

UNMANNED MEASUREMENT PLATFORM FOR PARAGLIDERS

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Abstract

The design of remotely controlled and unmanned aerial system (UAS) is an important direction in modern aircraft development. Some researches are aimed at UAS's which use paraglider canopy as their wing. This group of UAS's can be successfully used in applications where stable, low speed flying and mobility are required.

This paper introduces a UAS test platform developing for testing the different paragliders. The test platform is planned to use for different purposes: (i) investigation and calibration of the sensors developing for the special small (leisure or sport) flying machines, (ii) measuring the aerodynamic characteristics of the canopies, (iii) developing and testing the UAS subsystems, (iv) investigation and parameter and state identification of the paraglider motion equations, mathematical model that required for developing the automatic control of paragliders.

The developing unmanned measurement platform is equipped by (i) sensors and air data collection unit including GPS positioning, pressure and temperature sensors, MEMS based local force components/stress measuring sensors, etc., (ii) control sub-systems containing power and control forces' actuators and control unit as well as (iii) the info-communication system. The most challenging part of the test platform is the electronic system. We had provided a robust, fail safe remote control system for the test platform. The basic intelligent distributed control system consists of the ground station, the radio link and propulsion and control forces' actuators.

1 Introduction

Nowadays, the unmanned aerial systems (UAS) are developing very widely for many different application purposes as surveillance, fire, or lost persons surveillances, area monitoring, weather investigation, hurricane monitoring, land observation, pipeline inspection, traffic monitoring, damage assessment, and so on [1 - 3]. Most of them are fixed and rotary wing

aircraft that may have relatively high speed, large dimensions and weigh in comparison with the "commercial load", sensors, data collections, evaluation and communication equipments. Generally, the lighter than air UAS, airships and balloons have much more larger airframe then their payload.

Building UAV with paraglider canopy is not too old conception, still seems only one company in the USA developing his main activity in this field [4]. Other company is developing a special, man-portable hybrid UGV/UAV [5]. Such system has a very important advantage comparing to UGV or UAV, because the target areas can be investigated and monitored by the ground vehicle, why the vehicle can return to its home basis by air.

According to the US roadmap [2], after 2020 the UAS will be operated by autonomous control system, only. For developing the autonomous control system for PPG, its motion dynamics must be studied. Therefore a special PhD research had been initiated by the Department of Aircraft and Ships at the Budapest University of Technology and Economics (BME). The first part of research had a goal setting up and designing, realizing a special measuring system for estimating the PPG flight dynamics.

This paper gives information about the civilian application of PPG UAV, shortly introduces the motion equations, defines the requirements in measuring systems and developing the measuring system that in realization at the Department of Aircraft and Ships, BME.

2. PPG UAS

For understanding the requirements to measuring platforms the operational concepts, application of the PPG and its modeling and control developments must be analyzed.

2.1. PPG UAS application

A special UAS, paraglider has several advantages comparing to the other UAS when the stable, low speed flying and mobility are required [4]. May be, the most important benefit of the powered paragliders for unmanned aircraft use is their unique ability to glide to the ground in a relatively safe manner, even if all control systems are disabled. This is particularly desirable in urban environments where a failure of any large UAV would likely result in collateral damage to structures on the ground. Therefore the paragliders are widely used for leisure flying, they say it is the freest way of fly.

An another important advantage of the PPG UAV is their excellent portability [5], since it is folded on the ground, and unfolded when it flies. Because the paraglider is subject to wind disturbances, the portability justifies the uses of the paragliders as UAV, for example as a recovery system of a spacecraft [6]. However, in order to use the UAV not as a glider but as an aircraft, it needs thrust generated by a propeller, lift determined by a parafoil or canopy and a suspended payload body (traveler) (Fig.1).



Fig. 1. Powered paraglider

The paragliders have strongly flexible wing, the shape (and the profile) of the wing depends on aerodynamic forces which

developed on it, so it has coupled mechanical – aerodynamical behaviour.

Actually several types of an autonomous PPG have already been produced and sold on a commercial basis. For instance, the PPG, which is guided by GPS and flied for a long time (about 1.5 days maximum), was developed about ten years ago. In addition to the portability of a PPG, its low flight speed is suitable for land observation of a small area. Furthermore, a PPG is safe and survivable in case of engine failure, since it can continue a stable gliding flight without thrust and can be guided to a safe landing point.

The comparison of a powered paraglider (PPG) UAV with fixed (rigid) wing aircraft (Fig.2.) shows that the PPG UAV requires 2 - 4 times more fuel, while its cruising speed much more less. However, in case of area monitoring, when the cruising time is important, then the using the powered paragliders is a better solution.

	Atair LEAPP (Type I)	Cessna Stationair
Takeoff Weight	1633 kg	1633 kg
Length	2667 mm	8610 mm
Width	2108 mm	10970 mm
Height	2413 mm	2830 mm
Range	1500 km	1278 km
Weight of fuel	985 kg	237 kg
Fuel consumption	20 kg/h	23 kg/h
Fuel consumption	65,7 kg/100km	18,6 kg/100km
Cruising speed	30 km/h	250 km/h

Fig. 2. Comparison of rigid wing aircraft and PPG UAV

The missions outlined below are particularly well suited to powered paragliders, as opposed to conventional fixed-wing aircraft and rotorcraft, due to the PPC's unique flight characteristics [7]:

- Aerial Spraying (spraying of various fertilizers and pesticides thanks to large payload capabilities, coupled with the slow, constant-speed flight of PPG allow for a low-turbulence spraying platform with a long endurance time).
- High-Resolution Photography (due to slow-moving, low altitude platform).

- Tactical Unmanned Aerial Vehicles (PPG may use for such missions because its lightweight, collapsible wing, powering, allowing the deployment of man-portable units within minutes).
- Ground Penetrating Radar (this emerging technology developing for observing the underground anomalies needs slow flight ability, large wing area, keeping a fixed altitude).
- Radio Frequency Relay (ideally might be supported by PPG having low speed long endurance flight, high payloads, retaining its virtually static position in low altitude flight with sustained winds less than 10-20 mph).
- Aerial monitoring of air quality (due to low speed and altitude).

2.2. PPG aerodynamic and flight control models

Paragliders are unique flying vehicles, containing the flexible canopy and rigid (in case of human operator nearly rigid) body payload. The canopy is used for generation the aerodynamic lift required for flights. However aerodynamic forces and moments burning on the canopy depend on the actual loads (form of canopy). Generally, the estimated values from free flight test measurements [8, 9] show that, the observed maximum lift to drag ratios near 2.5, high profile drag and low maximum lift coefficients when compared to a standard rigid wing.

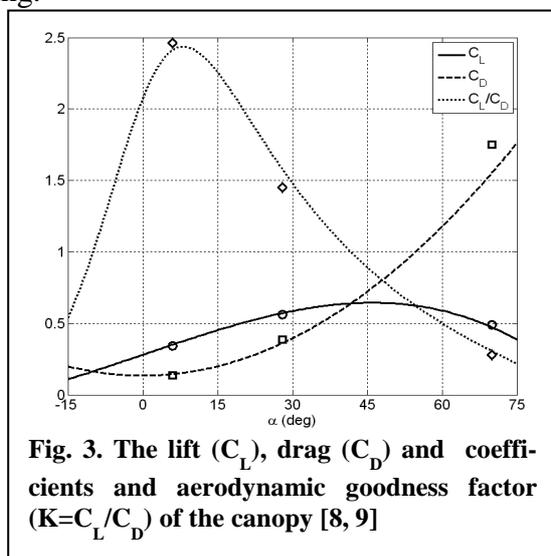


Fig. 3. The lift (C_L), drag (C_D) and coefficients and aerodynamic goodness factor ($K=C_L/C_D$) of the canopy [8, 9]

From the flight dynamics point of view, one of the most interesting features of the paragliders is their inconveniences to longitudinal control. They have only lateral control that can be realized by changing the length of the appropriate (left or right) suspension lines. By this way the canopy form is shaping (deforming) and the drag as usually rising significantly and lift increasing only slightly. So, this “breaking” and the moments developed cause the tilt of canopy. Canopy changes created by brake deflection subsequently cause predictable changes in aerodynamic loads which is leveraged for control of the vehicle [10]. For most parafoils, deployment of the right brake causes a significant drag rise and a small lift increase on the right side of the parafoil canopy combined with slight right tilt of the canopy. The overall effect causes the parafoil to skid turn to the right when a right parafoil brake is activated.

The developed and deployed paraglider dynamic models [8, 10 - 13] are based on the simplified concept: the paraglider is the rigid body, and the reference system is the body system put into the centre of the paraglider. In this case the flight dynamic can be described by using a 6 or 9 degree-of-freedom (DOF) model. The aerodynamic force and moment components generated on the canopy and payload must be transferred to the body system.

The non-traditional model, when the canopy is not fixed respect to the payload, the 6 DOF must include changing canopy orientation with respect to the payload and model apparent mass effects in a complete manner [8].

3. PPG test platform

3.1. Requirements

The requirements to the PPG test platform developing at the Department of Aircraft and Ships at BME, had been defined by goals of future application. These goals are the following:

- investigation and calibration of the sensors developing for the special small (leisure or sport) flying machines, for the small aircraft including the MEMS based sensors, micro

and mini actuators, cost sensitive solutions of new avionics, etc.,

- measuring the aerodynamic characteristics of the canopies, developing the aerodynamics models and their estimation,
- developing and testing the UAS subsystems,
- investigation and parameter and state identification of the paraglider motion models studying the system of motion equations, mathematical modeling and solving the models that required for developing the automatic control of paragliders.

Of course, these goals define not only the system elements, sensors, actuators, but the required accuracy for measurement:

- positioning system (like GPS) with accuracy 0.3 m for navigation purposes,
- attitude, heading and roll measurement with accuracy less than 2 degrees,
- cameras for image processing (for image detection and recognition) with accuracy 0.005 s (s – distance to the detected object, obstacle),
- communication system (data link)
- system monitoring (engine rotational speed, fuel consumption, speed (at least determined from the positioning measurement), monitoring telemetry and monitoring system (communication system)

3.2. General description of the test platform

The UAV platform developed by us has take-off weight up to 110 kg. It is fully developed and built on the department. The mechanical system consists of as follows:

- propulsion unit
- frame (3 wheeled trike)
- brake line actuators
- avionics block
- canopy (paraglider wing)

The propulsion unit is consist of the paramotor type Solo210, the fuel tank, the wooden propeller, the exhausting system, the transmission system, the starter motor and the propeller protection frame (Figure 4).



Fig. 4. The very first test of the PPG UAV developed on the department

The frame of the platform is made of steel, because we have to provide the necessary weight of the trike. The weight of the whole platform has to be in the range 75 - 105 kg, because the paraglider used has this range of total weight in flight. The material used allowed to manufacture the frame in the workshop of the Department.

Brake line actuators (left and right) consist of an actuator and its control circuit. On Figure 5 the brake line actuator can be seen on the test bench. It is able to develop forces of 400 N, which is enough to control the paraglider brake lines in normal flight conditions.

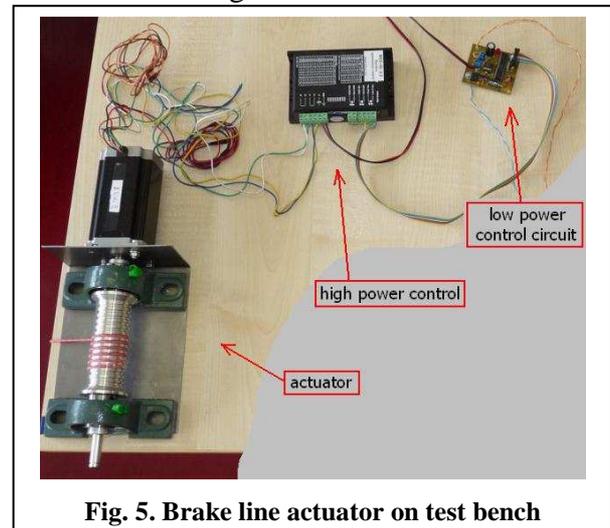


Fig. 5. Brake line actuator on test bench

The brake line actuators are critical units of the platform, so they have to be robust and have fail- safe features. One of the fail safe features is how these modules can manage the total power lost. If there is no power on actuators at all, the force developed on the brake lines can set the brake to its default position, in which the

platform is able to go back to ground gently and safely. Another fail-safe feature is managing the extreme high forces on brake lines. It can be developed by several reasons and several situations, but in normal flight. When over-force is developed on one of the brake lines, the brake line actuator automatically release the corresponding line to stabilize the movement of the paraglider and to reduce the brake force.

The 3D CAD plan of final version of the brake line actuator can be seen on Figure 6. Gear transmission has to be designed into the unit to ensure the fail-safe functions mentioned.

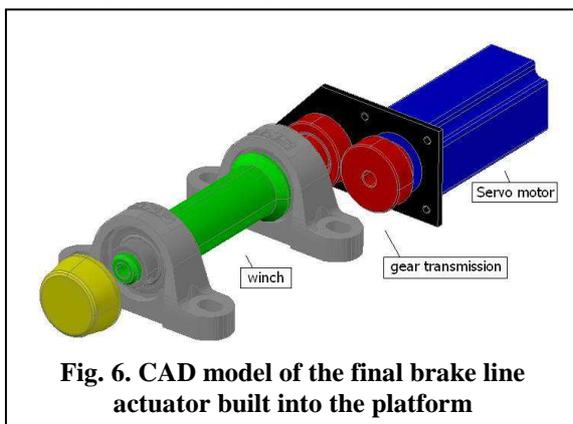


Fig. 6. CAD model of the final brake line actuator built into the platform

The avionics block is another important part of the platform.

It has two parts:

- Communication and Control Block (CCB)
- Scientific Measurement Block (SMB)

The first block listed is critically important for safe operation of the unmanned platform. The second one is only necessary for scientific measurements.

The CCB has its own shielded instrument case (it can be seen on Figure 7) to prevent electrical disturbance come from the propulsion unit (piston engine) and from the environment.

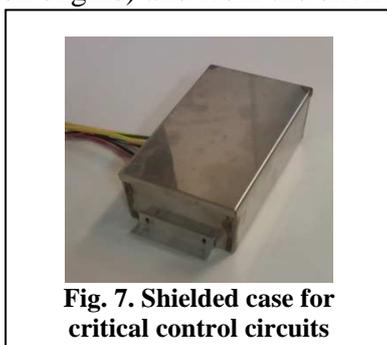


Fig. 7. Shielded case for critical control circuits

The CCB contains several individual circuits (units) with independent power supply for every single task.

It contains units as follows:

- Communication unit
- Brake line actuator control unit
- Propulsion control unit
- Logger unit
- Supervisor unit

These independent units communicate each other via CAN bus, which has developed to operate in electrically noisy environment. Although it is an automotive standard [14], it is widely spread in other applications like industrial and home automation as well as in aeronautical industry. The physical layer in the CAN standard is a twisted pair cable, with or without shield. All of the units realized with 8 bit microcontrollers, on Figure 8 the layout of this modular system can be seen.

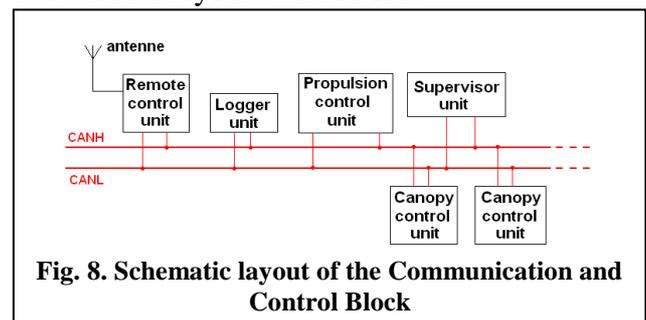


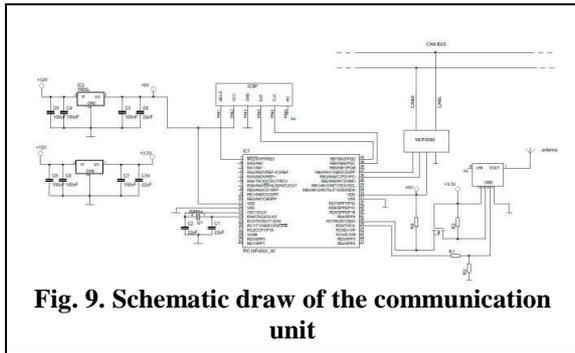
Fig. 8. Schematic layout of the Communication and Control Block

The main advantages of this layout are:

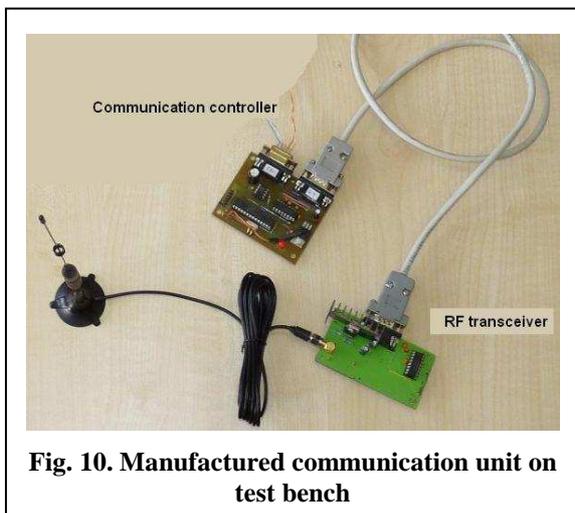
- distributed system, no central unit
- independent power supply for each unit
- easy to add/remove units
- easy to improve the individual units

3.3. The avionics block and communication unit

As mentioned the CCB is one of the two main parts of the avionics. This block is responsible for uninterrupted and robust control of the UAV. This block is also responsible for sending telemetry data back to the ground station, which are important for the pilot controls the UAV from longer distance.



The communication unit realizes the communication between the ground station and the UAV. On Figure 9 the schematic draw, on Figure 10 the manufactured unit can be seen.



This unit is based on PIC18F2580 microcontroller and RC-1280HP RF transceiver module. It can communicate with the ground station within 5 km on an ISM band frequency 868 MHz. The output power is 500 mW, the communication is based on the RC232 Embedded RF Protocol from Radiocraft [15]. This provides robust bidirectional wireless communication with data buffering, error checking and automatic retransmitting features. The communication module is in point-to-point topology with the ground station.

3.4 Ground station

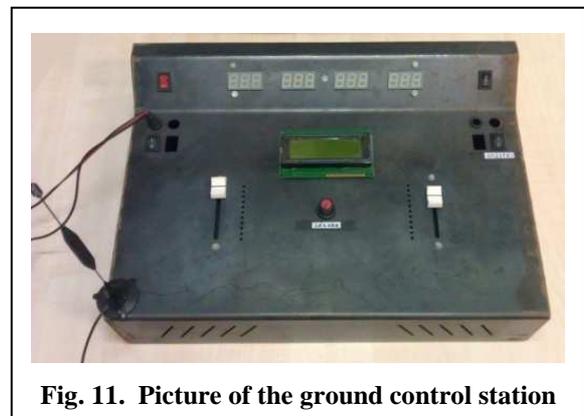
The ground station is used to control the UAV. The most basic functions are as follows:

- set the brake line positions
- set the thrust

- switch the engine off
- display some important telemetry data

This has built for robust control the UAV hence it has limited functions but it works without PC or any additional device. It is also possible that control the UAV from a PC through the ground station on RS-232 serial interface. In this case the ground station only transmits the data to the UAV and sends the data received to the PC.

One picture of the realized ground station can be seen on Figure 11.



It can be seen on the figure that there are 2 linear potentiometers on both side. It is used to set the brake line position absolutely. The potentiometer on the middle is used to set the throttle. Telemetry data are displayed on LED and LCD displays.

3.5 Brake line controller unit

The brake line controller units are one of the most critical units. They are responsible for the direct control of the left and right brake lines, so the state of these units is critical. These units have failsafe operation modes in which they can minimize the damage in the case of emergency landing even if the communication on the internal CAN bus is interrupted. On Figure 12 the layout of the communication can be seen.

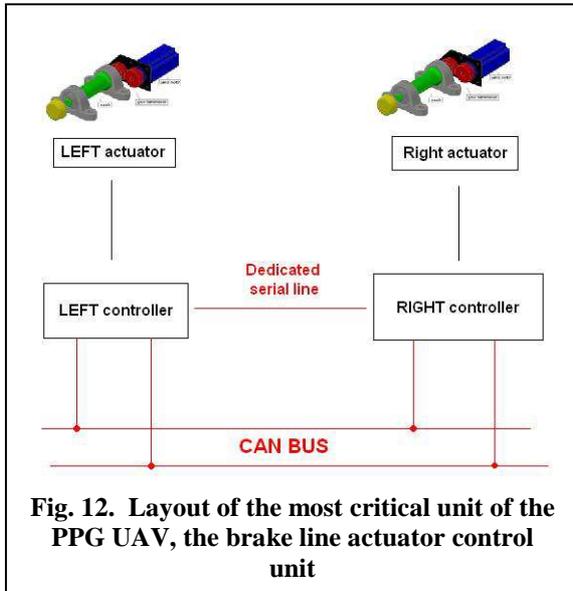


Fig. 12. Layout of the most critical unit of the PPG UAV, the brake line actuator control unit

To implement this failsafe function, left and right brake line actuator controller units have to communicate each other separately from the CAN bus. If the CAN bus is lost, units set the brake line position into a middle position in which the PPG UAV can gently glide back to the ground. If one of the actuator controller units goes out of work, the other sets its brake line continuously to the same position in order to keep the glider in stable straight flight. These functions require the communication between the left and right brake line actuator controller unit, this serves the purpose of the dedicated serial line, which can be also seen on Figure 12.

3.6 Propulsion control unit

This unit performs the control of the piston engine of the UAV.

It has several tasks:

- set the throttle to the correct position
- measure the engine rotating speed
- measure the temperature of the cylinder head
- cut off the ignition of the engine

The schematic draw of this unit can be seen on Figure 13. It is also based on PIC18F4580 microcontroller and has a built-in relay to switch the engine off. It measures the rotating speed based on optical measurement, the temperature measurement done by resistance thermometer.

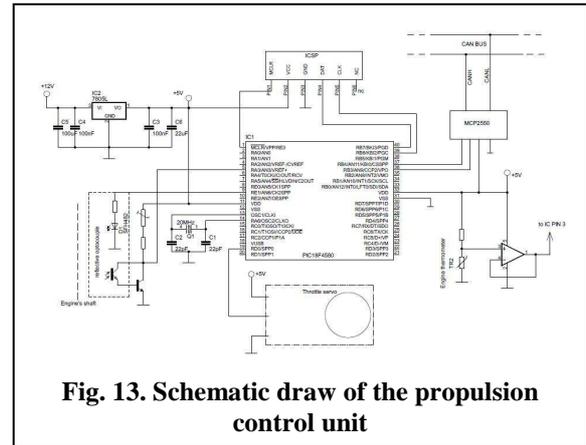


Fig. 13. Schematic draw of the propulsion control unit

The throttle can be set by a servo motor controlled and powered by this circuit. In the case of total power loss the built-in relay released and the engine ignition is cut. So in the worst case the engine stops and the PPG UAV can glide back to ground.

3.7 The logger unit

The logger unit logs every message transmitted on CAN bus. This activity is very important when system anomalies want to be investigated. The possibilities provided by data recorded by this unit:

- reconstruction of control and feedback data
- reconstruction of measured values of the units
- investigation of internal communication of units

The schematic draw of this unit can be seen on Figure 14 and 15. This unit is based on PIC18F2580 microcontroller, stores CAN bus travelled data on an SD card with virtually unlimited capacity. The data can be restored from the SD card on PC by custom software developed by us.

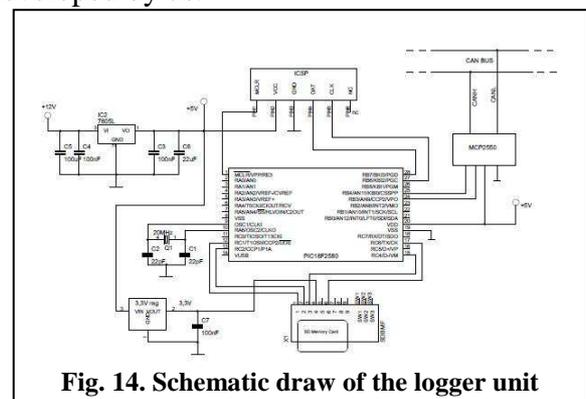


Fig. 14. Schematic draw of the logger unit

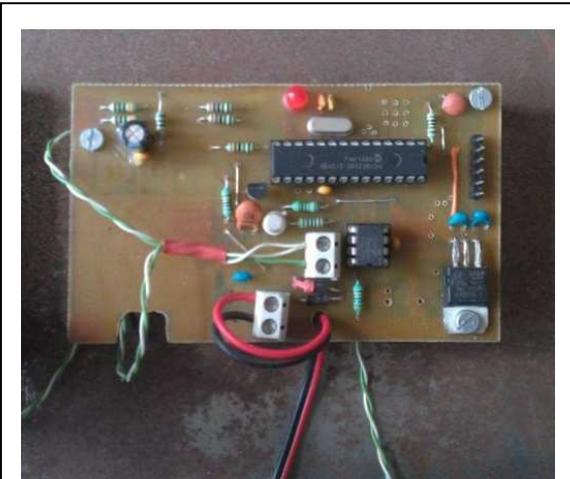


Fig. 15. Photo of the logger unit on test bench

Data are stored on SD card in raw form, no file system developed on it, which ensures the data security. All sectors on the SD card can be restored individually.

3.8 The supervisor unit

In order to make sure the system is in normal operation a separated unit has to be used. This unit supervises all other units by measuring the values as follow:

- voltage and current consumption of the units
- temperature of power elements

This unit continuously watches data traffic on CAN bus. In this way other abnormal operations can be detected. It can detect if a unit does not respond or sends abnormally number of messages. In these cases the supervisor unit can issue reset signal for the unit in question then if the problem cannot be solved, it can hold the unit in reset to prevent disturbance of CAN bus.

4. System testing

After tests of the separated units on test bench, the whole system has to be tested to investigate the system integrity. First tests were carried out with ground taxi tests, when mainly the control system was investigated. It is very crucial that the UAV can be controlled in all conditions.

The control system has tested in several aspects:

- The effect of piston engine on controllability

- The effect of heading of the UAV on the signal strength of radio link
- Range of the radio link

In the first case the effect of piston engine has been investigated. The engine generates several radio frequency disturbances into the environment. The control system could be disturbed by the running engine, so it is important to examine these conditions.

Three test cases are investigated:

- Piston engine switched
- Piston engine runs at idle
- Piston engine runs at half power

The operation of control system was monitored continuously while the engine was running. During these tests, the traffic on the CAN bus was recorded, the operation of the brake line actuators and the power and CAN bus signals were observed. Some electric noise could be seen on oscilloscope, but they have not disturbed the control system, all tests were completed successfully.

In second and third test cases the performance of radio communication link has been investigated. The basic questions are what the secure range of the radio link is and if there any effect of the heading of UAV on the range is. The answer for the first question is given by a simple distance test where the ground station and the UAV are carried away from each other.

The second question has come from the behaviour of the radio frequency used. The communication link established uses frequency 868 MHz. This frequency can be used free in the EU in low power and low duty cycle applications (ISM band). The spreading of radio wave in this frequency is straight line-like, so any object in line can decrease the range, hence when the fuselage of the UAV is in the line of radio antennas, it could decrease the range. So this effect has to be also investigated.

Based on these tests the secure range of the radio link has been determined for 3.2 km (~2 miles).

Tests proved the reliability of the control system, the UAV could be controlled in all conditions expected without any anomalies.

On Figure 16, 17 two pictures can be seen on the first take off of the PPG UAV. At the first fly it left the ground and climbed to 3-4

meters from the ground, then made a 90 deg turn, landed and stopped safely.



Fig. 16. First test fly of the PPG UAV



Fig. 17. First test fly of the PPG UAV

5. Conclusion

There is a special long term research program had been initiated by the Department of Aircraft and Ships at the Budapest University of Technology and Economics with goal: investigation and development of the small sport flying machines including hang gliders, paragliders, small and acrobatic aircraft. The project has got several national and international projects, like the "Development of the innovative safety technologies for a 4 seats composite aircraft - SafeFly" supported by Hungarian National Development Office and

Personal Plane - PPLANE Project supported by EU FP07 (Contract No - 233805) and the research is supported by the Hungarian National New Széchenyi Plan (TÁMOP-4.2.2/B-10/1-2010-0009).

This paper deals the development of a new test platform for investigation of the paragliders. The platform can be used for different purposes including the sensor and actuator validation, measuring the aerodynamic characteristics, study the flight dynamics, parameter and state estimation of the flight dynamic models, etc.

The paper had described the developed test platform including

- sensors and air data collection unit containing positioning, pressure and temperature sensors, MEMS based local force components/stress measuring sensors, etc.,
- control sub-systems as power and control forces' actuators and control unit,
- the info-communication system.

The platform is controlled by a robust, fail safe remote control system. This basic intelligent distributed control system consists the ground station, the radio link and propulsion and control forces' actuators.

The PPG UAV presented in this paper has take-off weight from 70 to 110 kg and can carry at least 15 kg payload, which can be any group of scientific instruments.

The first flight of the developed test platform has demonstrated the reaching the design abilities and possible using the system for the designed purposes. the results of the future measurements will be applied in a special PhD thesis about the developing a simulation model and of the powered paraglider and its identification ..

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