Aracnocóptero: An Unmanned Aerial VTOL Multi-rotor for Remote Monitoring and Surveillance

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Abstract. The Aracnocóptero is an aerial platform designed to capture photographs and images in multiple formats, and to carry sensors and scientific-technical measuring equipment. It is a collapsible, lightweight, multi-rotor, vertical take-off UAV (Unmanned Aerial Vehicle) aircraft, made of aerospace materials with maximum resistance. It includes a communication center and a station base, all of which are transportable, lightweight and compact. The Aracnocóptero platform's control and guidance software is composed of an agent based system whose agents are specialized in gathering and processing different types of information. The multi-agent system (MAS) that controls the Aracnocóptero uses different types of interfaces to facilitate its various uses and to facilitate the reconstruction of the telemetric values obtained from the UAV. The possibilities of the Aracnocóptero platform make it possible to expand the project in line with a number of uses.

Keywords. Aircraft, multi-rotor, VTOL, UAV, surveillance, geopositioning, image capture, multi-sensors

1. Introduction

Flying objects have always exerted a great fascination on man encouraging all kinds of research and development. The Arbórea Project consists of a program to design, create and distribute a VTOL UAV (vertical take-off and landing unmanned aerial vehicle) multi-rotor aircraft. This project started in 2009, a time at which the robotics community was showing a growing interest in Unmanned Aerial Vehicles (UAV) development. The scientific challenge in UAV design and control in cluttered environments and the lack of existing solutions was very motivating. On the other hand, the broad field of applications in both military and civilian markets was encouraging the funding of UAV related projects. It was decided from the beginning of this project to work on a particular configuration: the Aracnocóptero. The interest comes not only from its dynamics, which represent an attractive control problem, but also from the design issue. Integrating the sensors, actuators and intelligence into a lightweight vertically flying system with a decent operation time is not trivial.

The Aracnocóptero is an aerial platform deigned to capture photographs and images in multiple formats, and to carry sensors and scientific-technical measuring equipment. It is a collapsible, lightweight, multi-rotor, vertical take-off UAV aircraft, made of aerospace materials with maximum resistance. It includes a communication center and a station base, all of which are transportable, lightweight and compact. The robustness, versatility and flight capability of the Aracnocóptero provide great stability in high wind conditions; its ability to maintain a stationary flight allow for its use in surveillance missions, and for precise measurements and documentation.

The article is structured as follows: Section 2 makes a review of the state of the art both in UAVs and the technology used for the software, multi-agent systems. Sections 3 introduces the most important functionalities of the platform. Finally, some experimental results and conclusions are given in Sections 4 and 5.

2. State of the Art

The state of the art in multi-rotor control has drastically changed in the last few years. The number of projects tackling this problem has considerably and suddenly increased. Most of these projects are based on commercially available toys like the Draganflyer [12][5], modified afterwards to have more sensory and communication capabilities, or the Chinese Walkera UFO [12] . Others are derived from radio-controlled model field, such as German Mikrokopter project [12]. Mesicopter project [7] aimed to study the feasibility of a centimeter scale quadrotor. Castillo et al. [3] has also a strong activity on eight-rotors design and control [13]. N. Guenard [8] from CEA (France) is also working on autonomous control of indoor quadrotors. Starmac (Stanford/Berkeley Testbed of Autonomous Rotorcraft for Multi-Agent Control) [15], another interesting project, it targets the demonstration of multi agent control of quadrotors of about 1 kg. Other current projects include Falcon 8 [6], Microdrones [9], Aeryon Scout [1]. In Experimental Results section, the table 1 shows a comparison of features in question some of the most significant professional projects found and Aracnocóptero platform.

On the other hand, agents and multiagent systems (MAS) are adequate for developing applications in dynamic, flexible environments. Autonomy, learning and reasoning are especially important aspects for an agent. These capabilities can be modelled in different ways and with different tools [16]. Open MAS should allow the participation of heterogeneous agents with different architectures and even different languages [4][17]. The development of open MAS is still a recent field of the multiagent system paradigm and its development will allow applying the agent technology in new and more complex application domains. It is possible to highlight the use of artificial intelligence techniques in the software design. In particular, the use of MAS provides us advantages such as autonomy, saving time or improve the maximum range. In the field of multi-agent systems one of the objectives is to build systems capable of making decisions independently and flexible, and cooperate with other systems within an organization. From various scientific fields, researchers are addressing how to structure organizations so that they adapt easily and efficiently to changes in their environment. The social organizations of agents is presented as a good alternative for Aracnocóptero requirements [2][10][14][11]. Swarm intelligence (SI) is the collective behaviour of decentralized, self-organized systems, natural or artificial [2]. The concept is employed in work on artificial intelligence. SI systems are typically made up of a population of agents interacting with one another and with their environment. The inspiration often comes from nature, especially biological systems. With this approach is easier to understand how to work in swarms the Aracnocóptero platform. Each Aracnocóptero has the ability to act as a repeater of an order originally issued. Thus we get an optimized distribution in which the communication range can be considerably multiplied . In addition, we can expand the horizon of the work to be done without entering data overload and progressing in areas impossible to cover with a simple radio link to a single aircraft. A scheme based on multi-agent technology allows us to know the status of the participants. The changes in the behavior of participating agents are detected triggering actions. Always optimally and without human intervention in the decision process.

3. Platform Modeling

The Aracnocóptero platform is a first rate resource for air transport surveillance or for the identification of suspicious vessels in geographical hotspots for maritime piracy. The simplicity and immediacy of its use does not require take-off or landing strips, or additional infrastructure of any kind. It can be launched and picked up from any location without prior preparation. Its piloting does not require experience with aircrafts. It can carry out preprogrammed missions automatically, which facilitates routine observation and surveillance transects, and can be equipped with a variety of cameras and sensors to capture high quality daytime and nighttime images. The following photograph, provide a perspective of the use of the Aracnocóptero platform in action.

Figure 1. Aracnocóptero UAV

3.1. Aracnocóptero Subsystems

The experimental platform has three subsystems: (i) the first are the multi-rotor UAVs, like the one shown in Figure 1, which are directly in base station radio range. The units exchange commands and information with the second subsystem – the base station. (ii) the base station is composed of a graphical user interface (GUI) that allows the user to see in real-time the view from any multi-rotor, while controlling them with a wireless radio control unit. Any pertinent environmental information (e.g. infrared detection of heat signatures, radioactivity levels, etc. depending on the sensors installed) is transmitted via wireless from the eight-rotor to the base station. This data is also sent to the base station where a graphical representation of the multi-rotor vehicle network is displayed; (iii) the final subsystem will be composed of one or more follower multi-rotor UAVs. These are identical to first subsystem UAV aircrafts with the exception of they are not directly in the radio range of the base statio. By this way we increase the radio range of the swarm.

The main parts of Aracnocóptero platform can be seen in the following figure:

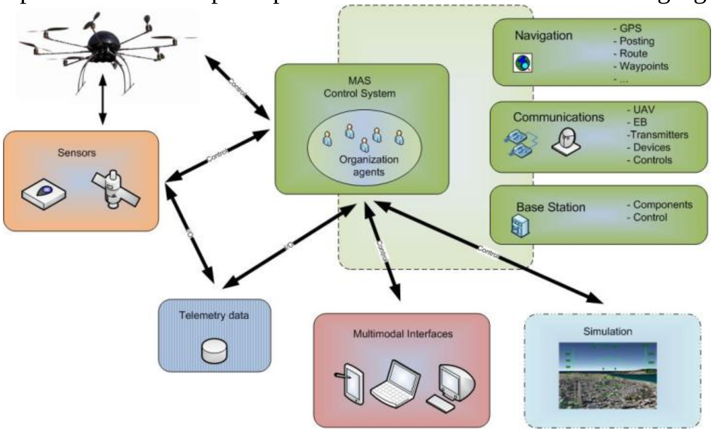

Figure 2. Aracnocóptero platform subsystems.

In the figure it is possible see in detail, besides the three main modules:

- A multi-agent system, which will be the core of the platform. It will process all information received and held control of the other subsystems through artificial intelligence techniques. Within the control subsystem can differentiate three main parts:
  - Navigation component. It is responsible for the identification and location periodically to the control system (GPS position, displacement, path, transects, waypoints, battery consumption, etc.).
  - A base station that contains the algorithms and artificial intelligence techniques (in addition to the hardware components needed) to process information.
  - Communications infrastructure to connect all components of the platform (UAV - base station (BS), BS - Transmitters, Transmitters - Devices, Devices - Control Knobs, etc.).
- A set of sensors (variables) that will send a variety of information (telemetry data) to the control subsystem.
- An information base that will store the data and the already processed by the control subsystem.
- A set of multimodal interfaces to interact with the platform.

It also includes a subsystem more, as future development of simulation techniques including scheduled flights, learning techniques of flying through the computer with the possibility of using a 3D simulator.

On the Aracnocóptero platform are included therefore a number of subsystems and specific features which support the services offered. This will essential to handle a large amount of telemetry data, some existing and which will from now on, and to be estimated by including intelligent systems.

It also includes, through the following figure, a communication scheme of the physical components of the system that can help understand the variety of communication techniques used in the complete system and processed by the platform.

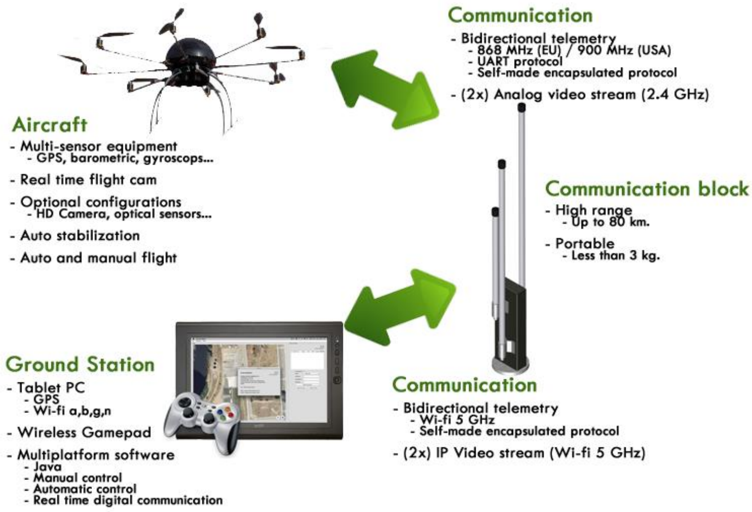

Figure 3. Communication scheme

As we can see in the communication schema in the figure 3, the whole platform is composed by the aircraft, which is equiped with several sensors (like GPS, gyroscops, ect.) and it can fly in an auto stabilized way.

The communication between the aircraft and the communication block uses 2 frequency bands: 2.4 GHz band for the video transmission and 868 or 900 MHz (depending on the country regulations) for the telemetry.

In the communication block, video is converted from analog to digital and the signal is received by the ground control station with an IP protocol stream with 5GHz (to avoid interferences with the video signal) Wi-Fi connection in addition to the digital telemetry messages.

In the ground control station, we can receive and send data to the communication block and watch in real time the video signal of the flight cam in addition to control the aircraft easily with the help of a wireless gamepad.

3.2. Technical characteristics of the multi-rotor UAV

The Aracnocóptero has a solid construction that is water resistant and capable of water landings and staying afloat. The platform contains a powerful radio link that enables the station base to receive data and images in real time. It is portable, lightweight and able to receive and transmit information within distances up to 30km. Its eight electric engines run silently, which makes it difficult to detect in the presence of normal sound conditions, such as on board a motor vessel with either an inboard or outboard motor. The ability to quickly change batteries allows the aircraft to easily engage in consecutive flight missions. It is equipped with multiple sensors that, along with a flight microprocessor, can maintain a freestanding position regardless of wind conditions or navigation commands.

In order to build the platform, the team researched the latest generation of aerospace materials, looking for the best possible quality in all pieces. The titanium Gr5 was chosen for the central frame; a high modulus carbon for the arms. Other elements were made of Kevlar and other composites with high mechanical quality.

The Aracnocóptero can maintain a static position with great precision, fly smoothly with efficient systems that eliminate vibrations, or move quickly and lift easily (we foresee speeds up to 100km/h). The Aracnocóptero can navigate with high winds of up to 75km/h. Extreme weather conditions may, however, increase consumption. It is prepared to transport heavy cargo, up to 3000g, which is greater than any other professional multi-rotor platform. It is quite silent and can fly more than 40 minutes depending on the weight and climate. Landing and take-off maneuvers can be performed automatically and easily.

The main electronic elements are:

- Autopilot sensors
- Brushless electric motors
- Wireless analog and digital communication

Moreover, the platform contains many sensors, such as gyroscopes, accelerometers, magnetic compasses, barometers, GPS, sonar, IR sensor or cameras. It is also designed to carry additional telemetry systems in the form of kits adapted to specific missions, such as laser scanners, InfraRed cameras, chemical or radioactive substance detectors, and a wide range of possibilities.

Its communication systems include a digital radio link, a high range analog link designed for military use, which has reached over 150km range in first person view test flights with RC planes.

3.3. Communication block

The communication block can be attached magnetically on the roof of a vehicle or carried in a backpack. It contains various communication systems according to the requirements on independent frequencies that can be adapted to diverse international guidelines. It includes a real time video receiver system with digital conversion. The reception of a telemetry digital signal passes through a bi-directional radio modem. It can incorporate an additional long range security radio for long distance missions or areas of rocky terrain. Communication with the control station is done through wifi omnidirectional antennas, or directional antennas with a motorized guiding system based on previous use.

3.4. Control subsystem

The Aracnocóptero platform's control and guidance software is composed of an agent based system whose agents are specialized in gathering and processing different types of information. The multi-agent system (MAS) that controls the Aracnocóptero uses different types of interfaces to facilitate its various uses and to facilitate the reconstruction of the telemetric values obtained from the UAV.

Complete control of the Aracnocóptero platform would require a technology that could process data with the wide spectrum of techniques used in the system the RCBUS communication and PWM (Pulse Width Modulation) signal used for the bidirectional transmission of telemetric data, control of the communication base (antennae, rx and video-diversity systems, displays), links to radio modems, interfaces (computer, tablet, remote control).

This project identifies a communication problem: the implementation of an ad hoc network and a protocol based on network control, and a consensus control algorithm for cooperative control of UAVs.

It has been necessary to reimplement the radiomodem communication protocol to control the packets to allow a bidirectional, efficient real time communication between the ground station and the aircrafts. Transit of messages between aircraft and computer tries to reach the highest range so we reduce the exchanged information amount. For this reason we have created a special adapted structure which we send with our own protocol. With this protocol we are able to send different kinds of messages like heartbeats (with information about status of the aircraft), position messages (which allow us to know continuously the situation of the aircraft), action messages (sent promptly when doing an action is required), automatic control messages (points of the route to follow) or manual control messages. All of them with a headed which identifies each destination aircraft (this allows a multipoint communication) and an error control (CRC) field to get a reliable communication.

The MAS facilitates the development of applications that can process a high number of data and images in a distributed and autonomous way; it also facilitates the qualitative analysis of the data obtained.

4. Experimental Results

Evaluation and verification of the hardware and software components is accomplished through measuring the performance of the multi-rotor's ability to fulfill the orders given from base station and the materials performance. In the future, it will be necessary to evaluate the system implemented on several UAVs and its ability to detect to each other.

The following table shows a comparison of hardware features in question some of the most significant projects found to make the study of art and Aracnocóptero platform.

Table 1. Performance Comparison*

Models / parameters	**DraganFlyer X8**	**Microdrones MD41000**	**Aracnocóptero**
Weight	1700g	2650g	1850g
Portability	High	Low	High
Stability / Engines	Medium	Low	Optimal
Flight with Wind	max 30km/h	max 47km/h	max 75km/h
Maximum autonomy	20 min	60 min	40 min
Maximum load capacity	1000g	1200g	3000g
Maximum landing weight	2700g	5550g	6000g
Radio link range	1-2 km	1-2 km	80km telemetry/20km video
Approximate Price	€ 45.000	€ 40.000	€ 30.000

Fail safe	No	No	Yes
Replacing damaged parts on the ground	No	No	Yes
Impact resistance	Medium	Low	High

*From the technical maker sheets

It is a comparison of benefits VTOL vehicles / UAVs for civil use. Two commercial platforms exist with similar performances to the Aracnocóptero's are compared. It is possible to observe that in most parameters Aracnocóptero platform is better than the remaining systems.

The Aracnocóptero is controlled by custom software with two primary goals: total control and ease of use. The application can be initially separated into three user modes: initiate a new mission; program a mission; or replay a previously taped mission. The general view includes real time flight video, the navigation parameters, information on geographical position and navigation route. This real time view of the flight shows the images that are captured both by the flight camera and the high definition camera. Moreover, it is possible to see the informational parameters for the various components and sensors, such as the battery level, consumption, motor use, or the artificial horizon. The following figure represents a full screen view of a map with all the flight path information, including the route covered, the route remaining, points of interest, etc. The mission can be modified mid-flight.

Figure 4. Control Software

One of the most important aspects of the platform is its simplicity, which does not mean it is any less efficient or functional. For this reason we designed a clean interface, easy to use, that contains the essential flight information that, in the case of a multi-rotor, is less than what is required by an airplane. The gamepad interacts with the application and is capable of sending commands to both the software and the actual craft in a very intuitive manner that includes graphics, which is in contrast with radio station training typically used to handle UAVs.

5. Conclusions

It is possible to observe how during the past few years, research in the field of cooperative control robots and specially Unmanned Aerial Vehicles (UAV) has continuously increased. Towards this goal this paper identifies three problems: the development of a new UAV with better materials, the implementation of an ad hoc network and a protocol based on network control, and the implementation of a global control system of UAVs with several possibilities of human control interfaces. Moreover, the possibility of offering multi-device integration within the system is an extension of the goals of this project and can incorporate real-time information on the data obtained to expand the business possibilities of the platform and therefore its profitability.

The platform currently enables us to perform waypoint navigation using a global positioning system (GPS) while at the same time maintains the UAV stable. Also, the control is transferable to similar UAV models with little to no change to the control software. The communication protocol designed for the ad hoc network has proved to be reliable for our application mid can be expanded to be used with different number of agents. Future work will allow implementing the control MAS as centralized control or distributed control. In this way, the platform will be to control one or more follower multi-rotor UAVs.

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