Quality assessment of system for automated multi-node environmental water parameter monitoring
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Abstract - This paper presents a system for automated multi-node environmental water parameter monitoring and makes an assessment of its measurement quality. Using this system, by constant monitoring of water quality in wetlands and surrounding areas, and analysis of long-term measured data can yield key and useful information for environmental protection and biodiversity actions and plans. The system is built as a network of independent measurement nodes, each equipped with probes for measurement several key physicochemical parameters. Acquired data are sent using commercially available communication networks to a central data-center for further processing, analysis and presentation. The system was tested in laboratory condition. Measurement results of water samples taken from wetlands are compared to results obtained by physicochemical laboratory analysis, resulting in the quality assessment of the designed system.

Keywords wetlands monitoring, sensors, multi-node, water quality

I. INTRODUCTION

One of the largest industrial pollutants are food, chemical and metal industry. The negative effects of intensive agricultural production on the environment are particularly evident in rural areas, as most of their territory is used for the food production. Agrochemicals, such as pesticides, fertilizers and salts, have the greatest impact on the environment. Only 10-15% of the applied pesticides reach the target pests and the rest ends up in the air, water and soil. Therefore, it is clear that the increase in the agricultural productivity and the development of industry has a significant impact on environmental pollution, especially on the river and underground waters [1]. Consequently, water quality is significantly important since this parameter facilitates the rational and efficient use of the water reserves.

There are several approaches to inspect water quality. Traditional methods involve the manual collection of water samples from different locations and at different time intervals. Then, laboratory analyses are conducted in order to determine the water quality. This approach has many drawbacks [2] – [4], such as repetitive departures to the field in inaccessible places in order to take a sample. Furthermore, the sample changes its chemical characteristics until it is being processed in the laboratory surrounding. Additionally, laboratory analyses can take significantly long time and can be very expensive.

On the other hand, optical methods [5] for remote measuring water quality offer high sensitivity, good diagnostic potential, compact and robust instrumentation. These methods use several techniques based on the spectral analyses of the transmitted and scattered light. Disadvantage of the measurement systems based on this principle is demand to regularly maintain the probes in order to achieve good optical visibility, which is a requirement for good results. Also, the instrumentation used for these methods is very expensive.

Water measurement systems used in water purification facilities are one of the most accurate commercially available methods for measuring water quality [6] – [7]. These systems are robust, have proper security protocols in order to prevent failures and provide extremely accurate results. Such systems are very expensive, require trained personnel to handle and include regular replacement of probes, as well as their calibration.

Information technologies in the conjunction with the development of sensors and electronic circuits provide the possibility of on-line monitoring of essential parameters that determine the quality of the water. One of the solutions that uses a low-cost and holistic approach to the water quality monitoring problem is described [8]. This system is portable, which means it must be brought to the appropriate locations, and it is not suited for autonomous operation.

Solution presented in this paper are designed so it can be placed almost anywhere, it is battery powered with years long battery life, and needs minimum maintenance. Presented solution will be used in building system for monitoring and measuring key factors and existing risks in the protection of biodiversity. The result of the project will be implemented, integrated and functional continuous supervision and measurement system for controlling the quality of the surface water in the capacity of the unified data system with international aspects. Locations predicted for implementation are Tompojevački Ritovi, municipality Tompojević, Mikluševci and Grabovo in Croatia and lake Zobnatica, municipality Bačka Topola in Serbia. Most of the measurement nodes will be placed in shallow boreholes surrounding wetlands in this area, and some will be placed directly in open water area.

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II. MEASUREMENT SYSTEM

Multi-node environmental water parameter monitoring system is consisted of several measurement nodes placed in measurement locations shown in Fig. 1.

The water parameters measured with this system are: pH, temperature, dissolved oxygen, conductivity, nitrate (NO3-). The water level is also measured and this information is used for determination of direction of groundwater flow in order to calculate quantities of groundwater which flows into the lake. For pH measurement, standard pH probe with glass electrode is used, combined with reference electrode. Measurement range of this probe is 0−14 pH. PT-1000 type of sensor is used for temperature measurement. Electrical conductivity probe consists of two measurement electrodes, and it is designed for measurement in range of 0.07 to 50,000 µS/cm. Dissolved oxygen is measured with galvanic probe consisted of Teflon sensing membrane, measurement range is from 0 to 100 mg/L. Selected nitrate probe is ion-selective type with solid state electrodes, like pH probe this probe also needs reference electrode, it uses the one from pH probe. Measurement range of selected nitrate probe is 0.6 to 31000 mg/L.

Since some boreholes are 10 meters deep and the water level in borehole can vary more than 3 meters during different seasons, the measurement node is divided in two part, CONTROL unit and PROBES unit.

In CONTROL unit a GSM module is placed, along with system battery and additional hardware. PROBES unit is placed on the floating cork with functions related to the probe managing and conditioning. In this way GSM module is on surface in order to minimize the length of the antenna cable. PROBES unit is floating on the water, so it is always on the same distance from the water level. Water pump is used to pump water up to the water sample box, where the measuring tips of all probes are inserted. If electronics of the PROBES unit were placed on surface, together with electronics in CONTROL unit, all the cables from the probes would need to be around 10 meters long. This probably wouldn’t be a significant problem for integrity of signals from probes since their outputs are low changing voltage signals, although electromagnetic interference could have significant influence to the signal because of its low amplitude, in order of millivolts. More important problem with long probe cables is the fact that water level can vary about 3 meters, and they can be easily tangled up when the water level is high. By splitting hardware in the two units, only one 4-wire cable is needed between these units so possibility of entanglement of cables is very low.

A. CONTROL unit

Structural schematic of surface, CONTROL unit is shown on Fig. 2. Selected microcontroller is low cost 8-bit ATMEGA328P, there was no need for more powerful MCU since no significant computation is required in these units. As supply for whole system a non-rechargeable Lithium Thionyl Chloride battery LSH20 is used, with nominal capacity of 13 Ah and nominal voltage of 3.6V. Because of its high capacity and small dimension, low self-discharge rate and wide operating temperature range (-60°C/+85°C), it is ideal for outdoor battery-powered systems. Also, selected battery has high drain/pulse capability of 4 A, so it can be directly used for powering GSM and similar modules. The most of the batteries of this type have much lower current capabilities, around 10-20 times lower, so they have to be combined with the supercapacitor to be able to power such type of modules.

To achieve overall system low-power consumption, ultra-low-power timer TPL5110 is used. Consuming only 35 nA, this timer drastically reduce the stand by current during the sleep time of the system. No other component in the system consumes power (expect RTC clock) during sleep time since output of TPL5110 switches of power to the rest of the system. For additional power saving, microcontroller controls three individual power switches for: GSM, all the other internal electronic and power send to the underground unit, so it can power off part of the system which is not currently used.

Measurement data is send via GSM/GPRS module which was selected for data transfers because the most of measurement nodes will be placed in rural locations with large distances between them, so no other communication network is available. If GSM communication is unavailable for prolonged periods of time, data is saved in I2C serial eeprom chip with 512 kB of data, where data from six months of measurement can be saved.
Humidity and temperature sensor is placed on CONTROL unit PCB, this sensor is used for monitoring status of the air inside surface unit enclosure. Since measurement nodes will be placed into borehole tube which will be closed on the top, there will be significant condensation inside. Therefore, sensor is placed to be sure that humidity and temperature inside enclosure are within limits appropriate for the electronic hardware.

Water level probe is based on the differential pressure sensor with analog output. Since level sensor has to be on fixed level below the water it is connected to surface unit, unlike all other probes which are connected to moving underground unit.

For testing of the system in-situ extern forced wake up hardware is used. Since whole system is powered on every two hours for short period of time, the operator has to have possibility to check functioning of the whole system when nodes are placed on the field. For this purpose a reed relay is used, connected to the input of the TPL5110, so the operator can power on the system just by bringing magnet in proximity to reed relay, which is placed on the wall of the CONTROL unit enclosure. In such a way there is no need for operator to open enclosure every time the system need to be tested, which will shorten testing time since opening and closing enclosure is time consuming task. Enclosure is IP66 protected and properly closing its lid is delicate process, especially when it is done on field during poor weather conditions. For communication needs between the CONTROL unit and the operator, CONTROL unit is equipped with the BT module to receive test commands and send data to the operator.

Communication between CONTROL unit and the PROBES unit is done via RS-485 communication, in some deeper boreholes distance between units is above 10 meters, so simple RS-232 communication could cause data loss in case of electromagnetic interference.

B. PROBES unit

Structural schematic of underground, PROBES unit is shown on Fig. 3. All probes for water parameter monitoring are acquired with custom electronic boards which communicates with MCU via I2C communication. These electronic boards process signals from probes, digitalize it and send measurement data to MCU. They can be also used for calibrating of the probes. Three I2C isolators are used in combination with the probes, primarily because of influence of probes to each other when placed in same water sample, which then acts as the low resistance current path between probes. Probe that has to be galvanic isolated are conductivity, dissolved oxygen and pH with NO3- probe. Like mentioned before, pH probe is used as reference probe to NO3- probe, so they have to be grounded together. As I2C isolators ADUM3260 is used, which also provides galvanic isolated power supply to the probes. Temperature probe does not need isolation, since its housing isolates temperature probe from surrounding environment.

Like on CONTROL unit, there is humidity and temperature sensor on probe unit PCB, to check conditions inside the enclosure. Also, there are power switches for powering off part of the system currently not used, and I2C isolators have enable input so they can power off the probes when the measurements are completed.
Average current consumption of whole system during measurement process is up to 150 mA, and duration of measurements is below 1 minute. During data transfer, continuous current consumption of GSM module is up to 500 mA, and data transfer can last up to 1 minute, mostly because of time needed for establishing the communication. For one measurement cycle and data transfer per day, battery life should be around 3 years. This estimation is made for worst case conditions, GSM module will in most cases have smaller consumption. Real current consumption of GSM module will depend of needed GSM transmitter signal strength which will be different for every location of measurement nodes, and will also vary for every data transfer since propagation of signal changes on daily bases.

III. SYSTEM LEVEL PROGRAM STRUCTURE AND SUPPORT

The software solution for this system is divided into two separate solutions. The term solution here represents all necessary software algorithms, development environments and hardware deployment tools used to create control, managing and processing algorithms. One of solutions is tailored for system that is placed above the ground (surface station / CONTROL unit) and serves as data sharing center with control ability in manner of managing the whole system operations. The second solution is made for system that is designed to be sensor hub (PROBES unit). This sensor hub is placed underground, in direct contact with measuring media. Also, the underground station serves operations related to the probes maintenance and data preconditioning, preparation and translation (conversion) into meaningful domain, preparation for raw transport to the main data center. Simplified functional layout of implemented algorithm is given in Fig 4. Also, all tools for programming and deploying are used according GNU and GPL principles.

The main targets that are accounted into core of implemented algorithms are oriented to achieve following objectives:

- to acquire raw probe measurements according probe specifications and rules for proper acquisitions (probe conditioning and readout),
- to condition and interpret raw measured data and translate into meaningful scalar domain,
- to maintain communication toward the main data center and respond to the custom control sequences for stations remote dynamic management (remote control),
- to support and serve maintenance service requests and actions (system diagnosis), and
- to control and manage ultra-low consumption power plan (power save and control).

The whole system is designed in a way to be very power conservative, power efficient respectively. Due that very restrictive policy a special attention is given to the part of algorithm that utilizes system power distribution. As it shown in Fig. 4, system wakes up from the almost zero-power state and regularly checks condition of meeting the scheduled fully system functionality. If that condition is fulfilled the rest of algorithm is activated according sequence for further proceeding in proper data acquisition. It is expected that once or twice a day for data acquisition will be enough due the fact that the hydrological processes are very slow. In consent with hydrological experts these intervals are confirmed as valid.

The period that is chosen for periodical waking-up the whole system is fixedly set to 2 hours. This is way too fast, according known needs for one or two measurements per day. The reason for select such period is tightly related to hardware properties of ultra-low power timing circuitry that is used for waking-up system power controller. The maximum delaying interval for such circuitry is set to maximum 2-hour interval. That fact somewhat makes complication in time and schedule management of this system however, it is solved in a way that system wakes-up every 2 hours, turns on only a main power that is sufficient for powering main controller only (that one in placed in the surface station), Fig 4. The main controller reads RTC state and last wake-up time-stamp, compares it according data obsolescence. If comparison results in wake-up due state, the whole system is powered-on, switched to the acquisition mode, and data was stored in memory and transported over communication interface to the main data center. If result of comparison results in wake-up trigger miss, main controller then shuts down power for all systems thus maintaining ultra-low power consumption.

![Figure 4. Program structure and flow diagram for probes and CONTROL unit](image)
Also, when data was acquired and stored in memory the system has obligation to transport data to the main data center utilizing some of communication media. This system utilizes GSMs GPRS communication infrastructure. Due the fact that GSM communication circuitry are big power consumers and have high current peaks/surges, one of tasks of this system is to maintain communication as short as is possible or lower frequency of communications establishments per given periods. This system utilizes one communication cycle per day and thus gathers all procured measurements in one day to the one data exchange over GSMs GPRS.

IV. MEASUREMENT RESULTS

System is realized and tested in the laboratory conditions. Measurement results of water samples taken from wetlands are compared to results obtained by analysis attained in accredited physicochemical laboratory.

<table>
<thead>
<tr>
<th>Water parameter</th>
<th>System measurement</th>
<th>Laboratory measurement</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.16</td>
<td>8.01</td>
<td>1.87</td>
</tr>
<tr>
<td>Dissolved oxygen(mg/L)</td>
<td>10.34</td>
<td>10.95</td>
<td>- 6.98</td>
</tr>
<tr>
<td>Conductivity ($\mu$S/cm)</td>
<td>1003</td>
<td>995</td>
<td>0.8</td>
</tr>
<tr>
<td>NO$_3^-$ (mg/L)</td>
<td>10</td>
<td>0.09</td>
<td>11000</td>
</tr>
</tbody>
</table>

Comparison of system and laboratory measurement can be seen on Table 1.

It can be noticed that temperature measurement is not included since water temperature obviously changed during transport to laboratory, but since the temperature sensor is well known PT1000, its measurement is known to be below 1 %, which was confirmed with additional measurement. Conductivity measurement error is in range of conductivity probe accuracy, it is below 1 %.

Dissolved oxygen measurement error is around 7 %, which is higher than rated probe accuracy of 2 %. This can be accredited to the fact that dissolved oxygen concentration is a highly unstable parameter of water, and its measurement is best performed in-situ with special method for water sampling [9].

Nitrate NO$_3^-$ measurement results done by system probe are 100 time higher than values attained by laboratory. Since measurement range of this probe is in range 0.6 to 31000 mg/L, values of 0.09 mg/L are outside its range. Such high error can be explained by low accuracy of used nitrate probe for low levels of nitrate, where response curve of this probe is in non-linear region. Also, the effect of interference from other ions in solution can have significanct effect on measurement.

V. CONCLUSION

This paper presents a system for automated multi-node environmental water parameter monitoring and conducts assessment of its measurement quality. Solution is realized as low-cost and robust system, it can be placed almost anywhere since GSM network now days can be reached anywhere. Power consumption is minimal, so system can work on battery for several years without need for replacing, and need for maintenance is minimal.

From measurement results of the probes in system, it can be seen that accuracy of the probes is adequate for environmental monitoring, except nitrate measurement. Nitrate probe error is extremely high for such low levels of nitrate in water, so this probe can be only used as detection of higher levels of nitrate concentration. There is a possibility that by additional laboratory measurement of water sample sources of interfering ions can be found and that measured results can be then corrected by additional calibration.

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