A MISSION PLANNER AND NAVIGATION SYSTEM FOR THE ARARA PROJECT

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Abstract

The ARARA project - Autonomous and Radio-Assisted Reconnaissance Aircraft, is centered on the use of Unmanned Aircraft for image acquisition. Its main goal is the replacement of conventional aircraft used to take aerial photographs for the monitoring of crops and areas under environmental control. This work describes the SiNaCoM, a Navigation and Mission Control System for the ARARA project. The SiNaCom, jointly with a stability augmentation system (autopilot), will provide ARARA aircraft with fully autonomous mission accomplishment capability. The SiNaCoM is split into two modules: the Mission Planner and the Navigation Controller. The first module allows the user to define the route of a flight and a set of tasks to be carried out at each waypoint in this route. The second module controls the navigation of the aircraft along the route defined by the user, performing course corrections due to wind gusts. Navigation is based on the GPS positioning system and a set of on-board navigational sensors. The SiNaCoM has been bench tested and should be flying by the end of this year.

1 Introduction

Aerial photographs have been used as an important tool to identify problems in agriculture, such as production losses caused by crop diseases, soil and atmospheric conditions [3, 11]. The advent of the GPS system [5, 2] and the reduction in size and cost of digital sensors, radio equipment and computer devices, have been made practical the use of UAVs (Unmanned Aerial Vehicles) to acquire monitoring data for a broad range of applications [12].

The ARARA (Autonomous and Radio-Assisted Reconnaissance Aircraft) is centered on the use of UAVs to collect monitoring data in agriculture and ecology. Its main goal is to replace conventional aircraft used to take aerial photographs.

2 The ARARA Project

ARARA is the Portuguese word for macaw, a big parrot-like bird that lives in some regions in Brazil. The ARARA project has 4 phases. Each phase defines a fully functional UAV system, with increasing levels of functionality, complexity and cost, towards a fully autonomous system capable of performing automatic missions.

Phase I: makes use of model airplane components (including the airframe), digital and video cameras to capture aerial images. A video transmitter sends video images from the aircraft to a ground station. Flights are remotely controlled and limited in range by the visual acuity of the pilot (less than 1 Km). Phase I systems have the smallest cost and are suitable for small-area applications with no need for precise positioning of the captured images [9].

Phase II: makes use of model airplane components and custom designed airframes. Aircraft include complete on board instrumentation [8]. A local area network (I2C) connects the on-board sensors to the main computer. Instrument data are downloaded to a ground station and the aircraft is piloted remotely using a computer system, resembling a flight simulator. The image presented on the screen comes from two video cameras: a downward looking camera, providing images of the area under monitoring and a forward looking camera, providing the pilot's view. Flights have a range of about 10 Km, depending on the power of the radio equipment. Figure 1 shows a typical screen of a phase II system. A block diagram for a typical system can be found in figure 2. Figure 3 shows the custom-designed aircraft for the project. The front part of the tubular fuselage holds all the electronics.

Figure 1 – Screen of a phase II system

Phase II systems employ of-the-shelf radio control equipment, analog video transmitter and modems boosted by linear power amplifiers. It is currently under development a digital data link for telemetry, MPEG4 compressed images and joystick input control, as shown in figure 2 [4].

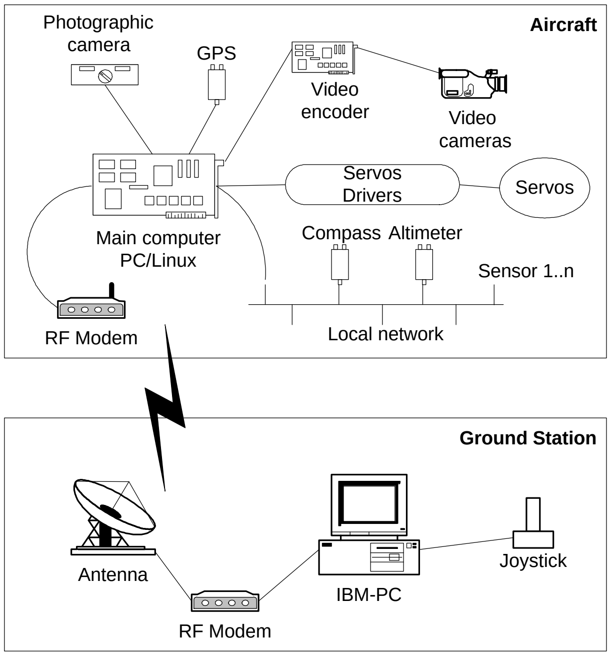

Figure 2 – Phase II system

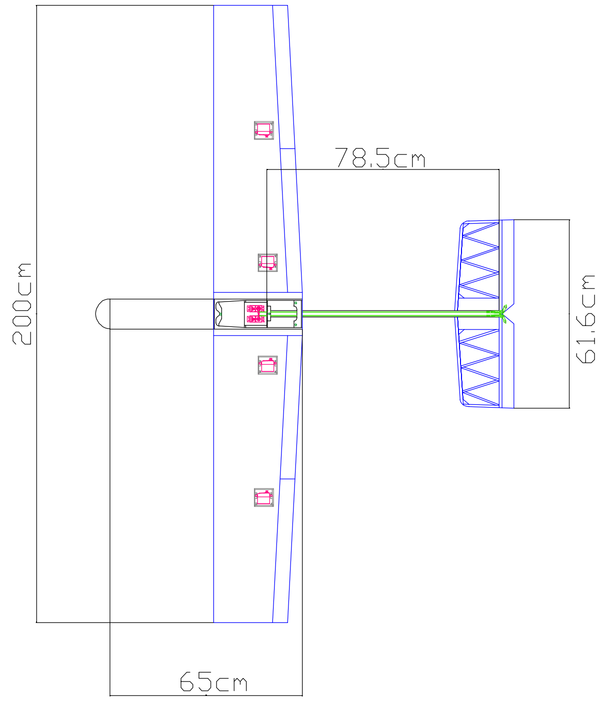

Figure 3 – Phase II aircraft

Phase III: a mission planner, a navigation controller and an autopilot (stability augmentation system, under development) are used to provide autonomous flight capability. Aircraft configuration is similar to phase II, scaled 150% to a wingspan of 3 meters. Users can program a route and a set of tasks to be accomplished autonomously by the aircraft. Missions will start by catapult launching and finish by parachute deployment [1, 7]. This paper describes part of the work done in this phase.

Phase IV: makes use of phase III systems to perform complex missions automatically. Onboard image processing is used to take mission decisions. Envisaged missions include power line monitoring and fault localization, animal count on farms, wild animal tracking, forest fire detection, etc. Applications currently under development are deforestation detection on riversides and automatic tree counting.

3 Overview of the System

The word “autopilot” normally refer to a system that maintains stable fligth and keeps the aircraft on route [6]. In this work, these two functions are split into two subsystems: the autopilot and the navigation controller. A context diagram of the system can be viewed in figure 4, where the interaction among the user, the mission planner and the navigation controller can be observed.

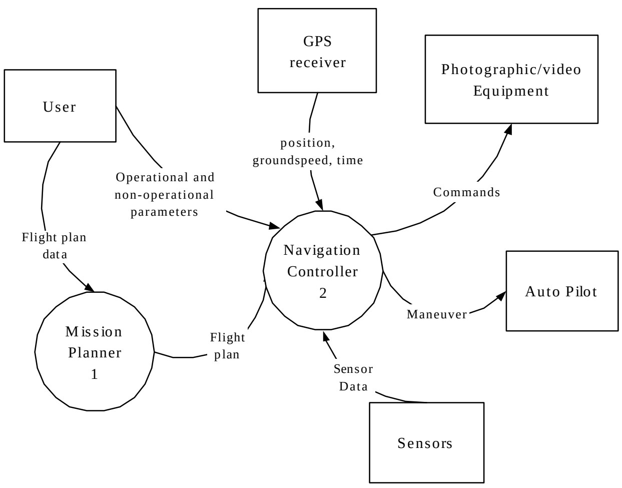

Figure 4 – Context diagram of the system

The user supplies the operational and non-operational parameters of the aircraft to the navigation controller. The operational aircraft parameters are:

Vy	Speed for best rate of climb
Mts	Best rate of climb
Vcr	Cruiser speed
Vne	Maximum speed
Rg	Radius, big, of a small angle of roll turn (15º)
Rm	Radius, medium, of a medium angle of roll turn (30º)
Rp	Radius, small, of a big angle of roll turn (45º).

The non-operational parameters are:

Vd	Speed in a dive
Td	Rate of dive
Dnv	Distance for leveling the aircraft after a climb or a dive

These parameters are introduced once into the navigation controller. There is no necessity to have accurate values. In fact, the navigation controller utilizes the user inputs as a first estimate for these parameters. Flying data are used in real time to calculate better values for these parameters.

The user interacts with the mission planner to produce the flight plan data, according to the expected mission. The flight plan is loaded into the navigation controller in the aircraft by a serial communication link. Once activated, the navigation controller carries out the flight plan sending basic maneuvers to the autopilot and commands to the image devices.

4 Mission Planner

Route planning (real time or not) is an essential part of an autonomous UAV-based system [10]. The mission planner allows the use of images or bitmap maps for mission planning. These images must have points with known latitude/longitude coordinates. It is possible to add landmarks to the map that can be converted to a set of route waypoints. Each waypoint has associated to it a position accuracy and a set of tasks that must be performed when the aircraft is within the position accuracy. Such tasks include taking photographs or record on tape downward viewed images. Some other rules can be added to control waypoint reachability, such as the number of tries to get to a waypoint within the specified accuracy. In each try, a new set of basic maneuvers is calculated and executed. After the specified number of tries without success, the aircraft leaves behind the current waypoint and heads to the next waypoint.

Figure 5 shows a typical screen of the mission planner. The mission plans generated by the mission planner that can be loaded into the aircraft navigation system consist of a sequence of lines of text.

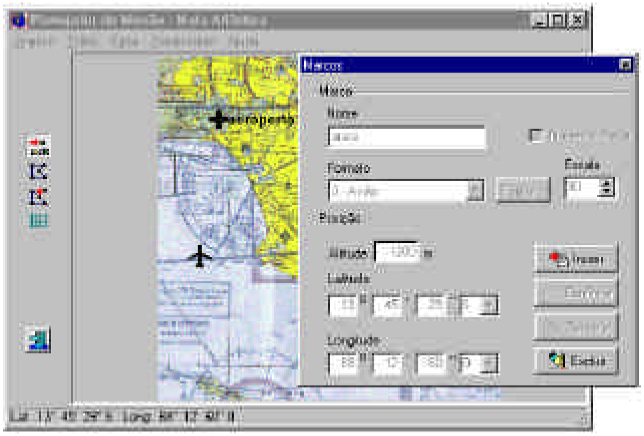

Figure 5 – A Mission Planner Screen

The system was implemented on a IBM-PC running the Microsoft Windows and the Borland Delphi. There are plans to change this platform to a computer running Linux and the Borland Kylix [1].

5 Navigation Controller

The navigation controller for ARARA aircraft was developed to guide the aircraft along the route and rules defined by the mission planner, accomplishing the set of tasks related to each waypoint. Figure 6 shows a state diagram of the navigation system.

The navigation controller was designed to maximize its independence from the autopilot and the operational parameters of the aircraft. The interface between the navigation system and the autopilot is done loosely by commands such as “right turn with small radius”.

The system works decomposing the route between each pair of waypoints in a set of basic commands (maneuvers). The maneuvers can be classified as course, corrective or adaptive. Maneuvers can be composed by one or more basic maneuvers. Course maneuvers are standard maneuvers between waypoints. Adaptive maneuvers are used to overcome position constraints between waypoints, such as one waypoint over another. Corrective maneuvers deals with wind influence and course corrections.

Maneuvers are calculated from GPS data, compass heading and indicated airspeed.

Table 1 shows the set of basic maneuvers defined.

Table 1 – Basic Maneuvers

Maneuver	Description
Level flight	Altitude, heading and speed steady (cruiser)
Climb	Heading and speed steady (best climb)
Dive	Heading and diving speed steady
Level turn	Altitude steady. Turn direction can be left or right. Turn radius can be small, standard or big
Abort mission	Stops the engine and deploys the parachute. This function can executed itself by the autopilot under major system malfunction
Finish mission	The aircraft is leveled, the engine is stopped and the parachute deployed. This is the normal end of a mission issued by the navigation system
Yaw correction	Used to compensate for lateral wind

This set is almost minimal and is considered a first approach. New maneuvers will be added in the future to improve the aircraft handling capabilities.

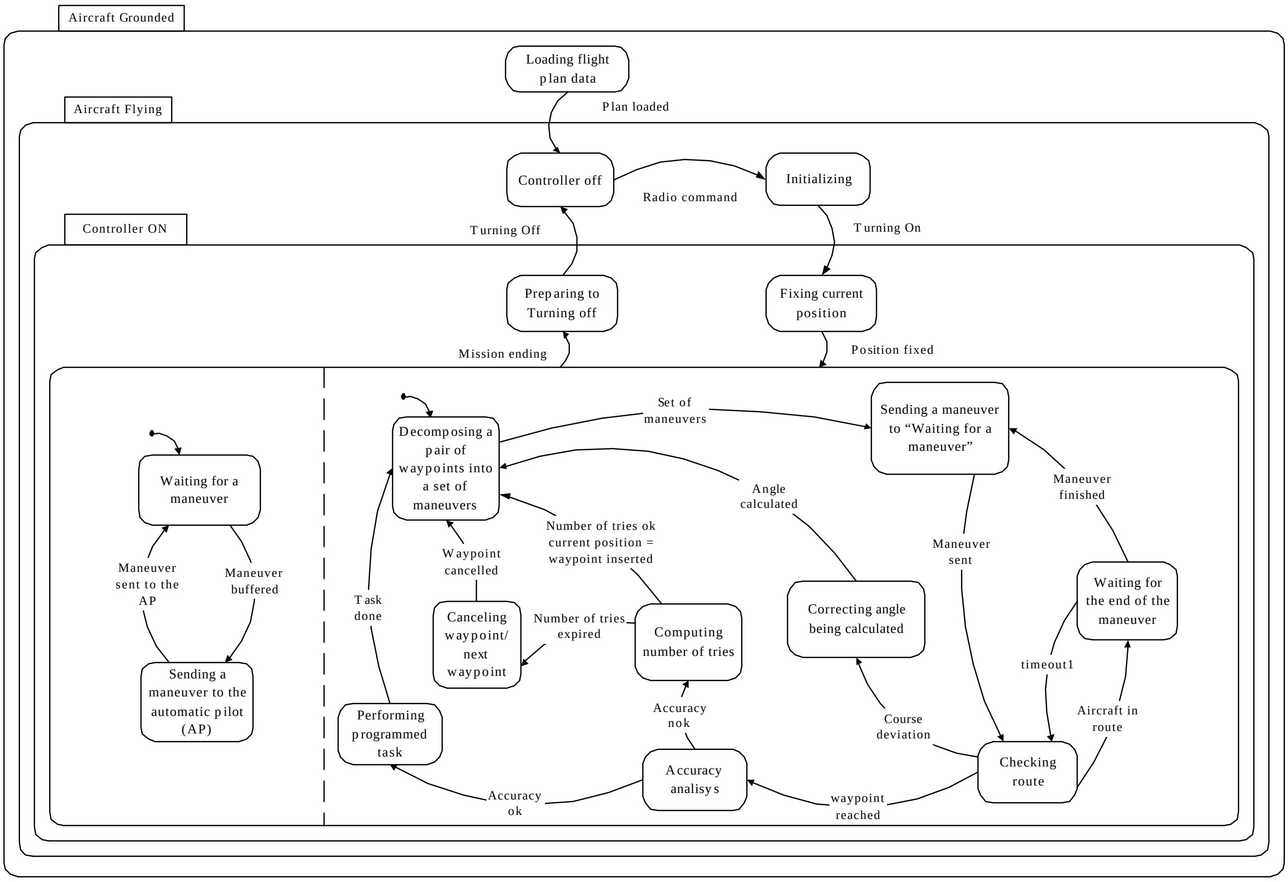

Figure 6 – State diagram of the navigation controller

The navigation system sends to the autopilot a basic maneuver and checks continuously its accomplishment. The completion of the current maneuver is done issuing the next maneuver. Course corrections are done defining a new waypoint in the route, related to the current off-the-course position. Horizontal wind influence is calculated and corrected by yaw commands. Vertical wind influence is corrected by the autopilot. Reaching a waypoint within its position precision triggers the programmed tasks.

Sensor failure is analyzed and can trigger the abortion of the mission by the autopilot (stopping the engine and deploying the parachute). At the final waypoint, the engine is stopped and the parachute deployed.

5.1 Flight patterns

The aircraft must transverse a waypoint leveled at the right altitude and over the line that connect it to the previous waypoint. Usually, is necessary a change in the direction and altitude of the flight after crossing a waypoint. Sometimes there is no room between the current waypoint and the next to accomplish this change of route and an adaptive maneuver is necessary. Such maneuvers are carried out following the flight patterns shown in figure 7.

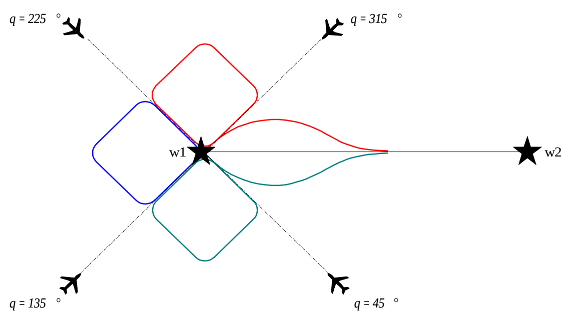

Figure 7 - Adaptive flight patterns

Such patterns are calculated from the following guidelines:

0° θ<90		Level flight length L Left turn 90° Level flight length L Left turn 90° Level flight length L Left turn 90° Level flight length L Right turn 90°-θ Level flight to the next waypoint
90° θ<180°	D DNc	Level flight length L Left turn 90° Level flight length L Left turn 90° Level flight length L Left turn 90° Level flight length L Left turn θ-90° Level flight to the next waypoint
	D<DNc	Right turn β° Left turn á° Level flight to the next waypoint
180° θ<270°	D DNc	Level flight length L Right turn 90° Level flight length L Right turn 90° Level flight length L Right turn 90° Level flight length L Left turn 270°-θ Level flight to the next waypoint
	D<DNc	Left turn β° Right turn á° Level flight to the next waypoint
270° θ<360		Level flight length L Right turn 90° Level flight length L Right turn 90° Level flight length L Right turn 90° Level flight length L Left turn θ-270° Level flight to the next waypoint

where (refer to figures 7 and 8):

$$L = Dest + Dc/4 \quad (1)$$

$$Dc = D - DNa\ (or\ DNd)$$

$$DNc^2 - b\,DNc + c = 0$$

$$b = 2r\cos j$$

$$c = 2r^2 \operatorname{sen} j - 2r^2$$

$$\cos b = \frac{\overrightarrow{C_1C_2}\cdot\overrightarrow{C_1W_1}}{\left|\overrightarrow{C_1C_2}\right|\left|\overrightarrow{C_1W_1}\right|}$$

$$j = q - 90^o$$

$$b + a = 180^0 - j$$

$$DNa = \overline{Vy} \times {}^{\Delta A}\!/_{Mts}$$

Mts	Best rate of climb
Vy	Speed for the best rate of climb
θ	Angle of arrival (at a waypoint)
Dest	Distance necessary for aircraft stabilization after a turn
D	Distance connecting waypoints
DNa	Distance necessary for an ascending flight
DNd	Distance necessary for a descending flight
∆A	Altitude difference between waypoints

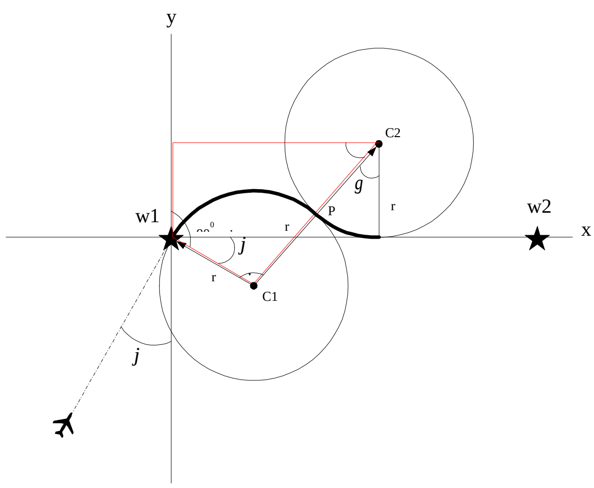

Figure 8 – Adaptive Maneuvers

5.2 Wind Influence

Wind affects the aircraft course. The aircraft nose leans towards the wind incidence. The navigation controller only corrects horizontal wind influence. The ground speed (*gs*) is given by the vector composition of the aerodynamic speed (*va*) and the wind speed (*w*).

$$\overrightarrow{gs} = \overrightarrow{va} + \overrightarrow{w}$$

To balance the wind influence on the course of the aircraft, the angle of yaw can be controlled, as suggested in figure 9.

The controller accepts a correction angle y, given by:

$$y = arcsen\left(\frac{-w_x \cos a_0 + w_y sen a_0}{\left|\overrightarrow{va}\right|} \right)$$

Where:

$$w_y = \left|\overrightarrow{va}\right| \cos a_0 - \left|\overrightarrow{gs}\right| \cos a_{gs}$$

$$w_x = \left|\overrightarrow{va}\right| \operatorname{sen} a_0 - \left|\overrightarrow{gs}\right| \operatorname{sen} a_{gs}$$

a_0 Current aircraft heading under wind influence

a_{gs} GPS reading of the aircraft heading

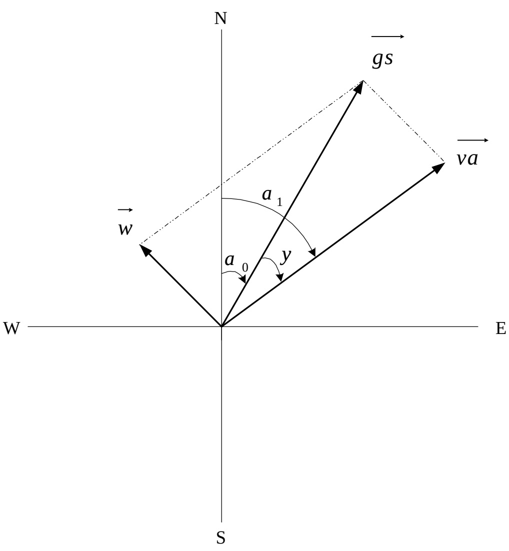

Figure 9 – Wind Influence

6 Conclusions

In this paper was presented the mission planner and navigation controller developed for the ARARA project. Both modules are being integrated with a stability augmentation system (autopilot, under development) to implement a fully autonomous UAV in phase III of the ARARA project.

The interface between the navigation system and the autopilot was simplified by the introduction of the concept of basic maneuvers. This concept makes easier the use of the system with different aircraft (and their properly tuned autopilots).

The proposed set of basic maneuvers is complete, in a sense that it can control the route of the aircraft, and is simple to implement. The first test flights are due to the third quarter of this year. New maneuvers can be added to improve the handling of the aircraft. Such maneuvers could include some form of spiral climb/dive, replacing the square flight patterns used so far.

The current set of basic maneuvers was tested, as part of the autopilot development, using the Matlab Simulink [7]. The bench test consists of the aerodynamic model of the aircraft, the autopilot control equations, a wind/turbulence generator and sequences of basic maneuvers as inputs. Results have shown good behavior of the system under severe wind/turbulence conditions. The autopilot is being implemented using a computer running Linux that also runs the navigation controller.

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