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Heterogeneous Control of Small Size Unmanned Aerial Vehicles

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Abstract: There are many ways to control an unmanned aerial vehicle. Not all of them can be applied to all category. There is often need to control a small size (0.5-25 kg) unmanned aerial vehicle via direct control within sight during the operation. This mode is practically the same as controlling a radio controlled (RC) model aircraft. The significant difference is this control is the normal mode in case of RC models but for UAVs it is used only some special maneuvers. The configuration of the autonomous – manual control mode switch subsystem is essential during the design procedure of the onboard systems.

1 Introduction

The setup procedure of a small size UAV starts with manual control. After the UAV is airborne can be switch to autonomous mode [1]. When the autopilot turns on in a safety altitude its operation can be well observed. There is enough time to switch back to manual control in the case of any malfunction. Many amateur autopilots can only navigate between waypoints. They can't perform the difficult takeoff and landing maneuvers so they are land and takeoff in manual mode [2].

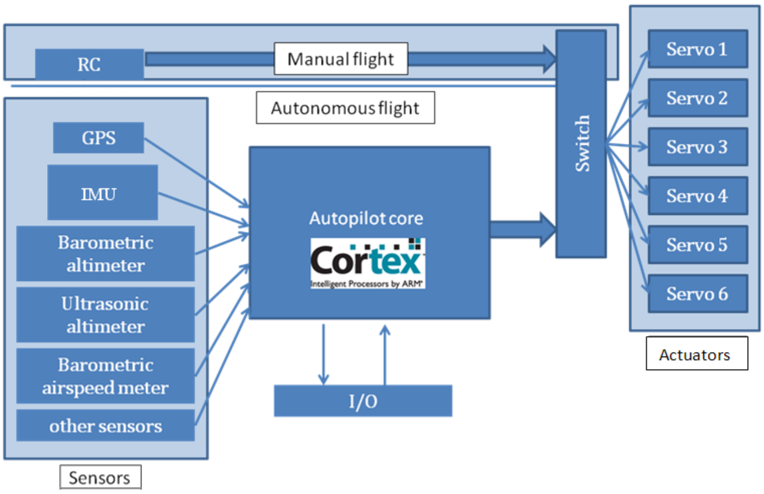

Figure 1

System architecture of a UAV's autopilot

2 Control Modes

2.1 Autonomous Control Mode

In manual control mode the actuators and the speed controller which controls the aircraft are driven by a human pilot via radio controller. During the manual flight the autopilot (Figure 1) simultaneously creates the same actuator controller signs but these are not setting off. Since the human pilot can switch between full control and autonomous control mode only tuning the independent controller channels (velocity altitude stabilizing and course attitude) is very difficult. Before every controller channel test the UAV's electric systems (RC receiver and autopilot) have to be connected in a different setup so the autopilot can drive only the expected control surface (Figure 2). This procedure is quite slow and it is a potentional error source (wrong connection of wires).

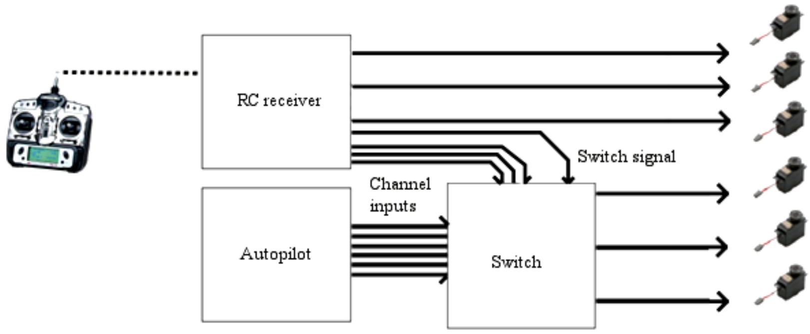

Figure 2

Theoretical full manual-autonomous switch circuit

2.2 Half Autonomous Control Mode

The half autonomous mode is the solution of the manual control mode's switch problem. For this mode we need a more complex switching circuit (Figure 3). The autopilot is capable of controlling the switching mechanism depending on the commands from the ground control station. We can decide which control surface is driven by the human pilot or the autopilot at any time even in flight. There is no need to modify the wiring of the electric system. The autopilot gets the switching parameters from the ground control station via telemetry. It forwards these signals to the switch circuit and the analogue-digital switch ICs make the rest. This solution is robust and eliminates the human error. The operation of this mode is resting on that supposition that the switching is always happen.

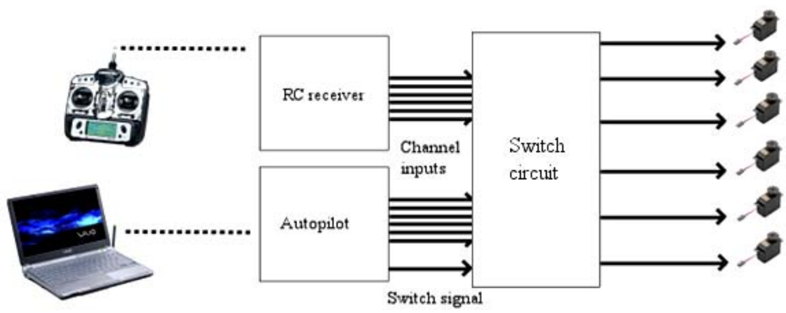

Figure 3

Theoretical half autonomous switch circuit

2.3 Heterogeneous Control Mode

The heterogeneous control mode is similar to the half-autonomous mode but it has an improved switching circuit. An additional switch signal is added via RC transmitter (Figure 4). This signal can override the signals of the autopilot so it can allow manual control even if the onboard autopilot software became out of order.

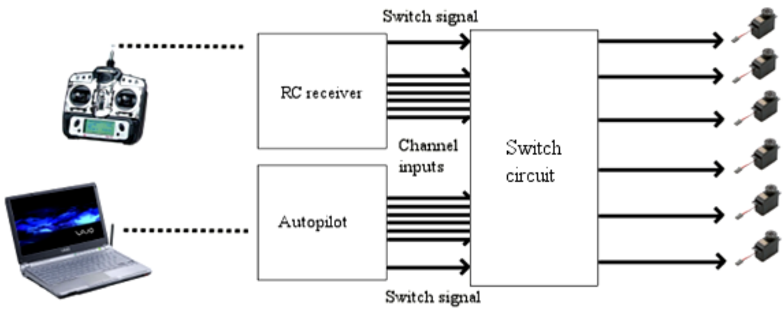

Figure 4

Theoretical heterogeneous switch circuit

3 Switching (Figure 5)

It is practical that the change between heterogeneous autonomous and manual control modes is driven by a three state switch from the RC transmitter. It controls the RC channel with a -100% 0% and 100% values. The software of the switch circuit's microcontroller unit (MCU) should be made to interpret these values securely and easily (for example thresholds are -50% and 50%).

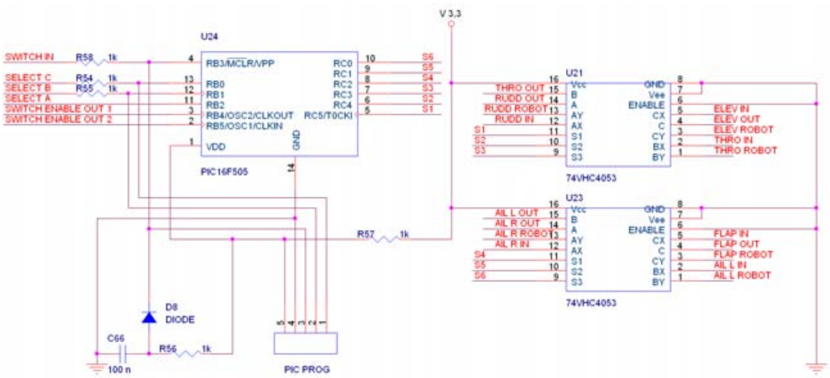

Figure 5

Potential heterogeneous switching circuit

4 Autopilot Setup Procedure

The barometric sensors (altitude and airspeed) of the autopilot should be calibrated before the first flight. For this process a calibrated analogue barometric aircraft instrument [3] or digital altimeter and airspeed meter for modelers [4] can use for reference value. The operational range should be considered for the calibration (for example average airspeed is 60-80km/h operational altitude is 0-2000m). The conversion functions should return the lowest possible error rates in these ranges because the speed and altitude controller is based on these values.

Before the first flight the autopilots signals have to be set for the control surfaces. We must define the center value, minimum and maximum end points. For safety reasons the control functions should use only about 50% - 75% of these ranges (except for stabilizing).

It is important that the first flights have to do in full manual control mode and in a calm weather. The crew has to check the sensor values. The barometric values should match the GPS values. If it is good enough and the telemetry is reasonable too we can begin to setup the controller functions.

It is essential to setup the control functions and inertial measurement unit's (IMU) amplification rates separately. We can use the heterogeneous control mode. We can use the base values what we calculated in advance simulations. If the controller functions based on the popular PID controller than the "I" factor has to be ignored during manual flight. (The "I" factor's error can reach high levels when the UAV is flying far from the aim value)

I suggest to setup the airspeed and altitude controllers in a long (800-1000m) straight lines while it is important that these should work also in turns (it can be achieve with elevator-rudder-aileron mixes). If these are working great we can test them together. The human test pilot has to control the UAV in course via ailerons and rudder only. If the settings are right the autopilot should control the airplane at the desired altitude and airspeed.

The autopilot has to stabilize the aircraft against the always changing directional and turbulent wind. We can use infrared based thermopile sensors or IMUs. The thermopiles are relatively cheap but they are reactive to the weather and relief. The IMUs are using a combination of accelerometers, gyroscopes and gravitational force sensors so they are much more accurate.

These sensors amplification level has to be fit for the UAV. With high G turns in manual mode we can set the values. If the values are wrong when the autopilot controls the aircraft will break out some direction after the turn because the X-Y-Z angle's zero values went wrong. We have to consider the UAV's propulsion too because electric and internal combustion engines can make a very high level resonance which can jam the IMU too.

4.1 Course Controlling

For course controlling the autopilot can use the direction computed from the GPS coordinates or the direction supplied by the IMU. The direction from the GPS data shows the real heading direction while the IMU based shows the direction where the aircraft's nose pointing. These are not the same because of the sliding caused by the wind.

4.2 Waypoint Navigation

During the navigation the autopilot controls through two factors. These are the course angle error and the course distance error. The course angle error is the signed difference of the course direction and the actual heading direction and the course distance error is the distance of the actual position and the course. The navigation is ideal when these two factors are near to zero (Figure 6).

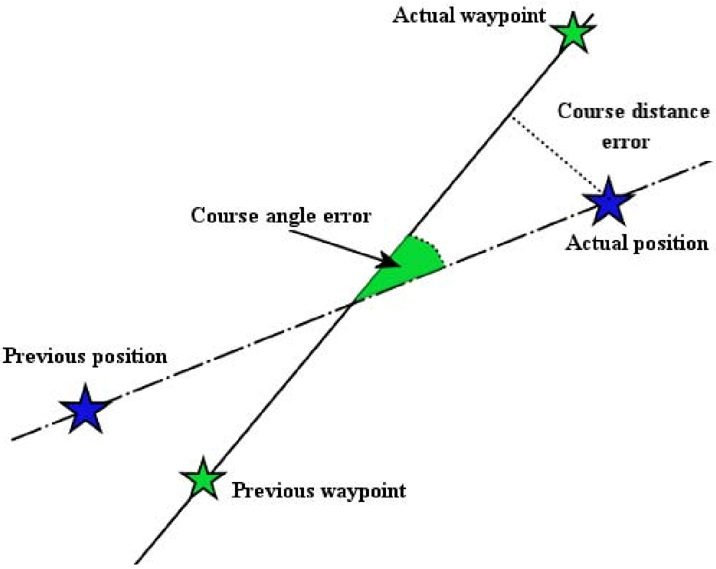

Figure 6

Navigation with waypoints

The plainer autopilots compute only with course angle error. The result of this is a large arc course far from the ideal course (Figure 7).

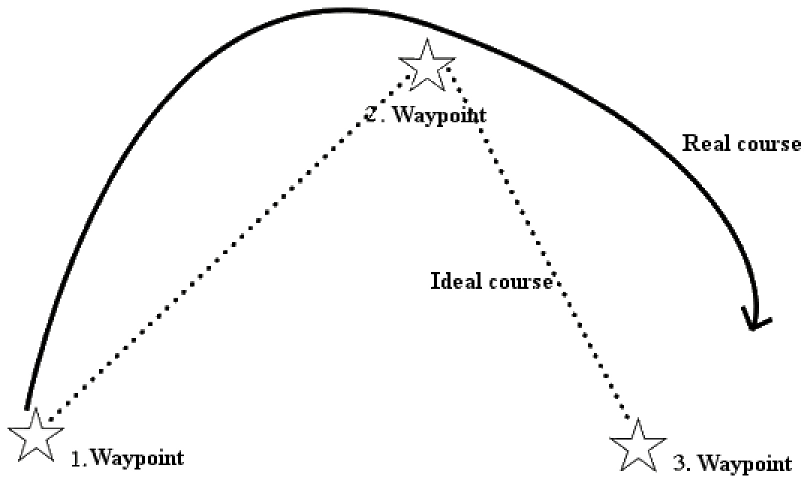

Figure 7

Navigation with course angle error only

This error can be corrected with the course distance error. The controller function should compute with both of them with a correct ratio (Figure 8). When the autopilot can control the airplane in the desired altitude and airspeed it's time to tune the navigation.

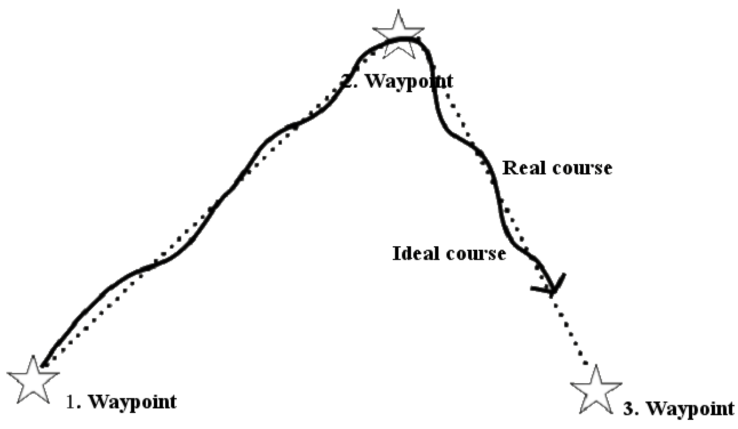

Figure 8

Navigation with course angle error and course distance error

5 GPS Modules

The modern GPS modules can supply 4-5 Hz data refresh and has 2-3m accuracy and can operate with weak satellite signals [5]. They have internal filters but although them it is not enough. When the UAV is flying with low speed over ground (SOG) the course errors (Figure 9) can be very false causing navigational malfunction. With 80km/h SOG, the GPS module supplies new position in every 4-5m. To eliminate this error the autopilot should compute with the direction supplied by the IMU at low SOG or additional position filtering required.

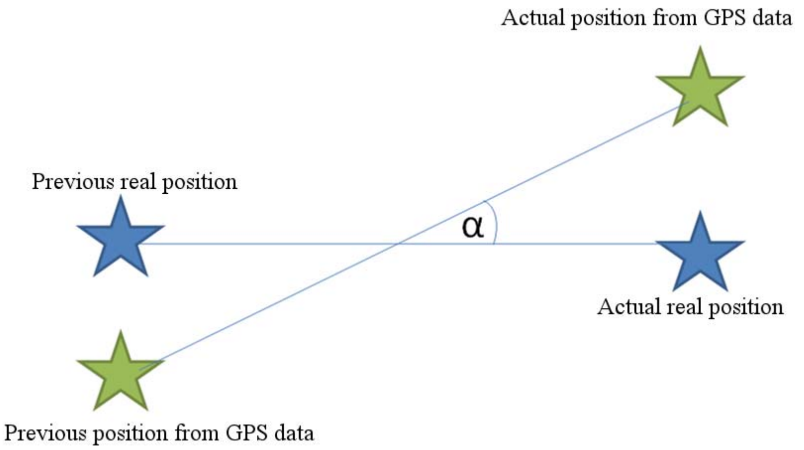

Figure 9

Worst case course error

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