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MEMS-Based Low-Cost Flight Control System for Small UAVs

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Abstract: Small unmanned air vehicles (UAVs) can be used for various kinds of surveillance and data collection missions. The UAV flight control system is the key to a successful mission. This paper describes a low-cost micro-electro mechanical system-based flight control system for small UAVs. The integrated hardware flight control system weighs only 24 g. The system includes a highly-integrated wireless transmission link, which is lighter than traditional links. The flight control provides altitude hold control and global positioning system navigation based on gain scheduling proportional-integral-derivative control. Flight tests to survey the grass quality of a large lawn show that the small UAV can fly autonomously according to a series of pre-arranged waypoints with a controlled altitude while the wireless video system transmits images of the surveillance target to a ground control station.

Key words: micro-electro mechanical system (MEMS); unmanned air vehicle (UAV); global positioning system (GPS); flight control; navigation

Introduction

Various kinds of unmanned air vehicles (UAVs) have been developed for various purposes. Small UAVs range in size from 15 cm to 1 m. They have drawn considerable interest because of their small size, portability, low cost, and their ability to provide inexpensive, expendable platforms for surveillance and data collection in situations where large vehicles are not practical[1,2]. The flight control system is a key part of UAVs which fly autonomously according to a series of pre-arranged waypoints while transmitting real-time images of surveillance targets to ground control stations[3-8]. Up to now, several kinds of commercial flight control systems have been developed, such as the MP2028g developed by the Micropilot[9] and the AP50XL developed by UAV Flight Systems[10].

However, the limited payload capability of small UAVs limits the use of ready-made UAV flight control systems that are too heavy. Less expensive designs are also needed[11]. This paper describes a low-cost micro-electro mechanical system (MEMS)-based flight control system for small UAVs. The system is used in a small UAV, called the TUAV1000, as the test flight platform. The integrated hardware includes three singleaxis MEMS rate gyroscopes, an absolute pressure sensor, a differential pressure sensor, and a miniature global positioning system (GPS) receiver with an antenna. Thus, the system includes an integrated wireless communication link. The flight control uses gain scheduling proportional-integral-derivative (PID) control[12] for the altitude hold control and the GPS navigation.

1 System Architecture

1.1 Experimental platform

The TUAV1000 shown in Fig. 1 has three servo units for the left and right elevons and an electrically driven propeller. Its wingspan is 1000 mm and carries a wireless video system as payload.

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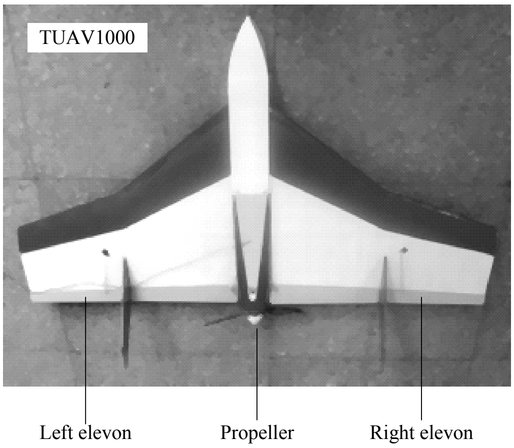


Fig. 1 Picture of TUAV1000

1.2 Hardware design

The hardware architecture for the flight control system shown in Fig. 2 includes sensor modules, a microprocessor unit, a wireless transmission system, a payload module, a servo module, and a power management module.

In the sensor modules, the data from the 3-axis MEMS gyroscopes is used to stabilize the UAV, the absolute pressure sensor measures the altitude, the differential pressure sensor measures the airspeed, and the GPS receiver acquires the UAV heading and position. The actual flight control system is shown in Fig. 3, which weighs only about 24 g.

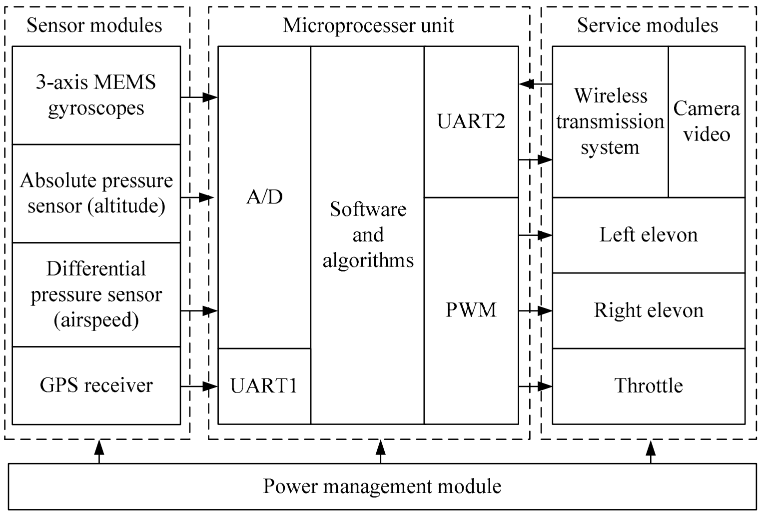


Fig. 2 Flight control system hardware architecture

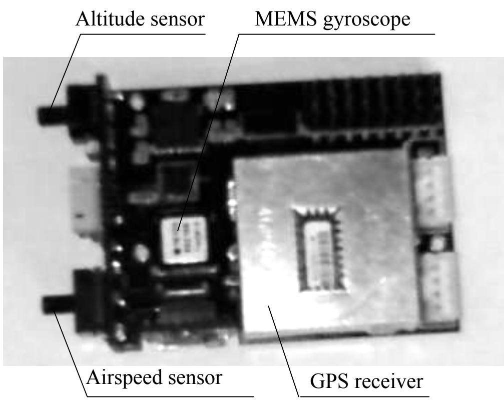
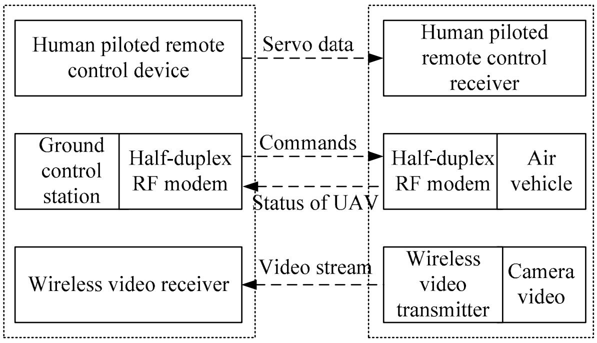


Fig. 3 Flight control system package

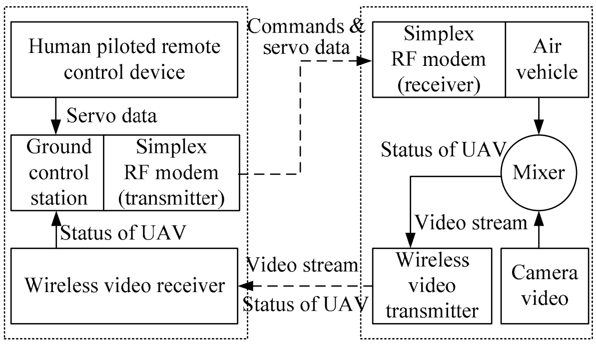
Three different wireless transmission devices are often used in UAVs, the human piloted radio control receiver, the wireless link for transmission of command, and the data signals and wireless video transmission system, as shown in Fig. 4a. As a result, the wireless transmission systems are quite heavy, which is not appropriate for a small UAV. Actually, the transmitted data in a UAV system can be classified as uplink (from ground to air) data and downlink (from air to ground) data. The uplink data includes the remote control data and commands or parameters from the ground control station to the UAV. The downlink data includes the UAV status information and the video data.

1.3 Integrated wireless transmission system

The remote control data can be sent to the ground control station and then together with commands from the ground control station to the UAV in one uplink channel (Band A). The data from the UAV to the ground control station and the video data can be mixed together for transmission in the downlink channel (Band B). The complex three-parts wireless system can then be replaced by a single, light weight, full duplex wireless link, as shown in Fig. 4b. RF is the radio frequency.



(a) Traditional wireless transmission system



(b) Integrated wireless transmission system

Fig. 4 UAV wireless transmission systems

2 Flight Control Block Diagram

The flight control system autonomously enables stable flight of the UAV according to the prearranged flight track with specified altitude and airspeed. This paper focuses on the realization of the gyroscope stable control, the altitude hold control, and the GPS navigation. The design assumes that the longitudinal and lateral dynamics of the UAV are decoupled so that the longitudinal and lateral flight controllers can be developed independently. The controllers are based on PID control method.

2.1 Longitudinal controller

The inputs to the longitudinal controller shown in Fig. 5 are the desired pitch rate, ω_y^{d}, and the desired altitude, H^{d}. The output is the elevator deflection.

For the UAV longitudinal stability, ω_y^{d} must be zero. The pitch rate stable controller then minimizes the difference between the desired pitch rate and the actual pitch rate, ω_y^{a}, with the rate error converted into an elevator deflection, $\delta_{\mathrm{elev}}^{\omega_y}$.

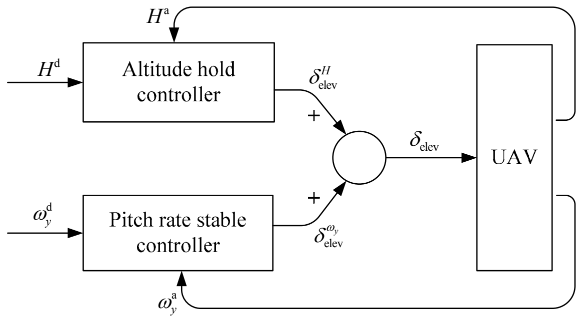


Fig. 5 Longitudinal controller

The altitude hold controller minimizes the difference between the desired altitude and the actual altitude, H^{a}, with the altitude error converted into an elevator deflection, $\delta_{\mathrm{elev}}^{H}$.

The total elevator deflection is then

$$\delta_{\mathrm{elev}} = \delta_{\mathrm{elev}}^{\omega_y} + \delta_{\mathrm{elev}}^{H}.$$

2.2 Lateral controller

The inputs to the lateral controller shown in Fig. 6 are the desired position, P^{d}, and the desired roll rate, ω_x^{d}. The output is the aileron deflection.

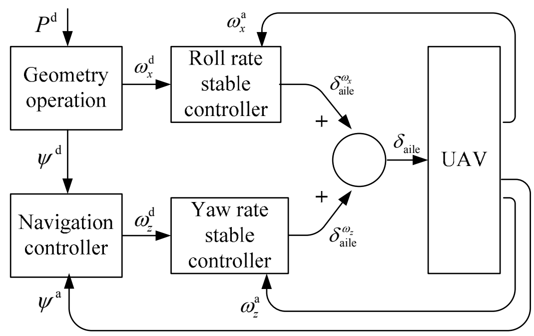


Fig. 6 Lateral controller

For the UAV lateral stability, ω_x^{d} must be zero. The roll rate stable controller minimizes the difference between the desired roll rate and the actual roll rate, ω_x^{a}, with the rate error converted into an aileron deflection, $\delta_{\mathrm{aile}}^{\omega_x}$.

The UAV position and pre-arranged flight track (WPT1-WPT2) are converted by geometry operation into the desired heading, ψ^{d}. The vertical distance from the UAV to the pre-arranged track (WPT1-WPT2), D, and the track heading, ψ_{t}, as shown in Fig. 7 are then calculated based on the following rules:

(1) When $D \leqslant D_{\text{Threshold}}$, $\psi^{\mathrm{d}} = \psi_{\mathrm{t}}$;

(2) When $D > D_{\text{Threshold}}$, $\psi^{\mathrm{d}} = \psi_{\mathrm{t}} \pm \psi_{\text{bias}}$ ("+" for the UAV going up the track; "–" for the UAV going down).

$D_{\text{Threshold}}$ is a threshold value given as the positioning precision of the GPS receiver. ψ_{bias} is a correction determined from D using a PID controller.

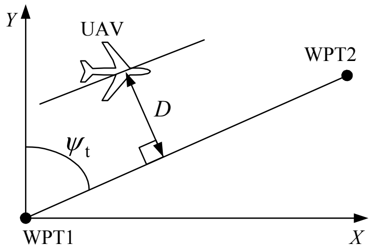


Fig. 7 GPS navigation geometry operation

The navigation controller minimizes the difference between the desired heading and the actual heading with the error converted into the desired yaw rate. The yaw rate stable controller then converts the yaw rate error into an aileron deflection, $\delta_{\text{aile}}^{\omega_z}$.

The total output of aileron deflection is then

$$\delta_{\text{aile}} = \delta_{\text{aile}}^{\omega_x} + \delta_{\text{aile}}^{\omega_z}.$$

2.3 Gain scheduling based on airspeed

The UAV dynamics changes with the operating conditions, so the flight control system is nonlinear. Thus, a simple PID control cannot provide stable flight of the UAV for all kinds of flight conditions[11]. Therefore, a gain scheduling algorithm based on the airspeed was designed to improve the PID controller. The parameters of the PID controller were tuned by monitoring the airspeed, as shown in Fig. 8.

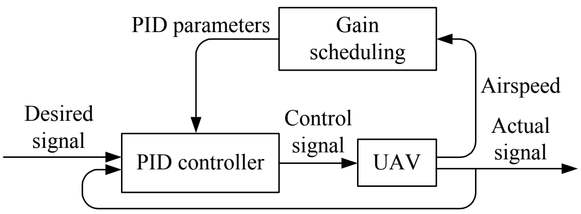


Fig. 8 PID controller using gain scheduling based on the airspeed

3 Flight Tests and Results

3.1 Mission description

Large lawns can have grassless spots because of natural conditions or man-made damage. However, the lawn maintenance workers desiring to repair these spots have difficulty finding them on the ground. Thus, the TUAV1000 was assigned to fly autonomously over a large lawn according to a pre-arranged track at an altitude of 70 m. The wireless video system then transmitted real time images of the lawn to the ground control station. Image processing was used to identify grassless spots, which were then marked on a map of the lawn so that the workers could then repair them.

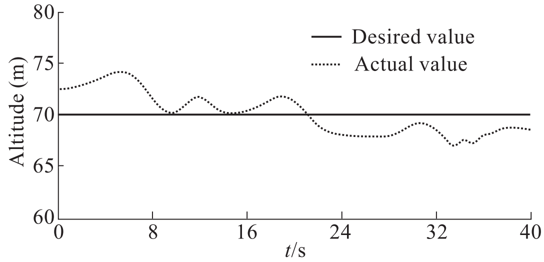
3.2 Flight results

The altitude hold control result shown in Fig. 9a shows that the maximum control error was about 4 m. Figure 9b shows how well the GPS navigation system controlled the flight path around the four waypoints, whose coordinates were (–70, 0), (30, 0), (30, 100), and (–70, 100). A 25-m-radius circle around the waypoints in Fig. 9b indicates the navigation precision. The tests show that the UAV can autonomously fly according to the pre-arranged waypoints with reasonable accuracy.

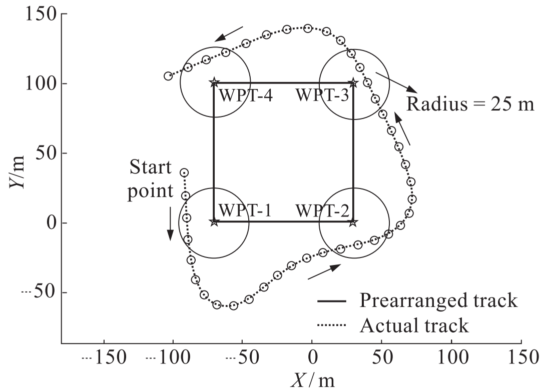
A typical real time image of the lawn transmitted to the ground control station is shown in Fig. 9c. The grassless spots in the lawn were easily found and labeled in the picture. A picture of TUAV1000 in flight is shown in Fig. 9d.

4 Conclusions

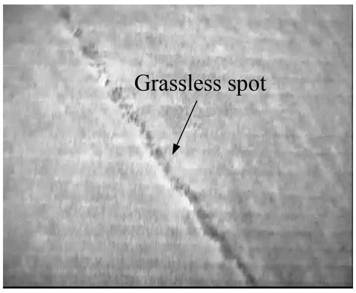
A small UAV can be used to execute various kinds of surveillance and data collection missions. The flight control system is a key part of UAV but there are few ready-made flight control systems. Thus, a low-cost, light weight, MEMS flight control system was developed including sensors, controllers, and the wireless transmission system. The software uses a gain scheduling PID controller for the altitude hold control and the GPS navigation. Flight tests show that the UAV flight control system is very effective and can be used for various surveillance missions.



(a) Altitude hold control result



(b) Flight track



(c) Image transmitted to the ground control station

(d) TUAV1000 in flight

Fig. 9 Flight test results

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