication between the two. Furthermore, it generates its own WIFI hotspot with a passphrase to create a more secure environment. These features are important in this modern world in which everything can be hacked.

Fig. 1. Intel Aero Ready-to-Fly Drone

B. PX4Flow

The optical flow and sonar setup, as shown in Fig. 2, allows the quadcopter to hover at a given altitude without human input. Although a stable flight height can be reached using the Intel Aero's built-in downward facing camera, the field of view of the Intel camera is too wide to be suitable for visual odometry [7]. The optical flow ground velocity (meters/second) of the drone computed by the PX4Flow can be directly converted to position units (meters). The sonar also acts as a substitute for the barometer, allowing for more stable flight. This setup allows for enough data to be published in the ROS topics for longitude, latitude and altitude, which would normally be published by the GPS.

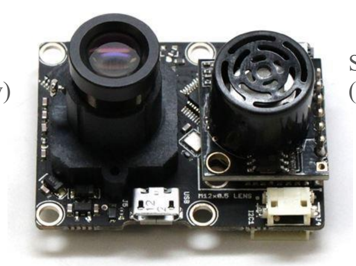

Fig. 2. GPS Substitute Build

C. Propeller Guard

Fig. 3 represents a custom propeller guard that was designed using SolidWorks, 3D printed, and mounted on the UAV, as shown in Fig. 4, to protect the propellers from objects such as walls and beams. To create such protection but not add too much weight to the UAV, a MakerBot Replicator 3D printer with polylactic acid (PLA) filament was used. This component proved crucial during the testing process when autonomous flight was being tested numerous times.

IV. Software Components

A. PX4 Firmware

This open source flight control software, designed for drones and other unmanned vehicles, will allow for a standard to deliver drone hardware support and software stack at no cost. This was modified throughout the project to enable testing capabilities both indoors and outdoors, as well as allowing flight without GPS.

Fig. 3. Propeller Guard CAD

Fig. 4. Drone with Propellers Installed

B. MAVLink

This is the messaging protocol for communicating with drones and between onboard drone components. Data streams are sent and then published as topics, while configuration sub-protocols are point-to-point with retransmission. This was required to enable certain features on the drone using the mission planning software, QGroundControl, which provides a graphical interface for the desired mission.

C. Robot Operating System (ROS)

This is the general-purpose robotics meta-operating system used with PX4 for publishing sensor data into the right topic nodes. It uses a package called MAVROS to enable MAVLink extendable communication between computers running ROS, MAVLink-enabled autopilots, and MAVLink-enabled ground control stations. Additionally, it allows the ability to save the log files of the drone testing data with a feature called "ROSbag." This feature was advantageous in ensuring the data was being published to the right nodes [8].

V. Modifying PX4 Firmware

To navigate the UAV, a GPS signal is still needed as a safety protocol [9, 10]. To circumvent this requirement, the PX4 Firmware was modified to send a signal to the GPS driver via MAVLink to simulate GPS without utilizing it, which is referred to as "fake GPS." With the fake GPS signal, the UAV is going to have the mission coordinates that the user predefines. Fig. 5 shows the modified diagram, which includes the fake GPS driver.

To use the fake GPS signal instead of the actual GPS, the change must be indicated within the MAVLink console in QGroundControl. The commands shown in Fig. 6 must be used. The "gps stop" command deactivates the GPS signal. Then, the fake GPS is activated using the "gps start -f" command. Finally, to ensure that the coordinate given in the source code is being published correctly, a check is done using “gps status.”

The firmware checks for the fake GPS and if it is enabled, uses the position data that was given by the user. In this case, the user needs to enter the coordinates manually inside of the GPS source code and compile the firmware and install it again. This allows for flight to be controlled by that information. Otherwise, the drone will use the GPS information that is published in the GPS Driver, then the Extended Kalman Filter (EKF2) is going to filter it and publish it to the corresponding nodes. The difference between the two cases is that in the fake GPS case, the EKF2 only processes this information once, based on the coordinates that were given in the local position node. Then, it is going to continue filtering the PX4Flow data and publish it to the other nodes. However, in the GPS case, the drone will be running in a loop, and every time there is new data, the EKF2 needs to filter the information. It should be noted that if GPS is disabled and fake GPS is also disabled, the drone will end in a failure mode, so it is important that the steps above are followed. Fig. 7 shows a representation of the GPS source code.

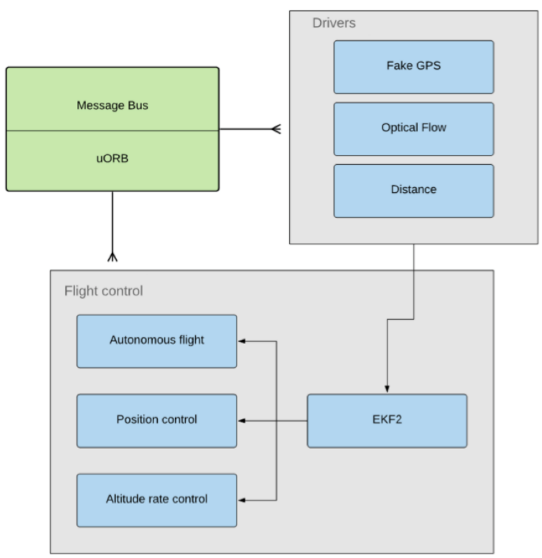

Fig. 5. Modified GPS Driver

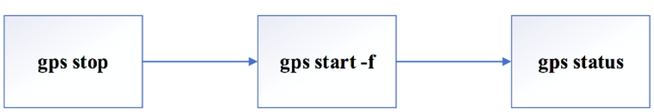

Fig. 6. MAVLink Console Command

VI. RESULTS

A. Simulation

Before testing was done using the drone, simulations were created using jMAVsim, a simulator specific for UAVs. This step was to ensure that the fake GPS driver was working properly and to avoid any fatal failures that can result in UAV failures during physical testing. The simulator was connected to QGroundControl via Wi-Fi, just as it would be to the drone via its self-generated hotspot. Then, four waypoints were selected to simulate the points that would be given for the actual drone.

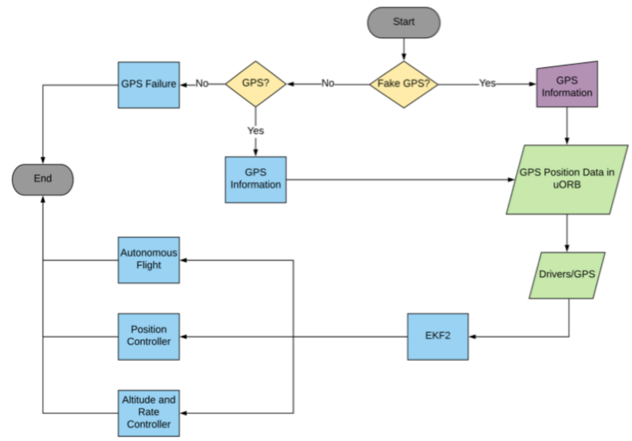

Fig. 7. GPS Source Code Unified Modelling Language Diagram

The points were followed with minimal error, as can be seen in Fig. 8. The red lines represent the path of the drone going to the assigned waypoints and returning home. On the left is the simulator and on the right is the mission control window showing the trajectory being followed by the drone.

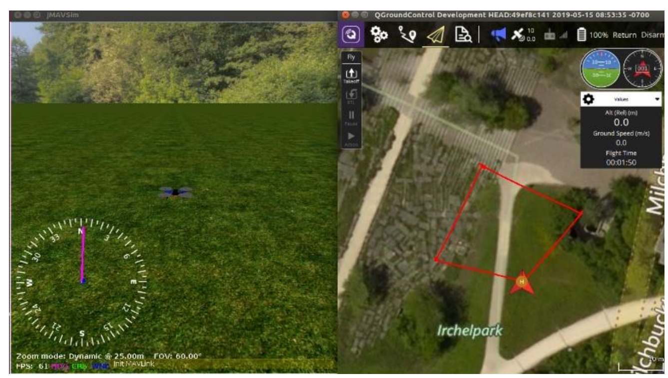

Fig. 8. Simulation Conducted Using jMAVSim and QGroundControl

B. Flight Tests

The drone was tested outdoors using two waypoints and was commanded to return to the starting location and land once this final waypoint is reached. For reference in future test conductions, it should be noted that the testing environment was a desert climate, with humidity of around 10-20%, and temperatures of 80-95 °F (26.7-30 °C). The trajectory given predefined in QGroundControl can be seen in Fig. 9.

The drone successfully navigated to the two waypoints that were assigned, as shown by Fig. 10. The position data was obtained through the data of both the optical flow and the sonar sensors, which were filtered by the EKF and then published in position and velocity nodes after activation of the fake GPS as expected. The data from the drone was recorded with ROS bag and a python script was created to graph the path of the UAV.

Fig. 9. Given Drone Trajectory

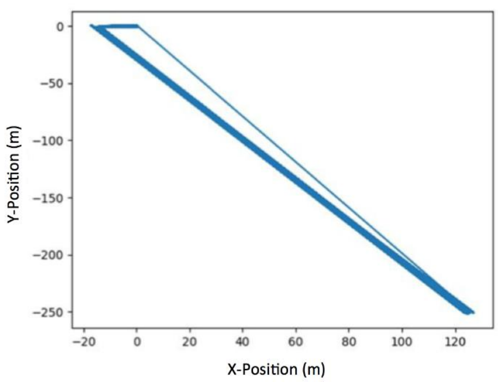

Fig. 10. Graph of Actual Trajectory

VII. Conclusion

The Intel Aero Ready-to-Fly Drone can be used to perform outdoor missions in GPS-denied environments using the PX4 Firmware, optical flow and range finder sensors, and a fake GPS signal commanded through ROS and MAVLink.

The fake GPS driver is the first step for inspection because the UAV needs to use simultaneous localization and mapping (SLAM) to know its current position, and to enable the user to assign waypoints and control the drone through a local computer. This setup provides the framework towards the possibility of conducting low-budget inspections without the requirement of human control.

VIII. Future Work

Since most power plant inspections are to be conducted indoors, the UAV needs to be more stable [11,12]. Thus, the future work plan is to replace the sonar with a lidar sensor capable of measuring up to 14 meters, with an update rate of 1000Hz. Additionally, image recognition capabilities are also in the works for the detection of abnormal features within the power plant.

Acknowledgments

The authors gratefully acknowledge the support in this work by the Department of Mechanical Engineering at the University of Texas at El Paso, Department of Mechanical Engineering at the University of Texas at El Paso, especially to Julio Reyes, Dr. Ahsan Choudhuri, and Dr. Michael McGee. Additionally, the authors would like to recognize the Consortium for Integrating Energy System in Engineering and Science Education (CIESESE), an initiative funded by the U.S. Department of Energy (DENA0003330) and the Department of Energy (DE-FOA0001842).

References

[1] E. Zwicker, W. Zesch, and R. Moser, “A modular inspection robot platform for power plant applications,” in Applied Robotics for the Power Industry (CARPI), 2010 1st International Conference on, oct. 2010.

[2] A. Breitenmoser, G. Caprari, R. Siegwart and R. Moser, "MagneBike - Toward multi climbing robots for power plant inspection", In AAMAS International Conference on Autonomous Agents and Multiagent Systems, Toronto, Canada, 2010, pp. 1713-1720.

[3] R. Mautz, “Overview of current indoor positioning systems,” Geodesy and Cartography, 2009. [Online]. Available: http://www.igp.ethz.ch/geometh/people/rmautz/mautz estonia08.pdf

[4] M. Achtelik, A. Bachrach, R. He, S. Prentice, and N. Roy, “Stereo vision and laser odometry for autonomous helicopters in gps-denied indoor environments,” in Proceedings of the SPIE Unmanned Systems Technology XI, vol. 7332, Orlando, F, 2009.

[5] G. Welch and G. Bishop, “An introduction to the kalman filter,” University of North Carolina at Chapel Hill, University of North Carolina at Chapel Hill, 2006. [Online]. Available: http://www.cs.unc.edu/~welch/media/pdf/kalman intro.pdf

[6] Intel-Aero. “Intel-Aero/Meta-Intel-Aero.” *github.com*, Nov. 13, 2017. [Online]. Available: https://github.com/intel-aero/meta-intel-aero/wiki/01-About- Intel-Aero.

[7] S. Luthra, “Simultaneous Localization and Mapping on a Quadcopter”. M.S. Thesis, Cornell University, 2018.

[8] C. Fairchild, T. Harman *ROS Robotics By Example*, 1st Edition, Packt Publishing, 2016.

[9] V.M. Sineglazov and F.M. Zakharin, Theoretical bases of designing of integrated navigation systems of unmanned aerial vehicles. Kyiv: Ukraine Osvita. 2015, p. 340.

[10] F.M. Zakharin, and S.A. Ponomarenko, “Concept of Desing Navigation Systems of UAV.” IEEE 3-rd International Conference “Actual Problems of Unmanned Aerial Vehicles Developments”, Proceedings. Kyiv. National aviation university. 2015, 13-15 October, pp. 261-264.

[11] K. A. Nelson, R. J. Davis, D. R. Lutz, and W. Smith, “Highly Compact Robots for Inspection of Power Plants,” Journal of Field Robotics, vol. 29, no. 1, Dec., pp. 47-68, 2012

[12] Mohammed, F., Idries, A., Mohamed, N., Al-Jaroodi, J., & Jawhar, I. (2014, May). UAVs for smart cities: Opportunities and challenges. In Unmanned Aircraft Systems (ICUAS), 2014 International Conference on (pp. 267-273). IEEE.