Data Processing Method and Experiment of Barometric Altimeter Based on Kalman Filter

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Abstract. It is an effective method to measure the height using a barometric altimeter, but there exists a larger noise defect. The principle of measuring height using the barometric altimeter is elaborated, and the measure noise is analyzed. In order to suppress the height measure noise, the Kalman filtering method is adopted. The state model of Kalman filter is constructed and the state recursive equations are given out. An experiment is done to measure the different floor height in the dynamic and static condition, and the results show that the Kalman filtering evaluation value can track the height change in real time and suppress obviously the height measure noise, and the noise fluctuation reduces to 1/4 of the raw data.

Introduction

In the three-dimensional navigation and positioning system, height is one of the most important three parameters, which denotes the vertical position. At present, there are three main methods of measuring height, such as mechanical pressure gauge, GPS system[1] and the barometric altimeter [2]. The mechanical pressure gauge has a complex structure and the data cannot be processed directly. GPS is a mature system that can measure the altitude, and there are many integrated modules available on the market. However the height measure error is large because of the asymmetrical earth shape. It is a promising approach using a barometric altimeter to measure atmospheric pressure and calculate height. Based on the MEMS technology[3], the barometer is of a little volume, low power and high accuracy, so that it is convenient to take. But the uneven temperature distribution and the flow velocity change of air will introduce the large measurement noise. In order to suppress the noise and increase the accuracy and stability, some measures must be taken. The first order lag filtering and polynomial correct methods are commonly used filtering methods[4-5], but they are not optimal in mathematics. In the article, as an optimal evaluate method, Kalman filter is used to filter the noise and tracks the real signal value[6].

Principle of Barometric Altimeter and Characters

The atmospheric pressure sensor is a piezoresistive sensor that can sense the atmospheric pressure changes. Commonly used pressure sensors are MOTO’s MPX4115A and BOSCH’s BMP085, the former outputs analog signal, which is necessary to further digital processing; the latter outputs digital signal, which can be directly received by the microprocessor. In this article, the new generation of digital atmospheric height sensor of BMP180 is used for sample the pressure. Next, the relationship between the atmospheric pressure and height is to be analyzed.

According to Boltzmann distribution law, assuming that the air is an ideal gas, the temperature is equal at different heights and the acceleration of gravity does not change, the relationship between height variation and atmospheric pressure can be represented as the following formula.
\[ h = \frac{kT}{mg} \ln \frac{P_0}{P} \]  

where, \( k = 1.3807 \times 10^{-23} \text{J/K} \), the Boltzmann distribution constant; \( m = 29 \times 1.67 \times 10^{-27} \text{kg} \), the air quality; \( g = 9.8 \text{N/kg} \); \( P_0 = 1013.25 \text{hPa} \), sea level pressure at 15°C; \( h \) is the height to be calculated, m; \( P \) is the pressure to be measured, hPa. The curve of atmospheric pressure change with height can be denoted as following figure 1.

From Equation (1) it can be seen that the height is calculated from the local atmospheric pressure relative to sea level atmospheric pressure. When the sea level atmospheric pressure changes due to weather, the atmospheric pressure at the measurement point will follow the change. However, the height of the measured point with respect to a ground plane is a certain difference value, so the relative height can be measured. As the atmospheric flow velocity is not uniform or the temperature is not balanced, the barometric pressure sensor measurement data will introduce some stochastic noise, even jump, resulting in instability. Therefore the measure noise must be filtered out.

**Height Data Processing Using Kalman Filter**

**Kalman Filter State Evaluation Model**

Kalman filtering is a state evaluation of stochastic processes proposed by the mathematician Kalman in 1960, which utilizes the linear system state equation, through the system input and output observation data, to achieve the optimal evaluation for the system state\(^7\)\(^-\)\(^8\). The state evaluation transforms the parameter measurement problem into state observation and state evaluation, that is, from observable variables to the evaluated value of unpredictable variables.

Let’s introduce a discrete control processes system, which can be described by a linear stochastic system state equation

\[ X(k) = AX(k-1) + W(k) \]  

(2)

Where, \( X(k) \) is the system state at time \( k \); \( A \) is the system parameter; \( W(k) \) is the system noise, and the covariance is \( Q \).

The system measured value can be denoted as

\[ Z(k) = HX(k) + V(k) \]  

(3)

Where, \( Z(k) \) is the measured value at time \( k \); \( H \) is the measured system parameter; \( V(k) \) is the measured noise, white noise, and the covariance is \( R \).
Kalman Filter State Evaluation Algorithm

Kalman filter algorithm is based on the previous state evaluation, according to the current moment of measurement, recursive the current state evaluation. Based on the system state model, to predict the next state of the system.

The predicted current state is

\[ X(k|k-1) = AX(k-1|k-1) \]  \hspace{1cm} (4)

Where, \( X(k|k-1) \) is the predicted result using the previous state; \( X(k-1|k-1) \) is the optimal result of the previous state.

Next, to update the covariance corresponding to \( X(k|k-1) \)

\[ P(k|k-1) = AP(k-1|k-1)A' + Q \]  \hspace{1cm} (5)

Where, \( P(k|k-1) \) and \( P(k-1|k-1) \) are the covariance corresponding to \( X(k|k-1) \) and \( X(k-1|k-1) \) respectively; \( A' \) is the transpose of \( A \).

Let's calculate the Kalman gain before updating the measurement process. The Kalman gain is

\[ K_e(k) = P(k|k-1)H'(HP(k|k-1)H' + R)^{-1} \]  \hspace{1cm} (6)

The optimal evaluated value at current time is

\[ X(k|k) = X(k-1|k-1) + K_e(k)(Z(k) - HX(k|k-1)) \]  \hspace{1cm} (7)

Finally, to update the covariance corresponding to \( X(k|k) \)

\[ P(k|k) = (I - K_e(k)H)P(k|k-1) \]  \hspace{1cm} (8)

Formulas (4) to (8) forms the entire recursive process of the Kalman filter.

Height Data Processing Using Kalman Filter

According to the relationship between height and barometric pressure, height can be calculated by the barometric pressure. The Kalman filter is used to evaluate the height optimal value.

First, the height data is taken as the measured value and constructs the height state equation, the current height optimal value is evaluated from the optimal result of the previous state and the current measured value. Then, the last evaluated height value and the current measured value are substituted into the formula (4). By the gradual recursion of the formulas (4) to (8), to calculate the current state and the corresponding covariance, calculate the Kalman gain, and update the state and the corresponding covariance. Through continuous cycle of recursion, the larger noise is filtered out, and the optimal height value is evaluated accurately.

Experiment and Analyzing

In order to verify the effectiveness of Kalman filtering, selecting the 4 layer building in Zhengzhou as the research object, to measure dynamically the height of each floor from high to low using the barometric altimeter; and then to build the differential state model using the measured floor data; By recursive processing of Kalman filtering, the evaluated data can be obtained.

The original data and Kalman filtering data is outputed to PC through the serial port, drawing graphics and forming the ladder-like curve corresponding to each floor height, as shown in figure 2, in which the sampling frequency is 5 data per second.
As can be seen in figure 2 above, the measured height decreases regularly with the floor lowering. In other words, Kalman filter can follow the change of the raw data in real time, and the measured data noise obviously reduces after Kalman filtering compared to before.

In the static case, a fixed height is measured for nearly one hour. Affected by the atmospheric pressure change, the measured height causes a small fluctuation, as shown in Figure 3. For the smoother sampling points 3000~5000, with the Kalman filter processing, the sampling data change range reduces to 0.5 m from 2 m before filtering; the standard deviation reduces to 0.1515 m from 0.4416 m before filtering, as shown in Figure 4. It can be seen that Kalman filtering has a strong suppression effect on stochastic noise, and the height data noise fluctuation reduces to 1/4 of the raw data.

Conclusions

In this paper, through analyzing the commonly used method of measuring the height, it is considered as a promising approach to measure height using the barometer. The defect is that it has a larger measure noise. In order to suppress the noise of barometric altimeter, the Kalman recursive filtering method is used. A state model is constructed and the state updating and recursion equations are given out. An experiment to measure the floor height of a building is done in dynamical and static condition, and the results show that the evaluating results of Kalman filtering can track the height change in real time and suppress obviously the measure noise, and the noise reduces to 1/4 of the raw data.
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