Coordinated control of autonomous aerial robots

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Summer Project

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Abstract

This project is about control and coordination of multiple UAV's. There has been significant progress in control and coordination of flights with the use of central processing unit, e.g. a -PC. However, for autonomous flight of swarm of UAVs involving de-centralized processing, selection of appropriate on-board embedded system and stability are challenges yet to be solved.

In this project, we have implemented one of the methods for creating a system for controlling UAV's in a coordinated manner. This has been built using easily available hardware modules of aerial robots, electronics, and software platforms. Various other options to implement similar control have been explored and presented.

Acknowledgement

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Introduction

Swarms of robots can accomplish complex tasks that a single robot cannot perform alone. For example, consider a group of UAV's coordinating in a search and rescue mission, exploring larger area quickly than an individual UAV can, taking panoramic photograph and sending them back to base station.

Swarm intelligence (SI) is the collective behaviour of decentralized, self-organized systems, natural or artificial. The concept is employed in the work on artificial intelligence. The expression was introduced by Gerardo Beni and Jing Wang in 1989 in the context of cellular robotic systems. [1]

SI systems consist typically of a population of simple agents interacting locally with one another and with their environment. The agents follow very simple rules, and although there is no centralized control structure dictating how individual agents should behave, local, and to a certain degree random, interactions between such agents lead to the emergence of "intelligent" global behaviour, [2].

The application of swarm principles to robots is called swarm robotics. Much of the recent work in the area of swarm robotics has been inspired by modelling the flocking behaviour of birds, shoaling behaviour of fish, swarming behaviour of insects and herd behaviour of land animals..

Unmanned Aerial Vehicles (UAVs) have potential applications in delivery of goods, agriculture, rescue and military missions and others. While a single UAV can have limited capabilities in terms of processing power, there is a risk of failure of mission if the UAVmisses its goal. Swarm of UAVs can overcome these issues by assigning work to each one and implementing intelligent algorithms that can reassign work of one UAV to other in case of failure of the first UAV.

Motivated by this concept of swarm robotics, we will discuss *various options available to control swarm of aerial robots in this research project.*

After considering various options, we developed a system using Parrot's AR Drone Quadcopters, Arduino Yun and Ad-hoc networking. Other possible options are also presented in this report. This work can further be extended to implement algorithms of coordination and cooperation of Swarm Robotics by having hardware and software which support communication between UAVs in addition to processing capabilities on-board.

In the first chapter, we introduce the Parrot AR Drone 2 Platform, which is a cost effective solution with open source SDK enabling third party developers to develop applications. The second chapter discusses Arduino Yun-a WiFi product which combines the power of Linux with ease of use of Arduino. In the third chapter, we explore Ad-Hoc network as a suitable method to establish network between UAVs and Arduino Yun. Later, we discuss the results of our test flights. This is followed by various other options to control multiple UAVs in Future Works Chapter.

The present work forms the basis to extend the research project in implementing “*Swarm Robot’’* algorithms. Hence we discuss the scope of this *Swarm Robotics* in Conclusion section.

Chapter 1: The Parrot AR Drone 2 Platform

We used Parrot AR Drone in this project. Parrot AR Drone is cost-effective, has open source SDK for developing our own part of client side code, a camera with high fps and a processor with good image processing capability.

Figure 1 Side view of AR Drone 2.0 Power Edition

Figure 2 Top view of AR Drone 2.0 Power Edition

AR Drone 2.0 is a radio controlled flying quadcopter helicopter built by the French company Parrot (Fig 1). The UAV is originally designed to be controlled by mobile or tablet operating systems such as the supported iOS or Android. However, unlike the firmware, the client protocol is open. Parrot publishes an SDK which includes good amount of documentation and C code. The protocol can also be used to receive video and sensor data, enabling developers to write autonomous programs. [3]

AR Drone 2.0 is77.7 x 38.3 x 12.5 mm in dimension. It comes with the following functionalities:

- Brushless DC motors
- HD front camera - 720p sensor with 93° lens, recording up to 30fps
- Vertical camera - QVGA sensor with 64° lens, recording up to 60fps, for ground speed measurement.

Its electronic Assistance includes:

- 1 GHz 32bit ARM Cortex A8 processor with 800MHz video DSP TMS320DMC64x
- Linux 2.6.32
- 1gb DDR2 Ram at 200MHz
- USB 2.0, Wifi b g n
- 3axis gyroscope 2000 degree/second precision
- 3 axis accelerometer +-50mg precision
- 3 axis magnetometer with 6° precision

- Pressure sensor +/- 10 Pa precision and
- Ultrasound sensors for ground altitude measurement[4]

Using UAV’s wifi we can telnet into the UAV’s Linux based operating system called **Busy Box**. This enables any wifi device to pass commands to UAV and receive feedback using wifi as mode of communication.

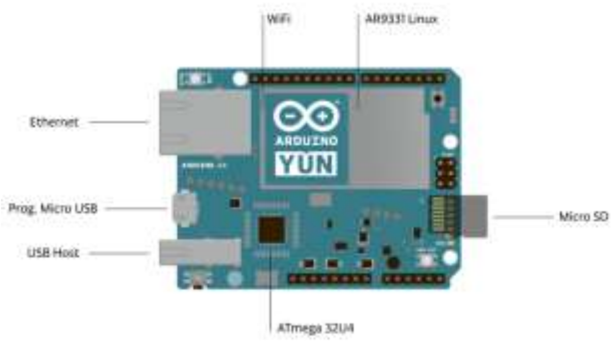
Chapter 2: Embedded System with Wi-Fi and Processing Capabilities

With the wifi capability of UAVs there arises a need for minicomputer/embedded system that can pass commands to the UAV, receive feedback, process the information and issue new commands. So we used Arduino Yun. We developed a software platform on it using nodejs, Ideino IDE and node-ar-drone library. Let us look at each one of them in detail:

a) Arduino Yun- Hardware:

Arduino Yun combines the power of Linux with ease of use of Arduino. It is a microcontroller board based on the ATmega32u4 and the Atheros AR9331. The Atheros processor supports a Linux distribution based on OpenWrt named OpenWrt-Yun. The board has the following functions:

- built-in Ethernet and WiFi support
- a USB-A port
- micro-SD card slot
- 20 digital input/output pins
- a 16 MHz crystal oscillator
- a micro USB connection
- an ICSP header and
- a 3 reset buttons. [5]

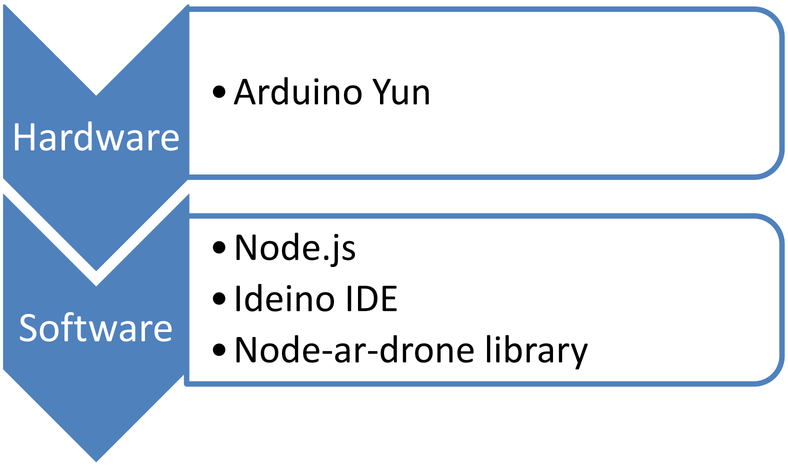


Using Yun's wifi we can connect and pass control commands to the UAV.

b) Ideino IDE- Software:

With this hardware platform we required software that could build communication between the UAV and Arduino Yun. Hence, we used Ideino IDE which runs on node.js platform and using which we can write codes on Yun. We installed the **node-ar-drone** library which enables predefined functions for UAV like take-off, hover, and fly-left, fly-right etc.

The abstraction layer diagram of software is as shown below:



i. Node.js platform:

Node.js is a platform built on Chrome's JavaScript runtime for easily building fast, scalable network applications. It is a server-side solution for JavaScript, and in particular, for receiving and responding to HTTP requests. It enables real time communication between two devices. It is designed to maximize throughput and efficiency, using non-blocking I/O and asynchronous events. Node.js applications run single-threaded, although Node.js uses multiple threads for file and network events. . [6]

Node.js exposes a high level Client API that tries to support all UAV features, while making them easy to use.

ii. Integrated Development Environment:

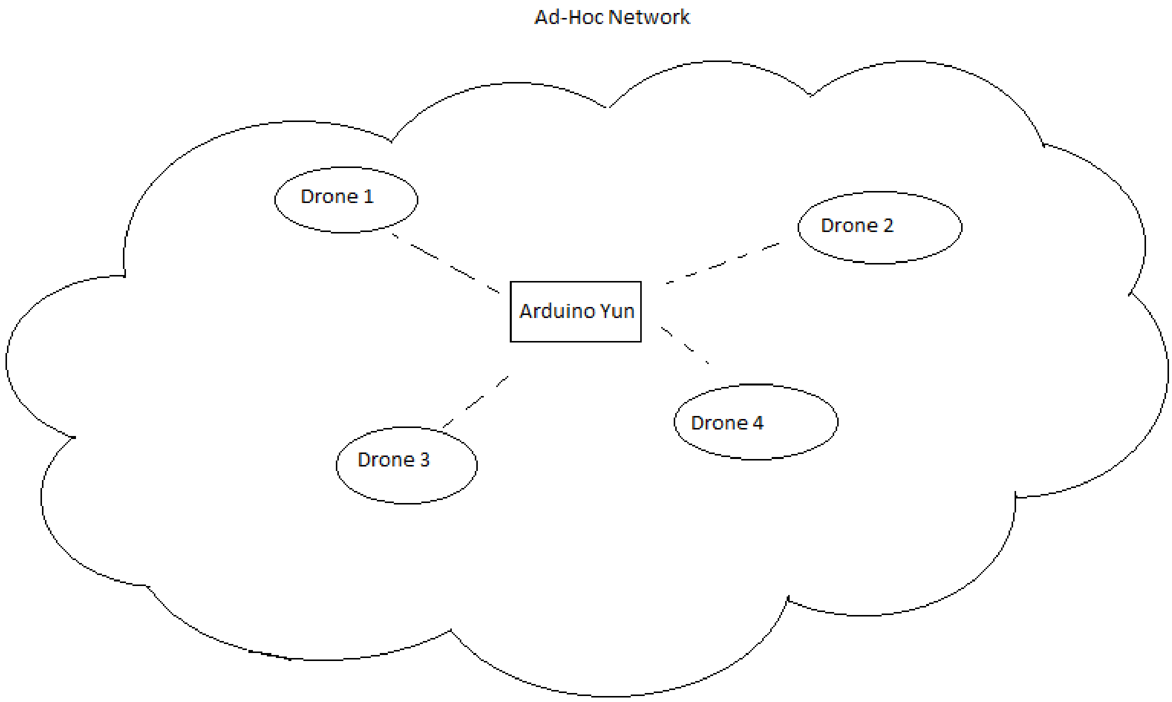
Linino IDE - Ideino is a node.js development environment for Linino operating system. Using linino IDE we can program Arduino Yun with the help of javascript code. [7]

iii. Node - AR Drone- Software Library for controlling UAV:

Using Linino IDE, we installed node-ar-drone module which is a library supporting all UAV features and is capable of sending commands to pilot the AR. Drone. [7]

Thus by installing Node.js, Ideino and Node-ar-drone module, we can send commands to UAV using Yun. Also by connecting Arduino Yun to UAV's wifi and setting up the code in auto-run mode, autonomous execution of code can be achieved. By powering Arduino Yun from UAV's on-board system and mounting Arduino Yun on the UAV, this system can be made autonomous.

Chapter 3: Establishing network



With UAVs and embedded system figured out, a network is required where Arduino Yun can communicate with all the other UAVs in the swarm. This way all the UAVs can work in sync as a team, indoor or outdoor.

An AD-Hoc network is peer-peer network. Configuring every UAV and Arduino Yun in ad-hoc mode enables communication between them. Each UAV is assigned a unique IP address using which the Arduino Yun sends data packets to each UAV.

Chapter 4: Results and Evaluation

Using the above discussed framework, we successfully demonstrated several collective flights with upto 4 units. Videos of flight are available here

Arduino Yun and Ideino IDE face the following issues:

- downloading packages
- installing dependencies
- wifi connectivity etc

Efforts need to be put in troubleshooting the issues which occur quite frequently.

One of the major advantages of this system is that it doesn’t require an extra embedded system for each of the UAVs. One central unit can control multiple UAVs.

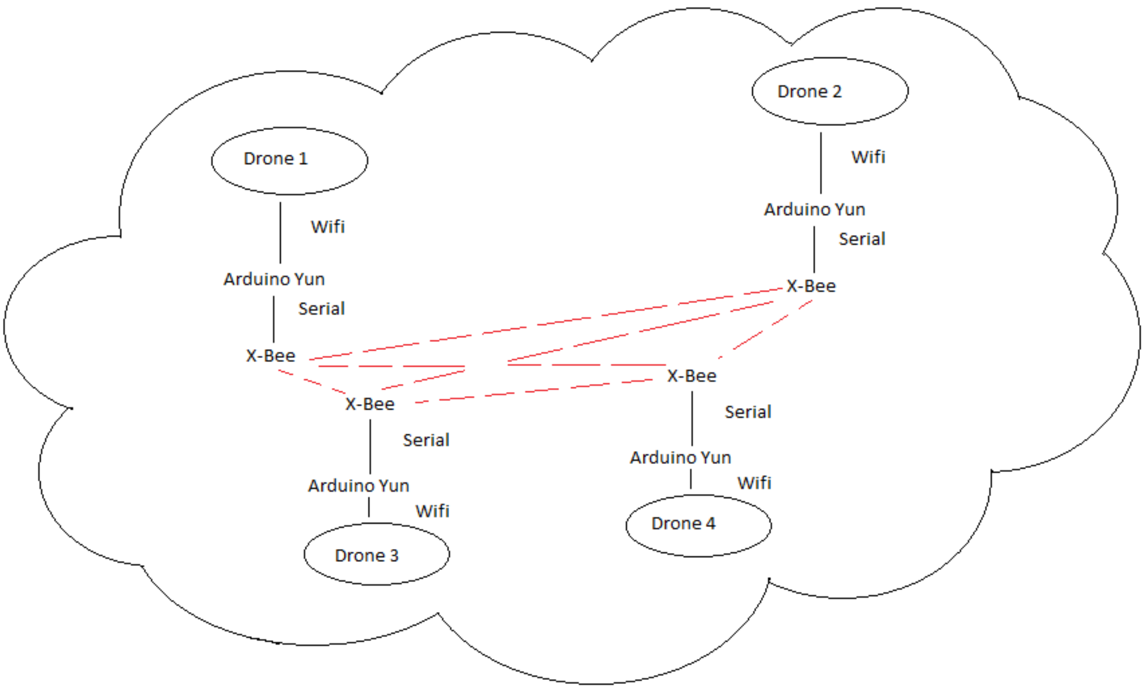
As the Linino IDE is yet in its beta version it is under heavy development. Right now there are issues about frequent broken connectivity and lost data packets. However, in the coming months, these issues are expected to be fixed by the Linino team. This will help in establishing better connectivity.

Asynchronous execution of commands has been observed. UAVs do not execute commands at the same time and for the same duration. This can be due to some of the data packets being lost, or because of late reception of commands by UAVs. Hence, ad-hoc method for Yun and UAV need to be studied further in detail and synchronization between UAV need to be improvised. Various alternate methods for developing the system are presented in the next chapter on Conclusion and Future work.

Chapter 5: Future work and Conclusion

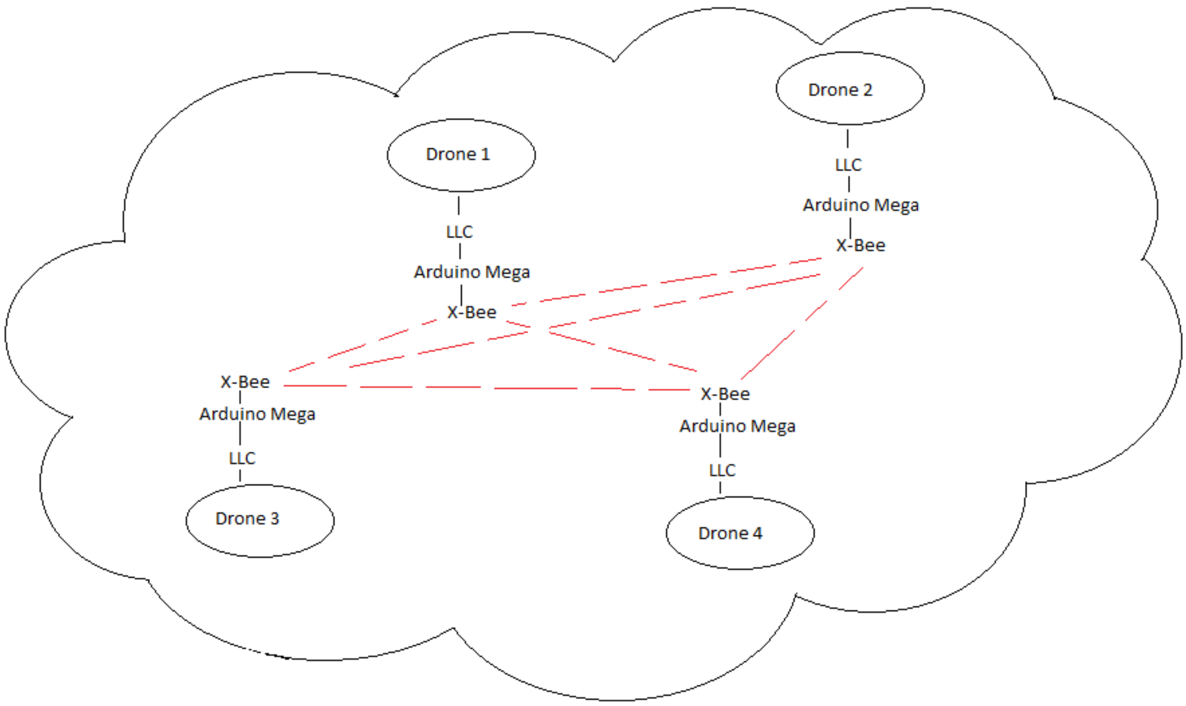
Other methods to implement communication between UAVs are:

1. X-Bee 802.15.4 module



Instead of using Yun and UAV in Ad-Hoc network, X-Bee with 802.15.4 protocol can be used. With this approach, each UAV connects to one Arduino Yun and an X-Bee module. Hence point to point communication between UAVs can be achieved

2. Serial Communication



Serial port offered by AR Drone can be used to communicate with the UAV (using a Logic Level Converter to convert drone's logic levels to standard serial communication logic levels). An Arduino module (even without Operating System) can then be connected with X-Bee module to communicate with other UAV unit.

AR drone being commercial product, has limited accessibly in hardware, to connect other device to the main board. Hence other open-source options like Ardu-Copter [8] can be explored. For coordination and cooperation other options for UAVs should be explored

Further access to Python Libraries can be useful in implementing Localization and Navigation algorithms for swarm of Robots.

Conclusion

A method to control multiple UAVs has been discussed, along with presenting other possible options. Insight on how to extend the project for swarm of Robots has been discussed.

For code and guide to implement the project see the repository Multiple-Drones at spartnTufts Github.

References and appendices

[1] Beni, G., Wang, J. Swarm Intelligence in Cellular Robotic Systems, Proceed. NATO Advanced Workshop on Robots and Biological Systems, Tuscany, Italy, June 26–30 (1989)

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