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Proposal for Generation of a Pseudo GPS Signal Used in Indoor Mode for Navigation Testing of Small Autonomous Flying Robot

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Abstract: In addition to the inertial navigation sensors embedded in an autonomous flying robot, Global Navigation Satellite Systems are most often used, in particular, the GPS (Global Positioning System). This offer information with an accuracy that depends on the arrangement of a constellation of satellites. It is very often that a measurement with errors of several meters is delivered by this system. With the need for agile decisions of the autonomous flying robot during its mission, especially in the case of rescuing people during disasters, it is not allowed for uncertainty to reign over the decision of the flying robot. In order to improve the estimators implemented experimentally, a secure laboratory test environment is more preferable. Here, we propose a way that helps researchers to conduct indoor experiments with a pseudo GPS that offers circumstances similar to outdoor navigation. The results that will be discussed are obtained with the Vicon motion tracker laboratory at Aalborg University, Denmark.

Keywords: Pseudo GPS, Outdoor navigation, UAV, Vicon motion tracker system

Introduction

Autonomous flying robots have the potential to revolutionize many industries and applications, such as delivery, logistics, search and rescue, and disaster relief. However, developing autonomous flying robots that are safe and reliable in real-world conditions is a challenging task. One of the main challenges is outdoor drone navigation, which is estimating the drone's position accurately in complex and dynamic environments.

Indoor autonomous flight tests of flying robots are only a preliminary step in developing controllers for real-world applications. In the real world, flying robots will not have access to the same navigation instruments that provide such accurate and convenient measurements of position and attitude. For example, GPS signals can be lost or unreliable in outdoor environments, and other sensors may also be inaccurate, especially in difficult environments such as urban areas, forests, and disaster zones.

To develop estimators or controllers for outdoor applications, it is important to perform continuous tests in real-world conditions. However, this can be dangerous and expensive, and it can be difficult to control all of the factors that can affect the performance of algorithms. Moreover, the main challenge to outdoor drone navigation is estimating the drone's position accurately. GPS signals can be lost or unreliable, and other sensors may also be inaccurate, especially in difficult environments. This can make it difficult for the drone to make decisions, especially in critical missions like disaster rescue (Ross, 2018). In these cases, human pilots often need to take over to assist the mission.

One way to address these challenges is to use simulated environments to test and develop autonomous flying robots. However, existing simulated environments do not fully capture the complexity and dynamism of real-world environments. Benjamin(2008) was an early temptation to simulate the GPS for outdoor simulations. The implementation of a simulated Global Positioning System receiver for the popular USARSim platform(Stefano, 2007; Shital, 2017) developed a simulator for autonomous flying robots by first implementing a quadrotor and then experimentally comparing the software components with real-world flights. The simulator is built on Unreal Engine and offers physically and visually realistic simulations. It includes a high-frequency physics engine for real-time hardware-in-the-loop (HITL) simulations with support for popular protocols such as MavLink. The simulator is designed to be extensible to accommodate new types of vehicles, hardware platforms, and software protocols.

An advanced novel hybrid architecture that uses an intermediate output from a fully trained attention DRL (Deep Reinforcement Learning) policy is proposed as a navigation cost map for outdoor navigation. This DRL network incorporates a robot-centric elevation map and IMU data to learn how to navigate in outdoor environments. In (Kasun, 2022), authors propose a new hybrid architecture that uses an intermediate output from a fully trained attention DRL policy as a navigation cost map for outdoor navigation. This DRL network incorporates a robot-centric elevation map and IMU data to learn how to navigate in outdoor environments.

These Simulating navigation perceptions are very powerful in virtual reality and simulators, but testing flying robots in real time requires deep study, control development, and real-time data processing. This is because the robot's controller must make decisions based on very uncertain and inaccurate measurements during some time lapses. To develop estimators or controllers for outdoor applications, it is important to perform continuous tests in real-world conditions. This is because outdoor environments are complex and dynamic, with many factors that can affect the performance of algorithms, such as wind, temperature, and electromagnetic noise (Lorenzo, 2021;Mozhou Gao1,2021). Many researchers believe that indoor tests are a valuable tool for developing and testing flying robot controllers. However, it is important to note that indoor experiments cannot fully prepare robots for the real world. One of the most successful indoor navigation methods is to use a constellation of cameras equipped with infrared sources, such as the Vicon MotionTracker system (VMTS). VMTS is commonly used to capture movement indoors for applications such as motion capture and virtual reality. Outdoor environments are more complex and challenging than indoor environments, with factors such as GPS outages, wind, and obstacles that can make it difficult for robots to navigate. Therefore, it is important to perform real-world testing of flying robots to ensure that their controllers can perform reliably in challenging environments. To develop algorithms that can reliably operate in the real world, it is important to first test them in controlled environments, such as indoors. However, GPS measurements are not available indoors, so alternative navigation methods are needed.

This paper proposes to modify a motion tracker system (VMTS) to generate simulated GPS measurements based on real Vicon motion tracking data. This simulated GPS can then be used to study the autonomy of flying robots in outdoor conditions without the need for real GPS signals. The modeling and performance of this simulated GPS will be discussed further in this paper.

The present paper is organized into five sections. The first section will briefly review satellite system positioning. The second section will describe the test bench used for the experiments, including the VMTS laboratory. The third section will describe the control scheme used during the experiments. The fourth section will present an approach to simulating the GPS signal. And, the fifth section will present the results of the experiments and conclude the paper.

GPS vs. Motion Tracker System

Accuracy of GPS Localization

GPS is a satellite-based navigation system that provides location, timing, and velocity information to users around the world. It can track the position of objects with an accuracy of up to 5 meters in most cases. GPS works by using a constellation of 30 satellites that transmit microwave signals to GPS receivers on Earth. The receiver calculates its distance from each satellite by measuring the time it takes for the signal to travel from the satellite to the receiver. By knowing its distance from three or more satellites, the receiver can calculate its position in three dimensions (Figure.1).

Figure1. GPS constellation

GPS accuracy can be affected by a number of factors, including atmospheric conditions, satellite geometry, signal blockage or interference, receiver quality, and the presence of buildings or natural obstacles. For civilian use, the US government intentionally degrades the accuracy of the GPS signal, but this was stopped in 2000. There are other global navigation satellite systems (GNSS), such as GLONASS, Galileo, and BeiDou, which can improve accuracy and reliability by using signals from multiple satellite constellations.

There are also differential GPS (DGPS) techniques that can further enhance accuracy by using additional reference stations to correct GPS measurements. In good conditions with a modern GPS receiver, we can expect accuracy within a few meters. However, the actual accuracy experienced in practice can vary depending on the factors mentioned earlier. The US Space Force is developing a new satellite constellation for localization, called the Next Generation GPS (NGGPS). The NGGPS is expected to provide more accurate and reliable positioning than the current constellation, and is expected to be fully operational by 2030. However, there is still much work to be done on developing controllers and estimators that can take advantage of the improved accuracy and reliability of the NGGPS.

Motion Tracker Accuracy

Analogous to a satellite constellation, but optic source, the motion tracking system typically consists of multiple cameras placed around the test area. These cameras are synchronized to capture the movement from different angles simultaneously. The cameras track the positions of reflective markers placed on the flying robot, allowing for accurate and detailed motion capture.

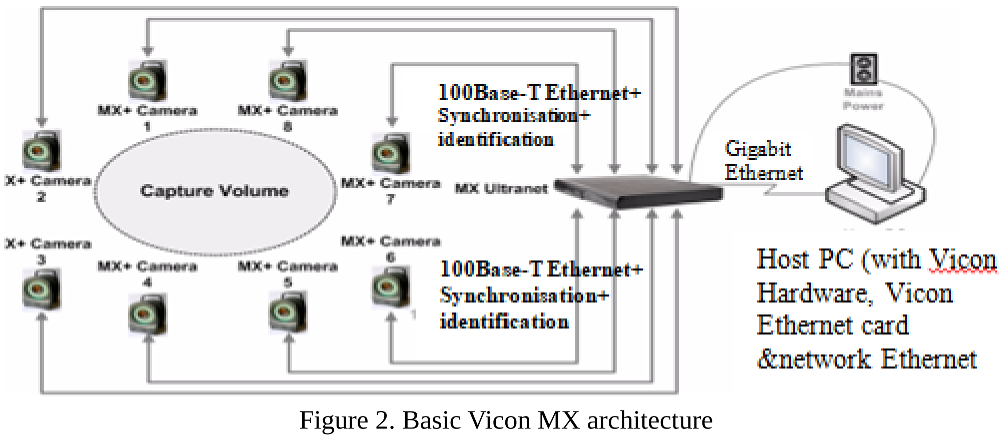

Figure 2. Basic Vicon MX architecture

ViconX motion trackers from Vicon were used in this study at the UAV Laboratory, Aalborg University, Denmark. VMTS accuracy depends on the number of cameras used, their placement, and the quality of the reflective markers. Nevertheless, VMTS is ultra-accurate compared to GPS, tracking 3D positions to 0.1 mm and rotations to 0.01 degrees.

GPS Simulator: Pseudo GPS

To simulate the real GPS signal in the laboratory, we will use the Motion Tracker Lab to track a quadrotor's position and inject a noise signal into the outputs of the Vicon MX system (see Figure 3).

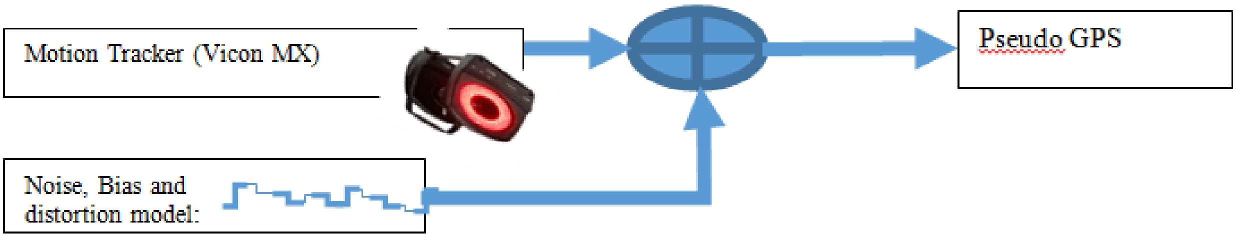

Figure 3. GPS simulator for indoor tests

Quadrotors are a good choice for indoor testing because they are versatile and well-suited for this purpose. They are relatively small and agile, making them easy to maneuver in confined spaces. They are also relatively quiet, making them less disruptive to people and activities in the vicinity. Quadrotors can also hover in place, making them easy to keep track of and control. The noise signal will have the same characteristics as the real GPS variance, but the limited space in the laboratory prevents us from running tests with an uncertainty cube greater than the size of the laboratory. We use a noise signal with a standard deviation of 30 cm, resulting in a positional uncertainty of less than 0.3 m in each direction. This space surrounding the quadrotor, known as the uncertainty cube, is shown in 3D in Figure.4. This means that the quadrotor will be able to fly freely within the laboratory, but it will not be able to experience the same level of uncertainty as it would in an outdoor environment. This is a limitation of the laboratory setup, but it is still possible to perform valuable tests and simulations of outdoor flight conditions.

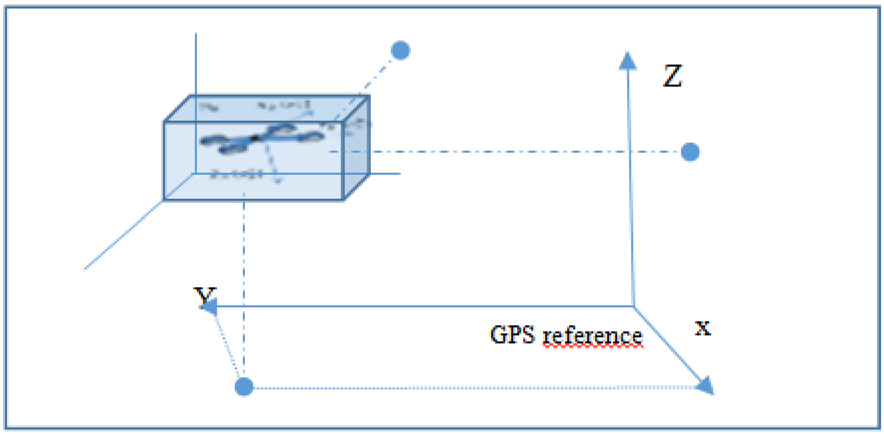

Figure 4. Cube of navigation uncertainty of the GPS

GPS Update Algorithm

To avoid malfunction or instability of the drone platform, a condition is necessary to proceed with a GPS update. This is the uncertainty cube that bounds the errors committed by the inertial measurement unit (IMU). The IMU is a collection of sensors that measure the drone's acceleration, rotation, and orientation. It is a critical component of the drone's control system, as it provides the drone with feedback on its current state. However, the IMU is susceptible to errors, which can accumulate over time.

The uncertainty cube is a mathematical representation of the possible errors in the IMU's measurements. It is a three-dimensional cube, with each axis representing a different error dimension (position, velocity, or orientation). The use of the uncertainty cube is a common technique used in drone control systems. It is a simple and effective way to improve the accuracy and reliability of the drone's navigation system. The size of the uncertainty cube represents the maximum possible error in each dimension. In summary, the uncertainty cube is a measure of the possible errors in the IMU's measurements. The drone's control system uses the uncertainty cube to determine when to trust the GPS measurement instead of the IMU's measurement.

A variety of algorithms to compare the GPS measurement to the estimated state and determine when to trust the GPS measurement has been developed in literature, (Aniket et al., 2022). The drone's control system uses the IMU's measurements to estimate the drone's current state. In time, the IMU's errors accumulate, and the estimated state may become inaccurate. The drone's control system can compare the GPS measurement to the estimated state to detect when the IMU's errors have become too large. If the GPS measurement is outside of the uncertainty cube, then the control system can assume that the IMU's errors are significant and that the GPS measurement is more credible. Algorithm in figure.5 gives an overview of this procedure. Where the uncertainty cube is represented as limits of the tolerance of the estimate on the three Cartesian axis.

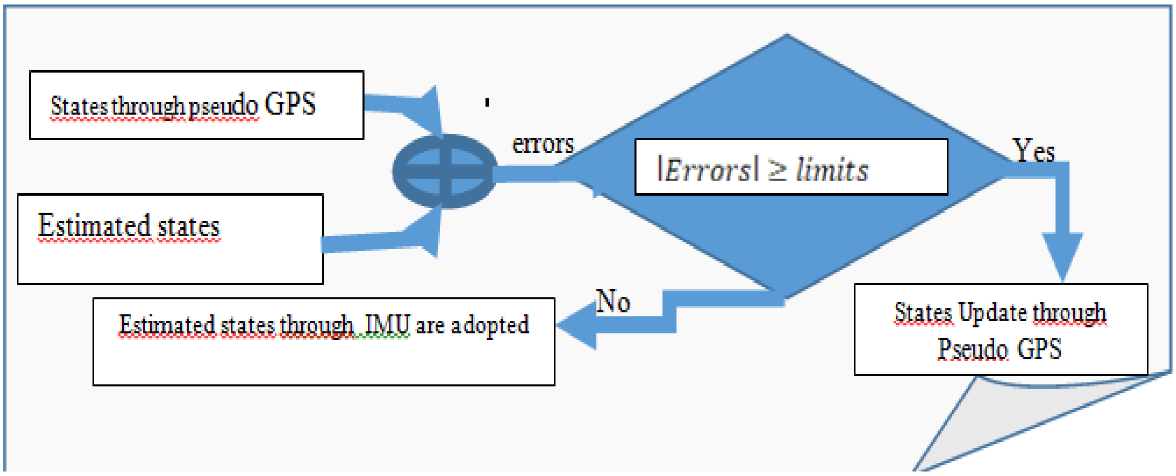

Figure 5. Quadrotor estimated states on cartisian axis update Algorithm

Indoor Experiments

The test bed consists of a laboratory equipped with a motion tracker system, a flying robot and a Matlab environment. The robot used in this study is a quadrotor X3D-BL from Ascending Technologies. It has the advantage of allowing access to its inertial sensor data for remote reading during flight. The radio remote control that links the ground pilot to this drone can also be accessed and manipulated by a URT communication. In a MATLAB environment, the position measurements from the inertial sensors are fused with the navigation data generated by ViconX. Thanks to the quadrotor model and the controller implemented by (Latroch,2019), commands are generated and sent autonomously to the robot's pilot.

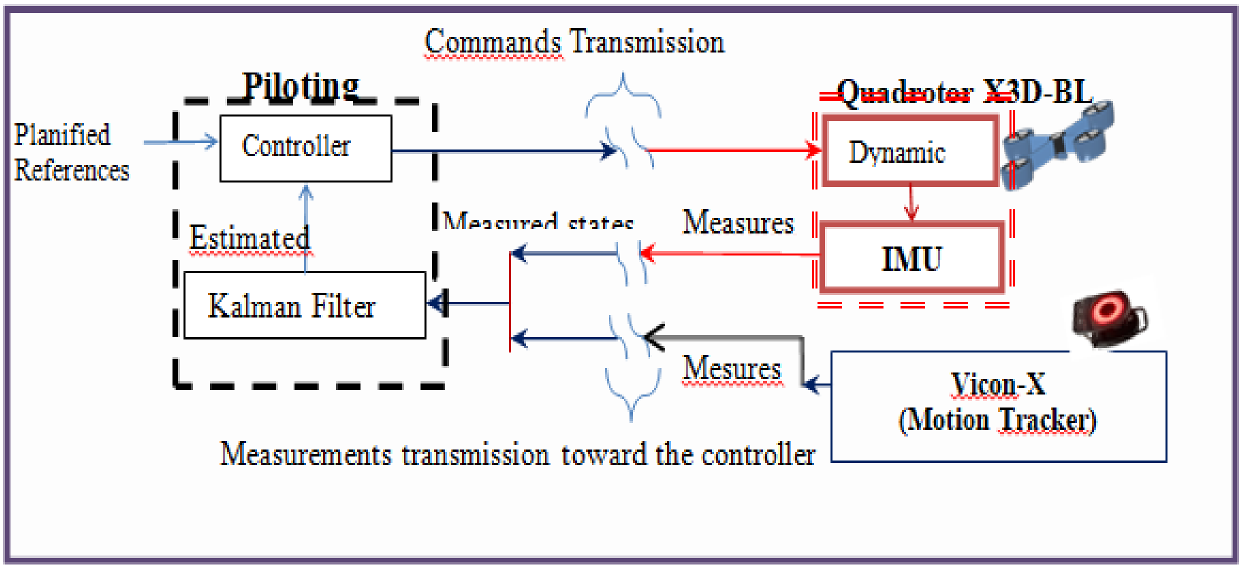

Figure 6. Closed Loop control of quadrotor X3D-BL scheme

The implemented controller is a linear-quadratic regulator (LQR). Due to noise and uncertainty in the measurements, it is always difficult to predict the integrated data from this model due to the accumulation of errors. Therefore, it is important to add an estimator filter capable of rejecting the terms induced by the noise process in order to obtain an output ready for use during closed-loop control. The diagram in Figure.6 illustrates the position of the controller in the closed-loop scheme of the quadrotor X3D-BL.

This controller is located on the pilot side with the extended Kalman filter. The IMU and motion tracker system measure the quadrotor's navigation states, which are sent to the controller via radio link. The Kalman filter then processes and fuses the data to generate an estimate of the quadrotor's navigation status as close as possible to its real position and attitude at the current moment. Based on this estimate, the controller can compare the quadrotor's actual state of navigation to the pre-planned trajectory. It can then send the appropriate control signals to the quadrotor's blades via radio link to autonomously follow the desired trajectory.

Tests of the Model and Controller

This same section describes indoor flight tests of a quadrotor assisted by a motion tracker. The quadrotor model was developed through identification and can be summarized as follows:

- The quadrotor is a nonlinear system with six degrees of freedom.
- The quadrotor's state is defined by its position, velocity, and attitude.
- The quadrotor's control inputs are the thrust and torque of the four propellers.
- The quadrotor's dynamics are described by a set of differential equations.

The controller is designed to stabilize the quadrotor and track a desired trajectory. It is implemented using a linear-quadratic regulator (LQR).

Results

Figure 7 shows the position of the quadrotor during a flight test, confirming the model's ability to describe the quadrotor's behavior successfully. The quadrotor is flying in a straight line, and the model's prediction of the quadrotor's position closely matches the actual position. This indicates that the model is accurately capturing the quadrotor's dynamics.

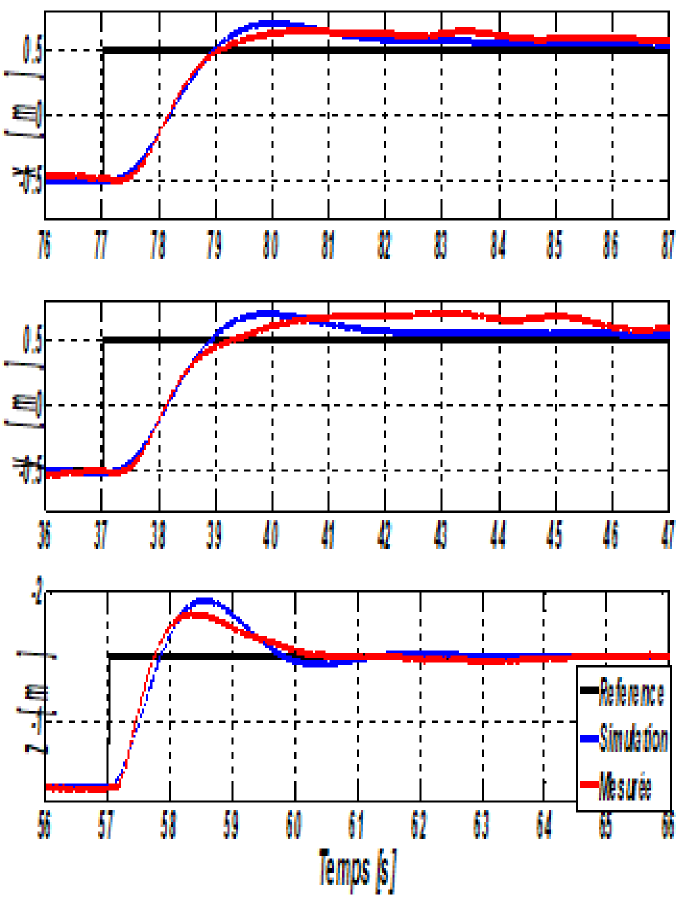

Figure 7. Comparison of step reference responses in cartesian positions: Simulation vs. Real X3-BL Quadrotor controlled by LQR in indoor flight test

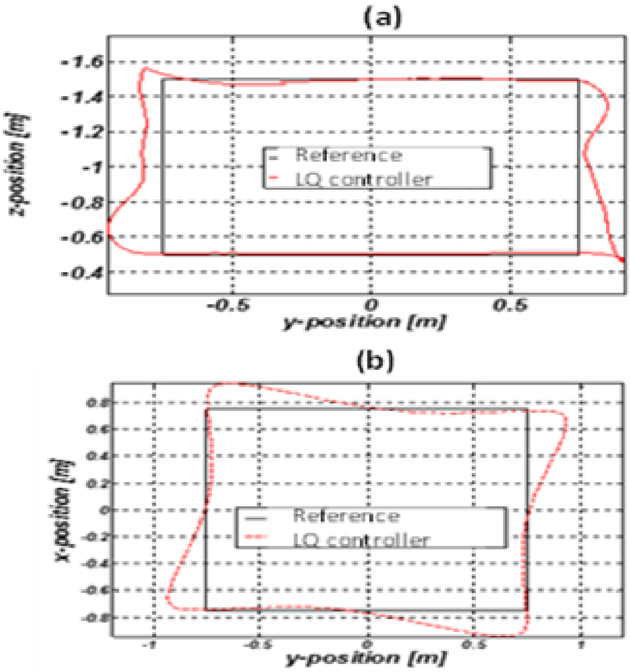

Figure 8. "Practical results of pre-planned trajectory tracking (Rectangle) of the quadrotor with LQ controller"
(a) Reference rectangle in [OY, OZ] (b) Reference rectangle in [OX, OY]

Figure 8 shows that the quadrotor can also track a pre-planned trajectory in the (x,y) plane with good accuracy. The quadrotor is following a square pattern, and the actual trajectory closely matches the desired trajectory. This indicates that the controller is able to effectively command the quadrotor to follow the desired path

The flight test results are encouraging and demonstrate the potential of the model and controller for real-world quadrotor applications. However, the controller can overshoot when changing direction, causing deviations from the trajectory near the corners of a rectangle. Despite this limitation, the model is still sufficient for testing purposes when the motion tracker is replaced with a GPS navigator. In the next section, we will perform the same flight tests, but with a simulated GPS signal generated through a modified motion tracker data sent to the controller.

Flight Test with Pseudo GPS Navigator

The following points will be considered during these tests. To wit that:

- The pure motion tracker (Vicon MX) will serve as a means of measuring the true position of the quadrotor without directly intervening in the correction.
- The drone will execute its flight using the pseudo GPS.
- Algorithm of figure.5 is considered for the generation of updates.
- The error tolerance limit, within the uncertainty cube between the estimate and the measurement by the pseudo GPS, is taken to be ± 0.3 meters on each Cartesian axis.

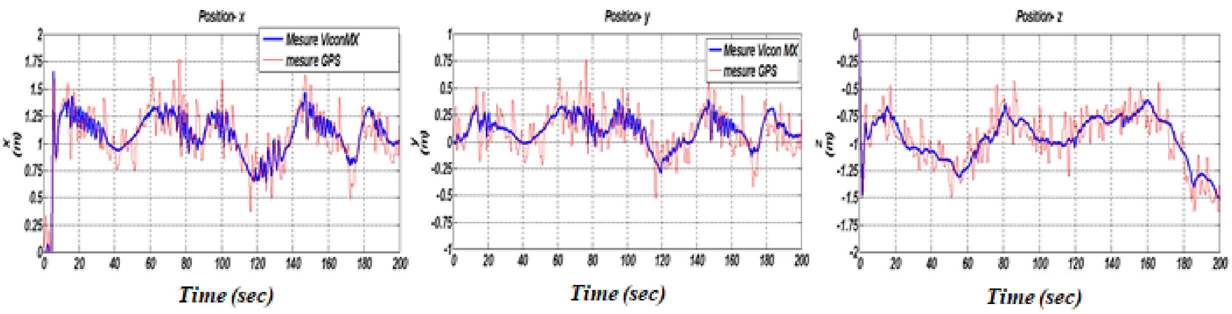

Figure 9. quadrotor xyz position during hovering flight around the cartisian position (1,0,-1) meseared by the Vicon MX and the pseudo GPS.

A hovering flight test of the quadrotor shows that the intrinsic errors of the inertial core induce, slowly, deviations of the quadrotor from the desired reference. Figure.9 shows the true position of this drone as seen by Vicon MX and Pseudo GPS. It is well noted from this figure that the drone performs a stationary flight with continuous displacement around the reference assigned to the controller. However, this displacement does not exceed the uncertainty band of the pseudo GPS in each direction. Updates are performed only when the estimate exceeds the error limits. This is the case during the time interval in seconds [10 30] and the time interval [140 160] where the controller start to relay on the pseudo GPS to control the quadrotor.

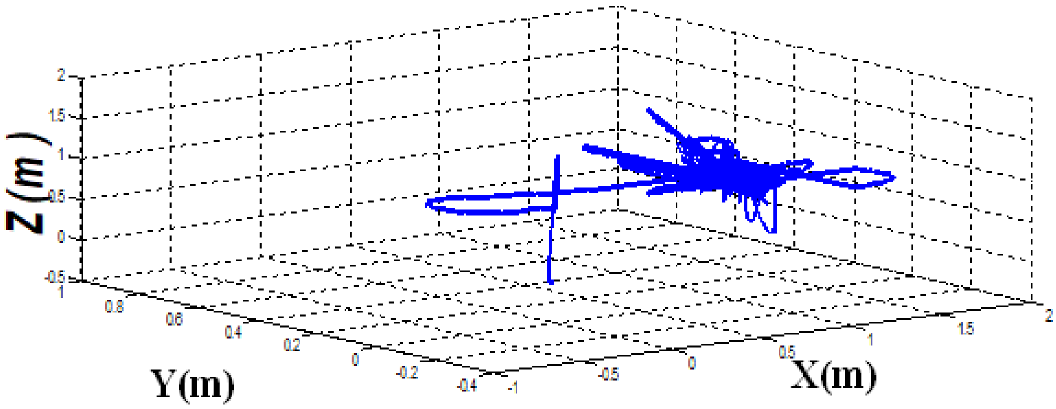

Figure .10 provides another three-dimensional overview of the pseudo GPS navigation from the hovering test.

As shown in this figure, the quadrotor is still flying inside the desired cube of uncertainty despite the distorted GPS signal. When these deviations exceed the estimation limit relative to the pseudo GPS measurement, an update is introduced. At this point, the controller becomes aware of its true position and begins to correct its errors.

Conclusion

To perform indoor tests of a flying robot that closely resemble real-world outdoor GPS navigation, we have developed and tested a new algorithm to substitute the GPS with a simulated GPS through a motion tracker. First, we confirmed the accuracy of the quadrotor model and the effectiveness of the controller using indoor tests. Then, we started injecting noise, biases, and distortions into the motion tracker data to simulate real-world GPS navigation.

A GPS simulator is a pseudo GPS that allows us to control the conditions in which the drone is being tested. This can be important for testing the performance of the drone in different environments, such as different levels of noise or interference. A GPS simulator can be used to troubleshoot problems with a drone's navigation system. By simulating different scenarios, one can identify the cause of the problem and develop a solution.

This pseudo GPS can be a cost-effective way to test drone navigation systems. Outdoor testing can be expensive, especially if one needs to travel to a remote location for safe tests. The results of this study show that the use of a motion tracker with this proposed algorithm is an efficient tool for outdoor conditions study simulation This algorithm provides a convenient tool for researchers to develop new models of GPS distortions and biases close to real GPS and perform tests in safe indoor environments without the influence of external.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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