Implementation of Height Measurement System Based on Pressure Sensor BMP085

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Keywords: BMP085, STM32F103RCT6, Linear interpolation method, Altitude measurement.

Abstract. This paper designs a kind of height measurement system based on BMP085 pressure sensor. One STM32F103RCT6 embedded chip is used as the main controller for the system, meanwhile one BMP085 chip is used to measure pressure data. The microprocessor reads the pressure data through the I2C hardware interface, then adopts linear interpolation method to calculate the absolute height based on the relationship of atmospheric pressure and altitude, thereby acquire the relative height. The experimental result shows that the relative height measurement error of this system is 0.4m, thus can achieve high precision requirement.

Introduction

In recent years, the application of Global Positioning System (GPS) in the field of positioning more and more widely. GPS can achieve global real-time positioning when the receiving signal is in good condition, but the positioning accuracy of GPS is greatly reduced because satellite signals are easily blocked under the environment of high-rise buildings or viaducts [1-2]. With the continuous development of sensor technology, the method of height measurement based on Micro Electromechanical System (MEMS) has become a research trend, which can be used to compensate for GPS positioning when the signal is blocked shortcoming. One kind of height measurement method based on BMP085 digital pressure sensor is proposed, and a height measurement system controlled by STM32F103RCT6 microprocessor is designed in this paper.

The Design of Hardware System

The hardware of the height measurement system designed in this paper consists of BMP085 pressure sensor module, STM32F103RCT6 microprocessor, power supply and so on. BMP085 pressure sensor module sends uncompensated barometric pressure and temperature values to the STM32F103RCT6 microprocessor through the I2C (Inter-Integrated Circuit) bus. The microprocessor will compensate for the data, then output pressure, height and other data to PC through the serial port. The system hardware block diagram is shown in Figure 1.

Figure 1. The system hardware block diagram.

BMP085 Digital Pressure Sensor

BMP085 is a low power, high precision MEMS digital pressure sensor produced by BOSCH company in Germany. Its supply voltage range is 1.8 to 3.6V, and the typical value is 2.5V. It consists of a resistive type pressure sensor, a A/D converter and a control unit with E2PROM, and the control
unit is connected with the microprocessor of the mobile device through the I2C bus[3]. Eleven calibration parameters are stored in the E2PROM. These 11 calibration parameters relate to zero drift at reference temperature, temperature coefficient of zero drift, and temperature coefficient of sensitivity for temperature compensation of barometric pressure [4].

The Design of Interface Circuit

The STM32F103RCT6 is an enhanced microcontroller based on the 32-bit ARM Cortex™-M3 RISC core [5], and contains two I2C interfaces (I2C1 and I2C2). The proposed system uses I2C1 interface for communication, and the SCL and SDA of BMP085 respectively connected with the PB6, PB7 pin of STM32F103RCT6. The STM32F103RCT6 microprocessor uses an external 8 MHz crystal oscillator to generate a maximum of 72 MHz master clock frequency via a phase-locked loop. In addition, the SDA and SCL signal lines must be added pull-up resistor Rp(Pull-Up Resistor) actually, for the general I2C bus devices with SDA and SCL pins are open-drain(or open collector) output structure. The pull-up resistor is generally 3 to 10 KΩ, the system uses 4.7KΩ pull-up resistor.

The measured data such as pressure and altitude are output to the PC via the USART1 serial port. The interface circuit schematic diagram between BMP085 and STM32F103RCT6 is shown in Figure 2. In which, U1 is a voltage conversion chip that converts a 5V voltage to a 3.3 V voltage, U3 is the BMP085 pressure sensor, U2 is the SP3232 level converter chip and connected to a PC via a serial port(COM), U4 is STM32F103RCT6 microprocessor that is the core chip of the system.

Software Design of Microprocessor

Microprocessor software flowchart is shown in Figure 3. System initialization is carried out first which includes system clock (RCC) configuration, interrupt vector (NVIC) configuration, GPIO configuration, USART serial port configuration and I2C interface initialization. Then microprocessor reads 11 calibration parameters from the E2PROM, and reads the uncompensated temperature and pressure values from the registers every 10ms, and compensates them with the calibration parameters, and calculates the altitude using the linear interpolation method, and then transfers the temperature, barometric pressure, altitude and other data to PC, and a row of data is displayed on the PC.

The following focuses on data compensation and linear interpolation for the calculation of altitude.

Data Compensation

Since the relationship between altitude and atmospheric pressure is affected by temperature, it is necessary to compensate the barometric pressure value with the temperature value. BMP085 pressure sensor in the E2PROM has the original 11 calibration parameters, which are different for each sensor. Before the first read of pressure and temperature values, microprocessor must read the calibration parameters from E2PROM, and reading the uncompensated temperature and pressure values from the
specified register, then uses the compensation algorithm provided by the BMP085 data sheet to compensate the temperature and pressure values. In this algorithm, microprocessor need to select the operating mode of BMP085 according to the value of OSS (oversampling setting). The measurement accuracy and the conversion time is determined by the OSS value [3]. The OSS value is set to 0 in the microprocessor software of the proposed system, which the low power mode is selected.

Atmospheric Pressure to Altitude Conversion

**Relationship Between Atmospheric Pressure and Altitude.** Assuming the air is the ideal standard atmospheric state, the atmospheric pressure has the following relationship with the altitude [6]:

\[
P_s = P_b \exp \left( \frac{-g_n}{R \times T_b} \times (H - H_b) \right)
\]

\[
h = \frac{r \times H}{r - H}
\]

On above, \(P_s\) is the static atmospheric pressure, which is the pressure measured by BMP085. \(P_b\) is sea level atmospheric pressure. \(H_b\) is sea level height. \(R\) is the gas constant. \(g_n\) is the standard acceleration of free fall. \(T_b\) is the atmospheric temperature of corresponding layer, and \(r\) is the radius of the earth. The values of these parameters are as follows: \(P_b=101325\text{Pa},\) \(H_b=0\text{m},\) \(R=287.05287\text{m}^2/\text{k}\cdot\text{s}^2,\) \(g_n=9.80665\text{ m/s}^2,\) \(T_b=288\text{ K}=15^\circ\text{C},\) \(r=6356766\text{ m}.\) And, \(H\) denotes the height of the gravity potential, \(h\) denotes the geometric height, which is the altitude above sea level. Thus, the altitude \(h\) above sea level can be calculated through the measurement of atmospheric pressure \(P_s\).

The formula for the relationship between atmospheric pressure and altitude is provided in the BMP085 air pressure sensor data handbook. When altitude ranges from 0~11000 m, the altitude calculation formula is as fallow [3]:

\[
Altitude = 44330 \times \left(1 - \frac{P}{P_o} \right)^{\frac{1}{5.255}}
\]
In the formula, the 'Altitude' represents the altitude above sea level which unit is meter, \( p \) is the compensated pressure value, \( p_0 \) is the standard atmospheric pressure, here \( p_0=101325 \text{Pa} \). It can be known from equation (3) that the altitude increases by 8.43m for every 1 hPa decrease in atmospheric pressure. At the same time, it can be found that there is a nonlinear relationship between the atmospheric pressure and the actual altitude. If the microprocessor calculates using the formula directly, the program is more complex for taking up a larger memory space and affecting the operation speed. Therefore, an algorithm is needed to convert the nonlinear relationship between pressure and altitude into a linear relationship, which will be advantageous to calculate the actual height for the STM32F103RCT6 microprocessor [7].

**Linear Interpolation Method for Calculating Altitude.** The basic idea of linear interpolation is as follow: since there are some change rule between two adjacent data points objectively in the static input/output data table of the system, a simple approximation function is constructed between adjacent known points, which value of the approximate function takes discrete data. Then, the function value of the measuring point is calculated according to the function value of the known point [7]. In this paper, the linear interpolation is used to calculate altitude.

Assuming that the system input is \( x \) and \( x_i<x<x_{i+1} \), the linear relationship between the static input/output of the measurement system can be approximated in this interval. That is, \( P(x)=a_0+a_1x \), the point-slope form is follows:

\[
P(x) = y_i + \frac{y_{i+1} - y_i}{x_{i+1} - x_i} \]

The atmospheric Pressure values corresponding to the height of each section between -100 and 20000 m is given in the International Atmospheric Pressure Data Sheet. Here the height data point \( y_i \) is corresponding to the barometric pressure data point \( x_i \). \( P(x) \) is the altitude of the system to be measured. In practice, the first step is to determine the corresponding height range according to the sensor pressure value, then the height is calculated using the linear interpolation method to avoid the complexity of the power operation in a large extent [8].

**Experimental Results and Analysis**

**Experimental Test Results**

The following is a record of the height measure test of a building. The experiment was performed twice, and the two experiments were performed in the same time period. First, the height of the building roof and the altitude of the ground are measured according to the proposed algorithm. Then the relative height of the two heights is the height of the building. In actual measurement of altitude, the 10 groups of the measured data is recorded, here each record is the average value of the 30 measure data once every 2 minutes. The results of the two experiments are shown in Table 1, in which the relative height and actual height of the building are given.

The average height of the 10 sets of relative height data is 13.8m according to the data in Table 1. The actual height of the building is 16.9m through field measurement. Therefore, the relative height error of the system is 0.3 m, which meets the expected accuracy requirement.

<table>
<thead>
<tr>
<th>Times</th>
<th>Target point</th>
<th>Ground</th>
<th>Relative height</th>
<th>Actual height</th>
<th>Measurement error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20.4</td>
<td>6.7</td>
<td>13.7</td>
<td>13.9</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>20.1</td>
<td>6.6</td>
<td>13.5</td>
<td>13.9</td>
<td>0.4</td>
</tr>
<tr>
<td>3</td>
<td>20.0</td>
<td>6.5</td>
<td>13.5</td>
<td>13.9</td>
<td>0.4</td>
</tr>
<tr>
<td>4</td>
<td>19.9</td>
<td>6.4</td>
<td>13.5</td>
<td>13.9</td>
<td>0.4</td>
</tr>
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<td>5</td>
<td>20.1</td>
<td>6.5</td>
<td>13.6</td>
<td>13.9</td>
<td>0.3</td>
</tr>
<tr>
<td>6</td>
<td>20.2</td>
<td>6.6</td>
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<td>13.9</td>
<td>0.3</td>
</tr>
<tr>
<td>7</td>
<td>20.4</td>
<td>6.4</td>
<td>14.0</td>
<td>13.9</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Error Analysis

Although resulting in the calculated absolute altitude height is not stable and existence larger error because the atmospheric pressure could be affected by the weather and temperature changes, the relative height values calculated in this experiment can be used to counteract this error.

Assuming that the building’s altitude measurement is \( H_1 \), the actual value is \( H_1' \), and the absolute height noise error is \( \Delta h_1 \), the noise error due to environmental factors such as weather and temperature is \( \Delta h \). whereas the altitude measurement of the ground is \( H_2 \), the actual value is \( H_2' \), and the absolute height noise error is \( \Delta h_2 \), the noise error due to environmental factors such as weather is also \( \Delta h \). Then the formula is given as follow:

\[
H_1 = H_1' + \Delta h_1 + \Delta h, \quad H_2 = H_2' + \Delta h_2 + \Delta h 
\]

Then the height of the building relative to the ground \( H \) is:

\[
H = H_1 - H_2 = H_1' - H_2' + (\Delta h_1 - \Delta h_2)
\]

The relative height noise error is \( (\Delta h_1 - \Delta h_2) \) from equation (6), so it can be known that part of the absolute height error due to weather and other environmental factors is offset. But when \( \Delta h_1 \) is positive maximum and \( \Delta h_2 \) is negative maximum, the relative height noise error may reach twice of the original absolute height noise error.

Summary

The height measurement system based on barometric sensor BMP085 is proposed in this paper. By means of the relationship between the atmospheric pressure and the altitude, the linear interpolation method is used to calculate the altitude, which reduces the complexity of the calculation. The experimental results show that the relative height error of the system is 0.4m and the proposed measuring method has some effective applicability. The system has the advantages of small size, high precision, easy to carry, etc. It is suitable for installation in mobile equipment, and can be applied to many fields and has a wide application prospect such as military, industry and commerce.

Acknowledgement

This work was supported in part by Zhejiang public welfare technology application research project No.2015C33023, 2017 Zhejiang college students science and technology innovation activity plan.

References


