The Height Measurement Device for Unmanned Aerial Vehicle based on Barometric Sensor

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Abstract

In order to meet the acquisition and processing of high signal for the small unmanned aerial vehicle flight control, a height measuring device was designed by using MS5611 air pressure sensor. Through collecting the data of sensor temperature to compensate the real-time temperature for the air pressure value, and using the smooth filter method to deal with the barometer of the original data, the high accuracy of the measured value can be obtained. By the impact of the external environment and the circuit, the output of the same height barometer will be jitter. With regard to this problem, it has made the output of the height do secondary treatment. The experimental results show that the accuracy of the height measurement system can reach to 1 meter, which can meet the basic requirements of UAV flight control for flight height data

Keywords

Pressure Sensor, Height, Filter, Controlts of UAV Flight Control for Flight Height Data.

1. Introduction

The accurate control of the attitude and the trajectory tracking for the UAV has always been a hot issue in the field of flight control[1]. It is difficult and challenging for people to locate the precise information, so it is an important index to control the safe flight of the aircraft [2]. Flight height is one of the important measurement signals of the small UAV flight control system. The significance of that is not only reflected in the accuracy of the target positioning, but also reflected to flight safety and the reliability of the height signal directly [3].

Aiming at the above problems, the use of MS5611 digital atmospheric pressure sensor and the STM32 microcontroller was designed and implemented a precision height measurement system which has the function of temperature compensation and correction [4]. The height measurement system also has some characteristics at the same time, such as low power consumption, simple interface, small volume, lightweight data output stability, fast response, etc. So it is especially suitable for small UAV height measurement [5].

2. The Working Principle for MS5611

The MS5611-01BA series of barometric pressure sensor is a new generation of high-resolution barometric pressure sensor with a SPI and I²C bus interface from MEAS (Switzerland), with a resolution 10 cm and a measuring range of 10 to 1200 mbar. The sensor module includes a high linearity pressure sensor and an ultra low power 24-bit sigma analog-to-digital converter (factory calibration factor). The MS5611 provides an accurate value of the 24-bit digital pressure and temperature, as well as different operating modes, which can increase conversion speed and optimize current consumption. The outputs of the high-resolution temperature do not need some extra sensors, which can realize the function of the altimeter/thermometer [6]. Because of the MS5611 built-in thermometer, it can be real-time compensation of the temperature for the pressure value on the hardware and software, which can reduce the influences of the ambient temperature changes to the pressure value. The MS5611 pressure sensor has a small size of only 5.0 mm× 3.0 mm × 1.0 mm. As shown in Fig. 1, the module is MS5611 barometer sensor and peripheral circuit, which communicates with the processor via 7 pins. The definition of the pins is Table 1.

Fig. 1 MS5611 real figure

Table 1. Pin definition

Pin	Type	Name	Description
1	P	VDD	Voltage
2	I	PS	I2C/SPI
3	G	GND	Grounded
4	I	CSB	Chip selection
5	O	SDO	Serial data output
6	O/IO	SDI/SDA	Serial data input/I2C data
7	I	SCLK	Clock

The MS5611-01BA has two types of serial interfaces: one is SPI, and the other is I2C. It can select the use of I2C or SPI communication interface by adjusting the PS pin voltage, as shown in Table 2.

Table 2. Communication interface selection

Pin	Mode	Pins used
High	I2C	SDA
Low	SPI	SDI,SDO,CSB
Pin	Mode	Pins used

2.1 SPI Mode

The external microcontroller transfers data by inputting SCLK (serial clock) and SDI (serial data). Based on the pattern of the SPI mode, the polarity of the clock and phase allow display of 1 and 3 simultaneously [7]. The SDO (serial data) pin is the response output of the sensor, and the CSB (Chip Select) pin is used to control the chip enable or disable, so other devices can share the same set of SPI buses. The CSB pin will be pulled high when the command is sent or the command is finished (for example, the end of the conversion). During the idle pattern of the SPI bus, the module has the better performance of the noise and links to other devices while the ADC module is conversion.

2.2 I2C Mode

The external microcontroller transfers data by inputting SCLK (serial clock) and SDA (serial data). The response of the sensor is built on the SDA line of the bi-directional I2C bus interface. So this interface type only uses 2 signal lines without the need for chip select signals, which can reduce board space. In the I2C mode, the complementary pin CSB (Chip Select) represents the I2C address of the LSB [8]. Two sensors and two different addresses can be used on the I2C bus. But the pin of the CSB should be connecting with VDD or GND.

3. The Working Process of the System

Each MS5611 has a special 6-level calibration module that is stored in the 128-bit PROM for the module during the factory settings. Microcontroller read the word1-word2 by means of the three-wire synchronous serial port from the MS5611 module after microcontroller initialization, which is converted to the six calibration compensation coefficient C1-C2 by use of the logical shift operation mode. Firstly, the controller continuously reads the absolute pressure value D1 and the temperature value D2 from the module. Secondly, the relative pressure value P is calculated by the calibration compensation coefficient calculation. Lastly, the pressure value is compensated by the temperature. According to the conversion height between the height and the air pressure, the height value which is corresponding to the pressure is obtained by processing the output pressure value that used by smoothing filter. In order to avoid the high degree of jitter caused by environmental and circuit interference, it can obtain the final height through the secondary processing to the output height. Through the wireless communication module transferring the height value to the ground controller, it is easy to master the height of UAV flight. The flow of the software is shown in Fig. 2.

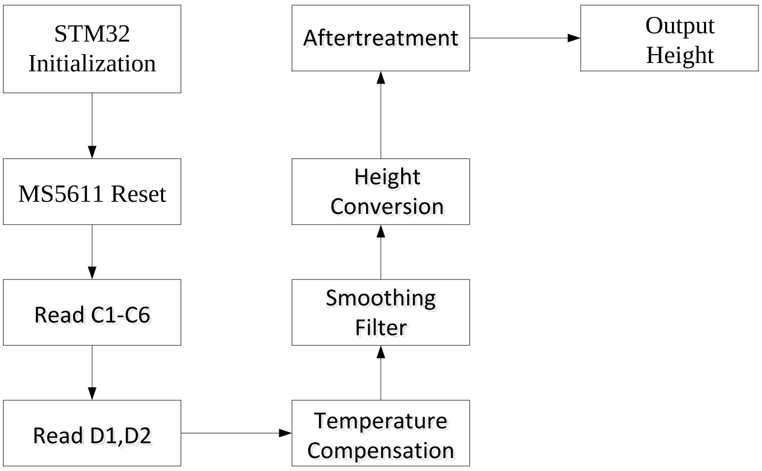

Fig. 2 System framework

4. Temperature Compensation for Barometer

As the temperature is the main factor about affecting the air pressure, it can obtain the accurate pressure information only when it is necessary to use the temperature to compensate for air pressure. Based on the principle of compensation, the temperature compensation needs calculate the value of the temperature compensation for the single chip computer reader to read out the pressure value. the temperature compensation is used to correct the temperature shift caused by drift and Sensitivity changes, thereby correcting changes in pressure values caused by temperature changes. It mainly utilize a second-order compensation algorithm to get the pressure value P.

4.1 Scale Factor

(1). Differences between actual and reference temperatures.

$$dT = D2 - T_{REF} = D2 - C5 * 2^{8} \quad (1)$$

(2). Actual temperature.

$$TEMP = 20℃ + dT * TEMPSENS = 2000 + dT * C6 / 2^{23} \quad (2)$$

(3). Actual temperature offset.

$$OFF = OFF_{T1} + TCO * dT = C2 * 2^{16} + (C4 * dT) / 2^{7} \quad (3)$$

(4). Actual temperature sensitivity.

$$SENS = SENS_{T1} + TCS * dT = C1 * 2^{15} + (C3 * dT) / 2^{8} \quad (4)$$

(5). Temperature compensated pressure.

$$P = D1*SENS - OFF = (D1*SENS) - OFF = (D1*SENS/2^{21} - OFF)/2^{15} \tag{5}$$

4.2 Temperature Second Order Compensation

(1). $TEMP \geq 20℃$

$$\begin{cases} T2 = 0, OFF2 = 0, SENS2 = 0 \\ TEMP = TEMP - T2, \quad OFF = OFF - OFF2, SENS = SENS - SENS2 \end{cases} \tag{6}$$

(2). $20℃ \geq TEMP \geq -15℃$

$$\begin{cases} T2 = dT^2/2^{31}, OFF2 = 5(TEMP-2000)^2/2^1, SENS2 = 5(TEMP-2000)^2/2^2 \\ TEMP = TEMP - T2, \quad OFF = OFF - OFF2, SENS = SENS - SENS2 \end{cases} \tag{7}$$

(3). $TEMP < -15℃$

$$\begin{cases} T2 = dT^2/2^{31}, OFF2 = 5(TEMP-2000)^2/2^1, SENS2 = 5(TEMP-2000)^2/2^2 \\ OFF2 = OFF2 + 7(TEMP+1500)^2, SENS = SENS + 11(TEMP+1500)^2/2^1 \\ TEMP = TEMP - T2, \quad OFF = OFF - OFF2, SENS = SENS - SENS2 \end{cases} \tag{8}$$

5. Barometer Data Filtering

In this paper, it mainly eliminate the noise of the barometer data caused by the impact of the circuit or environment, and make use of the sliding window on the collected data to filter, with the barometer sampling frequency of 50Hz, and the filter window setting of 50. In addition, the window uses the form of the queue, which is deleting a data in the head of the team when the data is into at the end of the team. The filter formula is

$$pre_{cur} = \frac{\sum_{i=1}^{N} pre_i}{N} \tag{9}$$

Where pre_{cur} is the current barometric value, pre_i is the barometric pressure stored in the window, and N is the filter window size. Filtering by this algorithm, it not only eliminates the noise of the barometer data, but also makes the curve of the noise smoother, the algorithm of which is the simpler and can reduce the memory resource consumption. As shown in Fig. 3, it is the effect of the filter algorithm on the data processing. According to smoothing, the noise curves of the original data receive a improvement and smoothness to a great extent, and the processed waveform preserves the basic characteristics of the original waveform.

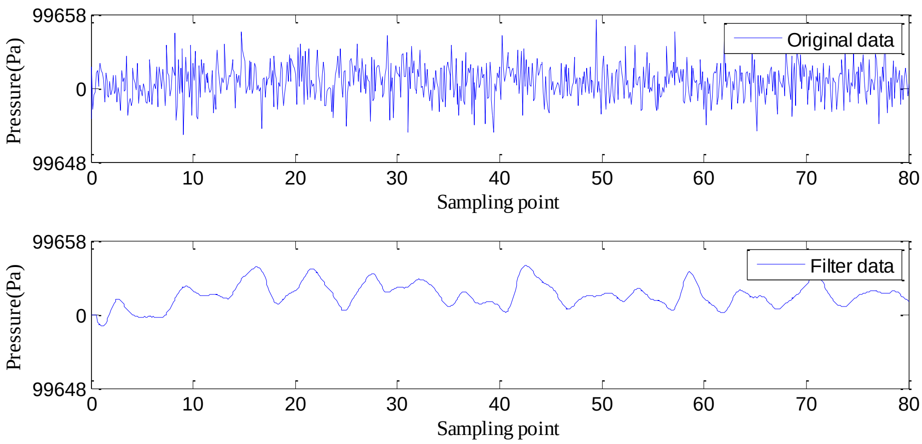

Fig. 3 The comparison figure of before and after smoothing filter for barometer data

6. The Height Calculation of Barometer

After the barometer data is smoothed filter, most of the noise in the data is eliminated, making the data smoother. According to the relationship between air pressure and altitude, it can convert the air pressure to height. The conversion formula is

$$H(t)=44330\times\{[1-(P(t)/1013.25)^{0.1903}]-[1-(P(0)/1013.25)^{0.1903}]\} \tag{10}$$

In the formula, m is the unit. $H(t)$ is the height. $P(t)$ is the air pressure value time after the filtered at the time of t, the unit of which is Pa. $P(0)$ is initial air pressure value, the unit of which is Pa. Fig. 4 is a simulation results of height during the static state , which need convert the barometer data of the collection to the height.

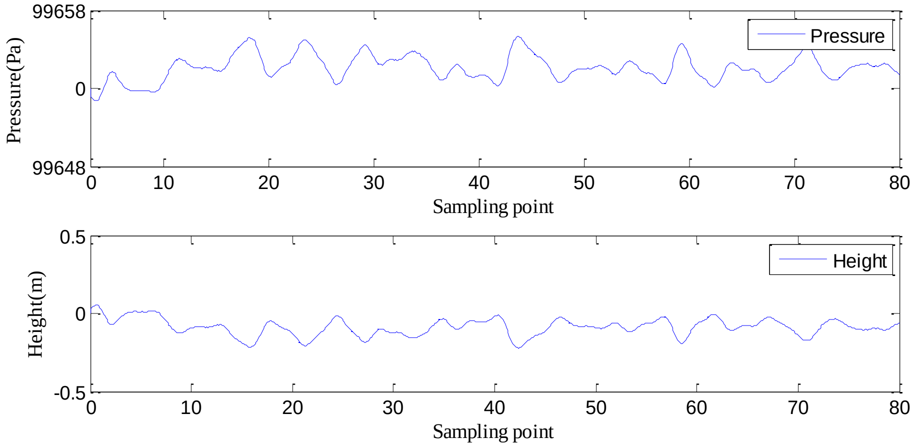

Fig. 4 Height conversion

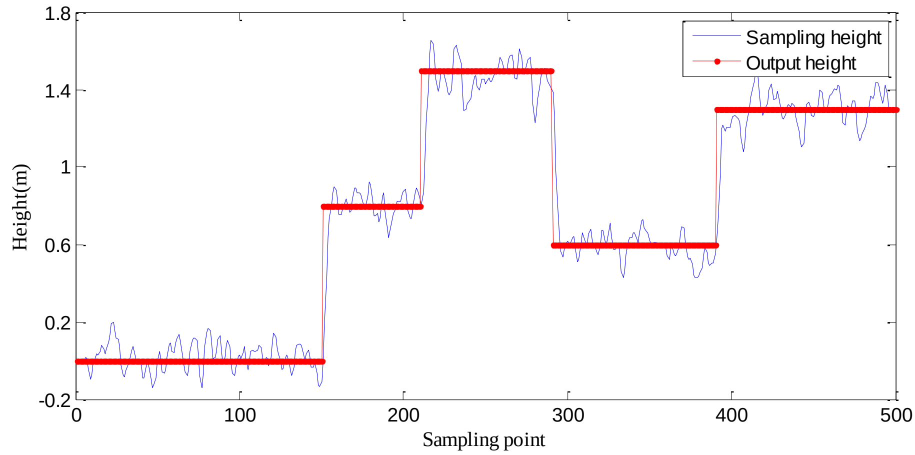

Fig. 5 the simulation results of height quadratic processing

From the above figure, it can find that the air pressure data after filtering still appear the some noise. due to the presence of noise, he height of the conversion is not the same level, which caused the occurrence of frequent ups and downs when it observed the height of UAV. Therefore, it needs secondary processing to the height of the conversion. The method is that it need set the height of the intermediate variables $Htmp$ and update threshold H_T, where the initial value of $Htmp$ is equal to the average of the height 5 seconds before the starting. The setting of H_T is based on the barometer noise at the state of static, where it selected 0.5m in this paper. Making the H_T and $Htmp$ real-time comparison, it can determine the height of the constant output. When the $H(t)-Htmp|\le H_T$, it will obtain that the output height $Htmp$ of the UAV is the constant. On the Contrary, when the

$|H(t) - Htmp| > H_T$, it is knew that the height of the UAV has changed. Then, $Htmp$ is updated, and H_T is assigned to $Htmp$. Fig. 5 is the simulation results before and after the height of the secondary processing. It can be seen that the output height remains unchanged at the static state, and when the height occurs change, the output height is also updated.

7. Experimental Results

To test and verify the performance of the height measurement device, it should place the UAVs on the different height, and then read output height data of the barometer. It can be seen that the maximum error between the measured height and the true height is 0.96m within 10 sets of linear experimental data from Table 3, which satisfies the design requirement that the horizontal accuracy is less than 2m. In summary, the height measurement devices basically meet the design requirements.

Table 3. Contrast analysis of actual height and measurement height

Actual height/m	Output height/m	Error/m
10	9.75	-0.53
20	20.74	0.74
50	50.82	0.82
78	70.15	0.15
90	89.35	-0.65
120	120.96	0.96
150	149.25	-0.75
180	180.16	0.16
210	210.89	0.89
230	230.97	0.97

8. Conclusion

Aiming at the commonly adopted scheme of the small UAV height collection and the method of data processing, this paper designed a height measurement device for UAV by use of the MS5611 barometer sensor. Through the temperature compensation and smoothing filter, it can effectively improve the accuracy of the measurement height. And according to the secondary processing to the height, it can raise the stability of the UAV height. The experimental results show that the error of the measuring device is less than 1m, which basically meets the requirements of UAV.

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