POLITECNICO DI TORINO
Master's Degree in Mechatronic Engineering

Title: PX4 autopilot customization for non-standard gimbal and UWB peripherals
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Abstract

Due to their extreme versatility, autonomous drones have been gaining a lot of interest over the last decades. Applications are mainly intended to reduce injuries, saving lives and optimizing already existing processes, covering a wide range of scenarios, such as smart agriculture, emergency situations and safety inspections.

PIC4SeR, PoliTO Interdepartmental Centre for Service Robotics, embraced this topic a few years ago starting to develop different UAVs, from ultralight models lighter than 250 grams to much heavier drones, in order to exploit technologies oriented to service robotics, smart cities, precision agriculture and search-rescue operations, which are the main topics of interest of the center. This thesis was born as one of the building blocks of a wider project about swarm flight, indoor navigation and robots cooperation, that will take place in the near future merging several technologies coming from different works carried by researchers, PhD students and master thesis works.

As most of the standard solutions implemented in autonomous drone navigation rely on GNSS positioning, indoor navigation represents one of the main challenges to be managed. Although computer vision is getting more and more accurate, allowing a possible solution to this problem, it always needs a lot of computational power, requiring the addition of companion PCs, increasing both the system complexity and the UAV's weight. Nonetheless, an emerging technology used to solve indoor navigation problems leaning on very low hardware resources components, is the Ultra Wide Band technology, an anchor-tag radio-frequency based positioning system. Considering that no drivers for the integration of UWB modules in UAV autopilots have been developed in literature so far, the goal of this thesis is the deep understanding of the RTOS PX4 autopilot firmware, and the implementation of custom modules, drivers and commands, with particular focus on UWB nodes.

1 Objectives

The goal of this thesis is the customization of the open-source autopilot PX4, for the integration of non-standard peripherals. The main focus is on the implementation of a lightweight camera gimbal into a drone mounting Pixracer flight controller, and the creation of a custom driver to leverage UWB technology for future works about indoor positioning and swarm navigation.
The work rotates around three concepts: the PX4 firmware architecture divided in middleware and flight stack, the mixer files used to convert control signals into actuator outputs, and the serial communication protocol used to develop the driver needed for the implementation of UWB modules.

2 Developed works

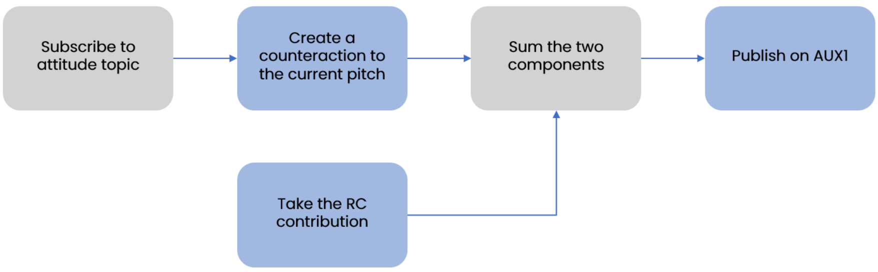
The work is divided in three main sections. The first part contains a deep study of the PX4 autopilot and a research on the State Of Art for the implementation of non-standard peripherals such as servomotors and distance modules. The second section is dedicated to the development of two firmware components: a module able to control the camera gimbal and a custom driver to integrate UWB technology. Lastly, the third part is devoted to the unit and integration testing of the implemented functionalities.

2.1 SOA and PX4 study

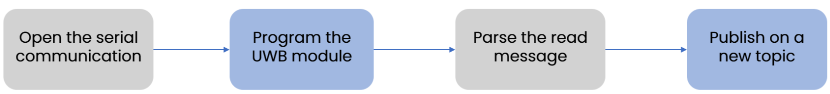
Initial researches on projects already developed have been done using biblio.polito, whereas the study of PX4 autopilot has been accomplished relying on both the official developer guide and user guide provided by the PX4 community. Previous projects analysis showed that standard 3-axis gimbal can be easily implemented in PX4-based system, however there is no official support for single-axis gimbal on Pixracer-based systems. Similarly, the State of Art analysis revealed that UWB modules are generally set up leveraging a companion PC. However, using such a powerful device just to measure UWB data is not only a huge waste of resources and a dangerous complexity increase, but also unfeasible for ultralight drones due to the companion PC weight. This is why the development of a stabilization module able to introduce a single-axis gimbal on an ultralight drone and the creation of a custom driver allowing to exploit the microcontroller processing power have become the goals of this thesis.

2.2 Firmware customization

The module developed for the introduction of a non-standard gimbal was intended to implement two features using an ultralight servomotor (only 2 grams weight), which are the stabilization of the camera pitch and the possibility of setting the zero-offset stabilization point using the radio controller. Camera pitch stabilization is attained publishing on the pin used for the servomotor connection to the flight controller a value that is inversely proportional to the current drone pitch. Current pitch is obtained subscribing to the drone attitude topic and converting the corresponding quaternion to Euler angles. The stabilization point is set exploiting the manual passthrough function, decoding a specific RC input channel and converting it into a normalized value between -1 and 1. The final actuation value is given by the sum of the stabilization contribution and the RC input.
The driver developed for the introduction of DWM1001 modules was aimed at creating a new topic which contains the estimated drone position in a known reference system to be used for future indoor navigation applications. Such a driver, based on serial communication, is intended to program the DWM1001 module in order to send position estimation data, to sort these information out and to publish them on a new topic named `dwm1001`. Moreover, it must be able to self-adapt to different number of anchors, to the presence or absence of the estimated position and to the occurrence of standard communication errors.



(a) *Stabilization module flow chart*



(b) *UWB driver flow chart*

2.3 Testing and troubleshooting

Testing phase was highly effected by COVID-19 pandemic, as PIC4SeR accesses for master thesis students were very sporadic. Nevertheless, unit and integration testing for the developed firmware components were successfully completed. Stabilization module was firstly tested in simulation environment (SIL) and then on the real hardware. During testing phases a lot of problems shown up, but most of them have been solved. In particular, the two modules related to the RC input and the stabilization effect were publishing on the same topic, creating conflict and making the application unusable. The solution was to join the two contributions on a single module, so that only one component would publish on the actuator topic.
Driver testing was much harder as it had to be accomplished directly on hardware, since no simulation environment was available. Furthermore, as many students were working on UWB technology in parallel in different places, I was given only 2 modules during the development stage, therefore I could not test the final application (composed by at least 4 modules). However, I developed an Arduino-based testing board publishing specific messages on the serial port in order to simulate different working scenarios, such as variation of the anchor's number, absence of the position estimation and standard errors, so that the driver could be considered compliant. During the last phase of the working period, when I had the opportunity to test the driver with 5 real modules, everything behaved as expected.

3 Conclusions

The goal of this thesis was to customize the open-source autopilot PX4 in order to introduce non-standard components focusing on ultralight gimbal and UWB modules. As demonstrated by this work, it is possible to integrate both technologies on any drone, including ultralight builds. In particular, the gimbal can be implemented using a lightweight servomotor, controlled by a firmware module able both to set the desired camera orientation according to RC inputs and to stabilize images. On the other hand, UWB modules can be integrated leveraging a custom serial driver able to program the tag, parse the received message and publish the correct information in specific topics to be used by the flight stack.
This work paved the way for future driver development and module creation providing a detailed guide on how to implement new firmware components into PX4. The next big step is the integration of the new topic containing the estimated drone position into the flight stack, allowing GNSS-free navigation. Indeed, this work is only one of the building blocks of a much wider project about robot cooperation in indoor/non-standard environments that is going to take place in the very near future, by merging technologies coming from different researchers, PhD students and master thesis students works.