AirTUB

1. Introduction

At Fusion Engineering we are working to create the most reliable, flexible and easy-to-use flight controller for any type of multirotor drone. We have started from the ground up, developing our own flexible and reliable software platform. On top of this platform, we built innovative flight control algorithms to ensure more accurate positioning, disturbance rejection, and fault tolerance.

The Fusion Reflex

The first version of Fusion Engineering's state-of-the-art flight controller—the Fusion Reflex—is the key to a new generation of drone flights. Designed with reliability and flexibility in mind, the Fusion Reflex is adaptable for any type of multirotor drone. Our flight control is built from the ground up for the commercial drone market. We use the latest research in state estimation, flight control and fault tolerance to make the most robust system possible with the newest algorithms; facilitating the next generation of drone applications. Where conventional flight controllers use Proportional-Integral-Derivative control (PID control), Fusion's flight controller uses a technique based on Incremental Nonlinear Dynamic Inversion (INDI): A novel method designed at TU Delft that overcomes the robustness issues of NDI by reducing the dependency on an accurate system model while still allowing for a precise and fast response.

2. WP 2: Automated drone research

2.1 Project details

This work package describes the research on automated UAV's. The core business of Fusion Engineering is creating state of the art flight controllers. All efforts at Fusion Engineering are focussed towards this goal, so all employees worked on this work package. During this project, Fusion's research has resulted in their first ever state of the art flight controller: the Fusion Reflex IM (introductory model).

2.2 Contents of the project

2.2.1 Summary

During the AirTUB project, the Fusion Reflex IM integrates state of the art flight control in a 100% custom software stack, on a 100% custom piece of hardware (see figure 1). The software is written in 'Rust' a novel language dedicated to speed, safety and performance. The software architecture is created with redundancy and safety as priority. Not one, but multiple software services run simultaneously allowing

Figure 1: Fusion Reflex IM

for backup processes such as backup flight control algorithms and backup state estimators running at all times, eliminating single points of failure from a software perspective. During this project, Fusion took a novel flight algorithm INDI (incremental non-linear dynamic inversion), and adapted it specifically for unmanned multirotor flight. Windtunnel tests show the faster response times and more accurate trajectory tracking in heavy wind conditions up to 90 km/h wind gusts. The full report is attached as 'FusionWindtunnelTest.pdf'.

2.2.2 Objective

Objective of WP2 for Fusion Engineering is to develop a flight controller that is capable of accurately tracking trajectories autonomously, as well as allowing piloted flight. We provide data of a working proof of concept.

2.2.3 Way of working/deliverables

The Fusion IM can be split into the software and the hardware.

The hardware has more computational capabilities of conventional flight controllers. A dedicated compute module runs all the software services, while a co-processor takes care of time sensitive tasks like motor control. A Wi-Fi chip takes care of wireless communication from user to the flight controller. Built in triple redundant IMU and a barometer ensure emergency landing is always possible, even if all external sensors fail.

Where conventional flight controllers run their software as one program, the Fusion Reflex IM runs many different programs (or processes) simultaneously. This allows for multiple controllers to run at the same time, allowing for realtime switching for backup or easy A-B testing. Also multiple state estimators can run simultaneously. Having this option removes the single point of failure from a software perspective.

<u>Windtunnel testing at TU Delft</u>
Early 2022 we conducted experiments in the windtunnel facilities of the TU Delft. The goal of this experiment was to investigate the wind gust response of the novel INDI algorithm with respect to the conventional PID control algorithm. We found that INDI outperforms PID with respect to absolute error and integrated error due to wind gusts, with the performance difference increasing in favour for INDI as wind speeds increase. See figure 2 for a graph comparing position displacement due to a wind gust for both PID and INDI algorithms.

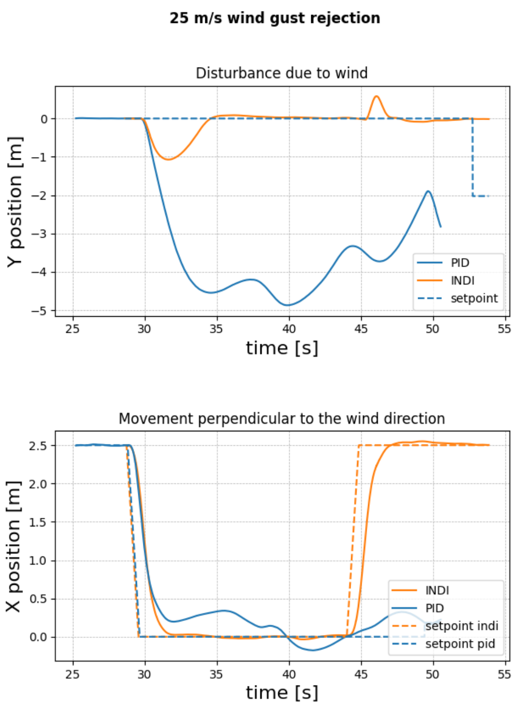

Figure 2: PID vs INDI, 25m/s wind gust

2.2.4 Possibilities for follow-up activities

The Fusion Engineering team has always been looking for ways to improve the product on hardware, software as well as control engineering perspective. As of December 2022, the first new batch of hardware prototypes have been produced and are being tested. New hardware includes (but is not limited to) a brand new compute module for running the computations, external Wi-Fi antenna connector for improved range, power connectors capable of higher currents and an updated set of connector ports. This new hardware will receive CE certification and will undergo component certification following EASA and FCC regulations.

The software gets updated every two weeks, when a new cycle of improvement has been finished. This can vary from bug fixes to new features. The software is currently in the process of being DO-178C certified.

2.3 Execution of the project

During the AirTUB project Fusion Engineering designed and developed a new flight controller from the ground up. Everything is completely custom made, from hardware to software and control algorithms. The developing of a completely new system turned out to be more time consuming than initially thought. In the end we used about 50% more hours in this work package than originally planned.
Another reason for the increase of hours was the miscommunication during the planning phase of the project with the Netherlands Aerospace Centre (NLR): We have been developing a prototype, but NLR was initially not willing to fly with less than a commercial product with the associated flight hours and track record. In the end this obstacle is overcome by creating a series of tests created with approval of NLR designed specifically for this project to prove the safety of the Reflex IM.

3. WP3:Drone prototyping integration and testing

3.1 Project details

This work package focussed on the integration of the drone with the payload and external position/velocity setpoints. Later in the project the scope of the project was redirected to more individual testing and less integration between partners. The drone capable of carrying the payload has a maximum take off weight (MTOW) of above 45 KG, and large motors and propellers. Large aircraft have different dynamics and electronics systems. Prior to this project, the heaviest drone flown with using the Reflex IM has a MTOW of 2.5 kg. For Fusion Engineering, this work package entails integrating the Reflex IM in increasingly large drone platforms ending with the Gaia120 platform. The testing and validation team of Fusion was responsible for this work package.

3.2 Contents of the project

3.2.1 Summary

The Fusion IM was integrated on the Gaia120 drone platform and performed an autonomous flight trajectory designed to inspect the leading edge of a windturbine blade. The laser scanner performing the inspection of the leading edge needs precise distance to the leading edge, resulting in the need for an accurate flight path with a maximum allowed position deviation of 20 cm from the path. The Gaia120 with the Fusion IM was able to fly this precise trajectory.

A testing table containing safety test procedures and piloted as well as autonomous flight tests is used as reference manual to create flight test reports that will allow Fusion Engineering to prove the stability and reliability of the Reflex IM on increasingly large drone platforms, in order to be able to fly with the Gaia 120. Three drones are flown during this work package:

- Fusion Hexacopter (MTOW 2kg)
- Fusion Hydra (MTOW 5kg)
- Gaia 120 (MTOW 10kg)

All three drones have completed autonomous trajectory flights successfully.
The Gaia 120 platform uses a higher battery voltage (12s). In the market of electronics speed controllers (ESCs), there is a lack of products that can handle high voltage and communicate via bi-directional Dshot protocol. The bi-directional Dshot protocol is capable of sending high frequency speed feedback from the motors to the flight controller, and is needed for the INDI algorithm, as well as fault tolerant control. The ESCs used are from a manufacturer 'APD'. The Gaia120 uses the type '120F3', but these components turned out to be unreliable in their communication. Their highest rated ESC, capable of delivering 200A continuous current turned out to be incapable of speaking the needed bi-directional Dshot.

3.2.2 Objective

Objective is to show a working Reflex IM capable of performing piloted and autonomous flight on the Gaia120 drone. All necessary safety features have to be tested.

3.2.3 Way of working/deliverables

Scaling up to Gaia120
In order to safely and reliably scale up the drone platform from the 2 kg test drone to the Gaia 120 drone, a testing table is created in agreement with the NLR. Tests in this table show important safety features and flight characteristics for both INDI and PID control. The tests proving flight control stability are split up in flights showing attitude control response, altitude control response, position control response and autonomous flight path accuracy.

The safety features tested are:

- Return to launch in case of geofence breach
- Flight mode switching in case of GNSS loss
- Return to launch in case of RC loss
- Observe altitude hold mode in case of lidar sensor loss
- Return to launch in case of low battery
- Manual control takeover from autonomous flight

For a full description of all tests, please refer to the attached documents 'TestTable.pdf'. Please note that the tests 'landing on blade' and 'Demcon integration', as well as all flight with the heavy hydra and 45kg drone have been dropped after the rescoping of the project. An example for the 'Return to launch in case of geofence breach' can be found in figure 3.

All test results are shown in the attached files 'HydraTestReport.pdf' and 'HexacopterTestReport.pdf'.

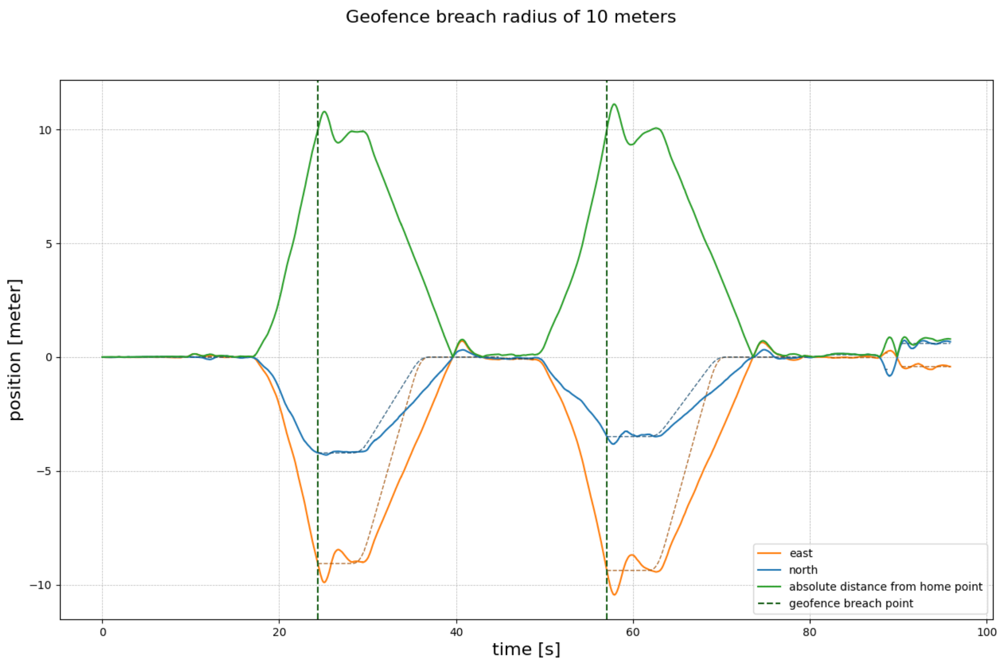

Figure 3: Log of Return to home procedure in case of ‘Geofence breach’

<u>Flying Gaia120</u>
The Gaia120 uses motors that need 12S voltage, which is approximately 50 volts. ESCs rated for such a high voltage while still communicating via the bi-directional Dshot protocol are not common. The company ‘Advanced Power Drives’ creates a type of ESC, the ‘APD 120F3’ ESC, rated for 50V, 120A continuous current draw, 200A burst current draw. According to the maximum take off weight and the motor specifications, the motors will draw approximately 3A continuous current each when in hover.
The ESCs as built in by NLR were not flashed with the firmware allowing bi-directional Dshot communication. All ECS’s had to be removed from the drones hull in order to acces the flashing port to flash the new firmware, quite the time consuming task. After reflashing, two ESCs did not deliver the proper rpm feedback to the flight controller and had to be replaced.
On November 22nd, a test flight was conducted at NLR ground to show trajectory functionality of the Gaia120 including the return to launch safety features. Wind turbine

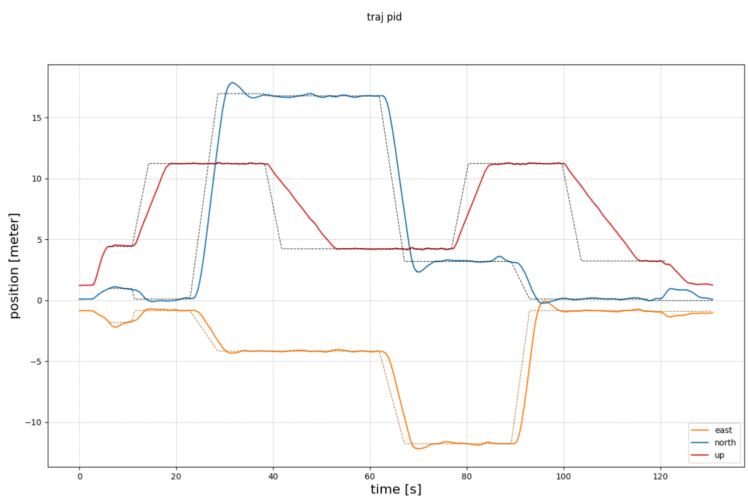

Figure 4: Gaia120 Trajectory showing East, North and Up position
with the respective setpoints

blade tip and base coordinates were gathered in a manual flight in order to plan the autonomous trajectory. The actual trajectory test was planned for the demo day on November 24th.
On November 23rd a trajectory test was conducted by Fusion Engineering on their testing grounds at Unmanned Valley, Valkenburg, with succes, see figure 4.

On the demo day last minute changes to the planning were not communicated to Fusion by official means, leading to Fusion not being able to perform a final test flight. Along with an adaptation to the flight path this led to an unexpected result from one of the sensors, causing a manual take-over to be required.

3.2.4 Possibilities for follow-up activities

Fusion identified and eliminated the error in one of the sensors that caused the need for manual takeover. The next step would be to perform the trajectory as planned for the demo day, and show that the system is capable of performing a fly-by of a wind turbine blade leading edge. When this is accomplished, increasing the weight of the drone and/or scaling up to a larger airframe are possibilities.

3.3 Execution

The need to document test flights according to a testing table proving stability and safety on increasingly large platforms was added to the project in a later stage. This drastically increased the time spent on the project. Removing the ESCs and uploading the proper firmware too some time to fix as well. In the end, flying autonomous trajectories with the Gaia120 drone was successful and the drone, showing stable flight behaviour and meeting all safety feature requirements.

4 Conclusion

Fusion Engineering delivered a new state of the art flight controller incorporating novel control algorithms along with all standard safety features, capable of flying autonomous trajectories: The Reflex IM. We successfully flown the Gaia120 drone in an autonomous trajectory designed to inspect the leading edge of a wind turbine blade.