Low Cost System for Detecting Leakages along Artificial Dikes with Wireless Sensor Networks

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Abstract

Recently, the number of floods has been increased worldwide enormously. Especially, the damage along flooded rivers cannot be significantly avoided with current techniques. That leads to a high demand for new approaches to detect leakages in the dike body early.

Therefore, we present our work in progress on developing a ”Leakage Detection System” (LDS). After this system has been installed alongside a dike, it operates autonomously and alarms the headquarter if the water level exceeds a critical threshold. This allows rescue workers to strengthen drenched regions preemptively. Real world experiments in a reconstructed dike environment demonstrate the feasibility of our system approach.

Categories and Subject Descriptors

C.2.4 [**Distributed Systems**]: Distributed applications

General Terms

Algorithms, Design

Keywords

wireless sensor networks, applications, dike leakage detection, disaster prevention

1 Introduction

In recent years, a worldwide dramatic increase of flood disasters can be noticed. In middle Europe and particularly in Czech Republic, Austria, and Germany floods caused human casualties and high financial losses. Just to mention some facts, in 1999 only in Bavaria the flood affected more than one hundred thousand people. The flood of the Elbe river in 2002 engulfed 9.2 billion Euro in Germany and 3 billion Euro in Czech Republic [1]. After that, only in Saxony more than 107.45 million Euro were provided by the federal sate and the German government to provide fast help [2]. There are still some existing techniques, which are principally feasible but not well suited due to the later discussed reasons to decrease the dimensions of floods.

Therefore, this paper takes advantage of the highly promising wireless sensor networks (WSN). We present a low cost and efficient system for early leakage detection in artificial dikes. This can be accomplished by a chain of wireless sensor nodes, placed alongside a dike, which continuously measure the water level in the dike body and automatically alarms the user before the dike bursts. Accordingly, endangered regions of the dike can be strengthened early and precisely.

This paper is structured as follows. Section 2 describes the related work. The novel idea behind our ”Leakage Detection System” (LDS) is explained in Section 3. After testing of LDS and the presentation of the appropriate results in Section 4, we conclude this paper in Section 5.

2 Related Work for Flood Detection

Castillo et al. developed a WSN for the detection of a phenomenon called flash floods [3]. Flash floods occur if huge masses of earth slip from slopes into rivers. This effect causes a displacement of water in a short time that leads to a flash flood.

In [4] WSN are used for flood detection of low water bridges. Grid-based computational models, which predict flood trends are described in [5]. In [6] sensor nodes were placed along the Ribble river in Yorkshire Dales.

Leakage detection systems are a big issue in the field of Geo Information Systems (GIS). We suggest among others [1, 7, 8] for more details.

3 LDS: Leakage Detection System

3.1 Approach and Design Considerations

Designing reliable sensor networks is very complex, because many considerations must be taken into account [9]. The dike scenario advantageously decreases the complexity because:

1. Nodes are placed on a long line.
2. Manual deployment is possible (infrastructure instead of randomized deployment)
3. Static network, as long as the dike is not broken
4. The required network lifetime is up to some weeks only

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3.2 Node Hardware

The dike sensor hardware principally consists of two main parts — an upper part and a lower part, as shown in Figure (Fig. 2). The upper part is a module for communication, computation and conversion of analog to digital values. Due to wireless data communication and the associated electromagnetic properties this module must be placed outside the dike body. Whereas the lower part includes a simple but efficient circuit to detect the water level within the dike body. The circuit is very robust against damages and also cheap. If the dike is already built, the lower part is rammed into the existing dike body. But, if the network installation process can be combined with the construction of the dike, the lower part of the nodes can be deployed directly in e.g. sand sacks.

Figure 1. Encapsulated CC1010 sensor evaluation module.

3.2.1 *Device for communication and computation (upper part)*

For communication and computation we used modules of the type CC1010EM (868/915 MHz) from Texas Instruments. These modules feature a low power consumption and a low transceiver sensitivity of typically -107 dBm.

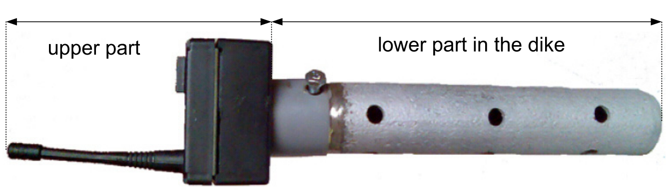

Figure 2. Sensor node equipped with a CC1010 evaluation module from Texas Instruments as upper part and a metal pipe containing the circuit to detect the water level as lower part.

The integrated 8051-microcontroller allows simple calculations and the control of the transceiver's hardware. Another essential component of the evaluation board is the 10 Bit ADC. Later, these ADC captures and digitize the analog measurement values. The evaluation modules (CC1010EM) supported hardware revision 3.0 and the evaluation boards (CC1010EB) hardware revision 4.0. We encapsulated the CC1010 evaluation modules in a chassis with additional wiring and batteries to allow free movement (Fig. 1). Due to the manual placement of nodes, no internal localization procedure needed. Every node gets assigned a fixed position at the installation process.

3.2.2 *Wiring (lower part)*

As we already explained, the lower part includes the water level detection circuit. Therefore, we divided the lower part in an outer pipe and an inner pipe. The circuit is attached to the inner pipe. The inner pipe is electrically isolated and must be inserted into the outer pipe. The outer pipe is more solid. Figure 5 illustrates our prototype with its components.

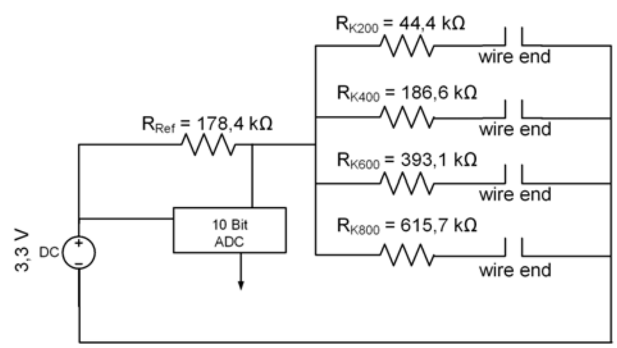

Figure 3. Circuit to detect the water level in the outer pipe.

We decided to use two pipes, because the circuit is protected against outer influences. The outer pipe consists of little holes. During an upcoming dike burst the water flows slowly into the holes of the outer pipe.

Before we decided to develop an own water level detection solution, some commercial humidity sensors were tested. However, main disadvantages of these sensors are that they (i) are expensive, (ii) measure the relative (absolute) humidity in the air, (iii) get destroyed if water floods the outer pipe.

Our approach rest upon the electrical conductivity of water. The conductivity is material specific and depends on the temperature. It is measured in Siemens per meter (S/m) and is reciprocal to the well known resistance. Tab. 1 lists some important conductivities of water in our region.

The idea is as follows: Let's assume a simple electric circuit with one wire (the resistance) and a power supply. If the wire of this simple circuit will be cut, no current flows anymore, because air is an isolator. However, if not air but water is between both wire ends and the distance between the wire ends is small enough, current flows again.

Water	Conductance κ at 4 °C [µS/cm]	Conductance κ at 24 °C [µS/cm]	Conductance κ at 40 °C [µS/cm]
Ultrapure water (fresh water)	1.2	2.0	4
Mains water in Rostock (fresh water)	321	529	782
Water from the Warnow river (salt water)	363	631	931

Table 1. Conductivity for different varieties of water.

Our first circuit basically consists of a power supply and two resistors. One of them is a reference resistor with R_{Ref} = 178.4 kΩ, which was empirically determined. The second one is the resistor that is affected by the water between the wire ends. An analog to digital converter (ADC) compares the sampled voltage over R_{Ref} with the reference voltage $U = 3.3$ V. We determined in experiments that a distance of one millimeter between both wire ends is well suited. To summarize, detecting water with this kind of circuit is very simple and cheap.

Further, it would be important to detect different water level in the outer pipe. Thus, we extended the before mentioned circuit with some parallel branches, each including one dropping resistor and after this resistor a gap of one millimeter between the wire ends. This circuit is shown in Fig. 3. If the dropping resistances are high enough, then the resistance of the water, which is ca. 311 Ω in our experiments (Tab. 1) can be neglected.

Moreover, if the dropping resistances are placed in a special order where the highest resistance is placed in the maximum depth of the dike body and the smallest resistance is placed on the dike surface, then the current flow chooses the branch, which was flooded latest. Thus, the length of the pipe and the number of branches regulates the resolution of the measurements on each node.

3.2.3 Detecting the water level

In our experiments, we have chosen four branches in the circuit. The distance between the wire ends was kept at 1 mm. Our CC1010 sensor node contains a 10-bit ADC to measure the voltage over the reference resistor and to convert it into an integer with the range of 0 . . . 1023. We empirically determined the values of the dropping resistances regarding a difference of 200 between the ADC values. Fig. 6 visualizes the ADC values if one branch after another branch was shortcut by (a) sweet water and (b) 11% salt water. Here, we took one measurement per minute. The circuit allows differing every water level precisely, although the fluctuations in sweet water are higher than in salt water.

4 Testing in a flooding environment

4.1 Preliminary and Environment

The practicability of LDS was examined in a simple real world flooding environment on an exemplary hill (Fig. 7). The hill was heaped up two years before our test was done. This guaranteed that the earth of the hill was compressed by natural influences.

On the hill, we flattened a rectangle of 150 cm × 300 cm, which should be act as dike top. In the middle of the dike surface, we dug a hole of the size 80 cm × 130 cm × 40 cm (length × width × depth), where the water was filled in. The ground of the hole was inlaid with a foil to avoid soaking of water into the dry ground. Fig. 7a illustrates the construction. We dug four small holes alongside the dike to be able to insert the four pipes vertically into the dike body. At this point, we decided to remove the upper part of the nodes, because the focus in this experiment was to analyze the feasibility of the water level detection circuit and not the wireless communication, which has been intensively studied in other projects. Therefore, the wires were directly connected to an evaluation board (CC1010EB) which was connected to a laptop via RS232. With this configuration, the experiment started by taking one measurement every 40 s.

4.2 Real World Experiment and Result

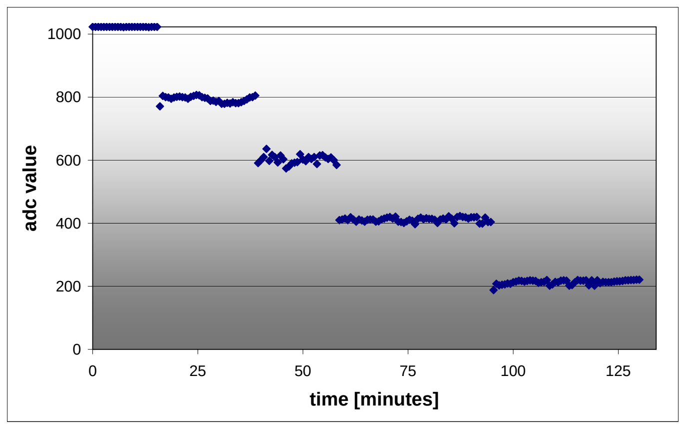

Figure 4. Measurements of one node, which was placed in an artificial dike.

We started the experiment by slowly filling the hole with water, which took at least 118 minutes, before the dike broke. In the first 92 minutes, the whole dike body sponged with water. After that period, the water sided bank disintegrated, which can be seen on Fig. 7b. After 26 minutes, it collapsed completely. Before it collapsed completely, the water break into the outer pipe step by step and the water level grew. In this period, we measured the water level with the node. The measurements of one node are shown in Fig. 4. Due to the fact, that we already knew the exact depth of the specific wire end, every point cloud in the figure indicates the high of the water level. At which height an alarm is triggered depends on the dimensions of the dike body. With more then four circuits on the inner pipe it is possible to detect the water level in the outer pipe more precise.

5 Conclusion

We presented a low cost system to observe dikes for possible leakages and to prevent serious breakage. It is an environmentally friendly, robust and low maintenance complete system. This ”Leakage Detection System” (LDS) is strongly demanded, due to the increasing endangerment of flood disasters worldwide. It was shown that our new approach combines the promising wireless sensor networks with a simple but very efficient water detection circuit. Many of these sensor nodes are manually placed alongside the dike and ensure a fine grained observation of the dike as well as early alarms to be able to strengthen weak parts of the dike. We estimated that the cost of one node is about 50 Euro caused by the expensive CC1010 rather than the water detection circuit. However, our system can be deinstalled after operation easily and thus it is ecological and reusable, which saves costs. The feasibility was shown in an experiment within a real dike environment. Future work deals with installing a larger LDS along a real dike controlled by our own network administration tool called Envisense [10].

6 Acknowledgment

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Figure 5. The node consist of a circuit that is mounted on an inner pipe. The inner pipe is moved into the outer pipe, which is made of solid metal and protects the circuit. The wiring of the inner circuit is connected to the pins of the sensor node.

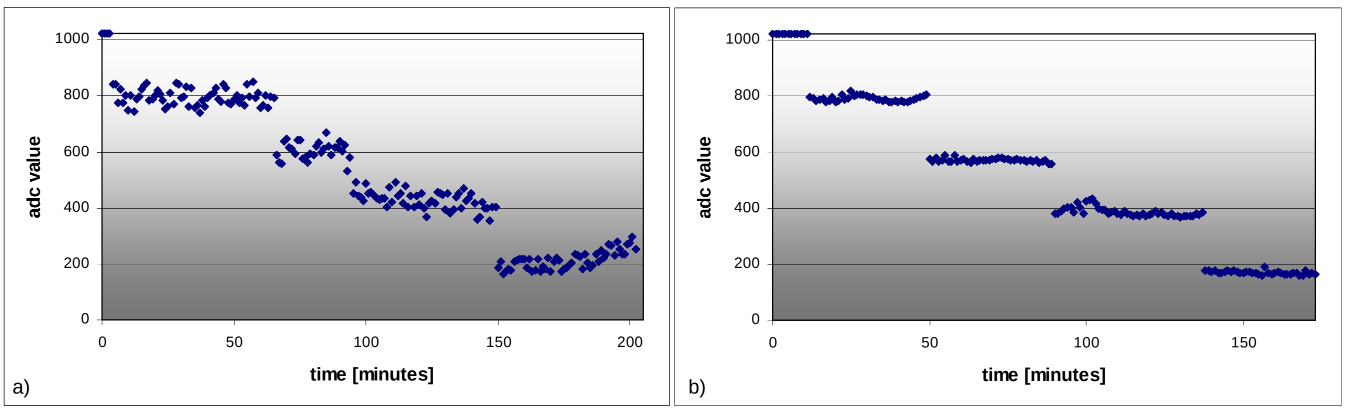

Figure 6. Measurements of the voltage over the reference resistor to detect a) pure sweet water and b) 11% pure salt water, which slowly floods the outer pipe.

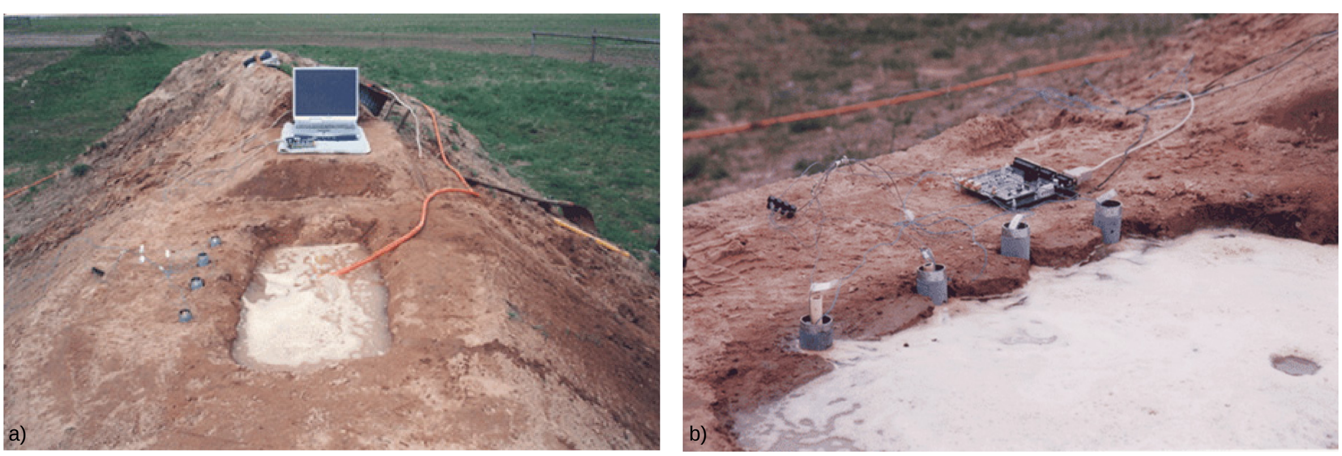

Figure 7. a) Artificial dike with four nodes (here without mounted CC1010 evaluation module on every pipe); b) Water has already eroded the surface and the dike threats to break.