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EXPERIMENTAL UNMANNED AERIAL VEHICLE FLIGHT DATA MEASUREMENT AND THEIR POST-PROCESSING ANALYSIS

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Abstract. *In the article the flight data measurement and transmission to the ground control station for further decoding and post-processing are described. The article demonstrates the developed flight data processing and visualization tool with its operation algorithm. Some possible options of the tool such as trajectory displaying in the three-dimensional coordinates, using Google Earth satellite mapping and arbitrary combining graphs of unmanned aerial vehicles real flight parameters with their explanation were represented.*

Keywords: Bytes Distribution; Data Processing and Visualization Tool; Flight Data Transmission; Narrow-Band Modem; Unmanned Aerial Vehicle.

1. Introduction

Testing of the onboard control system of unmanned aerial vehicles (UAVs), including the verification of the autopilot servo systems parameters, requires ground documentation of all flight data through the reverse radio channel [1, 2].

Using a reverse radio channel (or two-way radio) with the ground documenting the flow of data ensures the playback of events in flight, regardless of the subsequent state of the UAV.

On the other hand, the reverse radio channel loads a board and the power supply system additionally, and requires attention to the board equipment Electromagnetic Compatibility (EMC).

At a constant power level of the telemetry channel, and other constant conditions, a narrow-band radio channel provides a gain in the range due to the lower noise spectral band of the receivers and less interference to the other on-board equipment.

The purpose of the article is development and presentation of flight data measurement, encoding for transmission to the ground control station and further decoding for the post processing and flight analysis.

2. Flight data structuring and encoding description

With regard to the previous, the system in question provides data transmission in narrow-bandwidth mode — with an update rate of 1 Hz and a transmission rate 910 bit/s.

Used radio modem, with a rate of 1200 bit/s, provides high sensitivity –118...–120 dBm due to the minimal noise band of the radio receiver.

For the transmission and reception of UAV flight data, a set of parameters was selected according to the Table. Encoding format of the monitored parameters values are mainly selected on the basis, first published in [1] — each parameter is allocated one or two bytes with rough positioning allocated space in the transmitted data package.

For further economy such parameters as flight control mode, the refresh rate, the frequency of exchange are transmitted within one byte. For the accurate transmission of coordinates (longitude and latitude) 4 bytes for each is used (the total is 8 bytes).

Each group of data is transferred under a separate heading after the identifier of the group beginning; the overhead bytes transmit the number of bytes in the group, checksum and data termination mark (Fig.1).

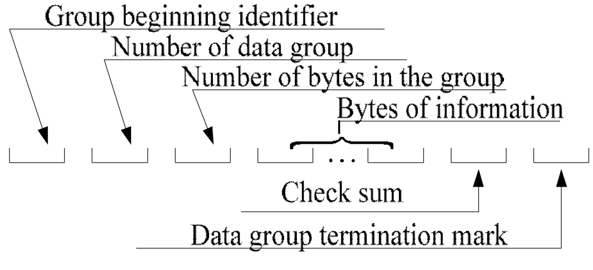

Fig.1. Bytes distribution in the data group

Grouping and composition of the transmission parameters

Parameter	Size, bytes	Clarification	Note
Positioning			
Current coordinates	8	WGS	One low bit corresponds to 0.006 acres
GPS current course angle	2	–	One low bit corresponds to 0.01 degrees
GPS current speed	2	0 …120 м/s	One low bit corresponds to 0,1 м/s
GPS current altitude	2	0 … 3000 м	–
Azimuth deviation	2	0 …1000 м	–
Attitude error	1	0 …1000 м	–
Orientation and Management			
Roll angle	2	+ — 90 deg	Attitude value
Pitch angle	2	+ — 90 deg	Attitude value
Throttle PWM command	2	1000 … 2000	Servomotor control signal
Aileron PWM command	2	1000 … 2000	Servomotor control signal
Elevator PWM command	2	1000 … 2000	Servomotor control signal
Rudder PWM command	2	1000 … 2000	Servomotor control signal
Flight mode and data exchange			
Control mode	1	Contains several different parameters of flying control mode	–
Type of Trajectory	1		
GPS refresh rate	1	Contains several different parameters of data refreshing frequency	–
Attitude data refresh rate	1		–
Data link refresh rate	1		–
Navigation Parameters			
Current target course angle	2	+ — 90 deg	–
Current target altitude	2	0…3000 м	–
Current target speed	2	0…120 м/s	One low bit corresponds to 0,1 м/s
Coordinates of current trajectory starting point	8	WGS	–
Coordinates of current trajectory final point	8	WGS	–
Power and Temperature			
Power battery voltage	2	–	One low bit corresponds to 0,1 V
Control battery voltage	1	–	
Power current	2	0 … 60 A	–
Power consumption	2	0 … 65 000 mAh	–
Current inner temperature	1	-40… +120 C	–

A typical flight task for UAV control system testing includes UAV placing on the flight mission trajectory in the manual mode, transfer to the automatic flight by specified points and landing in the manual mode with the stabilizer on the roll and pitch.

Automatic flight was carried out in straight lines connecting the points with a given coordinates [3], with the transition to a new site by the rule of "Fly by" on the basis of the given constraints on the minimum turning radius.

A telemetry data stream at the ground control station received from the board is divided into three areas: the visual display of the artificial horizon indicators, mapping of parameters in the form of graphs, data logging to a file for the further analysis [2].

3. Flight data processing and visualization tool

The central processing and flight data analysis unit of the program is a decoding block of the received data according to the Table.

The decoded data are represented in the form of graphs of parameters depending on time. Flight data processing and visualization tool operation algorithm is represented in Fig. 2.

Additionally it is possible to display the trajectory in the three-dimensional coordinates, using Google Earth satellite mapping; to perform statistical processing (moving average, variance, drift, harmonic analysis of periodic components) [4].

During the development of the tool user interface (Fig. 3) it was focused on the possibility of combining arbitrary graphs of different parameters.

For this purpose, the window of parameters to be displayed and the label over time is assigned.

When you run the flight data analysis tool the recording data file to be processed, the file of gridded map, cartographic representation and composition of the output parameters should be pre-selected.

The user can interactively change the parameters composition, using a label over time that appears on all the graphs.

Fig 4, 5, 6 show the examples of telemetry data presentation with events decoding in the course of the flight program.

The flight program lasting about 400 s provided climb in manual mode, the automatic flight path of “eight”, automatic flying in a circle with the center coinciding with the "eight" and landing in manual mode with the stabilizer on the roll and pitch.

4. Conclusions

Mastered transmission technology and visual representation of UAV flight enables the analysis of vehicle evolution with random assignment of investigated parameters.

Combined graphics of the controls position and graphics of the angular orientation provides verification and correction of UAV tracking systems coefficients.

For the flight parameters transmission from board to the ground control station, the narrowband radio transmission with 1.2 kbit/s transfer rate is used.

The proposed tool allows to recover the parameters of the experimental flights even if UAV was lost that is accompanied by a loss of on-board memory data.

Performed series of measurements listed in Table allowed to estimate the maximum speed range of UAV, the maximum angle of attack, performance maneuverability and adjusting the automatic control system.

The accelerated cycle of experiments is achieved without a stage of blowing in the wind tunnel.

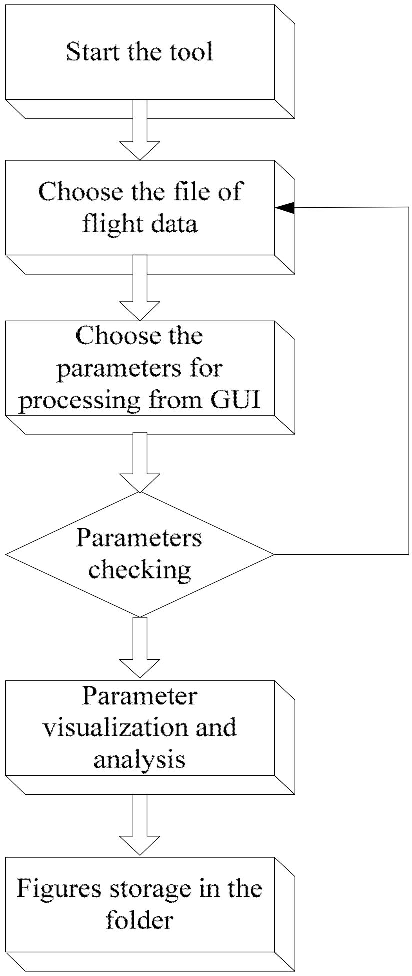

Fig. 2. Flight data processing and visualization tool operation algorithm

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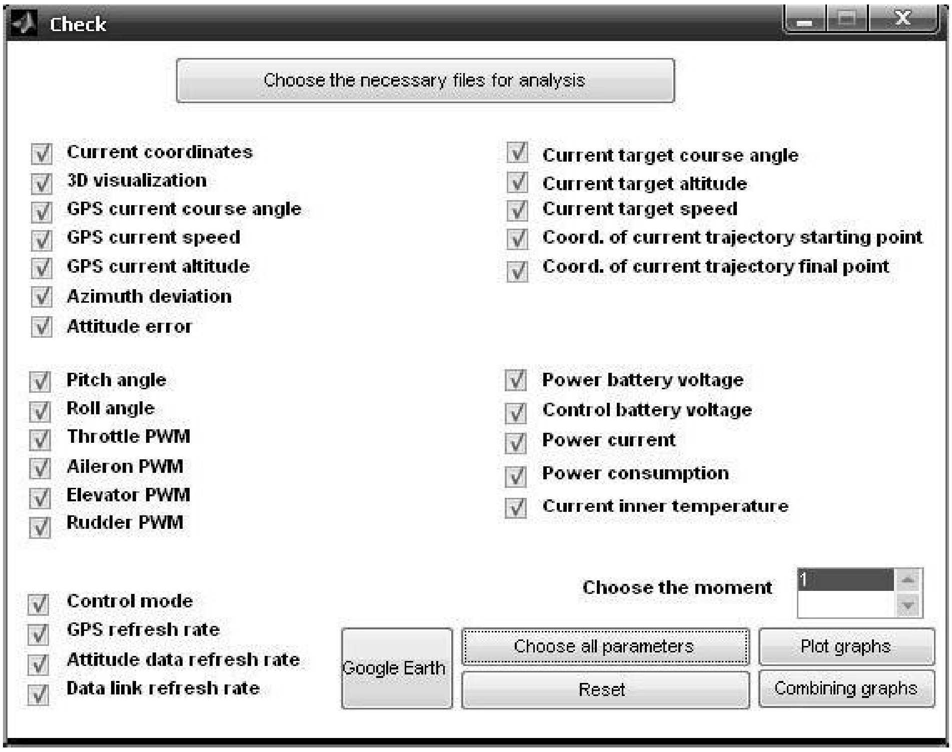
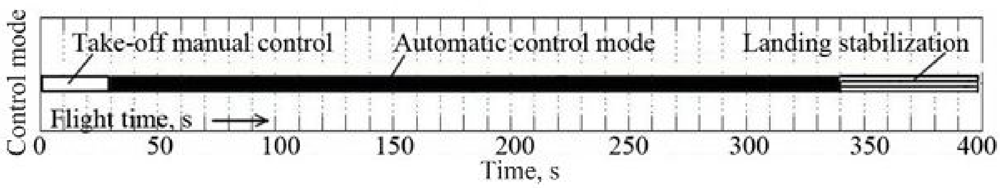
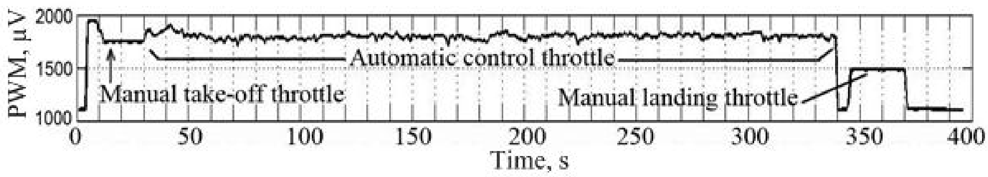


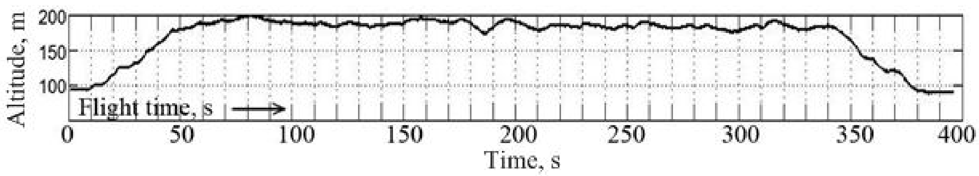
Fig. 3. Flight data processing and visualization tool user interface



a



b



c

Fig.4. Combined graphs of control mode, throttle and altitude:
a – control mode;
b – throttle PWM command;
c – GPS current altitude

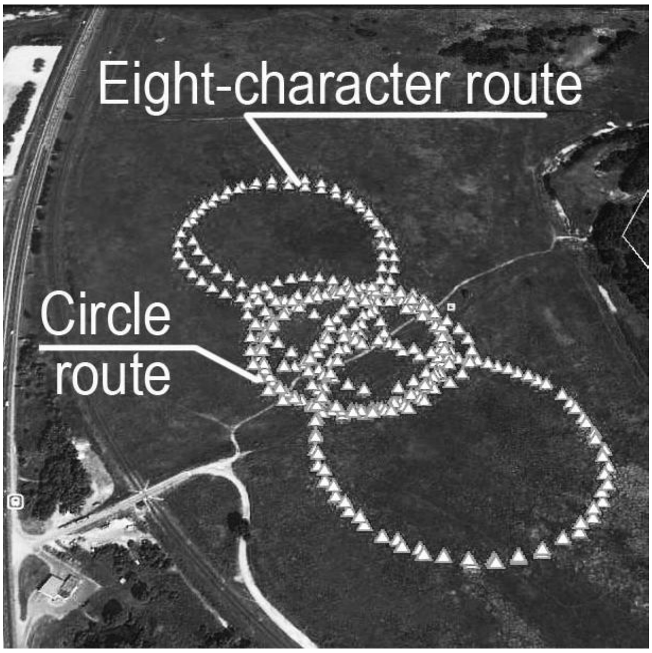


Fig. 5. The flight path using Google Earth

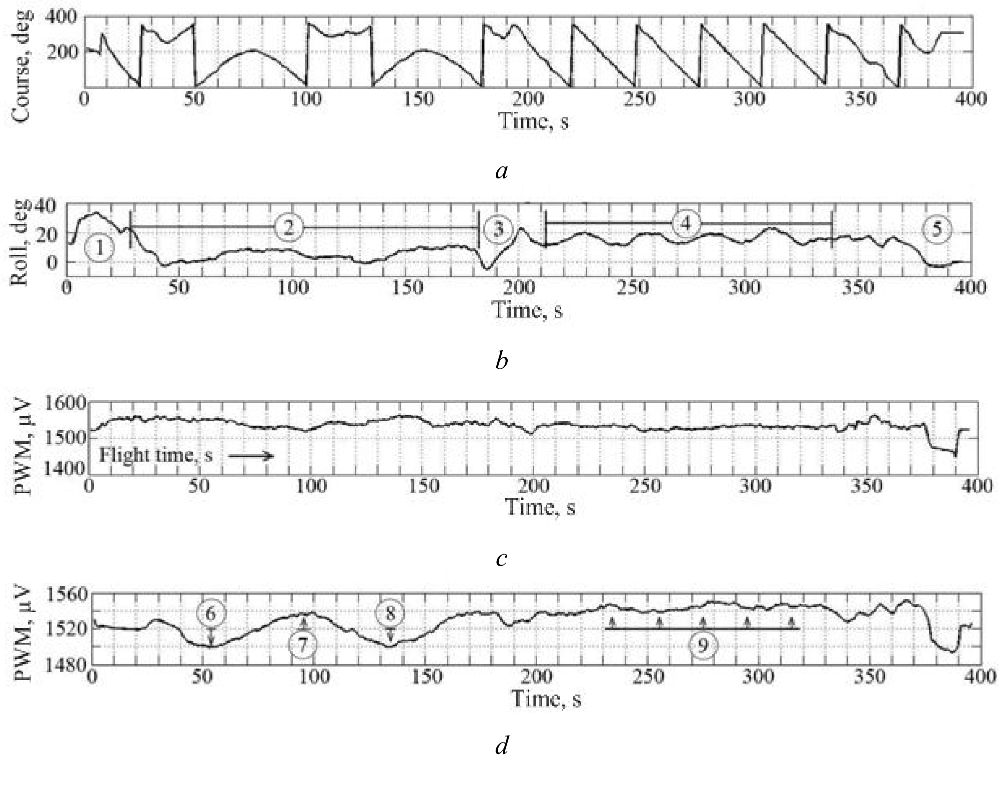


Fig. 6. Combined graphs of course, roll, aileron and rudder position:

a – GPS current course angle;
b – Roll angle;
c – Aileron PWM command;
d – Rudder PWM command;

1 – take-off area in the manual mode;
2 – two cycles of flight over a closed "eight";
3 – automatic switches to the trajectory of the circle;
4 – flying in a circle, four cycles;

5 – landing;
6, 7, 8 – rudder direction to the different branches of the "eight" trajectory;
9 – rudder allows movement in a circle

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В.П. Харченко[1], Н. С. Кузьменко[2], О. Ю. Михацький[3], О.В. Савченко[4]. Експериментальні вимірювання польотних даних безпілотного літального апарату та їх післяпольотна обробка
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Розглянуто питання розробки систем автоматизованого керування польотом безпілотного літального апарату, а саме вимірювання польотних даних, їх кодування для передачі на наземну станцію керування та подальшого декодування з метою післяпольотного аналізу. Запропоновано спосіб структурування та кодування даних, покладений в основу розробки власного програмного продукту обробки і візуалізації польотних даних безпілотного літального апарату. Декодовані дані подано програмним продуктом у вигляді графіків зміни параметрів залежно від часу. Показано додаткову можливість відображення траєкторії в тривимірному просторі з використанням супутникової картографії Google Earth. При розробці інтерфейсу програмного продукту особливу увагу приділено можливості довільного суміщення графіків різних параметрів. Описано вікно призначення відображуваних параметрів і часова мітка, яка з'являється у всіх графічних відображеннях.
Ключові слова: безпілотний літальний апарат; вузькополосний модем; передача польотних даних; програмний продукт обробки та візуалізації даних розподіл байтів.

В.П. Харченко[1], Н.С. Кузьменко[2], А.Ю. Михацкий[3], А.В. Савченко[4]. Экспериментальные измерения полетных данных беспилотного летательного аппарата и их послеполетная обработка
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Рассмотрены вопросы разработки систем автоматизированного управления полетом беспилотного летательного аппарата, а именно измерение полетных данных, их кодирование для передачи на наземную станцию управления и дальнейшего декодирования с целью послеполетного анализа. Предложен способ структурирования и кодирования данных, положенный в основу разработки собственного программного продукта обработки и визуализации полетных данных беспилотного летательного аппарата. Декодируемые данные представлены программным продуктом в виде графиков изменения параметров в зависимости от времени. Показана дополнительная возможность отображения траектории в трехмерном пространстве с использованием спутниковой картографии Google Earth. При разработке интерфейса программного продукта особое внимание уделено возможности произвольного совмещения графиков различных параметров. Описаны окно назначения отображаемых параметров и временная метка, которая появляется во всех графических отображениях.
Ключевые слова: беспилотный летательный аппарат; передача полетных данных; программный продукт обработки и визуализации данных; распределение байтов; узкополосный модем.

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