MULTISENSORS METEOROLOGICAL SYSTEM BASED ON THE RASPBERRY PI

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The document discusses the design and realization of multi-sensors meteorological system based on the Raspberry Pi. The document consists of four parts. The first part deals with meteorology in aviation. The second part describes the sensors used in the weather station. The third part describes design and construction of electronic circuits as well as housing of the sensors and software to the weather station. The last part discusses the usage of the weather station. The main contribution of this work is to verify the hypothesis of using the Raspberry Pi platform in multi-sensors systems.

Key words: meteorology, weather station, Raspberry Pi

1 INTRODUCTION

The issue of computer platforms based on ARM architecture processors receives increasing attention in the world. For the last three years there have been several companies and organizations dedicated to the development of such platforms. One of these computer platforms is the Raspberry Pi. A large group of enthusiasts was formed around this computer platform, which shares their experience with the Raspberry Pi and is involved in countless amounts of articles, manuals and various applications. The aim of this work is to design and build a multisensory weather system based on the Raspberry Pi, designed to collect and store the information about weather, and thus to verify the validity of the hypothesis of using this platform in multisensory systems.

2 METEOROLOGY IN AVIATION

Aviation meteorology is a branch of applied meteorology. The observation of processes and meteorological elements that affects directly or indirectly the air traffic are the main area of interest in aviation meteorology.[1][2] It also deals with the application of knowledge gained from other fields of meteorology, which utilizes the improved forecasts, streamlining operations and increasing security.

The task of aeronautical meteorology is releasing of special weather forecasts. The reports of these forecasts are broadcasted using a specialized code report such as Q-codes or as example:
METAR – periodic weather report,
SPECI – special weather report,
TAF – terminal aerodrome forecast,
ARFOR – area forecast,
ROFOR – route forecast,
ARMET – high altitude wind and temperature forecast,
GAFOR – general aviation forecast and etc.

The aviation meteorology helps to the flight crew and the air traffic control services to get an overview of the current or expected developments of weather and to customize flights according to it. The aviation meteorology can be subdivided into soaring meteorology and meteorology of civil and military aviation. The aviation meteorology uses knowledge from synoptic meteorology, atmospheric aerodynamics, physical and static meteorology, but also climatology.[3]

3 METEOROLOGICAL SENSORS

This section describes the sensors that have been selected for use in the weather station based on the search work aimed to their accuracy, sensitivity and availability in the market.

TMP102 is a two-wire, serial output temperature sensor available in a tiny SOT563 package. Requiring no external components, the TMP102 is capable of reading temperatures to a resolution of 0.0625 °C (12 bits) and accuracy of 0.5 °C. The sensitive element is formed by the PN junction of the heat sensitive diode. The TMP102 features SMBus and two-wire interface compatibility, and allows up to four devices on one bus. It also features an SMB alert function. The TMP102 is ideal for extended temperature measurement in a variety of communication, computer, consumer, environmental, industrial, and instrumentation applications in temperature range from -40 °C to +125 °C.

BMP180 is a new generation of high precision digital pressure sensors for consumer applications. The ultra-low power, low voltage electronics of the BMP180 is optimized for use in mobile phones, PDAs, GPS navigation devices and outdoor equipment. Due to a low noise level the altitude can be measured with the precision of 0.17 m in the advanced resolution mode. The I^2C interface allows easy system integration with a microcontroller. The BMP180 is based on piezo-resistive technology for EMC robustness, high accuracy and linearity as well as long term stability. The BMP180 consist of a piezo-resistive sensor, an analog to digital converter and a control unit with EEPROM a serial I^2C interface. The BMP180 delivers uncompensated value of pressure and temperature. The EEPROM stores 176 bits of individual calibration data that are used to compensate offset, temperature dependence and other parameters of the sensor.

SHT75 is a member of the Sensirion's family of relative humidity and temperature sensors. The sensors integrate sensor elements plus signal processing in a compact format and provide a fully calibrated digital output. A unique capacitive sensor element is used for measuring relative humidity while temperature is measured by a band-gap sensor. The applied CMOSens® technology guarantees excellent reliability and long term stability. Both sensors are seamlessly coupled to a 14-bit analog to digital converter and a serial interface circuit. This results in a superior signal quality, a fast response time and insensitivity to external disturbances (EMC). Each SHT75 is individually calibrated in a precision humidity chamber. The calibration coefficients are programmed into an OTP memory on the chip. These coefficients are used to internally calibrate the signals from the sensors. The 2-wire serial interface and internal voltage regulation allows easy and fast system integration. The SHT75 also has little demand on power consumption.

AS5040 is a contactless magnetic rotary encoder for accurate angular measurement over a full turn of 360°. It is a system-on-chip, combining integrated Hall elements, analog front end and digital signal processing in a single device. To measure the angle, only a simple two-pole magnet, rotating over the center of the chip, is required. The magnet may be placed above or below the IC. The absolute angle measurement provides instant indication of the magnet's angular position with the resolution of 0.35° = 1024 positions per revolution. This digital data are available as a serial bit stream and as a PWM signal. Furthermore, a user-programmable incremental output is available, making the chip suitable for replacement of various optical encoders. An internal voltage regulator allows the AS5040 to operate at either 3.3 V or 5 V supplies.

ADXL345-EP is an extended performance version of the ADXL345, which is a small, thin, ultralow power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16 g. The digital data output is formatted as a 16-bit twos complement and accessible through either a SPI or I^2C digital interface. The ADXL345-EP is well suited for extended temperature range industrial and aerospace applications. It measures the static acceleration of the gravity in the role of a tilt sensor, as well as dynamic acceleration resulting from motion or shock. Its high resolution (3.9 mg/LSB) enables measurement of inclination changes less than 1.0°. Several special sensing functions are provided. Activity and inactivity sensing detect the presence or lack of motion by comparing the acceleration in any axis with user-set thresholds. The tap sensing function detects single and double taps in any direction. The free-fall sensing detects if the device is falling. These functions can by mapped individually using two interrupt output pins.

4 RASPBERRY PI

The Raspberry Pi is a low cost, single-board computer developed by The Raspberry Pi Foundation with the intention of promoting the teaching of basic computer science in schools. The Raspberry Pi has a processor based on the ARM architecture of the ARM Limited company. These processors are now widespread in mobile and embedded devices (mobile phones, PDA, iPod, etc.). However, these processors have found their places in servers with low power consumption. The main advantage of these processors is the ratio of the performance to power consumption. Currently, performance of the ARM architecture based processors almost reaches a level of x86 architecture based processors, but with lower power consumption requirement.

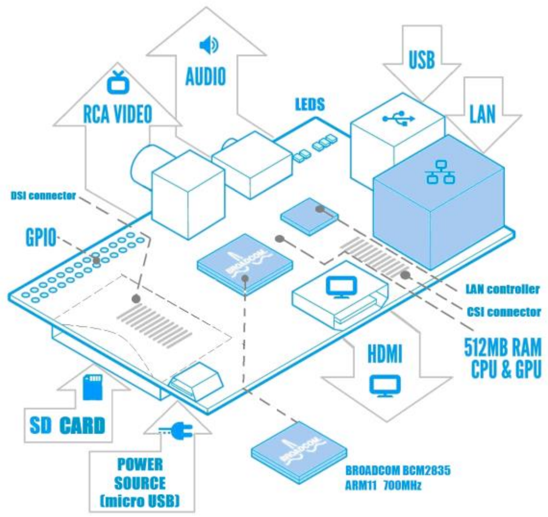

Figure 1 The Raspberry Pi

Center of the Raspberry Pi is equipped with SoC, which includes CPU, GPU, DSP, SDRAM and one USB port. Processing of the information is ensured by the ARM architecture based ARM 1176JZF-S 700 MHz processor. The Broadcom VideoCore IV chip is available to video processing. It easily handles with HD video, which means that with the suitable program the Raspberry Pi can be used as a home theater.

The Raspberry Pi has 256 MB of RAM in the A version and 512 MB in the B version. However, it is shared with the GPU. The A version has also an Ethernet controller which creates the possibility to connect the Raspberry Pi to the internet.

5 CONSTRUCTION OF WEATHER STATION

5.1 Electronic circuits

For the design of electronic circuits was used Eagle CAD program, which is a program for creating electronic schemes and design of printed circuit boards. Design of electronic circuits is based on the catalogue sheets of used sensors. Four PCBs containing all the necessary electronics for weather station were produced.

The first PCB includes a 3.3 V voltage stabilizer, which powers all sensors of the weather station. The voltage stabilizer was used, because the current load of the 3.3 V branch of the Raspberry Pi must not exceed 50 mA. As the voltage stabilizer was used APE1117 in SOT223 SMD housing. Maximum current load of this stabilizer is 1 A. 100 µF filter capacitors are placed on the input and output of the stabilizer. The stabilizer is powered from the 5 V branch of the Raspberry Pi, which is powered directly from the power adaptor.

In addition, first PCB consists of a circuit for the optic sensor CNY70, which senses angular velocity of the Robinson's cross. The CNY70 is powered by 3.3 V, the resistor R1 limits current for the light source to 33 mA. The detector has also limited current by 20 kΩ R2 resistor to 165 μA. Because the Raspberry Pi is a digital computer and contains no analog to digital converters, it was necessary to include circuits for these converters. Converters are also placed on the first PCB. Two MCP3021 analog to digital converters were used; one for the optic sensor CNY70 and another for the photodiode which is used for sunrise and sunset sensing. The MCP3021 is a 10-bit single-channel analog to digital converter, equipped with the I^2C serial communication interface. Its maximum current consumption is 250 μA and maximum sample rate 22.3 ksps. The circuit for A/D converter is simple and consists of 10 μF filter capacitor and two 10 kΩ pull up resistors R3 and R4.

The magnetic rotation encoder AS5040 is placed on the second PCB and contains only one 10 μF filter capacitor. The AS5040 has three types of digital data outputs – PWM, incremental and serial data output. In our case serial data output was used and therefore other output pins were unused.

On the third PCB BMP180, TMP102 and SHT75 are placed. Wires from the Raspberry Pi's +5 V power source are connected into this PCB and also wires of the I^2C and serial communication interface of sensors.

5.2 Housing of the electronics

It was necessary to place the electronics and sensors to the housing, to protect them against direct weather. However, the housing of the sensors must not restrict air flow as source of information. The moveable parts, like the Robinson's cross which senses wind speed and the direction wing which captures wind direction are also placed on the housing. The uniqueness of this solution lies in the integration of all sensors in a single housing. No other weather station that I have found has this solution. The entire housing was designed in the CAD program. The main parts were turned from a plastic rod with the 40 mm diameter. Drawings of individual parts are listed in the annexes. Rods, which connect semi spherical surfaces of the Robinson's cross with the top cover and direction wing with the bottom cover are made from a steel wire with the diameter of 2 mm. The direction indicator's wing is made from a plastic plate with the thickness of 1 mm. The bottom part is with the bottom cover connected with a shaft with the diameter of 4 mm. The bar magnet is firmly attached on the shaft inside of the bottom part. Magnet is made of neodymium and is diametrically magnetized perpendicularly to the shaft. The magnet was chosen in accordance with the datasheet of the magnetic rotary encoder AS5040. The encoder is placed in the bottom part of the housing at the distance of approximately 1 mm from the magnet and through it the wind direction is sensed.

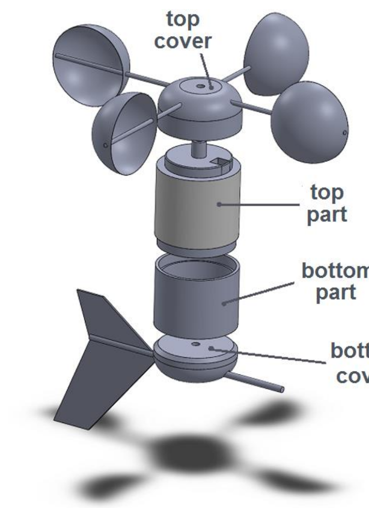

Figure 2 Housing of weather station

The holes drilled in the bottom part of the housing provide information about dynamic temperature, pressure and humidity changes of air. The holes are drilled at an angle of 45 °, so no rain water can flow inside.

5.3 Software

The main function of the program starts with the setup function. The setup function verifies if the program runs with the super-user permission (SUDO). The next step is to initialize wiringPi library using command *wiringPiSetupGpio()*. This command initializes the numbering scheme of the wiringPi library of the gpio pins. The wiringPi scheme replaces numbering of Broadcom processor's datasheet numbering, with virtual numbering of the pins.

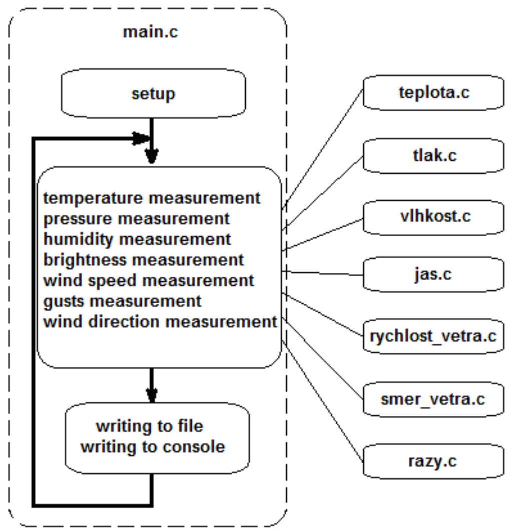

Figure 3 Program flow chart

The setup function continues by creating file descriptors for sensors that has the I^2C communication interface. The following command reads and stores calibration values from registers of BMP180. The measured values are stored in the file which is created at the end of the setup function. The created file is named by the current date. The file is created every new day. At first a column name is written into the file. If the setup function is successfully executed the program continues with the communication with the sensors. For a better clarity of the program all sub-functions of the communication with the sensors are stored in files with the extension .c and are included at the beginning of the program. When communication with the sensors is ended all values are stored in the previously created file and are at the same time printed into a console. The values of every cycle are printed into the console window. Every minute the values are written into the file. For writing in one-minute intervals, the sub-function is created.

6 PRESUME USE OF WEATHER STATION

Map available by Slovak Hydrometeorological Institute contains weather information from weather station that are located at the airports, towns and villages. Deployment of a larger number of weather stations in a given territory would enable to create more detailed map of weather.

Such a detailed map would be a good source of information for sport or recreation flying such as paragliding. Available weather information would also be appreciated by aeromodelers. For open air events like music festivals could be possible to check the current weather around a venue of the festival.

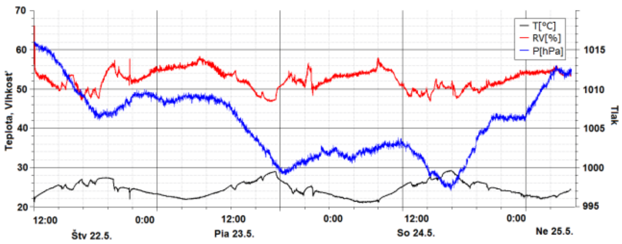

Figure 4 Three-day measurements

The figure 4 shows the three-day test measurements of the temperature, humidity and pressure, what proves the correct function of the weather station. By releasing of this work, everyone who wants to have this weather station could make it by own and possibly even to improve it later. It is necessary to think about the fact that not everyone has available the necessary tools for making the weather station as well as not everyone has the necessary skills. Therefore, it is suitable to distribute paid versions of finished meteorological stations. By selling of finished products that are ready for use, it would by possible to obtain additional funds for further expansion and improvement of this project. By creating additional software, which will automatically connect each new weather station into the internet network and into a global system, it would create useful information network. Such information network would be an excellent for example for tourists who would be able to see what weather is around a resort that they are just going, but also for example in the vicinity of the hotel where they will be staying.

7 CONCLUSION

The main contribution of this work was to design and realize a multi-sensors module for collecting and recording of meteorological information and software in C/C++ platform for the Raspberry Pi. The design of the weather station and the design of necessary electronics were realized in CAD programs. After the completion of the multi-sensors meteorological system the appropriate program was created for acquiring and storing the information from sensors in a form of text documents. Design and construction of this weather station has been achieved by the method of analysis and synthesis of available information. The hypothesis that the Raspberry Pi is suitable for a use in a multi-sensors system, and thus on a UAV board was confirmed by realizing of this meteorological system. The set goals of this work were reached. The outcome of this work will serve as a basis for a further research focused on the application possibilities of platforms based on the ARM architecture processor on boards of UAVs.

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