Pressure Sensor Data Processing for Vertical Velocity Measurement

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ABSTRACT

The paper describes design and realization of a sensor system for vertical velocity measurement using pressure sensor. The system solution is based on the basic equation for altitude calculation, including the effects of temperature. A linear interpolation function is used to speed up the altitude calculation. Problem of nonlinearity due to the exponential function of air pressure versus altitude is discussed. The transient analysis of the electronic circuit connection was used for vertical velocity simulation. A new method for distortion correction was used, for algorithm simplification and system linearization. New assets are represented by the new electronic circuit blocks. An electronic circuit was designed, taking care of the mathematical functions including compensation functions. The type MPX4115 pressure sensor was used in the system. The system is controlled by an ATMega16 microprocessor.

Keywords: vertical speed, pressure, nonlinearity, altitude, sensor, microprocessor

1 INTRODUCTION

The measurement of vertical velocity is necessary for different use. Typically methods are used in devices that measure the air planes rising or falling. There are several ways how to evaluate the vertical velocity. The solutions are based on principle of evaluating the change of an atmospheric pressure. This is relatively simple method but it has also some drawbacks that can not be omitted. First of all it is a nonlinearity of the exponential dependency of the pressure versus altitude. Also the air temperature plays a significant role in this method.

Compensated methods for measuring the vertical velocity embrace the vertical velocity correction. The correction is calculated from the horizontal velocity change which induces another vertical velocity change. The acceleration is evaluated in the horizontal direction using the information about the dynamic pressure [1]. It means that the kinetic energy (acceleration) is converted to corresponding change of the potential energy (altitude). Vertical velocity thus can be corrected by this value.

No-compensated simple methods are based on measuring the vertical velocity using the information about the change of the static air pressure. In regular time instances the absolute air pressure values are measured. The air pressure difference related to the time interval determines the vertical velocity.

2 PRINCIPLE OF ALTITUDE CALCULATION

The dependence which evaluates the vertical velocity is derived from the exponential form of the barometric equation which relates the air pressure versus the altitude

$$p(z) = p_o e^{-\frac{z}{z_o}}, \qquad z_o = \frac{kT}{gm_o} \tag{1}$$

where p(z) is the air pressure in altitude z, p_o is the sea level altitude air pressure, T (K) is the temperature. Other elements in the equation are constants, m_o (-), g ($m \cdot s^{-2}$), k ($J \cdot K^{-1}$). The exponential element e^{-z} in the equation can be converted to the Taylors polynomial. Omitting the powers from this polynomial bigger then one, it can be found

$$\frac{dz}{dt} = -\frac{z_o}{p_o}\frac{dp(z)}{dt} \tag{2}$$

If the air pressure sensor with the voltage output v(p) is used and if the output voltage is direct proportional to the pressure p(z) it can be obtained simple equation for the vertical velocity – equation 3.

$$\frac{dz}{dt} = -\frac{z_o}{p_o}\frac{dv(p)}{dt} \tag{3}$$

This equation is valid for no compensated method of the vertical velocity measurement. Dependency according the equation 3 can be realized using the differentiator. No-linearity compensation can be done using the circuit with the inverse characteristic (logarithmical circuit). It is essential to solve the temperature compensation as well. The circuit solution is depicted on figure 1. The first stage is the temperature compensated logarithmic circuit which realizes linearization of the input exponential voltage. Following circuits are the amplifier and the differentiator.

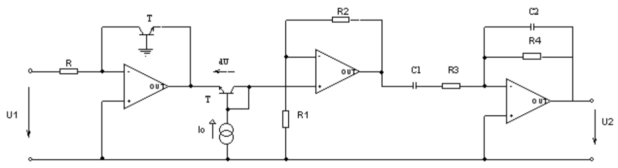


Figure 1: Temperature compensated circuit for the vertical velocity measurement (static measurement).

There can be expressed the output voltage from the simple differentiator with the feedback diode as follow

$$v_2 = -\frac{kT}{q} ln \frac{v_1}{Ri_s} \tag{4}$$

where R is the input resistor of the differentiator and i_s represents the current given by the diode technological parameters. Transfer characteristic according (4) depends on the temperature. The characteristic have the voltage shift c for different temperatures. The temperature dependency for the current i_s causes small distortion. Output voltage

$$v_2 = f(v_1) + c \tag{5}$$

Differentiating this equation the constant c disappears. This allows to use the feedback diode (distortion is thus given only by the temperature dependency of the technological factor i_s). The transfer characteristic according the equation (4) is very flat for higher input voltages v_1, so the sensitivity is small. The sensitivity can be increased using the amplifier which multiplies the characteristic by the constant. To obtain more precise calculation of the altitude the equation (1) can be modified to the form (6)

$$z(p) = \frac{T_o}{T_r}\left(1 - \left(\frac{p}{p_o}\right)^{\frac{T_r \cdot R}{Mg}}\right) \tag{6}$$

where z is the altitude, p is the air pressure, p_o=101.325 kPa is the sea level air pressure according the ISA, Tr=0.0065 K·m^{-1} is the temperature gradient according the ISA, R=8.3 JK^{-1}mol^{-1} is the universal gas constant, M=0.02894 kg·mol^{-1} is the air molar mass, g=9,81 m·s^{-2} is the gravitational constant, T_0=288.15 K is the temperature at the sea level according the ISA. Transient analysis of the circuit from the figure 1 with temperatures 273 K and 333 K indicates that the error can rise up to 20%. That is why it is essential to compensate this no linearity. Software solution and microcontroller were used for the compensation of this no linearity.

3 DESIGN OF SYSTEM

The system consists of several blocks. The analog differentiating network delivers the differentiation peaks at its output. The peaks are read off by the microprocessor. At the same time, the altitude above sea level is measured and its value applied for correction of the measured peak. The design must care for a quick and accurate measurement of the differentiation peaks. The parameters given in [2] were taken as the design basis. The manufacturer gives the output voltage dependence for the MPX4115 pressure sensor as [3]

$$v_{out} = V_{cc}(c_1 p - c_2) \tag{7}$$

where V_{cc} is the supply voltage and p is the pressure, c_1=0.009 a c_2=0.095. By arrangement of the equation we can obtain the formula for pressure

$$p = \frac{\frac{v_{out}}{V_{cc}} + c_2}{c_1} \tag{8}$$

By setting the constants into (6) and arrangement we can obtain the formula

$$z(p) = \frac{T_o}{T_r}\left(1 - \left(\frac{p}{p_o}\right)^{\frac{T_r \cdot R}{Mg}}\right) = c_3\left(1 - \left(\frac{p}{p_o}\right)^{c_4}\right) \tag{9}$$

where the constant c_3=44330.8 and c_4=0.190261. When the ATMega 16 processor is used, a 10-bit converter is available, its resolution can be increased to 12 bits [4].

Derivation of the correction data. The values read for altitude are used for the differentiation peaks correction. Under the assumption of direct proportionality, the differentiating network output (the differentiation peaks value) can be written as

$$v_{peak} = c_5 \frac{dv_{out}}{dt} \tag{12}$$

where v_{peak} is the output voltage of the differentiating network and c_5 is a constant. The equation (7) applies for the pressure sensor output voltage, and (12) can then be arranged to the form

$$v_{peak} = c_6 \frac{dp}{dt} \tag{13}$$

where c_6 is a constant. The following formula applies to the vertical velocity

$$\frac{dz}{dt} = \frac{dz}{dp}\frac{dp}{dt} \tag{14}$$

where the dp/dt term cornensponds to the v_{peak} measured voltage value. To express the dz/dp term, we start with the equation (6), and differentiate it over pressure

$$\frac{dz}{dp} = c_7 p_o^{c_8 p^{-c_8}} \tag{15}$$

where the values of the calculated constants after setting in are c_7=83.241276 and c_8=0.809739. By setting the converted pressure formula into (15) we get

$$\frac{dz}{dp} = c_7 \left(1 - \frac{z}{c_3}\right)^{-c_9} \tag{16}$$

By setting the converted equation (6) into (14) we get the formula for the actual dependence of vertical velocity on the differentiation peaks and on the altitude as

$$\frac{dz}{dt} = \frac{v_{peak}}{c_6} c_7 \left(1 - \frac{z}{c_3}\right)^{-c_9} \tag{17}$$

Marking one part of the formula (16) as a function F(z), we can use this function to generate a table with altitude values and values of the F(z) function as the corresponding corrections

$$F(z) = \left(1 - \frac{z}{c_3}\right)^{-c_9} \tag{18}$$

The resulting formula for the real vertical velocity ishas the form

$$\frac{dz}{dt} = c_7 \frac{v_{peak}}{c_6} F(z) \tag{19}$$

where the F(z) values relating to the particular altitude are stored in the table.

3.1 Hardware of sensor system

An electronic circuit was designed, taking care of the mathematical functions including compensation functions – figure 2. The analog differentiator processes the signal from the pressure sensor. Differentiation peaks appear at its output at nonzero velocities, they are conveyed to the microprocessor through an amplifier. The type MPX4115 pressure sensor was used in the system [3]. The whole system of measurements and calculations is controlled by an ATMega16 microprocessor. The converter is used to read-in the pressure sensor and differentiator data. A display is used to present the measured values. The system is complemented by an audio module connected to the microprocessor. The system communicates with a PC by means of a TTL to RS232 signal level converter.

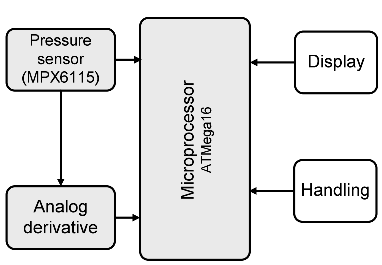


Figure 2: Block diagram of the realized sensor system.

A network with a time constant of 240 ms was used as the analog differentiating circuit. The differentiation peaks at the output are amplified by a non-inverting circuit using a Type-1666 amplifier. In the design it is necessary to pay attention to the parameters directly influencing the differentiating network quality (minimum voltage offset, minimum voltage offset drift, minimum supply current).

A microprocessor Atmel ATMega 16 with a 16 kB program memory was used. Clock signal is controlled by an 8-MHz oscillator, it is also possible to use an external 16 MHz oscillator. The microprocessor contains an 8-channel 10-bit AD converter, used to read data from the differentiating network of the pressure sensor. The microprocessor chip can be programmed in the design sample through the SPI and JTAG interfaces. Correct bypassing must be properly designed of the supply and reference voltages. Correct bypassing has a direct influence on the measurement accuracy.

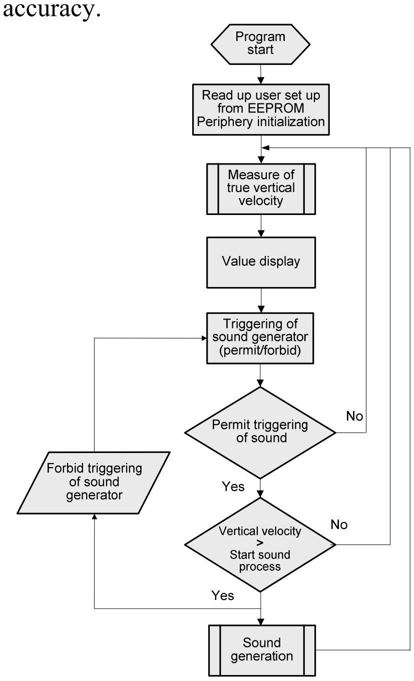


Figure 3: Main system algorithm.

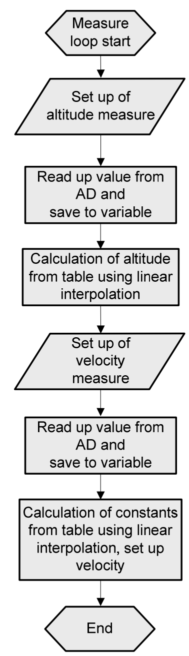


Figure 4: Real vertical velocity algorithm.

3.2 Software of sensor system

The measurements, calculations and other system activities are controlled by the specially designed software using several sub-processors. The main system operation algorithm is shown in figure 3. First, the real vertical velocity value is measured, then it is compared to the threshold rise and descent values. Then the calculations, comparisons and evaluation follow. A second channel is set up in the microprocessor control registers for the AD converter. Using a linear interpolation, the altitude is calculated from the measured value of the converter. The first channel of the AD converter is used for the velocity measurement. Using linear interpolation, the supplementary correction value is calculated from the altitude, and according to the equation that was derived, the real vertical velocity is calculated – figure 4. The drivers for all peripheral circuits were designed in the C language (display, AD converter, control elements etc.).

4 RESULTS OF THE WORK

Certain problems had to be solved due to the integrated AD converter used. To improve the measurement accuracy it is possible, for instance, to use data reading in the low-power microprocessor mode. This process is treated by means of software. A linear interpolation function is used to speed up the altitude calculation from the values read by the AD converter. The calibration of the designed system is performed by means of the SPICE program – figure 5 (simulation of the differentiator response.

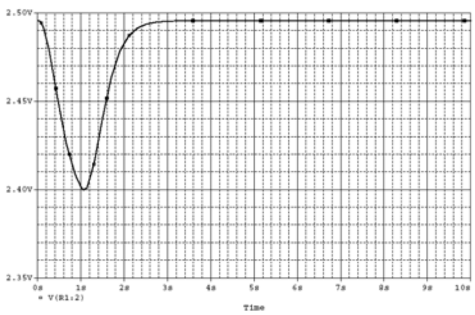
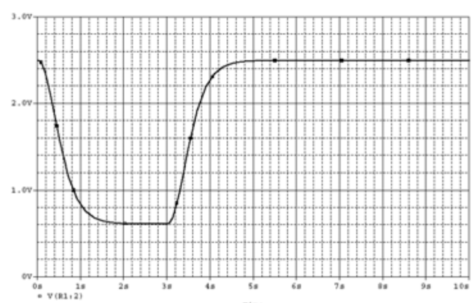
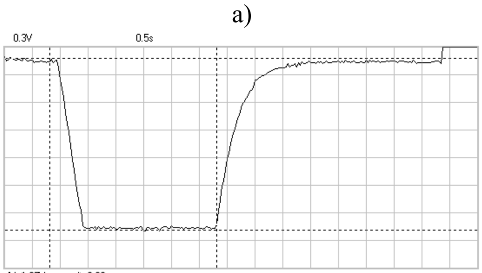


Figure 5: Simulation of the differentiator response corresponding to 1 ms^{-1} velocity.



a)



b)

Figure 6: The response form of the calibration section for the velocity 20 m·s^{-1}, a) simulated, b) measured.

The system designed includes distortion compensation, the program takes care of output information linearity. The system is capable to indicate a vertical velocity 0.1 m·s^{-1}. The altitude measurement is auxiliary information for the vertical velocity calculation, the measurement accuracy is 1 m. The system also contains a calibration section. The simulated and measured response form of the calibration section for the velocity 20 m·s^{-1} is shown in figure 6. A trapezoidal signal generator, series-connected with a controlled D.C. source, was used for calibration. A 12-bit DA converter MCP4921 was connected to the ATMega8 processor through the SPI interface. The implemented software makes possible to vary the parameters of the leading edge of the trapezoidal signal generator (corresponding to different velocities) as well as the D.C. level (corresponding to movements in different altitudes).

5 CONCLUSIONS

Problem of nonlinearity due to the exponential function of air pressure versus altitude is discussed in detail. The transient analysis of the electronic circuit connection was used for vertical velocity simulation. An electronic circuit was designed, taking care of the mathematical functions including compensation functions. The type MPX4115 pressure sensor was used in the system. The whole system of measurements and calculations is controlled by an ATMega16 microprocessor. The system communicates with a PC by means of a TTL to RS232 signal level converter. The measurements, calculations and other system activities are controlled by the specially designed software using several sub-processors. Using a linear interpolation, the altitude is calculated from the measured value of the converter. The drivers for all peripheral circuits were designed in the C language (display, AD converter, control elements etc.).

6 ACKNOWLEDGEMENT

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