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[1]O. A. Sushchenko,
[2]V. O. Golitsyn

DATA PROCESSING OF BAROMETRIC ALTIMETER

Educational and Research Institute of Air Navigation, National Aviation University, Kyiv, Ukraine
E-mails: [1]sushoa@ukr.net, [2]vova.gol@ukr.net

Abstract*—The paper deals with features of measurement of an altitude for unmanned aerial vehicles. Analysis of altitude sensors characteristics and the grounded choice of the low cost barometric altimeter is carried out. The procedure of data processing is developed. Filtration of data by means of the Butterwort filter is carried out. Simulation results prove efficiency of the developed procedure of data processing.*

Index Terms—Unmanned aerial vehicles; barometric altimiter; optimal filtration, data processing.

I. INTRODUCTION

Nowadays development of unmanned aerial vehicles (UAVs) is the perspective trend of air navigation development. Unmanned aerial vehicles of the multirotor type are of great interest for such applications as the aerial photography and aerial survey, and also monitoring of environments parameters. Small dimensions of such UAVs provide the possibility to perform flights in conditions of the restricted space and in places, which are dangerous for human life. Therefore, the basic trend of the multirotor UAV is increase of flight autonomy. This improves reliability and usability of UAV and decreases cost of its maintenance and design [1]. To solve problems of UAV control it is necessary to implement storage, processing and analysis of information about flight parameters. These tasks must be solved from the point of view of providing accurate and reliable measurements and flight safety.

II. PROBLEM STATEMENT

The problem is a choice of the altitude sensor, which can be effectively used on the above stated UAVs operating at comparatively low altitudes. Nevertheless this sensor must provide sufficient accuracy of the navigation processes and be sufficiently low cost and serviceable.

To improve accuracy the filtration can be used. In contrast to Kalman filtering it is desirable to develop a simple filter, which provides the high speed of operation and does not require using prior information about sensor errors. It is known that the Kalman filter has such disadvantages as the low capacity and the high sensitivity to inaccuracy of statistical characteristics of measuring channels. Covariance matrices of measuring errors influence on accuracy of data processing during Kalman filtering. As a rule, parameters of these matrices are chosen based on prior data obtained empirically and, therefore, required statistical tests. In many practical situations such a problem becomes very difficult because, in order to solve it, additional equipment, development of test methods etc., are required.

The problem is creation of a procedure for altitude and pressure measurement and improvement of measurement accuracy by means of filtration using simple filters based on sufficiently easy design procedure. The proposed technical solutions can be implemented in the computing unit by means of programs.

III. REVIEW

General principles of UAV control system implementation are represented in [1]. Structure of the control system and the grounded choice of its components are given in this paper. But data processing of altitude sensor is based on Kalman filtering with all the above stated difficulties in its implementation.

Characteristics of altitude sensors are given in many papers and textbooks including [2], [3], where one of the most widespread modern altitude sensors is described. The basic stages of filters design are given in [4]. The textbook gives useful recommendations for construction of filter with infinite and finite characteristics by means of Matlab.

IV. CHOICE OF ALTITUDE SENSOR

Flight autonomy can be provided by a miniature control system, which includes such basic components as microcontroller, accelerometers, gyroscopes, magnetometer, and pressure sensor [1]. The microcontroller provides execution of such functions as connection with peripherals, drivers and control algorithm, which implements stabilization and navigation of UAV.

A good choice of the altitude and temperature sensor for UAVs is BMP085 [2]. Such a sensor belongs to the new generation of high-precision digital sensors of the absolute atmosphere pressure. The sensor provides the low error of altitude measurement (0.25 m). It has the high time of transformation of information. The interface I^2C simplifies the operating integration with the micro-controller.

BMP085 is designed by the piezoresistive technology. This provides its high reliability, accuracy, linearity and long-term stability. The output information of this sensor is data about barometric pressure, and temperature of the ambient air [2], [3].

The typical BMP085 applications are CPS-navigators, barometrical measurement of altitude and navigation of UAVs. The sensor consists of piezoresistive sensor, analog-digital-converter, and control unit. The sensor is calibrated and has embedded system of temperature compensation [3].

The sensor can operate in the following modes [2]:

– the mode of the reduced power consumption;
– the standard mode;
– the mode of the high resolution;
– the mode of the ultra-high resolution.

Characteristics of these modes are given in Table I [2].

TABLE I

CALCULATION MODES

Mode	**Transformation time, ms**	**Mean current, mkA**	**Root-mean-square value of noise, hPa**	**Root-mean-square value, m**
Reduced power consumption	4.5	3	0.06	0.5
Standard	7.5	5	0.05	0.4
High resolution	13.5	7	0.04	0.3
Ultra high resolution	25.5	12	0.03	0.25

Availability of these modes makes the sensor versatile. By using different modes it is possible to achieve an optimal ratio between power consumption and resolution depending on what has a higher priority at the moment. Such advantages provide successful usage of the sensor in the above stated applications.

Choice of the appropriate mode provides rational combination of measuring accuracy and speed of operation. Such approach improves usage of computational burden.

V. PROCEDURE OF DATA PROCESSING

Altitude can be determined based on measured pressure and pressure at the sea level using the barometric formula [3]

$$H = \frac{T_0}{\tau}\left[1-\left(\frac{p}{p_0}\right)^{R\tau}\right], \qquad (1)$$

where H is the altitude and is calculated in meters; T_0, p_0 are temperature and pressure in the standard weather conditions; τ is the temperature gradient; R is the specific gas constant.

The equation (1) after substitution of the numerical data can be transformed to the form [2]

$$H = 44330\left[1-\left(\frac{p}{p_0}\right)^{1/5.255}\right]. \qquad (2)$$

In accordance with (2) change of the pressure 1 hPa corresponds to the altitude 8.43 m for $p_0 = 1013.25$ hPa. Analysis of BMP085 charac-teristics [2] shows that the error of pressure measurement is 0.03 hPa. This value corresponds to the altitude error 0.25 m [1]. It should be noted that nowadays sensor BMP085 is one of the best in the sensors of this class. But this sensor has some disadvantages. During measurement, it also takes the high frequency ambient air oscillations into account. This may lead to decrease in accuracy of measurement. To avoid this accuracy decrease, it is necessary to apply filtering.

The approximated graphical dependence of altitude on pressure is represented in Fig. 1 [2].

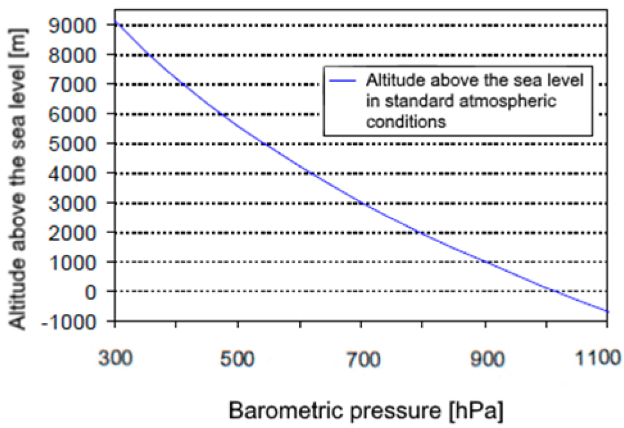

Fig. 1. Graphical dependence of pressure on altitude above the sea level

Digital signal processing traditionally includes the creation of means of converting the given (measured in discrete time) numerical array to a continuous process changing in the physical units and extracting useful information contained in the measured signal.

The data is read from the device memory. The data includes digital values of temperature and pressure, which are read from digital to analog converters and also calibration coefficients. Data is read in the digital format, and transformed to the standard measuring units by means of the formulae including (2). The filtering by means of the low-pass Butterworth filter is implemented in the program way.

The digital data is transferred by 11 words consisting of 16 bits and including 11 calibration coefficients. The data is checked of impermissible values such as 0 FFFF. Calculation of true pressure is implemented with the step 1 Pa (0.01 mbar) and the true temperature – with the step 0.1 °C [2].

The procedure of data processing includes the following steps.

- choice of mode of data processing;
- reading of calibration coefficients from the sensor memory;
- reading of data from pressure sensor in the digital form;
- reading of data from temperature sensor in the digital form;
- data filtering;
- reduction of data on pressure and temperature to standard measuring units;
- calculation of the altitude using the barometric formula;
- representation of the obtained data on display.

The represented procedure can be implemented in computing unit of UAV control system.

VI. Filter Development

The goal of filtering is to avoid the low noise. Development of filters with finite impulse response is more difficult in comparison with infinite impulse response filters with the similar characteristics.

To design a filter means to determine its parameters as a dynamic block. Calculation of these parameters is the difficult task. Usually it implements by choosing of some analog based on filters of the known types and following calculation of the analog parameter which will provide the required filter quality.

Filters with infinite response characteristic can be used for implementation of the classical filters such as Butterworth, Tchebyshev and others. Comparative analysis has been shown advantages of the Butterworth filter [4]. Such filters provide smoothness of the amplitude-frequency characteristics in the operating bandwidth. The finite task of the linear digital filter design is calculation of elements of the nominator (b) and denominator (a) of the discrete transfer function $G(z)$ written in the form [4]

$$G(z)=\frac{y(z)}{x(z)}=\frac{b_0+b_1z^{-1}+...+b_mz^{-m}}{a_0+a_1z^{-1}+...+a_mz^{-m}}. \quad (3)$$

Design of discrete filters can be implemented by means of the MATLAB Signal Processing Toolbox functions, for example, *butter*, *cheby1*, *cheby2*, and *ellip*. The basic difference of these functions application for development of the discrete filters is as follows. All frequencies must be given relative to the Nyquist frequency. The Nyquist frequency is called the half of the frequency of the signal sampling.

To design filters with the infinite-impulse response it is possible by means of development of the appropriate analogue prototype [4]. This way lies in determination of the transfer function of the continuous filter and next conversion to the digital filter. It can be implemented by means of the bilinear transformation of the s-plane into the z-plane. The bilinear transformation can be implemented by means of the MATLAB function *bilinear*.

Another way of creation of the digital filter by the analogue prototype lies in transformation of the analogue filter parameters into the discrete filter parameters [4]. The impulse response of the discrete filter must coincide with the impulse response of the analogue filter at the discrete instants of time. This is implemented by means of the MATLAB function *impinvar*.

To design the digital filter directly it is possible using the function *butter*.

As range of the discrete signal frequency change is always less than the sampling frequency, all frequency characteristics of the discrete filters are defined in the range from 0 to the Nyquist frequency only [5], [6].

Calculation of the filter with the infinite-impulse response may be carried out by the given amplitude-frequency characteristic.

To solve the problem of data processing the scheme of the Butterworth filter was chosen, which has the flat frequency characteristic and linear phase characteristic in the operating bandwidth.

The filter was designed by means of the Matlab Signal Processing Toolbox. The minimum order of the discrete filter was determined by means of the

Matlab function *buttord*. Synthesis of the discrete filter was implemented using the Matlab function *butter*. The filter provides limitation of the spectrum of the high-frequency noise. The filter (3) has been designed based on the following initial data

- frequency of input signal sampling;
- cut-off frequency;
- level of pulsations in bandwidth;
- level of pulsations in stop-band.

The impulse response and amplitude-frequency characteristics of the designed Butterworth filter are represented in Figs 2, 3.

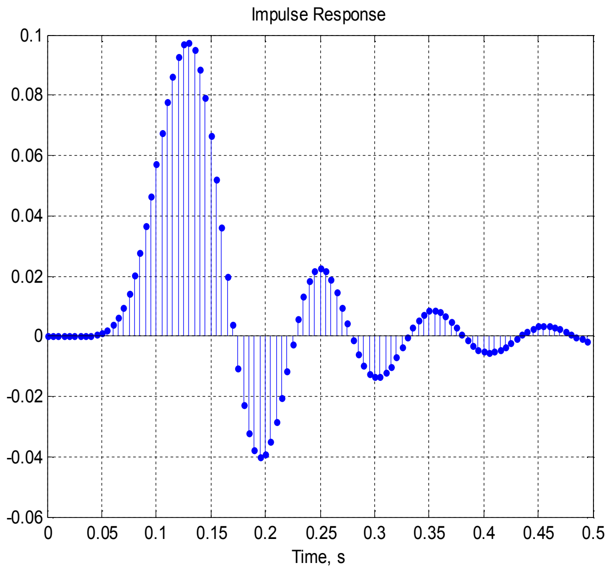

Fig. 2. Impulse response of the Butterworth filter

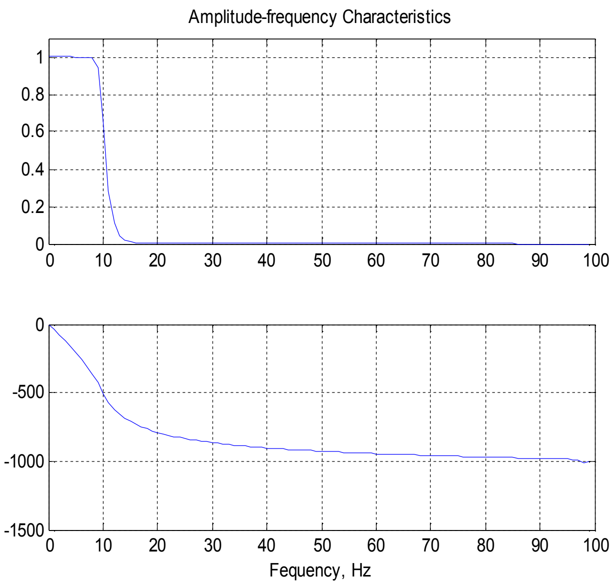

Fig. 3. Amplitude-frequency characteristics of the Butterworth filter

The obtained transfer function (3) of the designed filter looks like

$$
\begin{aligned}
&H(z) = 0.01\frac{b_{1n}+b_{2n}}{a_{1n}+a_{2n}},\\
&b_{1n} = 0.005 + 0.5z^{-1} + 2.5z^{-2} + 7.4z^{-3} + 15z^{-4},\\
&b_{2n} = 20.8z^{-5} + 2.1z^{-6} + 15.9z^{-7},\\
&a_{1n} = 1 - 8.8z^{-1} + 35.56z^{-2} - 86.4z^{-3},\\
&a_{2n} = 140.7z^{-4} - 160.9z^{-5} + 132z^{-6} - 77.65z^{-7}.
\end{aligned} \tag{4}
$$

The advantages of the designed filter are its simplicity and the possibility to carry out design procedure without any prior information about measurement errors and choice of the weighting coefficients.

It should be noted that proper sensor can be described by the transfer function

$$W(s) = \frac{1}{Ts+1},$$

where T is the time constant.

VII. Simulation Results

Results of calculation of temperature, pressure and altitude are represented in Figs 4 and 5.

Simulation was carried out using some tested signals such as stepwise signal with random noise, ramp signal, triangle signal, which imitates climb of the sensor on some altitude and further pulling down, sinusoidal with the given amplitude and frequency, which can be implemented by means of the special stand in laboratory conditions.

Results of filtration for the stepwise signal are represented in Figs 6 and 7. Analysis of represented plots shows significant attenuation of the high frequency noise. Such decrease is sufficient for low cost applications.

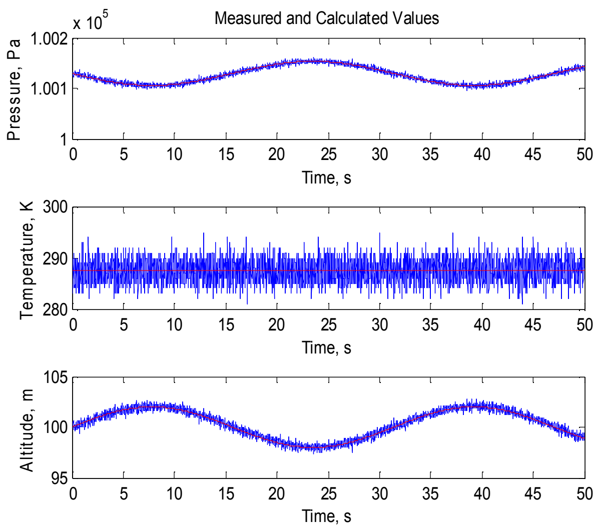

Fig. 4. Simulation of the sinusoidal test signal

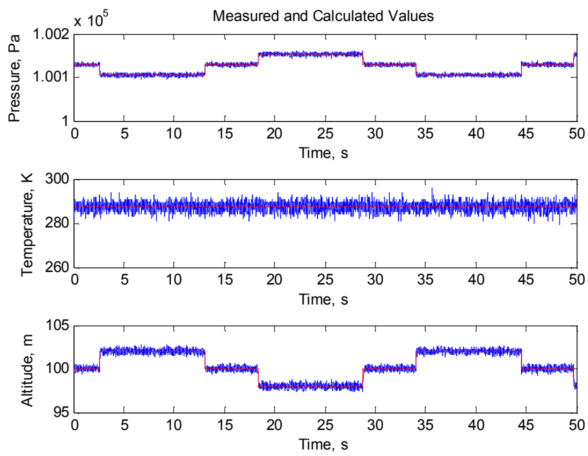

Fig. 5. Simulation of the stepwise signal

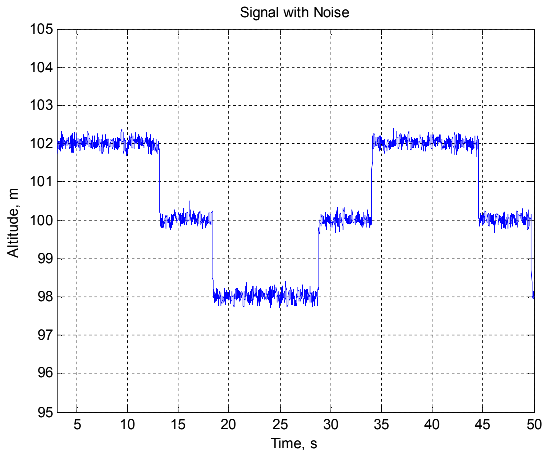

Fig. 6. The signal before filtering

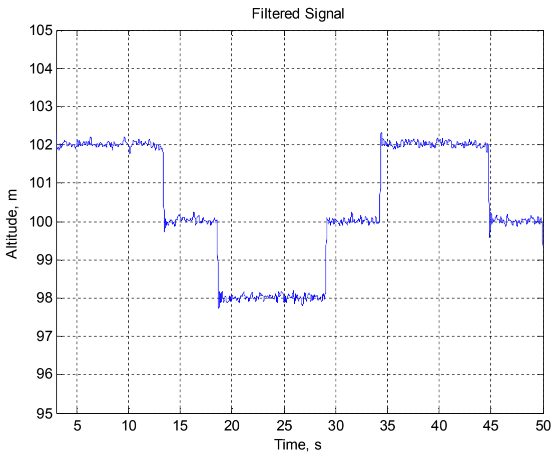

Fig. 7. The signal after filtering

The program realization of the developed filter (4) can be made on the Arduino platform, which represents the tool for development of the programmable electronic devices [7]. Aurdino is the open prototyping platform, which represents the card with the microcontroller, and also the special development environment for creation of microcontroller software.

The represented results prove efficiency of the developed procedure of data processing.

VIII. CONCLUSION

The proposed procedure of data processing provides improvement of measurement accuracy and reliability, as well as resistance to noise of the researched device BMP085. This can be characterized as indirect improvement to the performance of the device, because it does not in any way influence the device from within. Instead, the proposed procedure influences the input of data into the device. By eliminating unnecessary and irrelevant data (interferences) only the relevant data is left for the altimeter BMP085 to process. As the result, the control system of the UAV will operate with more accurate data. This leads to improvement in the reliability and safety of the flight.

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Sushchenko Olha Andriivna. Doctor of Engineering. Professor.
Aircraft Control Systems Department, Education and Research Institute of Air Naviagtion, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Politechnic Institute, Kyiv, Ukraine (1980).
Research interests: systems for stabilization of information and measuring devices operated on vehicles.
Publications: 120.
E-mail: sushoa@ukr.net

Golitsyn Volodymyr Oleksandrovich. Student.
Aircraft Control Systems Department, Education and Research Institute of Air Naviagtion, National Aviation University, Kyiv, Ukraine.
Education: Bachelor (2016).
Research interest: navigation and stabilization systems.
Publications: 1.
E-mail: vova.gol@ukr.net

О. А. Сущенко, В. О. Голицин. Оброблення даних барометричного альтіметра

Розглянуто особливості вимірювання висоти на борту безпілотних літальних апаратів. Виконано аналіз характеристик датчиків висоти та обгрунтовано вибір низьковартісного барометричного альтиметра. Розроблено процедуру оброблення інформації. Виконано фільтраціію інформації за допомогою фильтра Баттерворта. Результати моделювання підтверджують ефективність запропонованої процедури оброблення інформації.

Ключові слова: безпілотні літальні апарати; барометричний альтиметр; оптимальна фільтрація, оброблення даних.

Сущенко Ольга Андріївна. Доктор технічних наук. Професор.
Кафедра систем управління літальних апаратів, Навчально-науковий інститут аеронавігації, Національний авіаційний університет, Київ, Україна.
Освіта: Київський політехнічний інститут, Київ, Україна (1980).
Напрям наукової діяльності: системи стабілізації інформаційно-вимірювальних пристроїв, експлуатованих на рухомих об'єктах.
Кількість публікацій: 120.
E-mail: sushoa@ukr.net

Голицин Володимир Олександрович. Студент.
Кафедра систем управління літальних апаратів, Навчально-науковий інститут аеронавігації, Національний аіаційний університет, Київ, Україна.
Освіта: Бакалавр (2016).
Напрям наукової діяльності: системи навігації та стабілізації.
Кількість публікацій: 1.
E-mail: vova.gol@ukr.net

О. А. Сущенко, В. О. Голицин. Обработка данных барометрического альтиметра

Рассмотрены особенности измерения высоты на борту беспилотных летательных аппаратов. Выполнены анализ характеристик датчиков высоты и обоснованный вибор барометрического альтиметра низкой стоимости. Разработана процедура обработки информации. Выполнена фильтрация информации при помощи фильтра Баттерворта. Результаты моделирования подтверждают эффективность предложенной процедуры обработки информации.

Ключевые слова: беспилотные летательные аппараты; барометрический альтиметр; оптимальная фильтрация, обработка данных.

Сущенко Ольга Андреевна. Доктор технических наук. Профессор.
Кафедра систем управления летательных аппаратов, Учебно-научный институт аэронавигации, Национальный авиационный университет, Киев, Украина.
Образование: Киевский политехнический институт, Киев, Украина (1980).
Направление научной деятельности: системы стабилизации информационно-измерительных устройств, эксплуатируемых на подвижных объектах.
Количество публикаций: 120.
E-mail: sushoa@ukr.net

Голицын Владимир Александрович. Студент.
Кафедра систем управления летательных аппаратов, Учебно-научный нститут аеронавигации, Национальный авиационный университет, Киев, Украина.
Образование: Бакалавр (2016).
Направление научной деятельности: системы навигации и стабилизации.
Количество публикаций: 1.
E-mail: vova.gol@ukr.net