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BAROMETRIC ALTIMETER BASED ON MICROELECTROMECHANICAL SENSOR

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Abstract**—***The paper considers a barometric altimeter based on a microelectromechanical sensor. An algorithm for obtaining height using the BMP180 sensor is presented, which can be used in various fields of technology and industry. The work also used a variety of parts that ensured the quality and accuracy of the altimeter. A program code for calculating the height has been developed. An experimental study of the operation of the apparatus was carried out.*

Index Terms—Pressure sensor; microelectromechanical system; Arduino Uno; calibration; altitude; altimeter.

I. INTRODUCTION

Nowdays, modern aircraft use a system for measuring (information system) altitude parameters, in which the primary information is issued by sensors in digital or frequency form, and the decision is made by specialized or universal computer control systems. One of the important aerobatic and navigational parameters is the flight altitude of the aircraft. Knowledge of flight altitude is necessary for the pilot to calculate the approach, to maintain a given flight level, to perform special tasks, flight safety and the like. To ensure flight safety, increase airspace capacity and obtain an economic effect (fuel economy), there is a systematic reduction of vertical separation intervals. The main criterion of the flight separation system is its compliance with the allowable probability of critical approach of the aircraft [1], [2], which can occur during meetings during 1 hour of flight. This probability depends on the accuracy of maintaining the height of the crews of aircraft from the means of height stabilization and to a greater extent on the accuracy of the characteristics and reliability of the equipment for measuring altitude.

An altimeter is a device for measuring altitude. In the case of a manned aircraft, the altimeter is a flight and navigation instrument that indicates the flight altitude. According to the principle of the device, altimeters are divided into barometric, radio inertial, ionization and others. In the old days, the altimeter was called the simplest goniometric tool for determining the height of the luminaries (planets, stars).

The altimeter is an important navigational instrument. Its presence allows the pilot to properly approach the landing. Without information about the height, it is difficult to calculate the angle and descend to the runway in order to avoid a collision with it. The introduction of high-precision altimeters in aviation has significantly reduced the proportion of crashes during landing.

Knowing the height is also necessary when dropping paratroopers, because if you go too low, the parachute will not have time to sufficiently slow down the paratrooper's descent. When the plane rises too high, the rarefied air overboard can cause a person to lose consciousness.

Altitude data is also needed for balloons, hang gliders, paragliders and other devices. Without knowing the height, you can rise above the prescribed level, where it is difficult to breathe, there is a strong wind or migratory birds move.

In article [1] used an electronic barometric altimeter with real-time correction. Determination of barometric altitude using modern electronic sensors has a significant error due to the deviation of atmospheric pressure according to weather and time. The barometric altimeter must be accurate based on hourly data to maintain accuracy. Lynn presented an approach for calculating altitude in air using barometric measurements and calibration of actual time via the GPRS ascending line. This technique is convenient for finding the time error of the electronic barometric altimeter without human intervention. This helped to improve the measurement accuracy. The proposed method is suitable for ultralight aircraft or unmanned aerial vehicles.

In article [2] used a microbarometric altimeter with the use of altitude flight control for UAVs. He explained the progress of altimeters for microliths and its application in altitude flight. The BLAP could be used for military missions or investigations and rescue and field research. Height control is required for these tasks. The microbarometric altimeter was implemented as an element of the control system for maintaining altitude. The 3-gram altimeter provides greater resolution and accuracy.

In article [3] proposed a dynamic height sensor without drift using a pressure sensor microelectromechanical system (MEMS). An economical, less energy efficient solution with a small form factor for vertical positioning with better resolution has been created by integrating accelerometers with the MEMS barometric altimeter. This method is extremely reactive, but without drifting the characteristics of the MEMS accelerometers becomes constant with a barometric altimeter and receives highly reliable altitude tracking. With this method, you can track in real time the classic perpendicular human actions, such as ascent or descent. The effectiveness of the height of this method is checked using a standard data set and error analysis is performed.

In article [4] barometric altimeter system for the application of vehicular test of SINS has been designed. The altitude and speed information of the vehicle can be measured in real time.

In article [5] used an altimeter with an ocean wave period using a genetic algorithm. It is recognized that the wave period can be expected on the basis of altimeter measurements of wave height, wind speed, radar backscattering cross section using empirical association. The adaptive neural network method was used to obtain the wave period from altimeter data, and this approach is better than empirical methods. Oceanographic research is increasingly discussing an additional technique of genetic algorithm that adapts the data. In his work, this approach was used to obtain estimates of the wave period from the parameters observed at the altimeter. It has also been shown that the beginning of the wave age shows the way to a significant development of accurate estimates.

II. Problem Statement

It is necessary to develop system that will allow to obtain the information about the altitude and will have small size, cheap price and significant accuracy.

To achive this we must solve the following problems:

- analyze the existing types of altimeters, their strengths and weaknesses;
- analyze the main parts of Barometric Altimeter;
- develop the structure of the system;
- choose the main components of the system;
- develop the software part of the system.

III. Problem Solution

Since the main task was to develop a more acceptable result in terms of quality and price, the corresponding parts were chosen. This required Arduino Uno microcontroller with performance. It was selected with the requirement for specific tasks due to it`s characteristics and acceptably low price. Since the task at hand requires stable settings for calculating data I chose pressure sensor BMP180. To display obtained result I took high resolution display SSD1306 0.96. We will take also breadboard, where all our parts will be placed. The rest of the work was done using a (personal computer) PC and the WinForms and ArduinoIDE to develop GUI and software for our Barometric Altimeter.

IV. Pressure Sensor

Micromechanical pressure sensors are the most common in various electrical designs. The main two types of micromechanical pressure sensors are of two types: differential and absolute. The basic housings of the absolute and differential pressure sensors are identical. Consider the structure of the base housing in more detail (Fig. 1).

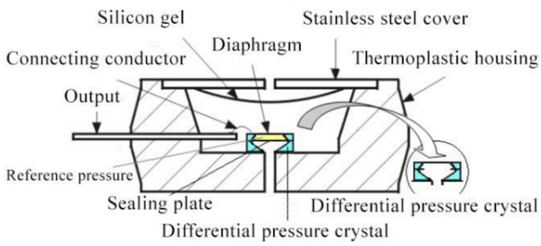

Fig. 1. Basic housing of the pressure sensor

The inside of the case is filled with silicone gel, which insulates the crystal surface and joints, but allows pressure to affect the diaphragm; this protects the device from the harmful effects of the environment.

Consider the integrated piezoresistive MEMS barometric pressure gauge BMP180 (Fig. 2). The crystal of the pressure sensor is located on a silicon crystal holder glued to the sensor housing.

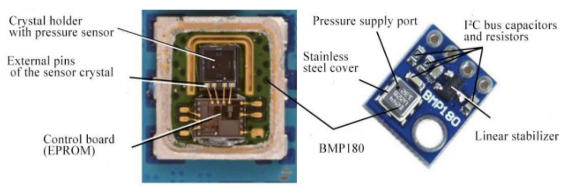

Fig. 2. Pressure sensor BMP180

The plastic housing with one or two supply ports is closed with a stainless steel lid. External terminals are pressed into the housing, which are connected to the crystal sensor output terminals by means of gold wiring.

The investigated pressure sensor BMP180 is a piezoresistive MEMS sensor for measuring barometric pressure. On the BMP180 board, in addition to the sensor, there is a linear voltage stabilizer with capacitors and I2C bus power supply resistors.

The sensor is calibrated and has a temperature compensation circuit. Individual calibration coefficients (11 coefficients) are embedded in the sensor's built-in EPROM memory.

In addition to the pressure, the sensor can output information about the ambient temperature. The sensor can operate in several modes:

- standard mode, including low power mode;
- high and ultra-high power mode

The sensor is controlled from a microprocessor control device, in our case from an Arduino controller. After connecting the sensor, you need to install libraries to work with the BMP180 sensor.

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Other, for example, publicly available software algorithms from the developer "Bosch Sensortec" can be downloaded from various resources. The library of work with the BMP180 sensor contains files of calibration, temperature compensation, and also some algorithms of calculation of absolute height.

After initializing the software (Fig. 3), the microcontroller reads the calibration coefficients with the built-in EPROM memory of the BMP180 sensor. Then, in an endless cycle, the measurement of pressure and temperature begins. The "raw" readings of the temperature sensor UT and the UP pressure are read by the processor, through the I2C interface then by a special algorithm using calibration factors and temperature values (to implement temperature compensation), calculate the true values of temperature t and pressure P.

In standard mode, the sampling rate is 128 measurements per second. In this case, it is possible to measure the temperature only once per second and use this value for all high pressures during the same period.

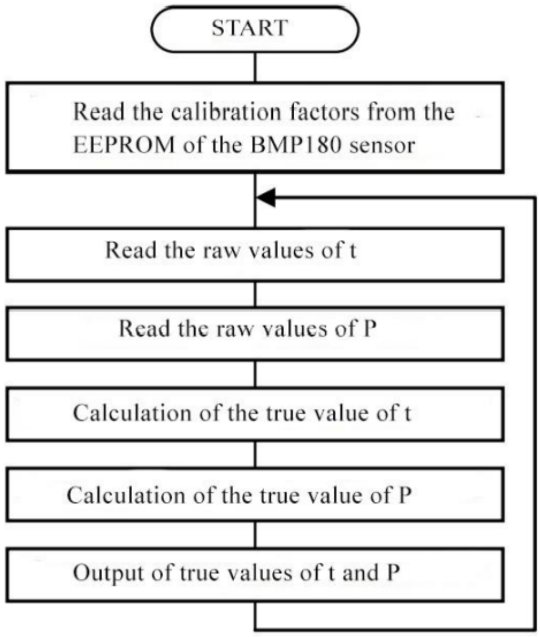

Fig. 3. Principle of work BMP180

Piezoresistive MEMS pressure sensors began to be actively used in aviation, especially on small UAVs, as measuring instruments of atmospheric pressure, which is the basis for calculating the barometric altitude as a function of static pressure Pst.

V. HYPSOMETRIC EQUATION

The hypsometric equation, also known as the thickness equation, relates an atmospheric pressure ratio to the equivalent thickness of an atmospheric layer considering the layer mean of virtual temperature, gravity, and occasionally wind. It is derived from the hydrostatic equation and the ideal gas law.

The hypsometric equation is expressed as:

$$h = \frac{R \cdot T_v}{g} \ln\left(\frac{P_1}{P_2}\right), \qquad (1)$$

where h is thickness of the layer [m]; R is specific gas constant for dry air; T_v is virtual temperature, [K]; g is gravitational acceleration, [m/s^2]; P_1 is Ground pressure, [Pa]; P_2 is Pressure, [Pa].

In atmospheric thermodynamics, the virtual temperature of a most air parcel is the temperature at which a theoretical dry air parcel would have a total pressure and density equal to the moist parcel of air.

The virtual temperature of unsaturated moist air is always greater than the absolute air temperature, however, the existence of suspended cloud droplets reduces the virtual temperature.

The virtual temperature can be calculated using the formula below:

$$T_v = \frac{T + 273.15}{1 - 0.379 \cdot \left(\frac{6.11 \times 10^{\left(\frac{7.5 \cdot T_d}{237.7 + T_d} \right)}}{P_{\text{sta}}} \right)}, \qquad (2)$$

where T is the air temperature; T_d is the dewpoint temperature; P is the station pressure.

To calculate the virtual temperature, the temperatures must be converted to units of degrees Celsius (°C) and the station pressure (P) must be converted to HectoPascals.

VI. Barometric Altimeter

Block diagram of barometric altimeter and wiev of laboratory prototype are shown in Figs 4 and 5.

Software part of barometric altimeter includes embedded part for microcontroller that performs all the measurement tasks, results display on built-in LCD screen and measurement data transmission to remote indicator (Fig. 6).

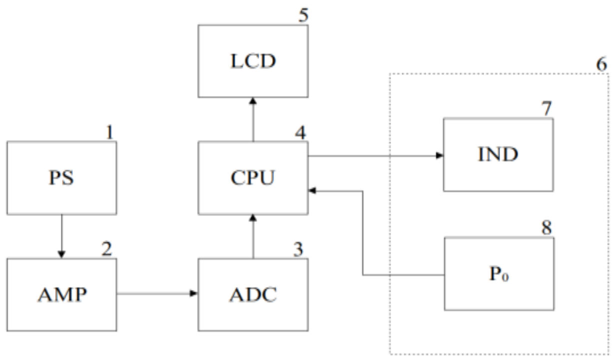

Fig. 4. Barometric Altimeter scheme: *1* is the pressure sensor; *2* is the amplifier; 3 is the analog to digital converter; 4 is the microcontroller; 5 is the liquid crystal display; 6 is the PC software; 7 is the indicator; 8 is the ground pressure setter

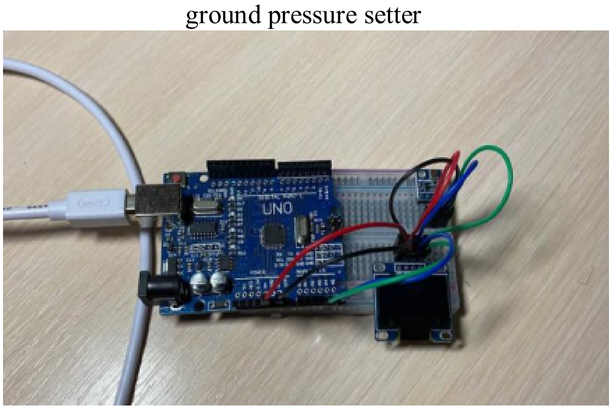

Fig. 5. Assembled MEMS Barometric Altimeter

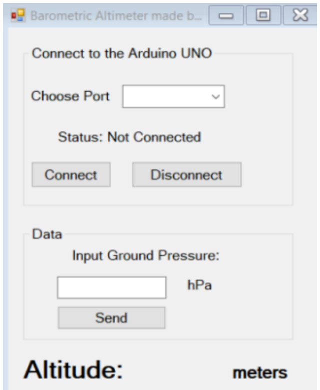

Fig. 6. Barometric Altimeter GUI

Indicator is a PC software that is used to establish data link between altimeter and computer, dislay measured altitude and set the correct ground pressure.

Fig. 7. Calculated altitude on screen

Operation of built-in display is shown in Fig. 7.

VII. Experimental Testing

Altimeter testing was carried out using checout equipment for barometric aircraft instruments that includes aneroid-barometric devices testing equipment, vacuum pump and pressurized case, where BMP 180 pressure sensor was placed [6].

Testing was performed by creating the pressures that correspond to the specific values of barometric altitude and checking the readings of altimeter and after that measurement error was calculated. True value of barometric altitude $H_{\text{abs.true}}$ was calculated using hypsometric equation (1). It indicates which altitude both devices must show in present atmospheric conditions. Existing barometric altimeter VD-10 was used to compare the errors.

Testing results are shown in Table I.

TABLE I. TESTING RESULTS

$H_{abs.prop}$, m	P, mm.hg.	P, Pa	$H_{abs.true}$, m	$H_{abs.meas}$, m		Error, m	
				BMP180	***VD-10***	***BMP180***	***VD-10***
0	760,0	101325	0.0	-10.0	-10.0	-10.0	-10.0
500	715	95325.5	511.8	500.0	500.0	-11.8	-11.8
1000	674,1	89872.6	1000.2	1000.0	1002.0	-0.2	1.8
1500	633	84393.0	1515.7	1500.0	1530.0	-15.7	14.3
2000	600	79993.4	1949.7	1967.0	1980.0	17.3	30.3
2500	550	73327.3	2645.5	2610.0	2690.0	-35.5	44.5
3000	520	69327.6	3088.0	3070.0	3079.0	-18.0	-9.0
3500	490	65327.9	3551.7	3500.0	3600.0	-51.7	48.3
4000	470	62661.5	3873.7	3900.0	3910.0	26.3	36.3
4500	435	57995.2	4465.0	4500.0	4495.0	35.0	30.0

Testing results show that BMP180 sensor provides altitude measurement accuracy comparable or sometimes even greater than existing and widely used VD-10 altimeter so it can be used to provide altitude measurements on small UAVs.

VIII. CONCLUSION

Barometric altimeters based on MEMS pressure sensor allow to significantly reduced the size and provide comparable accuracy of the existing barometric altimeters. In addition, the temperature sensor is connected to the system in order to implement the approach of dynamic temperature profiling as an attempt to eliminate temperature-dependent errors that prevail in modern standard altimeters with profiled temperature.

The results of the experiments prove that the pressure sensor based on the microelectromechanical system (MEMS) in the barometric altimeter provides greater accuracy in measuring altitude than the existing barometric altimeter.

The altimeter, built-in barometer, reveals many applications in the field of GPS systems, weather stations and industrial systems. This is a great solution for determining height. It has small size, cheap price and great accuracy. The barometric altimeter can be used by small UAVs or by skydivers.

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М. П. Василенко. В. І. Джус. Барометричний висотомір на основі мікроелектромеханічного датчика
У роботі розглянуто барометричний висотомір на основі мікроелектромеханічного датчика. Наводиться алгоритм отримання висоти за допомогою датчика диску BMP180, який може бути використаний у різних сферах техніки та промисловості. У роботі також використовувалися різноманітні деталі які забезпечили якість і точність висотоміра. Розроблено програмний код для обчислення висоти. Проведено експериментальне дослідження роботи апарату.
Ключові слова: датчик тиску; мікроелектромеханічна система; Arduino Uno; калібрування; висота; висотомір.

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Напрям наукової діяльності: відновлювальні джерела енергії, оцінка властивостей речовин та матеріалів за власними електромагнітними випромінюваннями.
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М. П. Василенко. В. И. Джус. Барометрический высотомер на основе микроэлектромеханического датчика
В работе рассмотрен барометрический высотомер на основе микроэлектромеханического датчика. Приводится алгоритм получения высоты с помощью датчика BMP180, который может быть использован в различных сферах техники и промышленности. В работе также использовались разнообразные детали, которые обеспечили качество и точность высотомера. Разработан программный код для вычисления высоты. Проведено экспериментальное исследование работы аппарата.
Ключевые слова: датчик давления; микроэлектромеханическая система; Arduino Uno; калибровка; высота; высотомер.

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