Phase III Evaluation Delay Justification

ARSI Deliverable

PDTI Urban Robotics - Sewer Inspection

December 18, 2018

1 Introduction

Following the first Phase III evaluation in July 2018, it was recognized that flights with our new platform design were too unstable for reliable sewer inspection. Therefore, after an analysis of the system, the ARSI team decided to carry out important changes to the propulsion system and autopilot firmware, in order to try and improve flight stability.

In this document we describe our changes in both areas, as well as how various issues encountered during their implementation resulted in delays which ultimately made it impossible for us to meet the deadline for the November evaluation. We also present results from the evaluation area in Av. Pearson, Barcelona, that we eventually were able to inspect with our MAV on December 11th 2018.

2 Propulsion system

The propulsion system of a Micro Air Vehicle (MAV) comprises the propellers, the motors, and their Electronic Speed Controllers (ESCs). In Phase II of the project, our prototype used 10 inch propellers with 4.5 inch pitch, and T-Motor MN3110 780kv (rpm*V) motors with 30A TBS ESCs running at 14.8V. Phase II showed that this configuration delivered reactive control in the sewers, but insufficient autonomy and payload capacity for sewer inspection.

In Phase III we decided to revisit the propulsion system in order to meet the evaluation requirements of longer flight times and additional payload capacity. We worked with our suppliers DroneTools to develop a new MAV design using overlapping 14 inch propellers with 5.5 pitch, using T-Motor Antigravity MN4006 380kv motors and Turnigy Flush 30A ESCs running at 22.2V. In this configuration the motors are slower but more powerful, and the larger propellers ensure that the MAV can fly longer and with a heavier payload. However, our various tests in the sewers showed that this configuration was unable to deliver stable flight in sewer conditions, as was visible during the July 2018 evaluation in Virrei Amat, Barcelona.

The ARSI team therefore decided to find a compromise between the Phase II and Phase III configurations, in order to obtain the reactive control required for operation in the sewers while providing satisfactory flight times and payload capacity. We introduced 11" propellers with 3.7" pitch, T-Motor MN3510 700kv motors and new T-Motor 45A ESCs running at 22.2V. However our laboratory tests showed that the ESCs were not adapted to this configuration, and after investigation we eventually had to revert to the Turnigy Flush 30A ESC models. We also experienced problems with the new batch of T-Motor MN3510 motors, where several brand new units got damaged inexplicably in the span of a few days. This also occurred repeatedly during field tests in the sewers, causing accidents and damage to the drone. This issue was very surprising to us given that we had used motors of the same brand throughout phases I and II without any fault or problem. We are now in contact with the providers to investigate this issue.

Each update to the propulsion system configuration required calibration and control tuning in our flying arena, so that these various hardware issues eventually delayed us significantly. The final configuration used 11" propellers with 3.7" pitch propellers with T-Motor MN3510 700kv motors and Turnigy Flush 30A ESCs running at 22.2V. It can carry a payload of 1kg for an estimated flight time of 14 minutes.

3 Autopilot firmware

The ARSI MAV carries a Pixhawk autopilot unit, running the open-source PX4 firmware stack. The Pixhawk has two main responsibilities:

- Estimating the real-time MAV pose and attitude by fusing information from various embedded sensors (accelerometers, gyroscopes, altitude sensor, etc)
- Executing high-level control commands (eg. waypoints) issued by the ARSI software stack, by converting them into low-level motor thrust requests.

PX4 is a rapidly evolving open-source project, maintained mostly by academics from various institutions around the world. Back in Phase I of the project, the ARSI team decided on a version of the PX4 firmware that met our needs for this project. However, after the July evaluation and further field tests in Mercat del Born, we realized that some of the issues observed in the MAV control could be explained by known limitations and even reported bugs of the PX4 version we were using. Therefore, we decided to upgrade to the most recent stable PX4 release, which not only resolved these known issues but also offered new functionality, in particular more robust algorithms for sensor fusion and localization.

Our first task was to upgrade the PX4 state estimator algorithm from that used in Phase I (a simple 3D complementary filter called INAV, now deprecated) to one of its replacements in the latest PX4 release (LPE or EKF2, two more advanced and robust Extended Kalman Filters). Unfortunately this task took a lot longer that we anticipated. We first worked with EKF2 to fuse accelerometer and gyroscope data with visual odometry from the RGBD camera and ground range measurements from the Teraranger infrared sensor. Although the results looked promising, we observed occasional unexplained resets of the odometry solution, which in a real flight conditions would almost certainly result in an accident. We looked at configuration, documentation, developer forums as well as the PX4 source code but were unable to resolve this issue and therefore decided to use the LPE state estimator. While LPE did not exhibit the reset issue, we encountered another problem with ground range measurements. A lot of work was again required to identify a bug in the fusion of ground measurements during the initialization of the state estimator.

Ultimately, we were able to use LPE to provide robust and precise state estimation, but it required a lot more work than we anticipated. These delays were due both to the scarcity of documentation and support typical of open-source projects, as well as flaws in the development process that allowed for bugs to be included in software releases. The lesson learned for us is that these disadvantages of open-source projects should be taken into account when estimating work schedules, and even when considering them as an alternative to commercial solutions.

4 Inspection results

The ARSI team carried out an inspection of the evaluation area in Av. Pearson on December 11th 2018 with a brigade provided by our partner FCC. The area is very complex for autonomous inspection: it comprises a narrow $\sim$30 meters long T111 section, which turns into a curve with a slight climb, before reaching a 90 degrees turn into a collapsed section. Another challenge of this area is that due to the geometry of the tunnels, WiFi communications to a router positioned at the entry manhole are lost immediately after the sharp turn.

By placing our WiFi router at the turn, we were able to perform a full autonomous flight from the manhole into the collapsed area, get a detailed view of the damage, then fly backwards all the way back to the manhole area. Figure 1 shows 3D reconstruction results of the T130 straight section and collapsed rocks in the Av. Pearson evaluation area, Barcelona.

Videos for this inspection are available:

- HD camera onboard the MAV (compressed video): download
- 3rd person view: download

Figure 1: 3D reconstruction of a T130 section in Av Pearson, Barcelona

5 Conclusions

The successful inspection of a complex area like Av. Pearson in Barcelona shows that the work carried out on the firmware and propulsion system of our MAV did bear fruit and allowed us to improve on the performances from Phase II. However, a number of hardware and firmware issues introduced significant delays which ultimately lead to us having to cancel the November evaluation. We hope that this document clarified the technical issues that lead to this decision.