Fusion Engineering Hexacopter test

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Abstract

This report describes the testing process of the Fusion Hexacopter platform, to be used for the collection of official flight test results. The tests are designed to analyse multiple aspects of the Fusion Reflex flight controller.

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1. Introduction

1.1. Fusion Engineering's Reflex

Fusion Engineering's goal is to create the most reliable, flexible and easy-to-use flight controller that can be used on any type of multirotor drone: the Fusion Reflex. Whereas conventional flight controllers use Proportional-Integral-Derivative (PID) control, the Reflex uses a technique based on Incremental Non-linear Dynamic Inversion (INDI). This is a novel method designed at Delft University of Technology (TU Delft). While control algorithms such as Non-linear Dynamic Inversion (NDI) are extremely sensitive to inaccuracies in system models, INDI overcomes this shortcoming by using sensors to reduce its dependency on accurate system models. It is a more robust algorithm which also allows for precise and fast responses.

1.2. Experiment goal

The goal of this experiment is to analyse the behaviour of the Reflex in flight while mounted on the Fusion Hexacopter. We want to test flight stability, position accuracy in hover as well as while following trajectories and, verify essential safety modes.

2. Equipment

2.1. Drone overview

The focus of this experiment is on the Fusion Hexacopter drone. This drone is made by Fusion Engineering to function as a testing platform for the Fusion Reflex flight controller.

The Maximum Take-Off Weight (MTOW) is 2.0 kg. The drone frame is a custom cut carbon fiber frame using a split deck configuration. The bottom deck is level with the arms of the drone and houses its power train: the Power Distribution Board (PDB), electronic speed controllers (ESCs) and a voltage/current sensor. The top deck is a mount for the Lidar sensor, Global Navigation Satellite System (GNSS) sensor, telemetry module and the Reflex flight controller. The Reflex is mounted on the top deck using a custom 3D-printed vibration damping mount. The drone is powered by a 4S 4000 mAh battery strapped to the underside of the bottom deck with a velcro strap.

2.2. Sensors

The Reflex has an IMU and a barometer for internal sensors. The PDB is a custom-made printed circuit board (PCB) that accepts battery voltage. The PDB splits the incoming power from the battery to all the motors and steps down the voltage to provide a clean 5 V supply for the Reflex and all the sensors. The external components used on this drone are:

- Garmin lidar lite v3
- A voltage/current sensor
- Ublox C94-M8P-2 developer board GNSS module
- HolyBro v3 telemetry radio
- Aikon AK32 35A 2-6S ESC
- Tmotor F90 1500 Kv motors
- Drotek RM3100 magnetometer

3. Experiments and metrics

To analyse the performance of the flight controller and determine if the tests have been completed successfully, each experiment is assigned a metric with corresponding outer bounds that the drone has to stay within.

3.1. Attitude response

We want to test multiple aspects of the flight controller. First, we want to make sure that the most inner control loop that stabilises the attitude of the drone is stable. This should have a max overshoot of 5° when a step input of 20° is applied in both roll and pitch direction:

$$O_{max} < 5[^\circ] \mid step = 20[^\circ] \tag{1}$$

The step inputs are applied 10 times in roll, and 10 times in pitch direction and are repeated for INDI and PID.

3.2. Position hold

To analyse the position hold behaviour, the drone is made to hover in place. According to the AirTub specifications, the drone can have a maximum deviation of 20 cm from its trajectory.

$$\Delta_{pos} < 0.20[m] \tag{2}$$

Position hold is tested by taking off and centering both the remote control sticks when the drone is in the air. Position hold mode will create a position setpoint at the location where the sticks are centered. The test has to be started with a full battery and the drone will return to the ground when the battery is depleted (3.5 V per cell). Position hold is tested in both INDI and PID.

3.3. GNSS loss

If the drone loses position information from the GNSS, the uncertainty of its position will increase, resulting in inaccurate position information. Therefore, as soon as position information is lost, the drone should not try to track position anymore. The Reflex carries out this function by setting the flight mode one level lower from position mode to altitude mode.

To verify the functionality of mode switching, the drone is flown in position mode while it holds its position. While holding position, the GNSS service is stopped in flight. The timestamp where the GNSS service is stopped is shown with a dotted vertical line in figure A.7. What we expect to see after shutting down the service is that the position estimation starts fluctuating, and the flight mode should jump from position mode (2.0) to altitude mode (1.0).

3.4. Lidar loss

The drone can get vertical position information from the internal barometer, external lidar and/or external GNSS. Whenever external sensors fail, the drone should still be able to land autonomously. For that autonomous landing, the barometer should be enough to have stable altitude information, and the controls should not automatically get pushed back to attitude flight mode because of the unreliable data.

To test this the drone is flown in altitude mode while holding altitude, after which we shut down the sensor service that the lidar is connected to mid-flight. We expect the drone to still hold altitude, however with an increasing deviation due to the lack of the precision provided by the lidar.

3.5. RC loss

Whenever remote control (RC) loss occurs, the drone has to either autonomously land, or autonomously return to home and land. In this experiment, we choose to test the safer option: return to home and land.

To test RC loss we put the drone in position hold, after which we shut down the RC. The commander is expected to initiate the return to home procedure: the drone will climb to a predefined altitude (3 m, in this case) after which the home position in x- and y-coordinates will be set as the target. Once above the home position, the drone will start to descend.

3.6. Geofence breach

The geofence is specified as a cylinder with radius r and height h around the takeoff location. Whenever the drone breaches these boundaries of the cylinder, the drone will start its autonomous return to home procedure. The condition for this is given in equation 3.

$$if(\sqrt{x^2 + y^2} > r) \vee (z > h) : RTH \tag{3}$$

3.7. Automated trajectories

For the prupose of this test, an additional raised antenna mount is fixed on the drone, 4 cm above the top deck with a patch antenna receiver to obtain GNSS data. The AirTub project has one experiment where the drone flies over the surface of a wind turbine blade. The safe flight envelope for this manoeuvre has room for a vertical position error of $\Delta_{z,max} = 0.20[m]$. This is taken as the required boundary metric for this test.

The trajectory inputted in order to test the trajectory mode in PID and INDI is a triangle oriented along east-north directions. After rising to an altitude of 3 meters, the first waypoint is -5 meters east, the second waypoint is -5 meters north, the last waypoint is return to home position.

The PID trajectory has an additional waypoint in vertical direction at 1 m, as seen in figure A.11

from approximately 3 to 23 seconds. This waypoint is added to the trajectory to ensure the integrator of the vertical position PID loop has converged. Since INDI does not use an integrator, this setpoint is left out during its testing.

4. Results

4.1. Attitude response

The attitude responses for PID and INDI are seen in figures A.3 and A.4. The maximum overshoot in roll seen in PID is 0.68° at a timestamp of 64.68 seconds and 3.40° in pitch at a timestamp of 49.34 seconds. The maximum overshoot for INDI is 0.60° in roll at a timestamp of 26.17 seconds and 1.03° in pitch axis at a timestamp of 19.47 seconds. These results are seen in figure 2. Both control algorithms have an overshoot that is lower than the predefined 5° maximum.

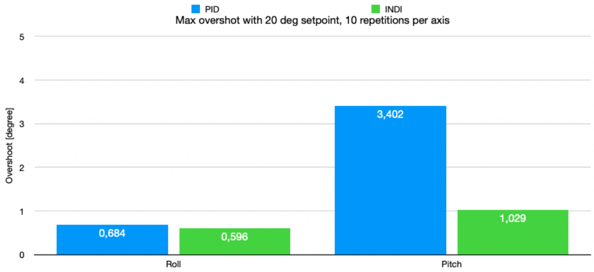


Figure 1

4.2. Position hold

The graphs for position hold for both INDI and PID can be found in figures A.5 and A.6.

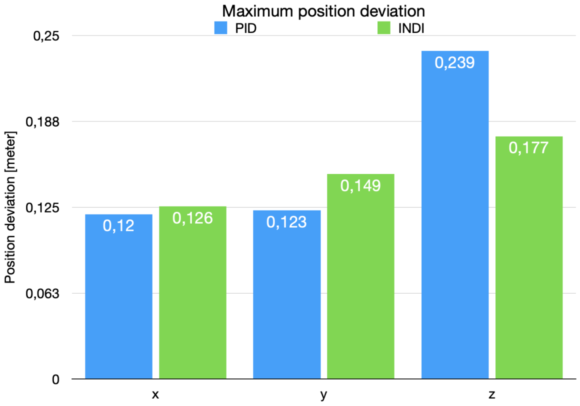


Figure 2

4.3. GNSS loss

The results from testing GNSS loss are graphed in figure A.7. The vertical line around 30 seconds shows the moment the GNSS service was stopped. We see that in both flights, the flight mode successfully switches from position mode (3.0) to altitude mode (2.0).

4.4. Lidar loss

The results from testing lidar loss are graphed in figure A.8. The dotted vertical line shows the moment the sensor service of the lidar sensor was stopped. The position was still maintained using only the barometer, even though the position keeping was less accurate compared to when the lidar was still active.

4.5. RC failsafe

The results for this experiment are shown in figure A.9. The green vertical dotted lines show where the RC signal was lost. The purple vertical dotted line shows where RC signal is regained.

First, the drone is put into position hold mode. The RC is then turned off as seen by the first dotted line at approximately 25 seconds. The drone starts the return to home sequence by first climbing to an altitude of 3 m. After the altitude is reached at approximately 32 seconds, the drone sets the x and y setpoints successfully to its home position and the position is properly tracked. After regaining control the drone is put back into position hold mode at a different xy location. The RC is turned off again. Again, the setpoint for its z-coordinate is set successfully first. After the drone reaches the setpoint for z, the setpoint is set for x and y position successfully as well.

4.6. Geofence breach

The results for this experiment are shown in figure A.10. The vertical dotted lines are the points where the geofence was broken. The radius of the geofence is 10 meters. After breaching the geofence, the drone starts a return to home procedure. When home is successfully reached, manual control is taken back after which the geofence is broken a second time. Again the return to home procedure is successfully completed.

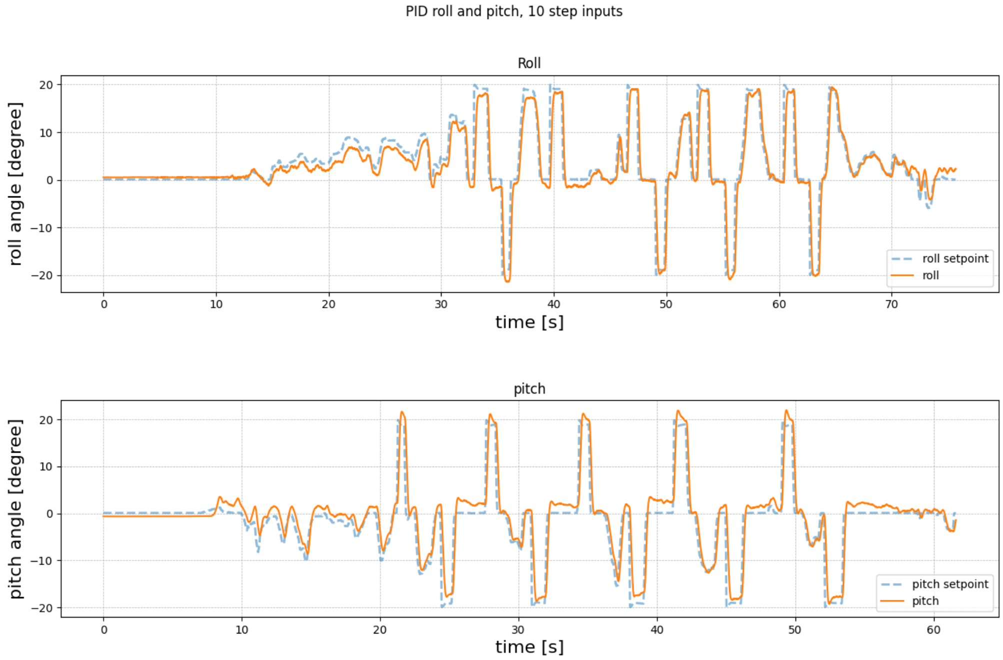
4.7. Autonomous Trajectories

The results for this experiment are shown in figures A.11 and A.12. Both trajectories were flown on September 1st 2022, with a wind speed of 30 km/h and gusts up to 45 km/h. Tracking in position is deemed to be sufficient. We can see a small offset of actual position with respect to its generated setpoint, indicating a delay with time.

This is caused by the setpoint trajectory generator. The trajectory generator computes a number of position setpoints with respect to time. If the error increases, the drone will correct its position. The setpoint will first have to move in order for the controller to perceive an error in position. The maximum vertical position deviation is 9.4 cm for PID and 6.5 cm for INDI. The maximum horizontal position deviation across the trajectory for INDI is 9.83 cm, while the maximum position deviation for PID is 21.42 cm.

Appendix A. Appendix A

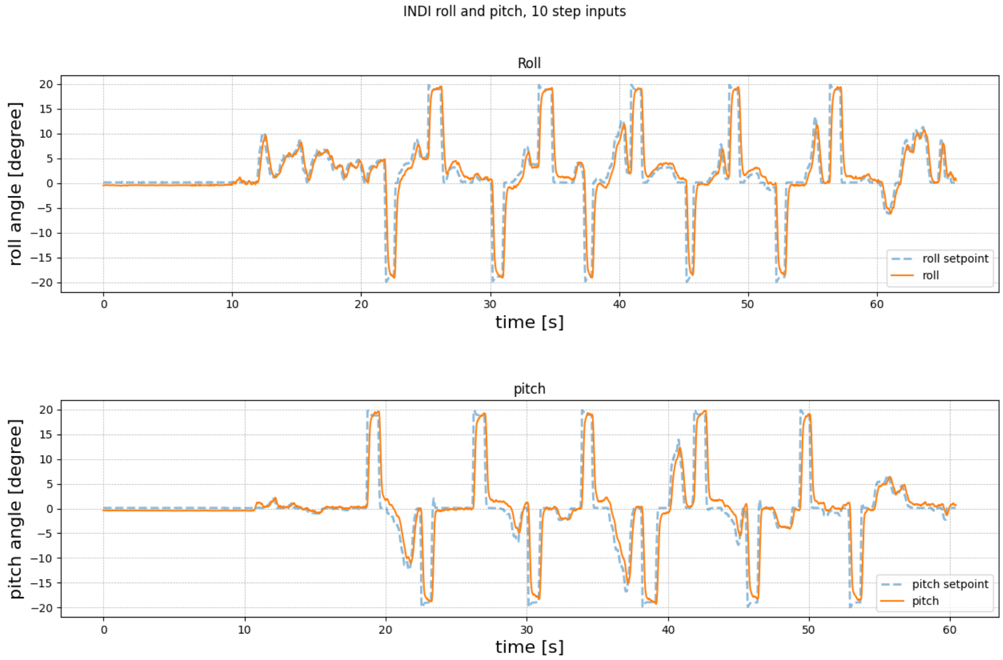
Appendix A.1. Roll Pitch


PID roll and pitch, 10 step inputs

Roll

pitch

Figure A.3: PID roll pitch


INDI roll and pitch, 10 step inputs

Roll

pitch

Figure A.4: INDI roll pitch

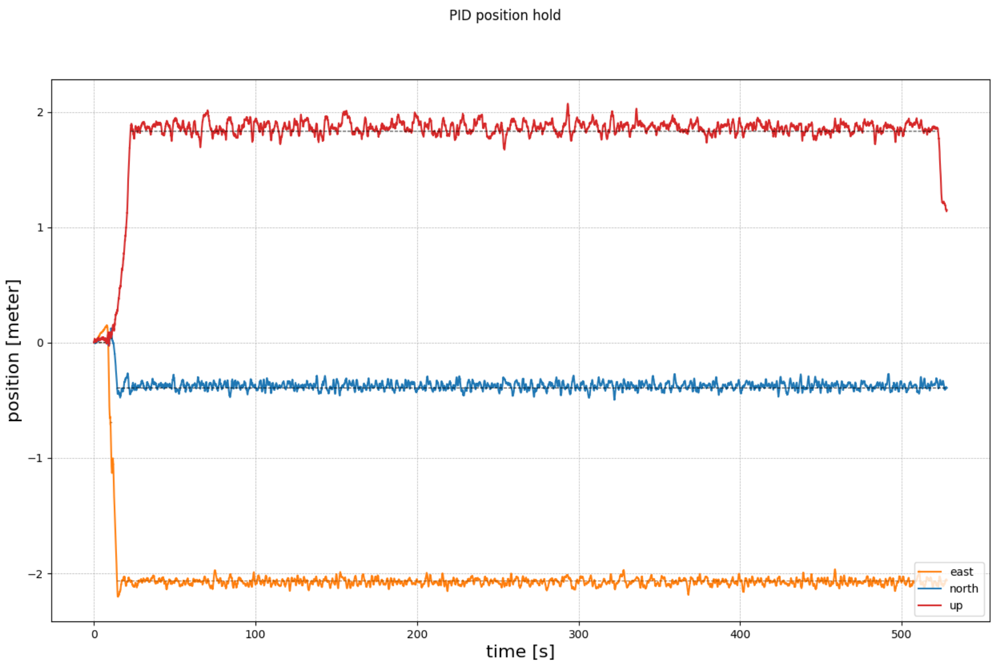


Figure A.5: PID roll pitch

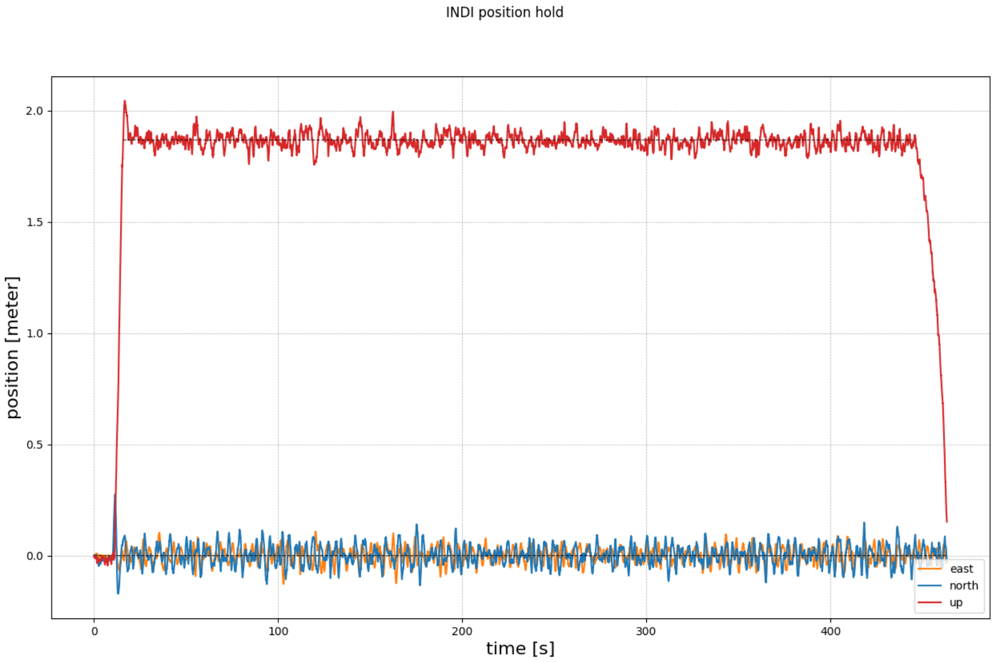


Figure A.6: INDI roll pitch

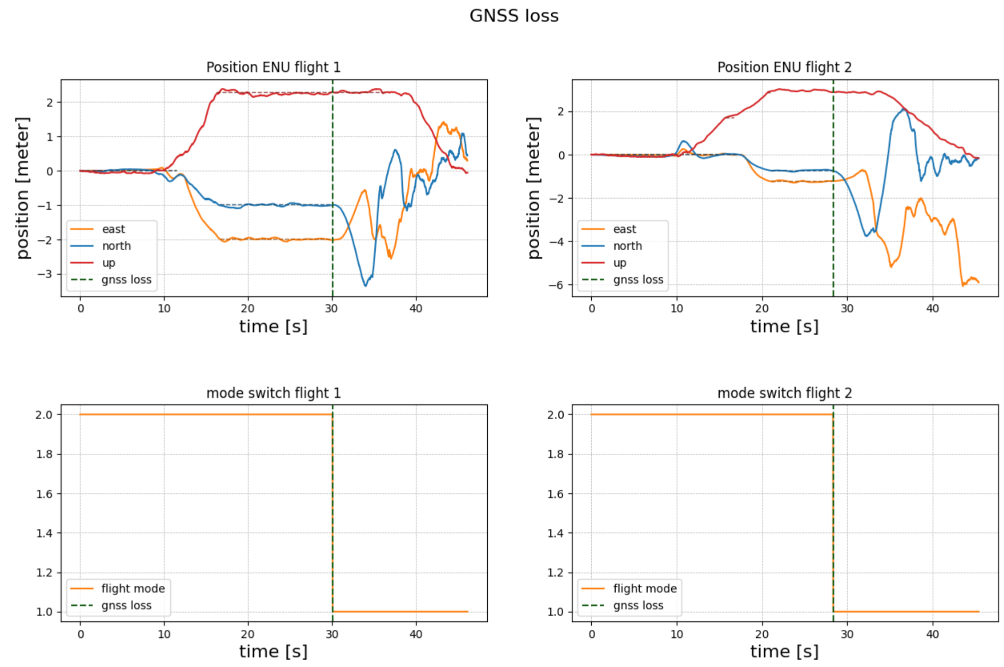


Figure A.7: GNSS loss

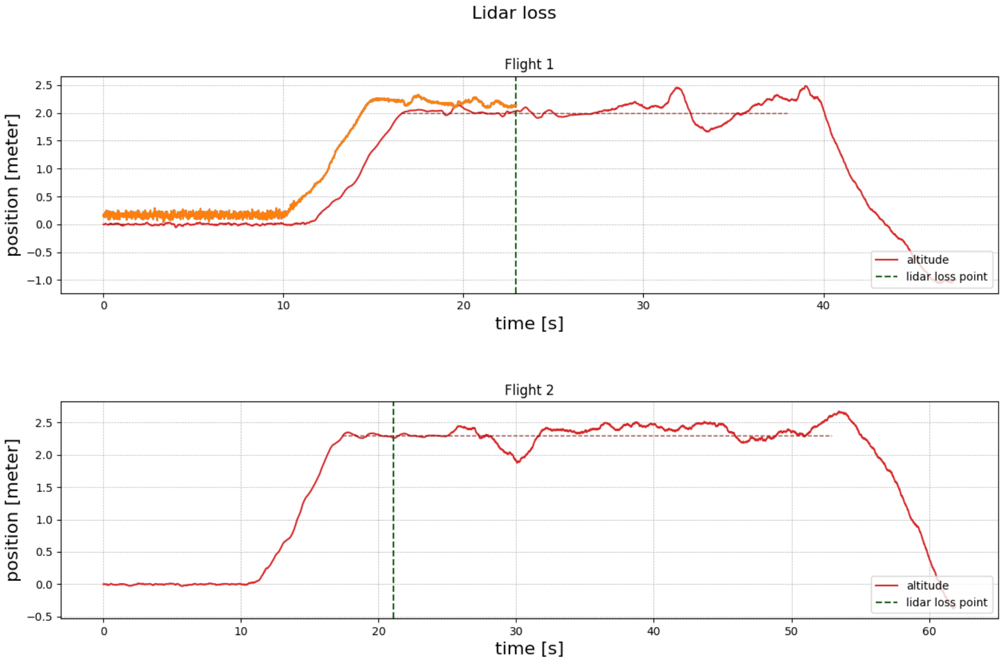


Figure A.8: Lidar loss

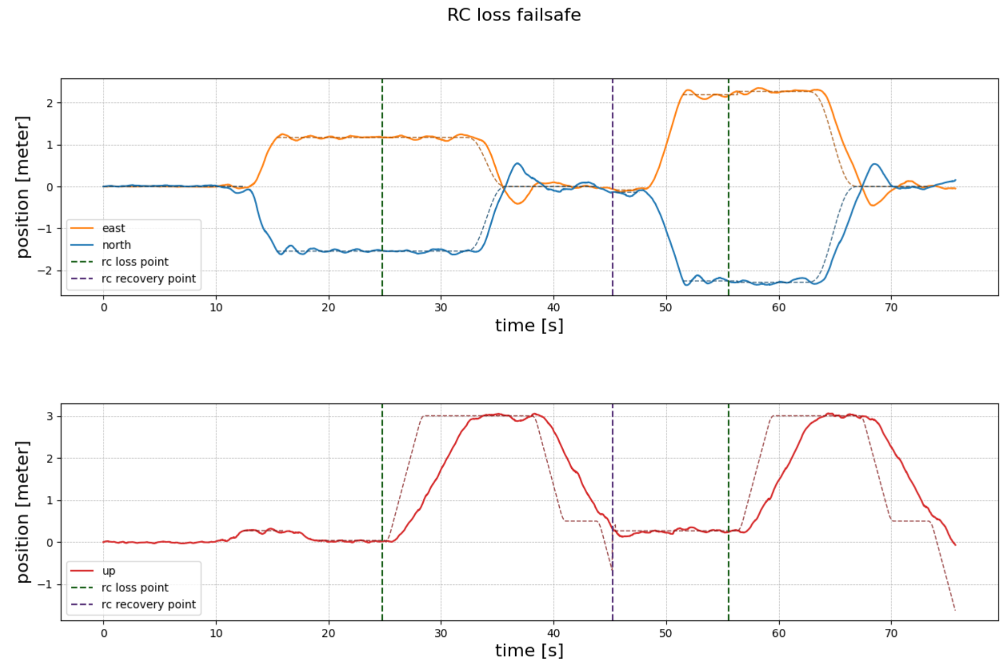


Figure A.9: RC loss

Appendix A.4. Geofence breach

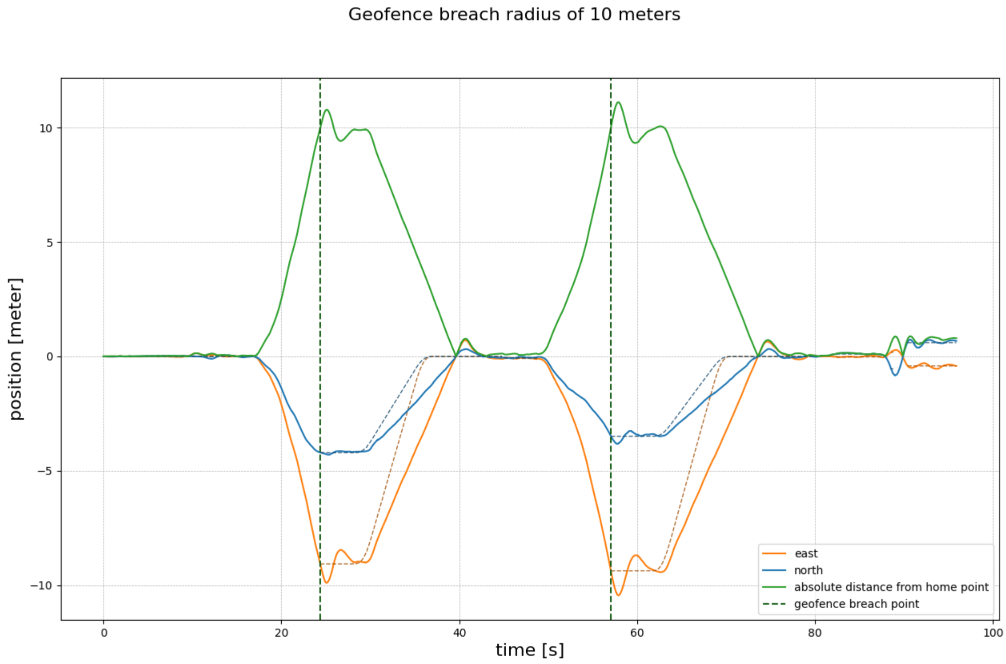


Figure A.10: Geofence breach

Appendix A.5. Trajectories

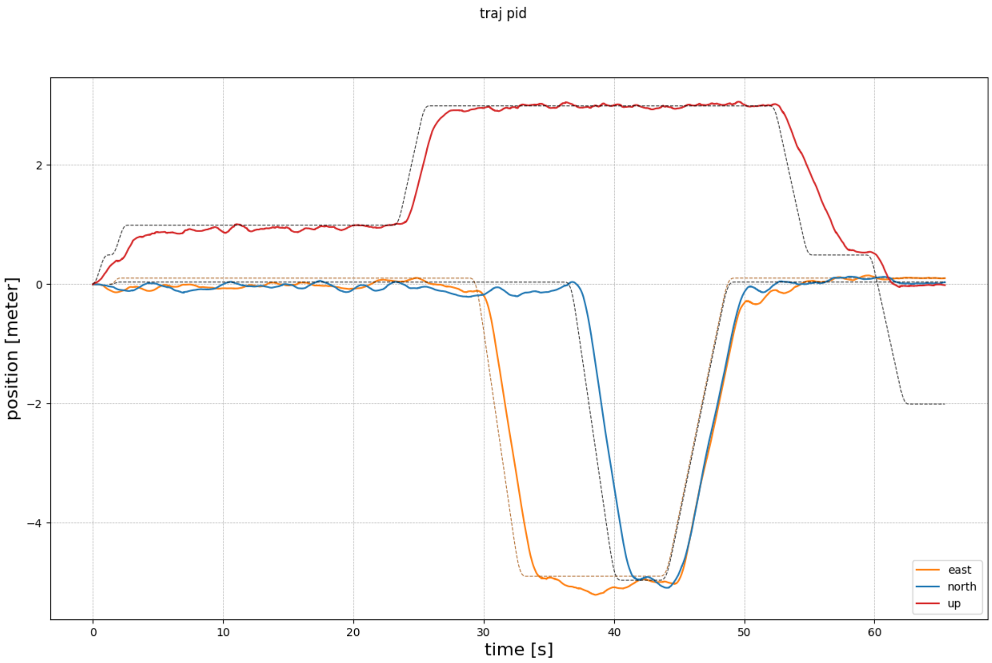


Figure A.11: PID trajectory

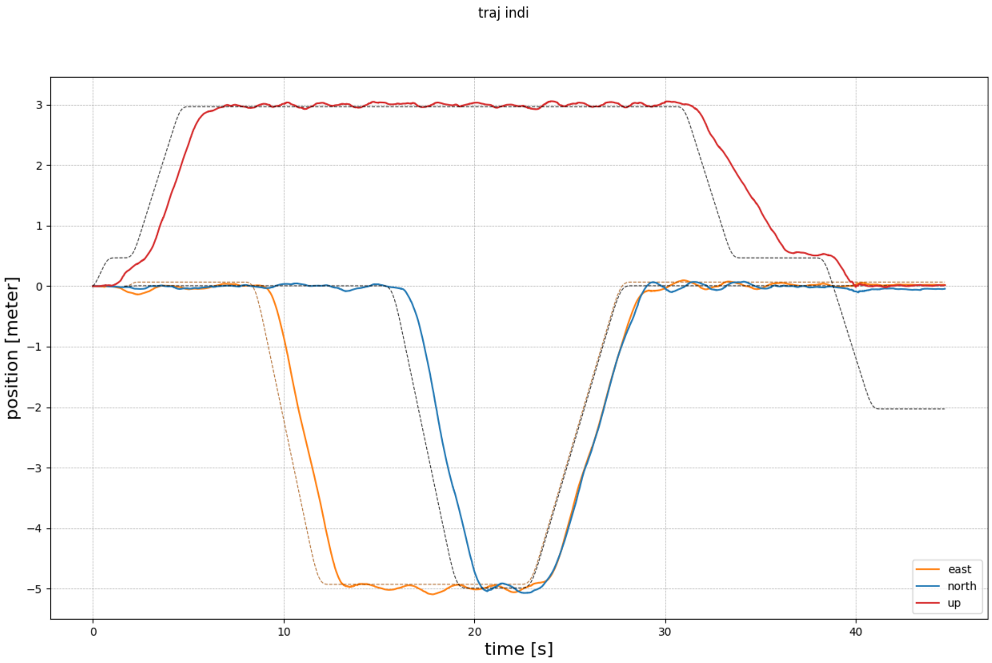


Figure A.12: INDI trajectory