

Autonomous Groundwater Monitoring Station with Wireless Communication

Ondřej Hanuš¹, Jan Mikeš¹, Jakub Kákona¹

¹*Czech Technical University, Faculty of Electrical Engineering, Technická 2, 166 27 Prague 6,
Czech Republic, hanuson1@fel.cvut.cz*

Abstract – Numerous scientific disciplines such as hydrology, meteorology, oceanography or geology take advantage of remote measuring and monitoring. Data measurement in distant locations and the transmission of measured data is an essential part of these disciplines. The critical element of remote measurement and monitoring systems is a data collecting station. When designing such a device, it is necessary to solve issues of the construction, power system, data transfer or autonomous operation systems. This paper introduces the Autonomous Groundwater Monitoring Station with Wireless Communication which has been designed and installed in a field application. The individual parts of the station such as construction, software, hardware, wireless communication system or systems for autonomous operation are presented.

Keywords – *Autonomous, Measurement, Wireless communication, GSM, Monitoring station, Groundwater*

I. INTRODUCTION

Remote measuring and monitoring is an essential activity with many applications. It is used in numerous field such as hydrology, meteorology, oceanography or geology [1,2]. For some applications, the remote measuring and monitoring is the only possibility how to get real-time data from distant locations. These systems are especially helpful in case of environmental pollution accidents. The collecting of data from in-situ sensors can help evaluate the progress of remediation processes [3,4].

The fundamental element of these systems is a data collecting station. The station must be designed to meet the demands for a specific application.

There are a few challenges which must be solved when designing such a station. The first challenge is to choose an appropriate source of energy for a station. The suitable source of energy is the power line. However, the power line is not accessible in locations where infrastructure is lacking. In that case, the other power sources such as energy harvesting systems, batteries or a combination of solar cells and batteries must be used.

Next challenge is to ensure the access to data measured on a remote station. There are two possible ways how to

get data from field station. One way is to do it manually by reading values from displays or downloading data from the data loggers. This way is not acceptable for a vast majority of applications where the real-time access to data is needed. The more suitable approach is to get the data automatically over existing communication media.

The communication media can be divided into guided media such as cables or optical fibers or unguided (wireless) media, for example, radio waves, microwaves or infrared. The guided communication offers many advantages, for instance, reduced vulnerability to interference and a more reliable connection, but it is not suitable for field applications. For applications where the station is placed in a poorly accessible location, the wireless communication is more preferred [5]. Selection of appropriate wireless technology depends on specific parameters, for example, radio transmission power, range, data rate, service availability or price. The most frequently used techniques with a short range transmission are ZigBee, Bluetooth or WiFi. For a long range, there are LoRa, Sigfox, cellular (mobile) networks, WiMAX, or satellite communication technology [6,7].

Next challenge is to ensure the autonomous operation of a station. The system must be able to operate automatically, regardless of operator intervention. Consequently, methods which can overcome unexpected errors and failures must be implemented.

The paper introduces the design of the autonomous monitoring station. The capabilities of a station, system of wireless communication, construction of a station and the systems for fully autonomous operation are described. The station has been designed as a part of the project which is dealing with the liquidation of environmental damage. It has been used to monitor groundwater at a site which was contaminated by polychlorinated biphenyls.

II. MONITORING STATION DESCRIPTION

The purpose of the monitoring station is to autonomously collect data at a distant location, processed them and transfer to a server where they can be further processed. The station was designed and constructed based on the predefined parameters. One of the main demands was to develop a portable system for field applications.

The system had to be water resistant and able to work in outdoor conditions. Also, the system had to be able to transmit data from poorly accessible locations. Therefore, the implementation of wireless communication was fundamental. Based on those conditions, the monitoring station described below has been created.

A. Block diagram of the monitoring station

The monitoring station is described by the block diagram depicted in Fig. 1.

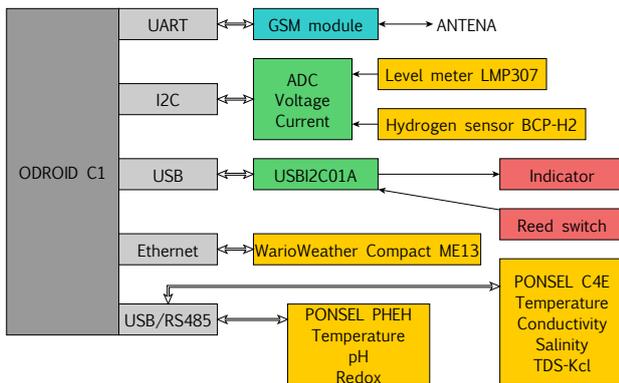


Fig. 1. Block diagram of the monitoring station

The fundamental component of the entire system is the single-board computer ODROID C1 from Hardkernel. This single-board computer has a lot of peripherals such as general-purpose input/output pins providing UART, SPI or I2C buses, gigabit Ethernet or USBs. The GSM module which provides wireless communication is connected over the UART. The I2C bus is used for communication with an analog-to-digital converter (ADC). ADC allows reading measurements from both, the sensors with voltage output or sensors with the current loop output. The groundwater level meter and hydrogen sensor are connected over the current loop in a current implementation.

The monitoring station is equipped with the active input component in the form of a reed switch which can be switched by the magnet. The magnetic contactless switch is necessary in order to keep whole system water resistant. The reed switch allows creating of time mark that can be used for service purposes. The LED indicator is used as feedback for the reed switch.

The Ethernet port is used for communication with the weather station. The weather station provides meteorological measurements such as local temperature, wind speed and direction, precipitation, humidity, solar exposure or atmospheric pressure. These measurements help to understand the conditions which are at the location and affect the groundwater parameters.

The last peripherals are the groundwater measurement probes which are connected over the USB/RS485 converter using the Modbus protocol. These probes provide information about groundwater properties, for example, temperature, conductivity, salinity, pH or redox.

The entire system of a station is powered by the power line which is available in the location.

B. Construction

The monitoring station has been designed to endure field application. The system is composed of two boxes made of duralumin. The first box contains the single-board computer, power circuits, and GSM communication module and the second box contains all of the terminal blocks for sensor connection. Both boxes are placed in a plastic case which provides protection against the water and humidity. Power and data cables are routed over the cable glands with a rubber seal. The monitoring station is depicted in Fig. 2.



Fig. 2. The monitoring station in plastic case

C. Wireless communication

The monitoring station communicates through the internet via GSM modem. The GSM modem with a mini-SIM card uses GPRS technology. The GPRS technology has been chosen despite its' low speed. The main advantage is the coverage which is better in comparison with the more advanced technologies such as LTE. The low bitrate is not a problem since the amount of data transferred is small. Figure 3 illustrates the diagram of wireless communication.

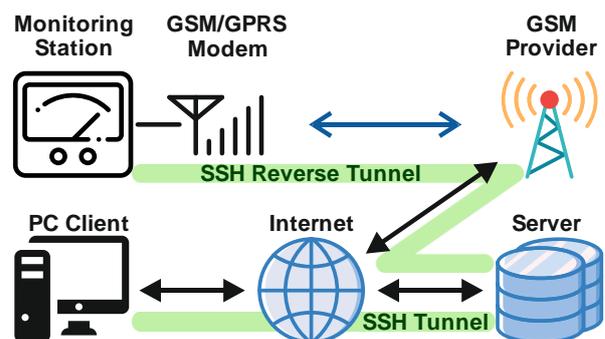


Fig. 3. The diagram of wireless communication

The assigning of the IP address depends on the GSM provider addressing policy which means that the IP address of the GSM modem can vary over time. Therefore, the remote access to the monitoring station is ensured through a reverse SSH tunnelling. The GSM modem is connected through reverse SSH tunnel to the server with the public IP address. To get the access to the monitoring station, the PC client must create the SSH tunnel to the same server. The server connects those tunnels and allows remote control of the monitoring station from the PC client. The remote control is essential for system maintenance. To achieve more stable connectivity, two independent servers have been used.

Another way how to access the monitoring station is using the Telegram application [8]. The Telegram is originally a smartphone instant messaging service which allows creating of a Telegram Bot. The Telegram bot is machine controlled program that can be programmed for a specific purpose [9]. The particular Bot has been programmed for communication with the station. The Bot allows basic data exchange and remote restart which is helpful in a case that other communications channels are not responding.

The data measured by the monitoring station are uploaded to the server in the form of CSV files. The server offers a simple web interface where the data from the selected day can be plotted in graphs. Also, the data can be downloaded directly from the web interface or the data storage on the server.

D. Software

The single-board computer uses the Linux-based operating system. All of the scripts of the monitoring station are written in Python. Each script works independently not to affect the other scripts and functionality of the system in case of error.

There are two main processes for collecting of data, one for the groundwater measurements and second for meteorological measurements. Each of them collects data to CSV files. Collected data are processed and prepared for upload to a server once in 24 hours. Only the processed data are uploaded, which decrease the amount of data transferred and also the network traffic. In cases when the real-time access to the measured data is needed the Telegram application is used. The Telegram Bot process can send the most recent measured values as well latest data files.

E. Systems for autonomous operation

The station uses systems which have been designed to ensure autonomous operation. The structural diagram of systems for autonomous operation is depicted in Fig. 4. These systems can be separated into individual parts.

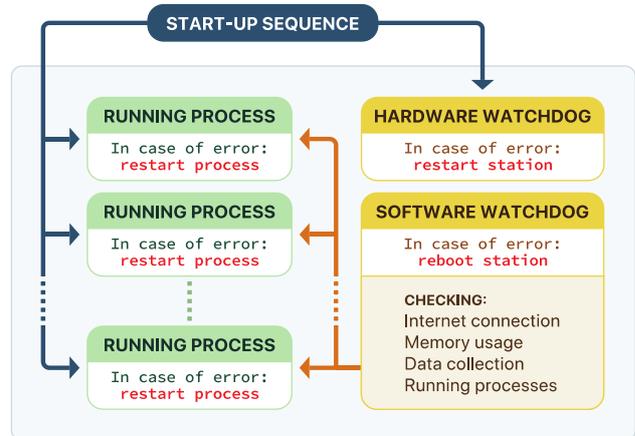


Fig. 4. The diagram of systems for autonomous operation

The task of the first part is to perform the start-up sequence correctly. During the start-up sequence, all necessary processes must be started in the correct order. The start-up sequence also includes some system settings, for instance, the connection of data storage or network routing settings.

The second part deals with the autonomous recovery from errors. Each process of the monitoring system is designed in a way that it can handle unexpected errors. When the unexpected error occurs in some of the monitoring processes, the system reports an error, waits certain time and then tries to restarts that process. This procedure can deal with errors such as communication errors, reading errors or errors causing data inconsistency. Each of the monitoring processes runs independently in order not to influence the rest of the operations. This approach makes the error handling procedure efficient.

The last part contains the station supervisor. This process in the form of the watchdog is responsible for checking the proper operation of the whole station. The watchdog is composed of two parts, a hardware section, and software section.

The hardware section uses the hardware watchdog timer which is part of the single-board computer. During the normal operation, the timer is regularly reset to prevent system reboot. The hardware malfunction cause that the system is unable to reset the watchdog timer and entire system is restarted.

The software section regularly monitors whether all system components are running. It is responsible for checking internet connection, memory usage, running processes or data collection. In a case that some system component does not work correctly, the error counter is increased. When the counter exceeds predefined boundaries, the entire system is rebooted.

The station supervisor is a critical component and it is essential for the autonomous operation of the monitoring station. It can recover the system from faults such as improperly operating hardware components, memory

leaks or unidentified random errors.

The station supervisor has been designed in a way that it is possible to control it remotely. An operator must be able to manage the station supervisor in case of some malfunctions or maintenance. There are two ways how to control the station supervisor, over the SSH tunnel and the Telegram application. The SSH tunnel allows full control of the system including the system supervisor. Telegram application can send only the request for system reboot in case that the SSH tunnel is not responding. This request is processed by the station supervisor, which has permission for a system reboot.

III. RESULTS

The groundwater monitoring station has been created to collect, process, and transfer groundwater parameters. These data are used in a project dealing with remediation work after the ecological accident which caused contamination of groundwater by polychlorinated biphenyls.

The photo of the monitoring station installed next to the groundwater well is depicted in Fig. 5.



Fig. 5. Installed monitoring station

The station collects data describing the quality of groundwater such as water level, temperature, conductivity, salinity, TDS-Kcl, pH, redox or concentration of hydrogen evaporating from the groundwater. An example of measured data is depicted in Fig. 6. The Figure shows a relation between the temperature and conductivity during two weeks of measurement.

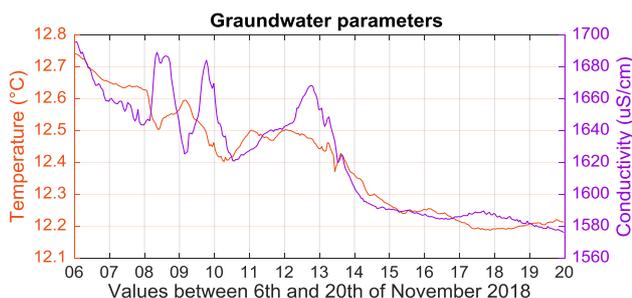


Fig. 6. Collected groundwater parameters

Also, it collects meteorological measurements such as wind speed and direction, precipitation, air temperature, air humidity, atmospheric pressure or solar exposure. These measurements also influence the groundwater properties. An example of meteorological measurements is depicted in Fig. 7. The Figure shows fluctuations in air temperature and atmospheric pressure during the same period.

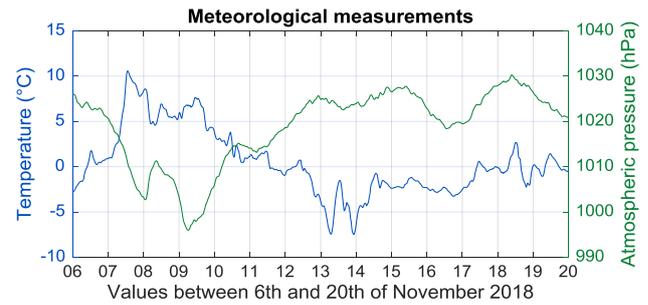


Fig. 7. Collected meteorological measurements

These two plots demonstrate the capability of the station to work for an extended period without any significant outage. The continuous operation has been achieved thanks to autonomous systems.

The station can be easily extended due to a large number of peripherals such as USB, RS-485, RS-232, I2C, Ethernet, SPI or analogue measurements of current or voltage. Although the station has been designed for groundwater measurements, the multi-peripheral design allows using of the station in almost any application which requires remote measurements and field applications.

Systems for autonomous operation have a significant influence on the stable operation of the station. Even though there are various random outages such as voltage drops or communication errors, the station has always been able to resume operation automatically.

IV. CONCLUSIONS

In the article, the autonomous groundwater monitoring station has been introduced. The station was designed as a portable system for field applications. The solution utilizes wireless communication via GPRS technology which is available even in poorly accessible areas. The primary function of the station is collecting and processing data and wireless data transfer. It allows measurements of groundwater properties as well as meteorological measurements.

The station has innovative systems for autonomous operation. These systems are responsible for the stable operation of the station even in case of hardware and software errors and ensure automatic restoration of the station operation in the event of a failure.

The monitoring station has been used in a project that is dealing with remediation work after the ecological accident.

V. ACKNOWLEDGMENT

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