A Liquid Level Monitoring System for a Remote Reservoir

Petr Chalupa
Faculty of Applied Informatcs
Tomas Bata University in Zlin
Zlin, Czech Republic
chalupa@utb.cz 0000-0002-9229-7483

Martin Vláčil
Faculty of Applied Informatcs
Tomas Bata University in Zlin
Zlin, Czech Republic

Jakub Novák
Faculty of Applied Informatcs
Tomas Bata University in Zlin
Zlin, Czech Republic
jnovak@utb.cz 0000-0002-9336-8044

***Abstract*—The paper deals with the design and implementation of a system for monitoring the level of liquid in a remote reservoir without power supply from electric network. The hardware of the solution is based on Arduino Mega platform with GSM / GPRS sending data and level measurement using hydrostatic pressure gauge. An internet server is used to collect data in a database and to present data to users in a form of web pages. The work focuses on high precision, low power consumption and low cost of the final system. The paper describes the developed hardware and software. The paper also present testing of the system in real conditions.**

Keywords—liquid level measurement, Arduino, wireless data transfer, embedded systems

I. Introduction

The paper deals with the problem of measuring the height of the liquid level in a reservoir with special attention paid to the price of the system and its power consumption. The monitoring system is focused on non-aggressive liquids such as water. The solution is designed as a complex system for monitoring the time course of liquid level, special events triggered by extreme conditions (too high or too low level) or potential undesirable behaviour (rapid changes of the level).

It is required that the system should be able to operate in a distant location without power supply from the electric network. For this reason, great emphasis was placed both on the low consumption of the end product and on the fact that the measured data cannot be transmitted using physical media such as cable Ethernet or power lines but wireless transmission must be implemented. Requirement that the designed system has to fulfil are summarized in TABLE I.

TABLE I. System Requirements

Parameter	Required value
Level measuring range	0 – 500 cm
Resolution	1 cm
Inner diameter of the reservoir	> 10 cm
Environment protection	IP54 (outdoor environment)
Operating temperature	-25 °C – +40 °C
Power supply	Batteries
Battery run time (1 cycle)	> 4 weeks
Data transmission type	Wireless
User interface for presenting measured data	WWW based
Price of the components	Up do 150 EUR

The problem of measuring liquid level is very common in the area of control and monitoring systems. Extensive survey of low-cost level measurement systems is presented in [1] where different physical principles are discussed. Low cost water level monitoring systems based on capacitive sensing are presented in [2] and [3] while pressure sensor is used in [4].

This paper extends the work carried out in diploma thesis [5] and is organized as follows: Section II presents general concepts of the proposed system; Section III is focused on monitoring unit attached to the reservoir with special attention paid to its hardware components; Section IV describes Web server used to present measured data to users and Section V describes set-up and results of the system in real conditions. Section VI concludes the paper.

II. General Concept of Proposed System

The first crucial point of system design is selection of appropriate type of level sensor. There are two basic sets of level sensors: contact and contactless [6], [7]. The contactless sensors are generally more reliable but on the other hand more expensive and more difficult to deploy in real conditions (e.g. detection or avoidance of reflection from the reservoir walls in case of ultrasonic sensors). A contact hydrostatic sensor was selected as an appropriate for designed system.

The second very important part of the monitoring system is control unit which is responsible for collection of data from level sensor and its transmission to an internet server. This server subsequently presents the data to users in the form of web pages. The Arduino system with GSM shield was chosen as a suitable control unit that is capable of bi-directional communication with the server [8], [9]. Proposed concept of the monitoring system can be summarized into the following points:

- Monitoring unit is located close to the reservoir; hydrostatic level sensor is wired to the unit.
- Monitoring unit collects data from the level sensor with given sampling period and saves them locally to SD card.
- If any of pre-defined event occurs (i.e. level too low, level too high, level decreasing too rapidly, battery voltage below limit) message is sent to server and server sends an email to predefined email addresses.
- After a given number of samples is collected, GSM communication is initialized and data are transmitted to an internet server.

- Internet server stores data from monitoring unit into a database.
- Internet server is equipped with web interface which presents collected data to clients (users) in the form of web pages.

All the measured data are also stored locally in the monitoring unit as a backup for the case on loss of the internet GSM connection. Measured data contain following items:

- liquid level,
- battery voltage,
- ambient temperature,
- ambient humidity,
- GSM signal strength

As mentioned above, the data are not directly transferred to the serves at time when collected. Rather a batch of data is transmitted at once. This approach saves batteries because the GSM module requires relatively a lot of energy to work. When the GSM module is not used, it is powered off.

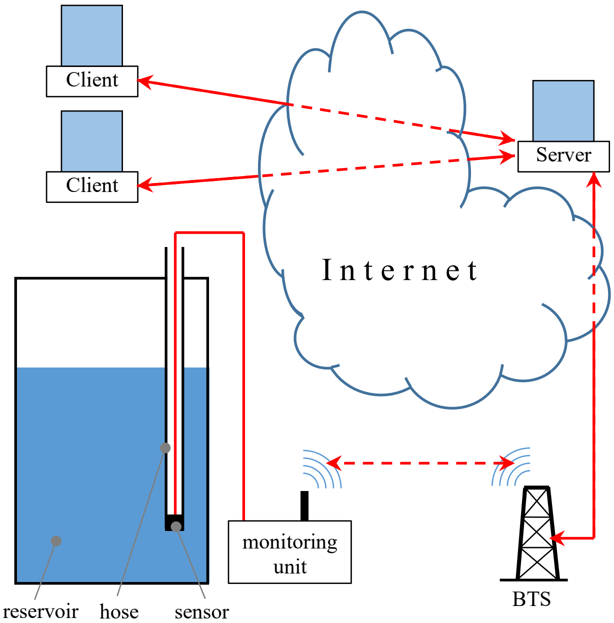

Fig. 1. Simplified scheme of the proposed system

A simplified scheme of the proposed system is presented in Fig. 1 where BTS stands for Base Transceiver Station which is a piece of equipment that facilitates wireless communication between user equipment and a network. The hydrostatic level sensor is based on differential pressure sensor and therefore nozzle of the hose must be opened and placed above liquid level.

III. Monitoring Unit

The monitoring unit is a heart of the designed system. It contains modules which are necessary to carry out the operations described in the previous section. The level sensor is connected to the unit by a 4-wire cable. The only other wire connection is a USB communication of Arduino with PC / laptop which is used only temporally for programming and debugging purposes.

All the parts of the unit are encapsulated in a plastic box to ensure required IP protection. A photo of inside of the box is presented in Fig. 2. One or two pairs of Li-ion 18650 batteries are used for power supply. Two sets of batteries are used for the system. While the first set is used for supplying power, the second set is recharged and stored for later use. Ehen the voltage of the first set goes below limit, the sets are interchanged. There are two reasons for not using solar panels for charging batteries:

- Price of the solar panels is too high to reach desired price of system components.
- The reservoir is located in a wood and available solar energy is limited by treetops.

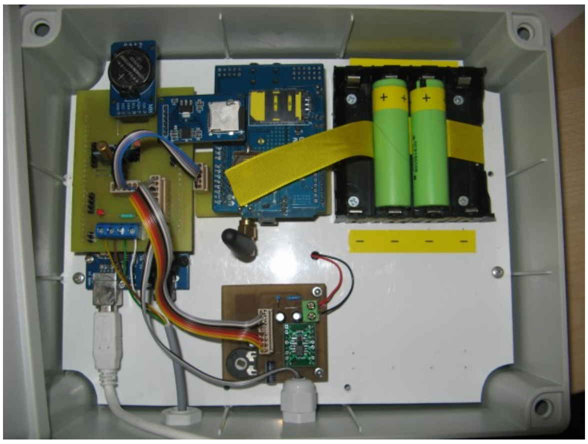

Fig. 2. Photo of monitoring unit

Individual parts of the monitoring unit are shortly described in the following sub-sections.

A. Arduino board

A family of Arduino controllers contains many boards designed for various purposes. They differ in the processor used, size of the RAM and flash memory, number of IO pins etc. The Arduino MEGA was selected for the monitoring system.

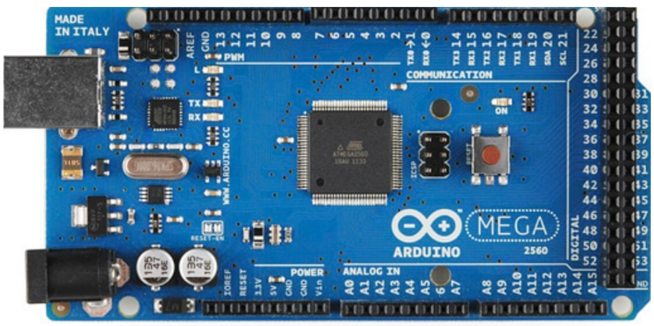

Fig. 3. Arduino MEGA

The Arduino Mega board has dimensions 10.2 x 5.3 cm (see Fig. 3) and is based on the MCU ATmega 2560 series of the AVR family [10]. Integrated oscillator ensures operating frequency 16 MHz. A USB connector is provided on the board and it serves to:

- power Arduino,
- connect to a computer to upload a new program,

- serial communication (especially for debugging purposes)

Arduino Mega offers 54 digital I/O pins with software-driven pull-up resistors and 16 analogue-to-digital input pins with a 10-bit analogue converter. Analog pins typically have a range from 0V to 5V, the upper limit depends on the supply voltage. The maximum current through individual pins is 20 mA. Some pins perform extra features supported by the hardware itself. The pin no. 13 is connected to the LED that lights when the pin value is in the logic one. There is also a power connector and a reset button on the board.

B. Power source module

A special power module was designed to power the station. Three linear low drop-out stabilizers are used in the module. All stabilizer inputs are connected to the battery output (7.4 V).

The first stabilizer is LP2981IM5 - 3.3. It has a fixed output voltage of 3.3V, maximum output current is 100mA and this stabilizer is always connected. The stabilizer has very low self-consumption (in the order of µA).

The second stabilizer is MIC5201. It has a fixed output voltage of 5V and maximum output current is 200mA. The stabilizer is switched on by a TTL input signal, supplies the awakened Arduino and other peripherals except GSM module.

The third stabilizer is MIC29302. It is adjustable and is set by a trimmer to 5V. The maximum output current is 3A, is switched on by the TTL input signal from Arduino and powers the GSM module. It has a relatively high idle power consumption (approx. 10 mA), but it is only switched on when the GSM module is operating. If the stabilizers are off (0 on the enable input), they have very little power consumption (in the order of µA).

Another part of the power module is a fixed 2:1 voltage divider composed of two resistors of 55 kΩ (together 110 kΩ) consuming 67 µA. The output of this divider is connected to the 10-bit A / D converter of Arduino where the current voltage of the accumulator is measured.

C. Peripheral base board

The design of the peripheral base board (see Fig. 4), which was necessary to integrate all the required peripherals, was created in the Eagle program, which is dedicated for the design of printed circuit boards.

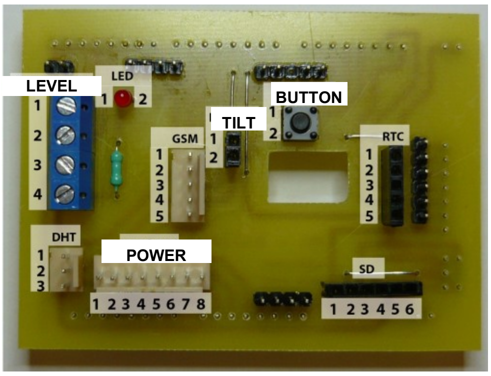

Fig. 4. Peripheral base board

The board was designed as an Arduino shield because of simple manipulation, since the connection of a shield to Arduino is a trivial matter. Additionally, all the connectors are different from each other preventing the module from being plugged into a connector that is not intended for it.

D. SD module

The SD board is the official IO module for accessing a micro SD card (Fig. 5). Communication between Arduino and this module is carried out via the SPI bus [7]. The module supports Micro SD cards up to 2GB and Micro SDHC up to 32GB of space.

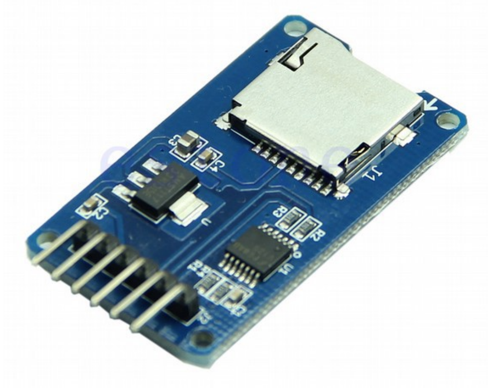

Fig. 5. SD module

The module can be controlled using the built-in SD library, but because of an inability to shut down and re-enable this module during the program run, the unofficial SDFat library was selected to communicate with the module. The library / module supports only FAT8 and FAT16 formats. For this reason, the maximum file name length is limited to 8 characters + 3 characters of extension.

E. GSM shield

The GSM module (Fig. 6) enables to connect Arduino to a mobile network, allowing it to receive and send SMS / MMS messages, made phone calls, and connect to the Internet using GPRS. The module communicates with Arduino via serial communication (UART) by sending special AT commands. These are short text sequences that control various devices, most commonly modems. AT commands are characterized by starting with AT letters followed by a specific query. The answer is also a text message.

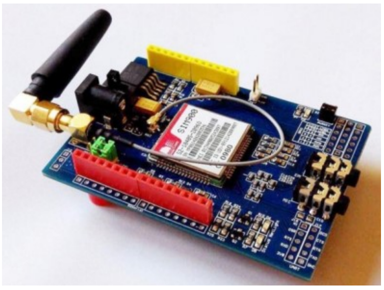

Fig. 6. GSM shield

GSM modules for Arduino are most often designed as shields, which just need to be connected to the Arduino board, have a SIM card inserted and the module is ready for use. If the GSM module is not used as a shield, it is necessary to connect the correct pins between Arduino and the GSM module. The software wakeup is used to wake the SIM900 chip [11].

Fig. 7. RTC with alarm module

F. RTC with Alarm

The real-time clock module (Fig. 7) is used to maintain current time information. The DS3231 module is used. It communicates with Arduino via the I2C bus and the built-in RTC control library offered by the Arduino IDE. DS3231 provides seconds, minutes, hours, day, date, month and year. Additionally, the module includes correction for a leap year, calendar, and two configurable alarms. The alarm clock can be used as a source of external signal to wake Arduino from a deep sleep state.

G. Temperature and humidity sensor DHT22

The DHT22 is temperature and humidity sensor. The module sensors are calibrated in a special calibration chamber and the calibration coefficient is then stored in the internal memory. The sensor is suitable for its small size and low consumption. Sensor data is transmitted using one half-duplex wire [12].

H. Pressure sensor

The heart of the level sensor is the MPS20N0040D-D pressure sensor. This pressure sensor is designed to measure barometric pressure from 0 kPa to 40 kPa, which can be converted to liquid level using its density (in case of water the range is from 0 to 4 meters). This would not fulfil the required range (5 m). However, it is clear from the datasheet that the actual range of this barometer is -100 kPa to 70 kPa, which corresponds to 7 meters of depth. The pressure sensor returns the voltage value directly proportional to the difference in pressure on its front and rear, or more precisely, the pressure difference in the measuring tube and the ambient pressure.

The pressure sensor is sealed in a waterproof housing. One end of a hose is attached to this housing while the other hose nozzle is above the liquid to introduce atmospheric pressure to the pressure sensor. Since the reservoir is not hermetic, the atmospheric pressure also affects the liquid level measurement. Using above-described configuration, effect of the atmospheric pressure is neglected and the sensor measures only the pressure invoked by liquid without effect of the atmospheric pressure. In addition, the same hose is provided with a cable for communication and power supply of a pressure sensor that will not come into contact with the liquid. Moreover, the 24-bit A / D converter HX711 (Fig. 8) is present inside the waterproof housing for the pressure sensor. It translates the measured voltage to digital values right next to the sensor to suppress problems such as interference or voltage drop due to wire resistance which depends on wire length and temperature.

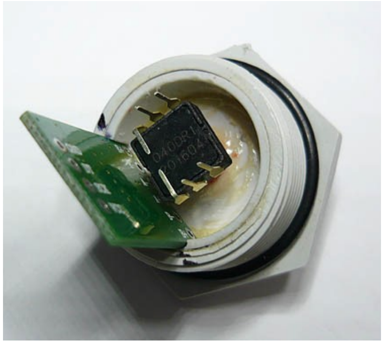

Fig. 8. Pressure sensor with A/D converter

The HX711 is a 24-bit A / D converter designed for high precision analogue signal measurement. HX711 contains two analogue inputs (channels), namely channel A with optional gains 128 and 64 and second channel B with fixed gain 32. It is primarily used in bridging, where small differences in resistances of individual resistors are used [13].

IV. Internet Server

The internet server caries out two basic tasks:

- Communication with monitoring unit and saving received data to SQL database
- Presenting data to users

The server consists of PHP scripts, html pages and supporting files. User access is restricted to registered users.

Communication from the server side is always passive, meaning that all communication is initiated by monitoring unit. The monitoring unit uploads data to the server by using the HTTP command GET. The GET sends the name of the function it wants to call and the parameters of that function. There are 4 four functions implemented:

- recording a fault on the monitoring unit side,
- confirming that the data sent to the station is OK,
- download of a new setting of the monitoring unit,
- receive data function

The server communicates with the monitoring unit at a time when the unit sends data to the site. A batch of data is sent in the CSV (Comma Separated Values) format after a number of measurements defined in settings is performed. The data is parsed and stored in the SQL database. If any configuration setting has been changed on the server side, this new setting is sent as a response. The current server time is used to synchronize the clock on the monitoring unit.

Main www page presenting measured data is shown in Fig. 9. It presents to the users the current (last) values measured by the monitoring unit. For fast orientation, the liquid level, temperature, battery, signal strength are pictured. Pictures are accompanied by a table that contains the exact values of the liquid level, battery voltage, temperature, humidity and GSM signal strength along with the time of the last measurement. The page is especially intended to display the main measured value – i.e. the liquid level. Its time course is displayed in the graph. The user has the option to choose the time range of the graph. In addition to selecting a custom range, the user has the option to use pre-configured buttons to display the dates of the last week, last two days or one day.

Moreover, it is possible to save the values in a chart to a CSV file.

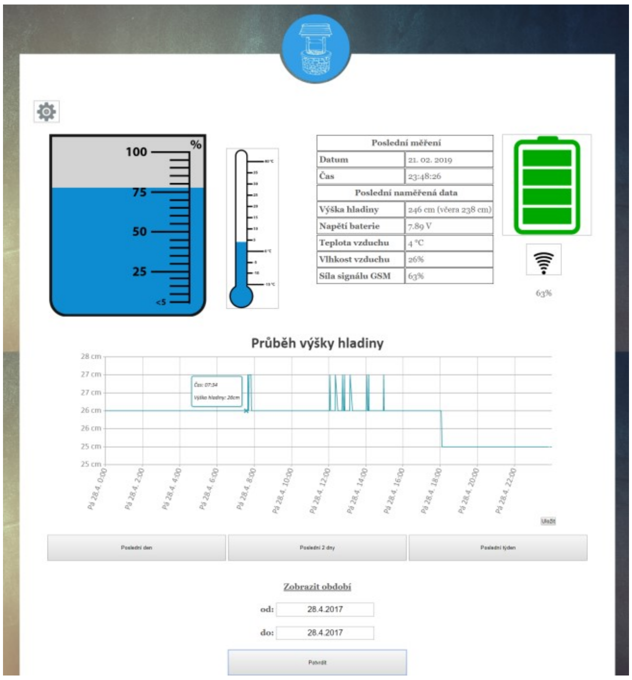

Fig. 9. Main page (Czech version)

Time courses of temperature, humidity, battery voltage and GSM signal strength are available via separate web pages accessible by clicking to picture of the desired value.

V. Verification in Real Conditions

The system has being verified in real conditions by measuring water level in a reservoirs which is a part of a standalone water supply system for a small settlement close to Zlín, Czech Republic. In fact development of the presented monitoring system was inspired by problems of this water supply system.

A. Set-Up of the water supply system

A simplified scheme of the water supply system is presented in Fig. 10.

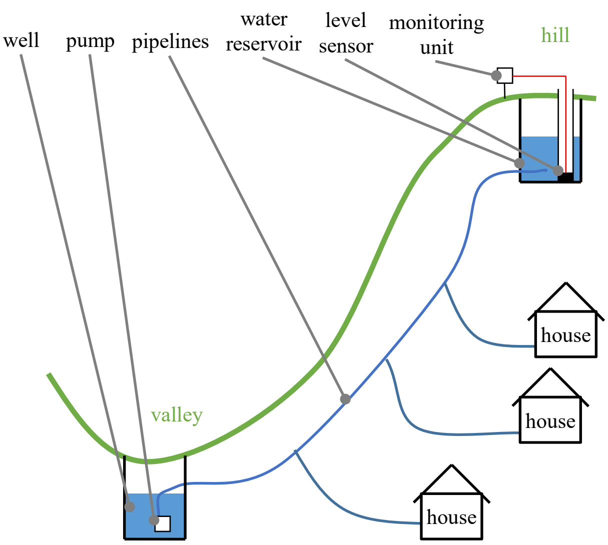

Fig. 10. Simplified scheme of water supply system

There is a water well in the valley with a deep-well pump installed. This pump regularly transmits water via pipeline from the well to the subterranean reservoir on a hill. Several houses are attached to the same pipeline and water is transmitted to them gravitationally. There is no electricity supply available close to the reservoir.

The functionality of the system is supervised by dedicated person. Several types of problem can occur leading to lack of water for the houses:

- The pump is not pumping
- Forgotten open water tap
- Too high demands of the users.
- Too low flow of the spring of water

The depth of the reservoir is approximately 3 m and its full capacity is sufficient for 2 – 3 days. All the above mentioned problems can be detected by the water level monitoring system installed in the reservoir. The measuring period has to be small enough to cover pumping which runs for 20 minutes.

If the there is a problem with the pump and it is not pumping, the water level is monotonically decreasing. If some user has forgotten to close a water tap, the water level will decrease by a higher rate comparing to normal state. It is possible to empty the reservoir in several hours by a fully opened tap. If demands of users are too high, the level slowly decreases comparing its current level to the level 24 hours ago. The situation is similar to “open tap problem” but the decrease of the water is not that rapid and the consumption is not constant during the day. If the flow of the spring is low, the pump is switched-off by its protection system (float switch). In this case pumping cycles are irregular or shortened.

The monitoring system was configured to measure data each 10 minutes and to send data to the server after each 6 measurements (i.e. with the period of 1 hour). These values have seemed to be a reasonable balance between power consumption of the monitoring unit and topicality of the provided data. In case of decrease of water level by more than 10 cm in 20 minutes, an alarm SMS is sent to a defined cell phones and an email is sent to defined email addresses. Similar SMS and email is sent if water level is below 60 cm. Notification email is also sent when the supply voltage is below 6.9 V (i.e. 3.45 V per battery cell).

The installed monitoring unit as well as the hose to level sensor are depicted in Fig. 11.

Fig. 11. Installed monitoring unit

B. Results

Just several courses are presented in this section. Detailed analysis of the time courses especially of the water level from statistical as well as sociological point of view exceeds the focus of this paper.

The monitoring system was installed in July 2017 and without any serious problems works up to the present days – i.e. February 2019.

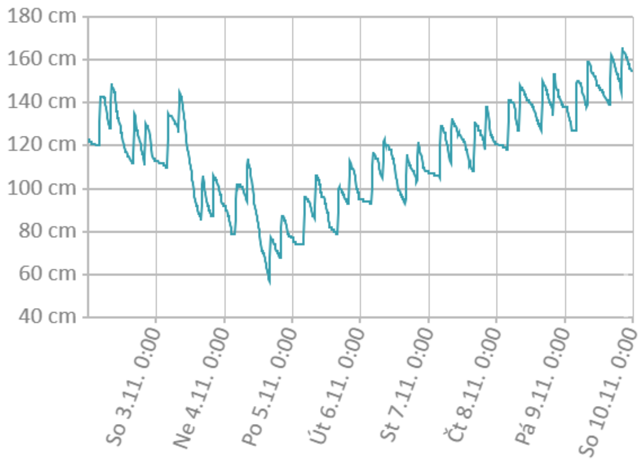

Fig. 12. Course of water level during a week

The course of water level during 8 days from Friday November 2, 2018 to Friday November 9, 2018 is presented in Fig. 12.

It can be observed that the consumption during weekdays is significantly smaller comparing to weekend. Each increase of water level corresponds to a pumping. Closer view unfolds that the flow of the spring was insufficient for 6 pumping a day which were scheduled (pumping every 4 hours to be more precise). The pumping was realized in "2:1" ratio. After two pumpings were realized one was missed due to lack of water in the well.

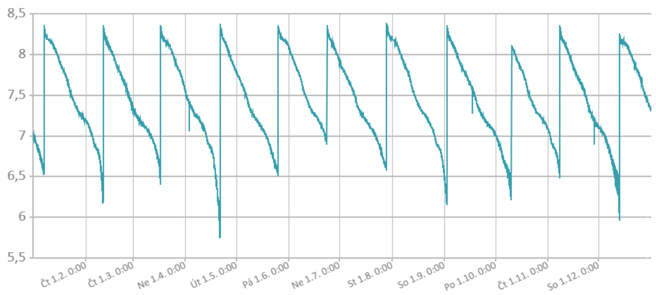

Fig. 13. Course of battery voltage during a year

The course of battery voltage during whole year 2018 is presented in Fig. 13. Each steep increase of voltage to approximately 8.2 V represent battery replacement. As a two pairs of battery cells were used, only 11 battery replacement was needed.

VI. Conclusion

The paper presented a liquid level monitoring system for a remote reservoir. Although many similar systems exists, the proposed system is special in combination of two requirement: very low power consumption as it is powered from Li-Ion batteries and low cost – the total cost of its components is approximately 100 EUR (2500 CZK). The measuring unit is based on Arduino MEGA controller equipped with several modules: RTC, GSM, etc. The level sensor was designed especially for this project by combining a differential pressure sensor and an AD converter. Data are transmitted wirelessly to an internet server and presented to users in a form of web pages. The system has being verified in real conditions. It has been running for more than 1,5 year with battery charge cycle of approximately 5 weeks. Ambient temperature was in range -14°C to +33°C and many rainfalls and snowfalls occurred. Further work will focus on detailed analysis of collected data.

Acknowledgment

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