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A step forward in the in-line river monitoring of nitrate by means of a wireless sensor network

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ABSTRACT

This paper is based on our previous work consisting of the development and deployment of a wireless sensor network for the continuous in-line monitoring of the content of nitrates in a river in Eastern Spain. We present new contributions that significantly enhance its applicability, improve its features, and increase its reliability and useful life.

For this purpose, an expert system has been developed in order to improve the features of the whole system operation in an intelligent, flexible, user friendly way. This expert system offers several policies to optimize the times at which measurements are to be carried out (and sent), sampling frequency being altered according to the system evolution, the user preferences and the application features. The implemented policies are as follows: (a) periodic transmission; (b) gradient transmission; (c) user request and (d) peer request.

Additionally, in order to increase the reliability of the system, a triple modular redundant transducer in each sensor has been implemented, increasing dependability of the system with a very small affection of cost and consumption. Prior to the field trials, some laboratory experiments have been performed for parameter adjustment and checking purposes. As in the previous work, the proposed system has been deployed along a certain stretch of the river, its operation being studied and validated.

1. Introduction

Just like dissolved oxygen, temperature, and pH, the amount of nitrates in water is determined by both natural processes and human intervention. All aquatic organisms excrete wastes and aquatic plants and organisms eventually die. These activities create ammonia. Some bacteria in the water change this ammonia to produce nitrite which is then converted by other bacteria to nitrate. Nitrates also come from the earth. Soil contains organic matter, which contains nitrogen compounds. Just like the ammonia in water, these nitrogen compounds in the soil are converted by bacteria into nitrates.

Although nitrates occur naturally in soil and water, an excess level of nitrates can be considered to be a contaminant of ground and surface waters. However, most sources of excess nitrates come from human activity. The source of excess nitrates can usually be traced to agricultural activities, human wastes, or industrial pollution. Nitrates have traditionally been used as fertilizers in agriculture. Rainwater can then wash nitrates in the fertilizer into streams and rivers or the nitrates can seep into ground water. This can also occur with animal waste and manure. In addition to animal waste, untreated human sewage can contribute to nitrate levels in surface and ground water. Leaking or poorly functioning septic systems are a source of such nitrates. City sewage treatment plants treat sewage to make it non-hazardous, but treatment plants still release nitrates into waterways. Furthermore, industrial plants and agricultural processing operations are also potential sources of nitrate pollution.

All in all, excess levels of nitrates in water can create conditions that make it difficult for aquatic insects or fish to survive. Nitrates are nutrients that typically promote excessive growth of algae. As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water of available oxygen, causing the death of other organisms, such as fish. On the other hand, if you drink water that is high in nitrates, it can interfere with the ability of your red blood cells to transport oxygen. And infants who drink water high in nitrates may turn “bluish” and appear to have difficulty in breathing since their bodies are not receiving enough oxygen.

Therefore, it seems obvious that the monitoring of water quality in aquifers and rivers may result fundamental to preserve both the environment and public health [1]. Initially, it was carried out off-line in the laboratory by means of different instrumental techniques [2]. Nevertheless, it is also known that during storage

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the integrity of the sample may not be preserved, due to several effects that include biological activity and matrix effects, even when correct sample handling protocols are strictly followed. A recent alternative approach consists of performing the measurements at the location of interest (in-line analysis) with electronic handled devices, a procedure that is straightforward with: (a) the elimination of contaminants due to sample handling, i.e., no or minimum sample transformation; and (b) the minimization of the overall cost of data acquisition (in particular, due to a reduction of time for sampling, handling and analysis of the sample) [3]. These measurement techniques, based on handled devices, still suffer several drawbacks, such as the requirement of a human employee to move to the sample place, being still expensive. In addition, poor results are obtained, due to the low numbers of samples taken, even in time and in space. It also results very difficult the synchronous acquirement of data in several sample points. Finally, as it is not a real time acquisition system, several features or applications may not be obtained, for instance, the use of the sampling system to generate fast response alarms. Anyway, this is a cumbersome process and often does not provide the required spatial discrimination and/or the large sets of data necessary to describe the temporal evolution of the parameters of interest [4]. This implies the need for research on new approaches for in-line monitoring providing this real time space–time information with a higher number of samples without increasing – and even reducing – the process cost. There is no doubt that this trend toward in situ monitoring has been consistently reinforced over the last years, i.e. most new sensors for water quality monitoring are designed for direct installation in the medium, compact in size and use measurement principles which minimize maintenance demand. Ion-sensitive sensors (Ion-Selective-Electrode – ISE) are based on a well known measurement principle and recently some manufacturers have released probe types which are specially adapted for application in water quality monitoring.

Nowadays, ISE-probes are preferably built as compact dip-in probes, which can be installed directly in the medium. This compact dip-in assembly allows easy installation, which makes them suitable for an appended installation at an existing plant, short term installation for special monitoring campaigns or even application in a mobile monitoring station. No additional equipment like sample filtration units, supply pumps and interconnecting pipe work is needed. In some cases, the probes are even equipped with an automatic cleaning system using pressurized air, which proved to work reliably.

In this sense, our research group has been proposing over time several improvements in the automation of the monitoring process, based on innovative technologies, such as, for example, artificial intelligence techniques (expert systems, a.k.a. knowledge-based systems) to automate the analysis “off-line” using Flow Injection Analysis (FIA) [5]. Another step was the introduction of the analysis “in-line” by means of nodes with GPRS-based wireless communications [6]. And more recently we have highlighted the advantages of the application of the so-called wireless sensor networks (WSNs) for chemical analysis systems [7], an interesting study being carried out along 35 km of the River Turia (province of Valencia, Eastern Spain); it shows an automatic system, based on wireless sensor networks that allows for a real-time low-cost, and efficient monitoring of the nitrate concentration in the river [8]. Additionally, and beyond other approaches that only provide new concepts, this contribution has also dealt with the real applicability, and hence it has solved some usually unconsidered problems, such as energy consumption, system durability, and so on.

Following this research path, the present work represents an important step forward in in-line chemical monitoring of fresh water quality, since we present new contributions that significantly enhance the applicability of the aforementioned WSN to the in-line river monitoring of nitrate, improve its features, and increase its reliability and useful life.

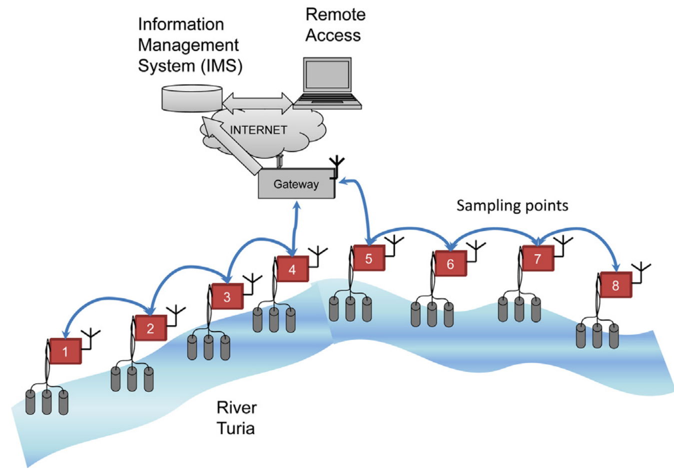

Fig. 1. Scheme of the proposed system.

2. System description

Despite of the success of the previously commented system [8], we have improved it with several features that open new possibilities, allow for its application to a wider range of environmental analysis process, and increase the reliability of the system, with a small cost increase.

In this new version, our system has been provided with more than one probe (ISE) due to: (a) its intended intelligence ability, (b) the low consumption of the probes, and (c) the importance of the correct functioning of the sensor, since the transmission of a wrong measurement would result in a considerable energy cost. The option consisted of using three probes (triple modular redundant), their relative consumption with respect to its reliability being evaluated. In this way, three identical probes will be available for each node sensor, a set of rules being in charge of deciding how the respective values should be merged.

A set of 8 nodes was then strategically deployed following the course of the river. The same sampling points as in the previous system were used. But now the nodes equipped with a single nitrate ISE (Ion Selective Electrode) probe have been replaced by others having a new microprocessor and, above all, a redundant probe system composed of three ISE transducers. The power requirements of the new system make it necessary to utilize two solar panels to guarantee the correct functioning under the hardest circumstances. As in our previous work, communication was carried out by means of multi-hop wireless communication [8], nodes being used not only as sensors but also as relays of information from nodes located further away (Fig. 1).

Data are also sent to the gateway using wireless transmissions, but the communication protocol has been improved to allow for two-way communications [9,10]. On the other hand, a new module added to the IMS (Information Management System) permits the edition, formal verification, simulation, and automatic distribution of the system behavior rules in a remote way. The module itself decides which rules should remain in the IMS for local information management, which ones should be run in the gateway, and those that should be distributed among the nodes for local running. Finally, the parameters associated with these rules are also shown and may be edited in a friendly way for inexperienced users.

Additionally, the IMS has been improved to receive (from the gateway) and process, not only information on the obtained measurements and the energy level in the nodes, but also the new