Flight Data Acquisition System for Small Unmanned Aerial Vehicles

Vladimir Brusov [1], Józef Grzybowski [2], and Vladimir Petruchik [1]
[1] Moscow Aviation Institute, Russia
[2] Rzeshow Technical University, Poland

Abstract

Flight investigations of aerodynamics and flight dynamics for micro-UAVs and mini-UAVs stimulate us to use automatic data acquisition systems to obtain valid estimations for UAV performances and characteristics. There exist many kinds of microprocessor-based and microcontroller-based data acquisition systems but all of them do not satisfy specific requirements of UAV flight tests. A Flight Data Acquisition System (FDAS) is suggested to provide support for flight data gathering and registration processes. This FDAS consists of microcontroller-based flight data recorder equipped with SD/MMC memory card to store experimental data, set of sensors to measure UAV flight parameters and software utility providing experiment planning, processing and visualizations of recorded data. Some examples related to UAV flight tests are presented and discussed to demonstrate features of the proposed approach.

1 Introduction

Flight investigations of aerodynamics and flight dynamics for small UAVs demand usage of automatic data acquisition systems to support valid estimation of UAV aerodynamic and flight performances. There exist many kinds of microprocessor-based data acquisition systems but all of them do not satisfy specific requirements of UAV flight tests.

Investigation of aerodynamic and flight performances for small UAVs is rather complicated problem because of severe dimensions, mass and power restrictions for a Flight Data Acquisition System (FDAS) needed to support flight data gathering and registration [1], [7]–[9]. Another difficult problem is a selection of composition and placement for FDAS sensors.

A programmable micro-controller unit (MCU) based flight data recorder (FDR) is the main component of the FDAS. The FDR is intended to measure and record analog voltage signals incoming from sensors and converters dealing with various physical quantities. The PRP-J5 recorder described in the paper is based on the PRP-J1 type of FDR developed and tested earlier. The tests of PRP-J1 device had revealed necessity of real-time verification for measured and recorded data. In addition we use plug-in memory card to provide quick and convenient data reading from the card outside of FDR. In addition plug-in FDR data memory allows preprogramming of flight experiment schedules to enhance efficiency of flight tests.

2 Description and Performances of the Flight Data Acquisition System

The FDAS is composed of several units including MCU-based flight data recorder (FDR) equipped with flash card external memory, card reader to transfer recorded data from the memory card into memory of personal computer, software to manage measurements and to process obtained experimental data, storage battery, gyroscopic motion sensor card, linear accelerometer card, pressure sensor card, voltage stabilizer to supply external devices, temperature sensor card and three converter cards to transform remote control radio commands into voltage signal for recording with FDR.

The PRP-J5 allows us to register up to 24 UAV flight parameters. An SD/MMC flash memory card is used as plug-in recording media in the FDR.

Figure 1: PRP-J5 flight data recorder placed into container housing.

An acquisition of values for needed physical quantities is carried out using such devices as:

- integrated Motorola MPX4115A and Freescale Semiconductor MPX7007 absolute and differential pressure sensors to measure velocity and barometric altitude values [2, 3];

[1] E-mail: vsb@mai.ru
[1] E-mail: jozef.grzybowski@pilc.pl

- high performance STMicroelectronics LIS344ALH 3-axis linear accelerometer to measure accelerations along UAV body axes [4];
- two STMicroelectronics LPY530AL dual axis analog gyroscopes to measure angular velocities around UAV body axes [5];
- deflection sensors for UAV control surfaces implemented through conversion of PWM (Pulse Width Modulator) command signal obtained from remote radio control unit.

Block diagram of the Flight Data Acquisition System is presented on Figure 4.

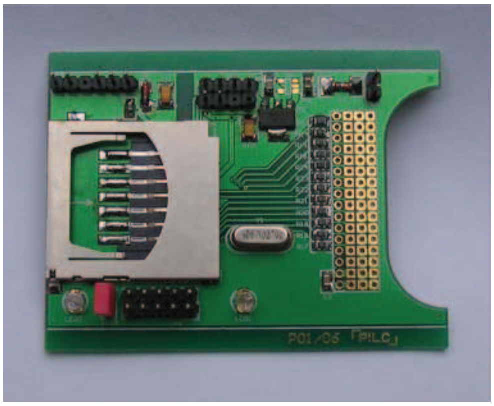

Figure 2: Flash card side of the FDR board.

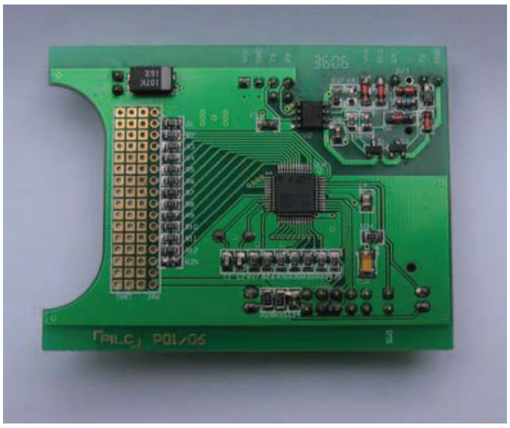

Figure 3: MCU side of the FDR board.

The described FDR is characterized by following features:

- input signals – 24 programmable external analog inputs, ADC with 12-bit resolution, programmable amplifier gains of 16, 8, 4, 2, 1, and 0.5 for each channel;
- memory – plug-in SD/MMC memory card with capacity up to 512 MB;
- measurement/recording frequency – programmable time intervals (1 ms, 5 ms, 10 ms, 50 ms, 100 ms, 200 ms, 500 ms, 1 s, 5 s, 60 s) for each channel;
- reading of recorded data – with SD/MMC PC-connected card reader;
- power supply – Li-Po battery or DC source with 4.5-12 V voltage and 20 mA maximum operating current;
- dimensions – 57 x 37 x 9 mm;
- weight – 17 g without container housing and battery.

3 MICRICONTROLLER BASED CORE OF THE FDAS

Flight data acquisition system presented in the paper is based on the C8051F206 micro-controller unit of the Silicon Laboratories C805F2xx family [6], which is a family of fully integrated, mixed-signal System on a Chip MCUs. The C8051F206 is available with a true 12-bit multi-channel ADC. It features an 8051-compatible microcontroller core with 8 kbytes of flash memory. There are also UART and SPI serial interfaces implemented in hardware. The C8051Fxxx family matches well to build systems with high throughput and low power consumption providing high-precision measurement and recording of experimental data. The C8051F206 microcontroller of this family was chosen for PRP-J5 FDR because it allows us to use SD/MMC card as an external memory for experimental data recording.

On-board JTAG debug support allows non-intrusive (uses no on-chip resources), full-speed, in-circuit debug using the production MCU installed in the final application. This debug system supports inspection and modification за memory and registers, setting breakpoints, watchpoints, single steppings, run and halt commands. All FDAS peripherals are fully functional when emulating using JTAG.

The C8051F206 microcontroller used as the FDAS core has following features:

- high speed 8051 microcontroller core – pipelined instruction architecture; executes 70% of instructions in 1 or 2 system clocks; up to 25 MIPS throughput with 25 MHz clock; expanded interrupt handler; up to 22 interrupt sources;
- memory – 256 bytes internal data RAM; 1024 Bytes extended data RAM; 8k bytes FLASH, in-system programmable in 512 bytes sectors;
- analog peripherals – 12/8-bit resolution; up to 100 ksps; up to 32 channel input multiplexer, each port I/O pin can be an ADC input; programmable amplifier gains of 16, 8, 4, 2, 1, and 0.5 for each channel; two comparators (16 programmable hysteresis states; configurable to generate interrupts or reset);
- digital peripherals – 32 port I/O, all are 5 V tolerant; hardware SPI and UART serial ports available concurrently; three 16-bit counter/timers; dedicated watch-dog timer; bi-directional reset;
- clock resources – internal programmable oscillator, 2-to16 MHz; external oscillator (crystal, RC, C, or clock); can switch between clock sources on-the-fly;
- on-chip JTAG debug – on-chip debug circuitry facilitates full speed, non-intrusive in-system debug; provides breakpoints, single stepping, watchpoints, stack monitor; inspect/modify memory and registers;
- supply voltage is 2.7V to 3.6V, typical operating current is 9 mA at 25MHz, and 0.1 μA at sleep mode;
- temperature range is from –40^0C to +80^0C.

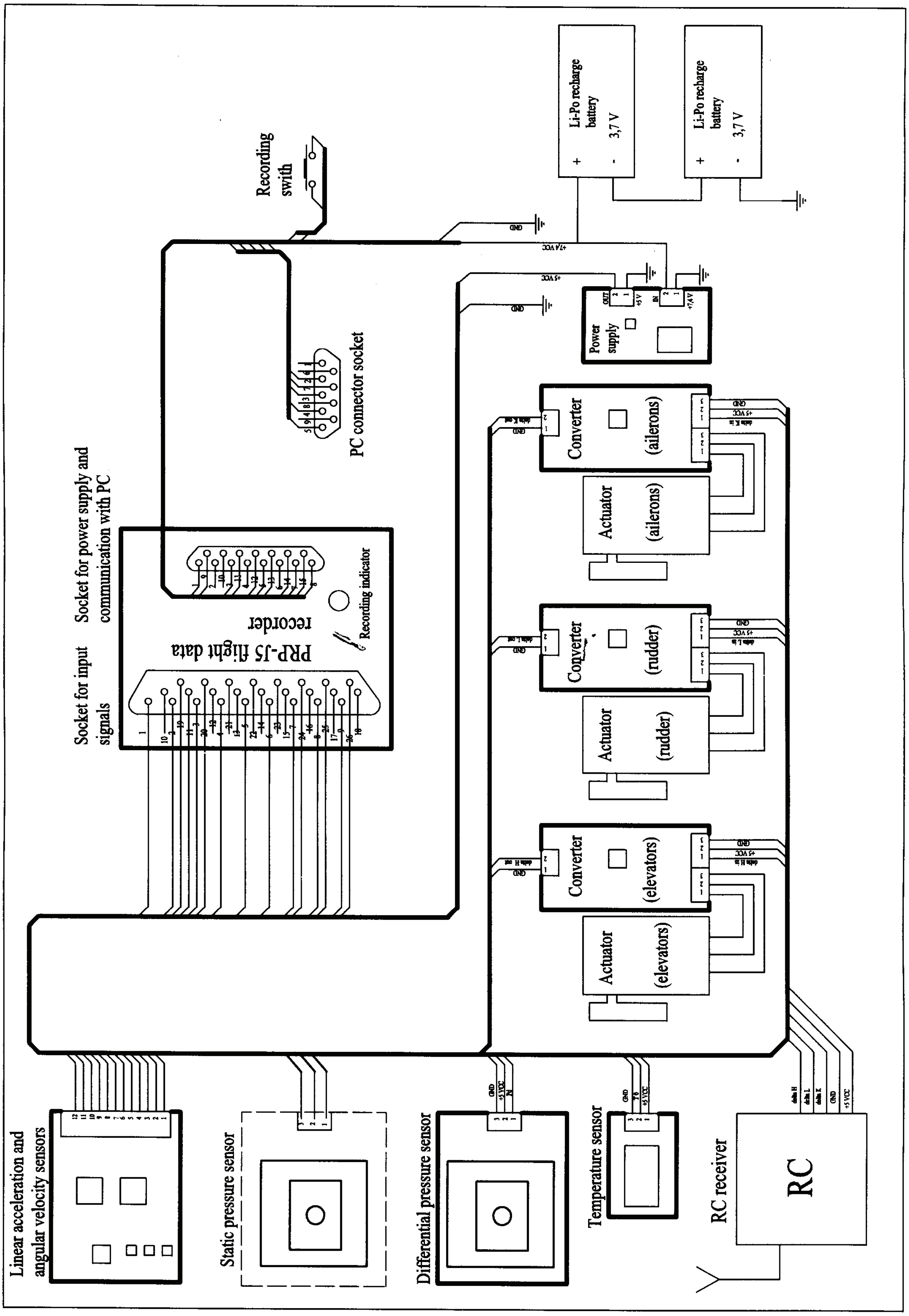

Figure 4: General block diagram of the Flight Data Acquisition System.

4 SOFTWARE USED TO MANAGE FLIGHT DATA ACQUISITION WITH FDAS

Management of measurement and recording processes for UAV flight data is implemented using a configuration file. This file is generated by means of PC-running utility program and it is stored in flash memory card pulled into FDR socket. The utility program allows us to perform such operations as setting of parameter values to handle data acquisition, to read experimental data recorded on the SD/MMC memory card, and to convert source (raw) data into appropriate text and graphical format.

Screenshots presented on Figures from 5 through 7 demonstrate usage of the FDAS software.

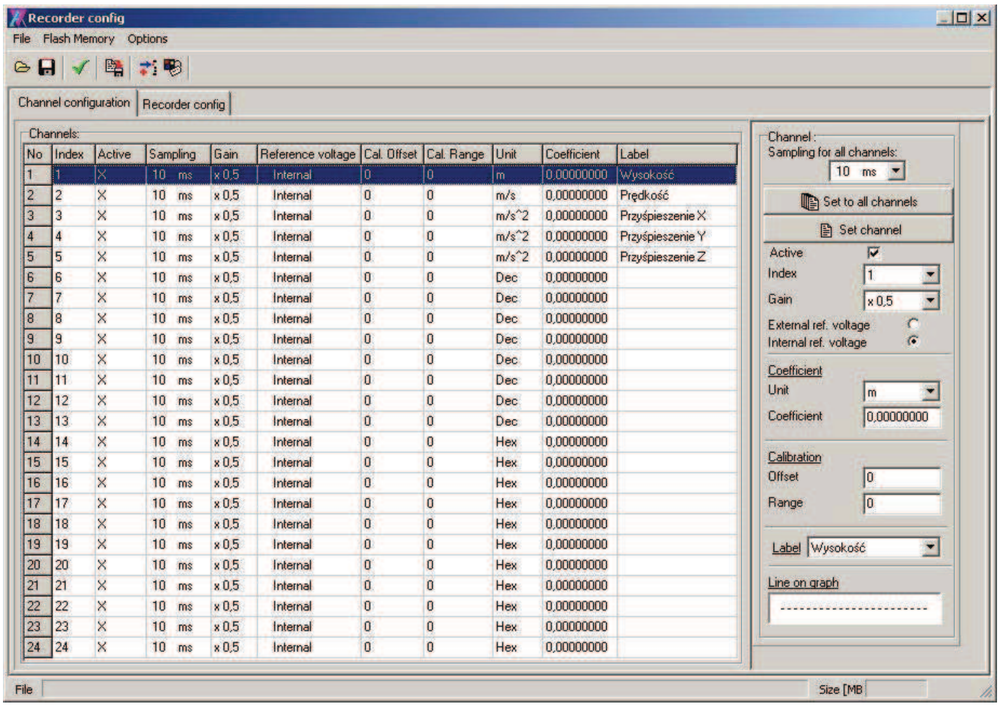

Figure 5: Adjustment window for parameters of recording channels.

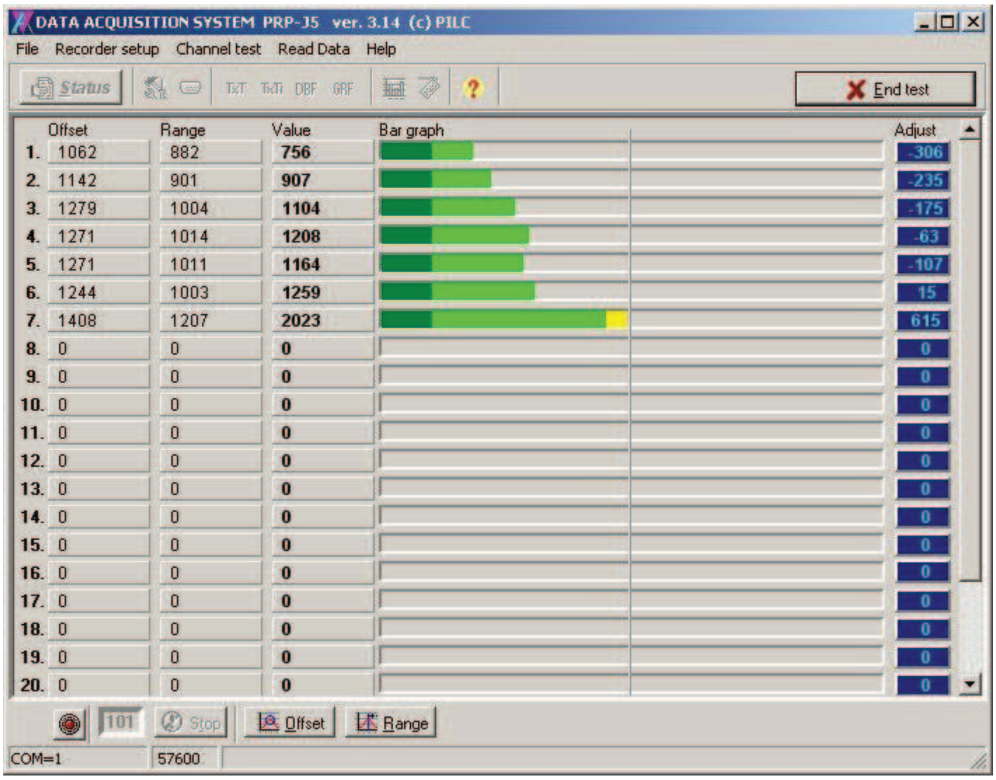

Figure 6: Range adjustment for measured UAV flight parameters.

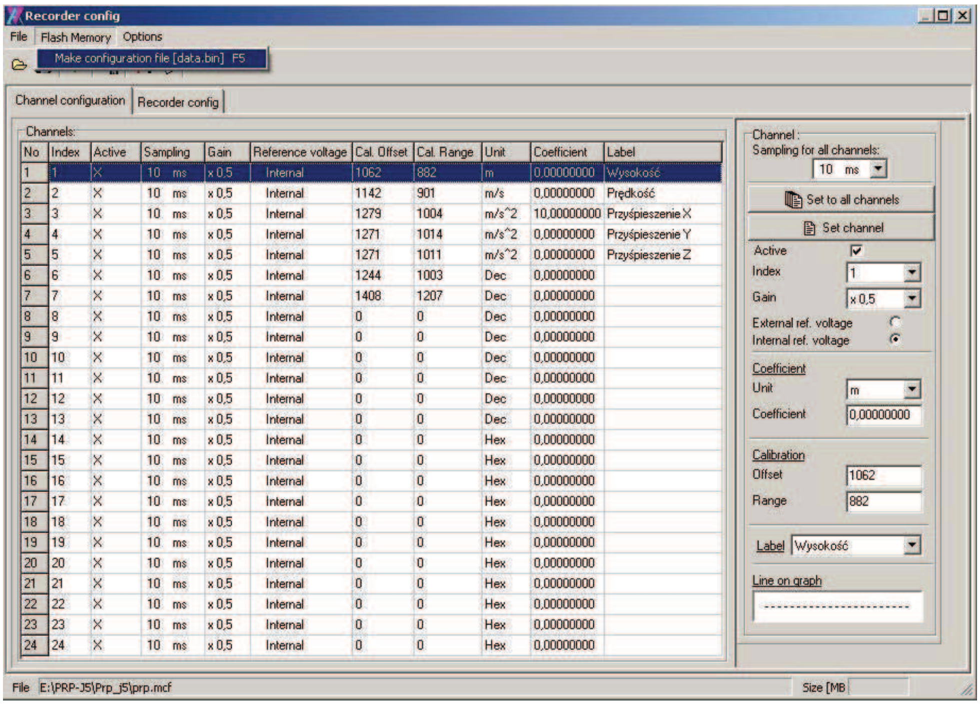

Figure 7: Generation of file with experimental data.

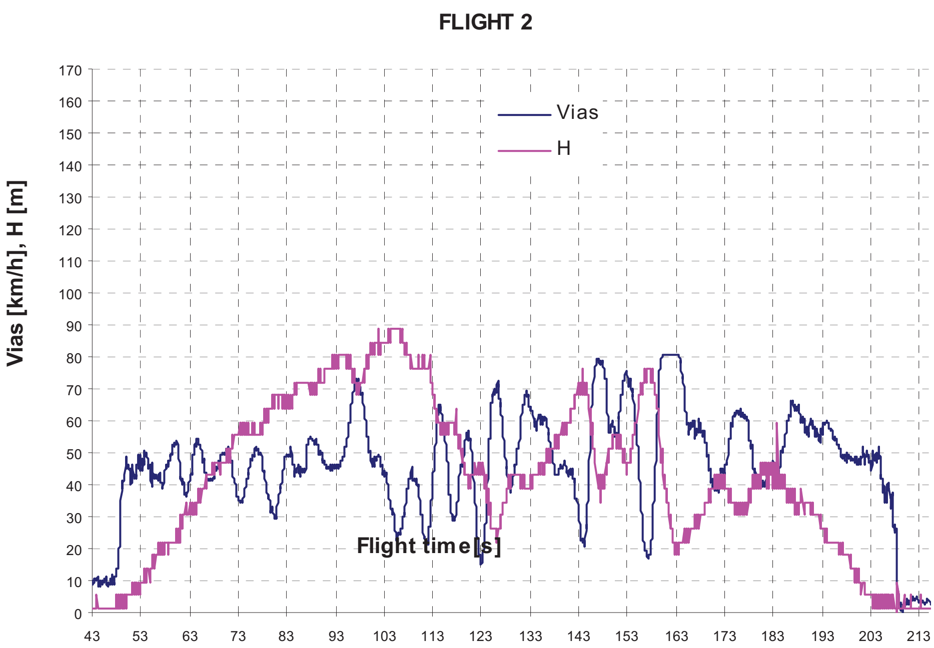

Figure 8: Micro-UAV altitude and airspeed registered in a flight test.

Flight data recording is started by means of FDR power switch on. The recording process is terminated with power switch off then SD/MMC card is pulled out of FDR and is processed off-line with PC to process and visualize obtained experimental data.

Flight test results are presented on Figures 8 and 9 as an example of acquisition and visualization of micro-UAV flight data.

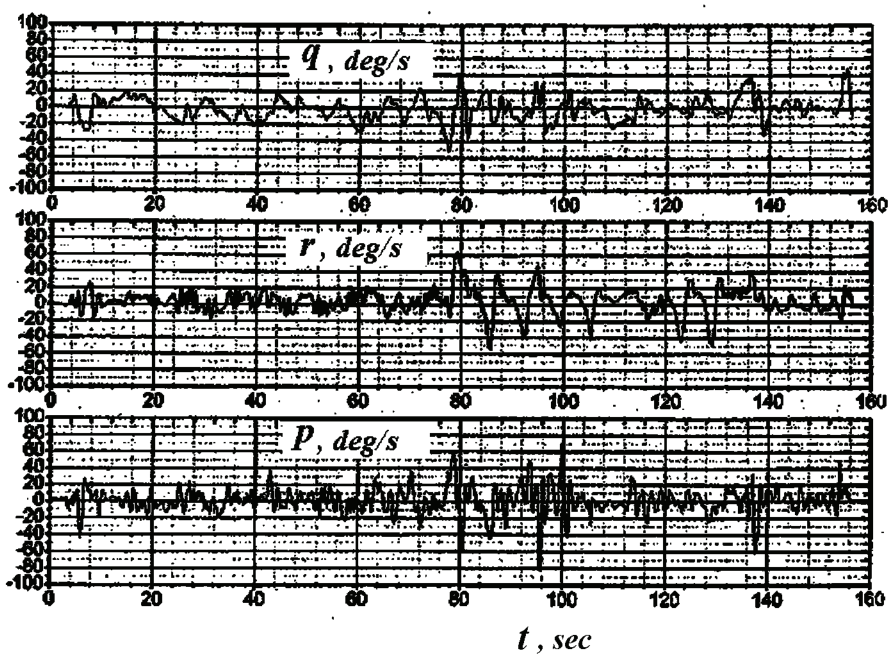

Figure 9: Micro-UAV angular velocities registered in a flight test.

5 Conclusion

1. The MCU-based automatic data acquisition system (FDAS) is developed and tested to record flight parameter values for small UAVs.

2. Flight Data Recorder as the main part of FDAS has small dimensions (57 x 37 x 9 mm) and weight (17 g without FDR case and battery).

3. If appropriate sensors are available then the FDR provides recording up to 24 flight parameters of a small UAV using a memory card as well as reading of the recorded data on a personal computer and visualization of the measured data.

4. The FDAS discussed in the paper is equipped with such kind of sensors as:

- absolute and differential pressure sensors to measure air speed and barometric altitude values;
- three-axis linear accelerometer to measure accelerations along UAV body axes;
- two dual axis analog gyroscopes to measure angular velocities around UAV body axes.

5. The FDR can also record angle of attack and sideslip values if appropriate sensors are in the FDAS.

6. Recording of deflection angles for UAV control surfaces (elevator, rudder, ailerons) is carried out trough conversion of autopilot control signal or remote radio control pulse signal into analog signals. Three conversion units is used in the FDAS for elevator, rudder and ailerons channel.

7. Innovation of the described FDAC system is to record configuration parameters in the same file as the recorded data. While making experiments it allows us to configure the system very quickly, by inserting an appropriate programmed SD memory card. Working ON-LINE allows to load initial values from the sensors and calibrate their offset and gain, which are then credited to the configuration file on some SD card data. This increases the system modularity and allows us to install other sensors to perform different measurement tasks.

8. The FDAS can be used not only for flight tests but to support wind tunnel tests of real micro-UAVs [10].

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