Thesis Proposal: Applications of Nano-Drones in unknown indoor environments

Lorenzo Bellone, Michał Barciś, Enrico Natalizio

Summary of the Proposal

The research on nano-drones has always been an exciting field to observe. It promised many interesting applications and potential benefits of tiny and quiet robots being able to move in very constrained environments. However, the practical realizations are still very limited. With a fast development of new and even more powerful micro computers, this might soon change.

During the proposed research, a student will investigate various possibilities enabled by the use of AI-deck — a recently introduced expansion for a popular nano-drone called Crazyflie. The AI-deck allows to realize various artificial intelligence methods on the tiny drone through the use of integrated camera and a powerful parallel processor, the GAP8. Together with extended communication capabilities provided by the NINA module, the AI deck serves as a powerful tool at a disposal of the tiny Crazyflie.

Background

Nano-size UAVs, or nano-drones, are highly miniaturised UAVs with a 10cm diameter, a weight of few tens of grams, and a power budget of few Watts. They are usually equipped with a simple Micro-Controller-Unit (MCU) and few MB of memory on-board. With these limitations, tasks that are well supported by standard-size UAVs (e.g., pose estimation, trajectory planning, collision avoidance), cannot be easily accomplished by nano-drones through standard techniques, including CNNs deployment or visual SLAM.

Despite these constraints, nano-size UAVs are the ideal candidate for autonomous indoor navigation. They can safely navigate close to humans and reach narrow spots. Because of this reason, several works have proposed their exploitation in a wide range of applications. McGuire et al. [3] underlined the great potential of a swarm of tiny flying robots for exploring an unknown environment. They implemented a minimal navigation solution, called Swarm Gradient Bug Algorithm (SGBA), that allows a swarm of nano-quadrorotors (BitCraze's Crazyflie 2.0) to navigate an environment and to deal with obstacles through visual odometry and wall-following behaviours. The previously mentioned "Crazyflies" are small and versatile quadcopter, whose capabilities can be easily enhanced through "expansion decks", providing the tiny robot with sensing, positioning or visualization skills. They are widely used in research ad education, given the quantity and quality of online support and open-source projects developed with these robots.

Since several works are also based on the transmission of information from a nano-drone to a base station, or between nano-drones, their performance should also be analyzed under the communication point of view. The Crazyflie 2.4GHz radio system allows for a stable radio link up to 1km distance [1] when LoS conditions are met, but it sharply deteriorates in NLoS conditions. Laclau et al. [1] exploited Crazyflies for navigating subterranean networks, proposing a distributed algorithm to coordinate a communication chain of drones between one exploration drone and one operator.

Recently, low-power System-On-Chips (SOCs) have also been introduced to enhance the capabilities of the nano-drones' MCU with ML-oriented computations. Palossi et al. [4] proposed a first navigation engine for autonomous nano-drones based on a end-to-end CNN-based visual navigation system. By deploying a CNN on the GAP8 processor, they were able to process images directly acquired from the drone's camera, predicting the probability of collision and yaw rate to control its trajectory. The deployment of a CNN was made possible by the quantization and parallelization of the residual neural network used in [2] for standard-size drones.

---

[1] https://www.bitcraze.io/documentation/hardware/crazyradio_pa/crazyradio_pa-datasheet.pdf

Objectives and Methodology

One of the main challenges when dealing with the exploration of unknown indoor environments is the inability to determine the absolute drones' position. GPS cannot be used, and, although there are auxiliary devices to determine the nano-drones' relative position, they rely on fixed infrastructures that cannot be deployed when the environment is particularly constrained. Furthermore, the communication between drones plays a fundamental role in several scenarios. Their ability to collect and transmit measurements coming from their sensors can be exploited in a wide range of applications, from being processed at a base station to be used by other drones for a better understanding of the surrounding situation.

The objective of this research can be extended to multiple goals that could span interdisciplinary fields. In [1], Laclau explored a subterranean environment in which the chain of drones follows a tunnel with no intersections, the first UAV is manually controlled, and the other UAVs imitate the movement of the head and adapt their position based the quality of the signal received. However, this is often not the case of more general indoor environments, where the UAVs have multiple available paths to improve the information transmission. The objective is to allow the UAVs to coordinate into a more "open-space" indoor environment, in order to find the best placement to transmit a certain information. A first step towards this direction will be a study of feasible options in a simulated environment, where already existing algorithms and their potential improvements with respect to this scenario will be safely tested. Eventually, the proposed solution will be directly implemented on nano-drones (BitCraze's Crazyflie 2.1) through hardware experiments for the "real-life" validation of the simulated framework.

We also propose a set of more precise tasks that can help in the achievement of this main goal:

- The absolute position of a drone is difficult to estimate without the use of well known technologies, such as GPS or other infrastructures. However, each drone could estimate its relative position with respect to another drone in the environment, and this might help in their proper placement for the creation of the communication chain. A possible way to achieve this, is to detect and identify the other drones through an embedded camera. Unfortunately, when more than two drones are flying together, the identification of the robot that is detected in the picture is not trivial. The solution proposed to solve this problem is to find a way to exploit the correlation between the received signal strength of the messages coming from the other drones and their distance perceived from the camera, in order to dynamically map the drones' IDs with their relative position.

- A proper drones' placement in the space is of fundamental importance for the correct multi-hop transmission between source and destination nodes. Although there is already a standard framework that allows the automatic creation of a mesh network with ESP32 SOCs (ESP-MDF), the positions of the nodes should be carefully selected for a successful transmission. Supposing a scenario in which the nano-drones are randomly exploring an environment, and that the absolute positions are known, this second task aims at finding a proper placement algorithm that allows the creation of a mesh network whenever a drone has something important to send towards a base station through a multi-hop route.

- The third and last proposal regards the achievable data rate that we can achieve in the nano-drones communication chain. The Crazyflie's on-board radio system allows for a data rate of up to 2Mbps towards a base station. Usually, for a point-to-point transmission of logged parameters, that is an adequate rate. However, considering the possibility for a video streaming over a multi-hop route, this rate starts to become a problematic bottleneck. In this third proposal, a second communication device (Nina Module) is considered. It exploits Wi-Fi protocol to communicate with higher rates (up to 25 Mbps), but worse connectivity ranges[2] (400-500m). A proper synchronization between these two different communication devices would be fundamental to find a trade-off between data-rate and connectivity according to the environment conditions.

Image acquisition, CNN deployment, mesh network configuration, together with improved communication capabilities on a Crazyflie, are all enabled by the AI-deck expansion board. This board includes the GAP8 processor and an ultra-low-power camera for capturing, processing and classifying the surrounding environment.

---

[2] https://www.u-blox.com/en/product/nina-w10-series-open-cpu

References

[1] Pierre Laclau, Vladislav Tempez, Franck Ruffier, Enrico Natalizio, and Jean-Baptiste Mouret. Signal-based self-organization of a chain of UAVs for subterranean exploration.

[2] Antonio Loquercio, Ana I. Maqueda, Carlos R. del Blanco, and Davide Scaramuzza. DroNet: Learning to fly by driving. 3(2):1088–1095.

[3] K. N. McGuire, C. De Wagter, K. Tuyls, H. J. Kappen, and G. C. H. E. de Croon. Minimal navigation solution for a swarm of tiny flying robots to explore an unknown environment. 4(35):eaaw9710.

[4] Daniele Palossi, Antonio Loquercio, Francesco Conti, Eric Flamand, Davide Scaramuzza, and Luca Benini. A 64mw DNN-based visual navigation engine for autonomous nano-drones. 6(5):8357–8371.