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A LOW POWER WIRELESS SENSOR NODE FOR THE MEASUREMENT OF HEIGHT VARIATIONS OF COASTAL SAND DUNES

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Abstract: in this paper the authors describe the structure of a wireless sensor node designed to measure height variations in coastal sand dunes. The paper focuses on the project and development of a sensing device able to measure the changes of height of sand dunes, based on an array of photoresistors (LDRs), designed to withstand the critical atmospheric conditions of coastal environments. Together with the sensing device, also a power control logic has been studied and developed, to reduce the power consumption leading to an ideal life time of the node of around two years. The sensor node is also provided with wireless communication capabilities based on the ZigBee communication protocol and is integrated in a network infrastructure for remote data collection.

The proposed sensor node, together with a minimal network architecture, has been developed and tested directly on the beach to prove its effectiveness. In this paper, the overall structure of the node is described, along with its operating principle and the functioning of the power control logic.

Keywords: Wireless Sensor Network, ZigBee, Sensor, Environmental Monitoring, Coastal Dune.

1. INTRODUCTION

Sand dune morphodynamics is often closely related to coastal erosion [1], because dunes act as a dynamic barrier preventing storm waves to inundate the inland. They are affected by many factors (waves, wind, availability of sand), which all concur to lead their evolution and development towards different states, such as equilibrium, accretion, and erosion [2]–[5]. Therefore, it is crucial to define dune height variations in the short term because it is a key parameter for the evaluation of sediment transport rates (volume and direction) on a dune field [6], [7].

The general idea of this paper is to enrich the existing data collection systems (e.g. environmental parameters monitoring systems) with the data obtained by monitoring sand dune height variations, in order to estimate the temporal evolution of the dune field and eventually to hinder possible erosive phenomena through ad hoc interventions. Preliminary results obtained in this work will be used to set up an heterogeneous monitoring infrastructure to be deployed on the sand dunes located in the Migliarino, San Rossore, Massaciuccoli Regional Park near Pisa, Italy [8].

2. SENSOR NODE STRUCTURE

The developed sensing device is comprised of three parts: the transducer structure that performs the data collection, the control logic system and the data transmission module. The structure that physically performs the measurement is constituted of an array of 24 photoresistors (LDRs) arranged on a plastic plank at a distance of 5cm from the adjoining (Fig. 1). The plastic plank is then put inside a transparent protective plastic tube that ensures the protection against atmospheric agents. Each LDR is able to detect the presence of sunlight, transforming this information into an electrical signal ranging between 0V and 3.3V. The value of this signal can be analysed to estimate whether or not the LDR is sunk into the sand dune: a value close to 0 means that no light is detected and that the LDR is sunk under the dune surface. The overall number of sunk LDRs is used to determine the length of the emerged portion of the tube and subsequently the sand level.

The proposed sensing structure (composed of 24 LDRs positioned at a 5cm distance) can cover 120 cm of length with a resolution of 5cm. While 12 LDRs are sunk, a 0cm value is detected. When all the 24 LDRs are sunk, a +60cm value is detected, while if all the LDRs are exposed to sun light, the detected value is -60cm.

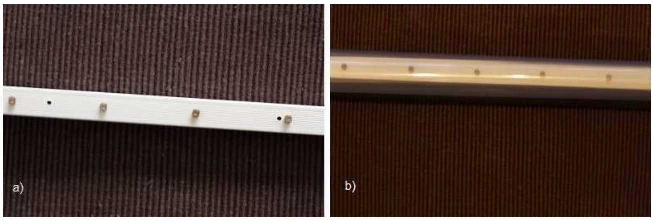

Figure 1: Section of the array of 24 LDRs: a) without protective tube; b) with protective tube.

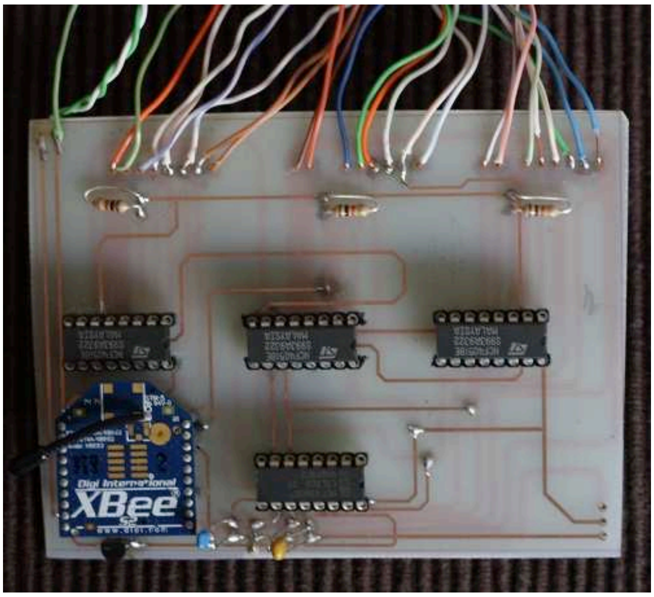

Figure 2: The assembled power control logic system and radio transmission module.

The second part of the sensor node is composed of the control logic system in charge of the overall operation of the device. This structure is made up of a binary counter, 3 Multiplexers (single 8-channel analog MUX) and a MOSFET (used as a switch).

The third part is composed of the radio transmission module in charge of the data transmission, i.e. an XBee Series 2 wireless transmission module by Digi, which implements the ZigBee protocol. Fig. 2 shows the board including the control logic system and the XBee module.

The following are then the main components used for the sensor node:

- 1 HEF4060BP binary counter with 10 outputs. The design parameters to determine the oscillation frequency f_{osc} of the counter are R_t = 470KΩ and C_t = 100nF, therefore, the oscillation frequency is equal to

$$f_{osc} = \frac{1}{2.3 \times R_t \times C_t} = 9.2506Hz \qquad (1)$$

and the oscillation time t_{osc}

$$t_{osc} = \frac{1}{f_{osc}} = 108.1ms \qquad (2)$$

Selecting 3 of the 10 outputs of the counter, they can be used to drive the selection bits of the MUX (logic signals of selection). For the developed sensor the chosen counter outputs were O_6, O_7, O_8. For these outputs the clock cycle can be calculated as follows:

$$t_{O_6} = t_{osc} \times 2^6 = 6.918s \qquad (3)$$

$$t_{O_7} = t_{osc} \times 2^7 = 13.836s \qquad (4)$$

$$t_{O_8} = t_{osc} \times 2^8 = 27.673s \qquad (5)$$

It is noted that O_6 has the shortest duty cycle and therefore it must be connected to the least significant selection bit of the MUX (pin 11); O_7 is connected to pin 10 and O_8 to pin 9.

- 3 Single 8-channel analog MUXs with 3 logic selection signals (HCF4051BE). The state (0, 1) of the selection bit, as described above, is operated by the binary counter. The task of the MUX is to select a single input (that is connected to an LDR) at each change of state. The outputs of the MUX are connected directly to the analog pins of the XBee transmission module that collects the data and sends them to a ZigBee Coordinator for each state variation.
- 24 VT900 Series LDRs, each of which is connected with one end to an input of the MUX and with the other end to the supply voltage.
- 1 XBee S2 transmission module that implements the ZigBee protocol and can cover distances of around 100m outdoors. For each transmission, a 36 byte API frame containing different information is sent: in addition to values relating to the data acquired by the LDR, the frame includes a byte that indicates the start of the frame, two bytes that indicate the length of the frame, and eight bytes that identify the module that is transmitting. The module operates in cyclic sleep mode.
- 1 MOSFET (BS170) that is used as a switch. The on/off switch is managed directly by the XBee module; in particular, when the XBee goes into sleep mode, it enables the open circuit function of the MOSFET, which disconnects the power from the entire control logic.

The electrical diagram of the control logic system is shown in Fig. 3, where $R_1 = R_2 = R_3$ = 1kΩ are pull-down resistors, R_4 = 2.2kΩ is used to limit the current flowing

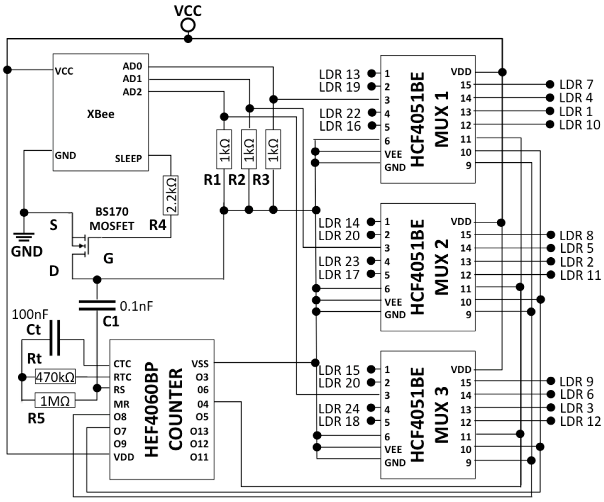

Figure 3: Circuit diagram of the control logic system.

Figure 4: The completed sensor node installed on the beach for test measurements.

through the MOSFET's gate and $R_5 = 1M\Omega$ and $C_1 = 0{:}1nF$ are required by the oscillator circuit of the counter.

3. OPERATING MODE

After the activation of the sensor, the three outputs of the binary counter drive the logic selection signals of the MUX. Each change of state (logic signal selection) selects a single input of each MUX (i.e. 3 inputs) that is connected to a single LDR: data of the first 3 LDRs is then acquired and sent to the outputs of the MUX. The outputs of the MUX are connected directly to the analog pins of the XBee module: data is then received at the appropriate pin and transmitted to a ZigBee Coordinator through wireless connection. While each transmission includes the measures of 3 LDRs, after the eighth transmission, data from all 24 LDRs of the array is sent. At the end of the eighth transmission, the whole sensor node is put in sleep mode to minimize power consumption. The sleep mode is allowed by the XBee transmission module that, after proper setting and thanks to the addition of the MOSFET (working as a switch), is able to disconnect the power supply of the entire sensor node, turning then it on when the next measurement is required.

The eight data sets are received by the Network Coordinator (i.e. the ZigBee Coordinator) that is in charge of calculating the overall dune height and transmitting this value to a remote data acquisition server. The Coordinator is composed of an Arduino UNO board, in charge of data elaboration, an XBee series 2 module in charge of receiving the data from the Sensor Nodes and a GSM Arduino shield in charge of transmitting the calculated height value to the remote server by GPRS connection. The Coordinator is also provided with an energy harvesting solution based on the use of a solar cell.

The dune height values are received by a Glassfish server that stores them in a MySQL database, and is also provided with an on-line data visualization service.

4. RESULTS

The sensor is designed to acquire data every 4 hours: about 1 minute is required to capture and transmit all the data relating to the height of the dune. The minute of activity is then followed again by 4 hours of sleep. The period of sleep can be obviously modified according to specific requirements. The XBee S2 transmission module implements the ZigBee communication protocol and is able to cover distances of communication equal to about 100m. Two 1.5V AA batteries connected in series provide the power supply (3V).

According to the specifications described previously, the overall consumption of the sensor is approximately 41mAh: this value includes the XBee consumption, that is around 35-40mAh, and the LDRs consumption, that is lower than 0.3mAh for each LDR. The energy consumption of the sensor node in minutes of work (**c**) is then

$$c = \frac{41mAh}{60} \tag{6}$$

Using the system with the proposed data sampling settings, in particular with 6 minutes of activity per day, the lifetime of 2AA batteries (1.5V) with a capacity (C) of 2900mAh can be calculated as follows:

$$D = \frac{C}{6c} = 707.32days \tag{7}$$

23	-60	2016-08-10 13:32:42
22	-60	2016-08-10 13:13:12
21	-60	2016-08-10 12:53:42
20	-60	2016-08-10 12:34:11
19	-60	2016-08-10 12:14:41

Figure 5: sand dune height as measured by one of the sensor nodes.

meaning around 2 years of activity using common and cheap power supplies.

5. SYSTEM TEST

The functioning of the sensor was tested on the Gombo sand dunes in the Migliarino, San Rossore, Massaciuccoli Park (Fig. 4): the tests focused on the functioning of the sensor, i.e. the correct acquisition of the sand dune height variations, while the real life time of the battery is expected to be tested only after the final installation of a Wireless Sensor Network composed by a larger number of nodes.

The overall effectiveness of the sensor node together with a minimal network architecture was tested: this architecture included three sensor nodes and a Coordinator node. The sensor nodes were aligned perpendicular to the coastline, around 10m apart from each other. The Coordinator was positioned close to the upper node. The data acquisition was performed for a 24 hours period in August, 9th, 2016: in order to speed up the data acquisition process, the sleep period was reduced from 4 hours to 30 minutes. The sampling of the second node was performed 10 minutes after the first one, and the sampling of the third after another 10 minutes, in order to avoid possible collisions. The data packets were sent to the Coordinator that calculated the height value and sent it to the Glassfish server. The value was then stored inside the MySQL database together with a Timestamp. These data were then directly available on line: Fig. 5 shows a screenshot of the database table as visible through a common browser.

The tests proved the effectiveness of the sensor in measuring the height variations: in particular, dune height was measured with an approximation of around 5cm. While the totally sunk LDR provided a value close to 0 and the visible ones provided a high value, the 2 LDR close to the dune surface measured intermediate values: this allowed the calculation of the approximate position of the sand level. This calculation could be easily refined defining a mathematical relation between the LDR values and the measured sand level values: this could lower the approximation value down to 1cm. Nevertheless, for the system requirements in terms of morphodynamic analysis, a 5cm approximation value can be considered acceptable.

6. CONCLUSION

The sensor node described in this paper proved to be able to measure the height variations in sand dunes with an acceptable degree of accuracy. The functioning of the node was successfully tested in a real environment: additional tests are required to prove the real life time of the batteries, that has been theoretically calculated obtaining a value of around 2 years.

While this paper focuses on the description of a sensor node together with a minimal network architecture, the effectiveness of this solution can be mostly appreciated when a larger number of sensors is arranged in a network structure. When using 4 sensors positioned at the corners of a rectangle, an estimation of the sand volume variations can be provided, allowing thus to study the sediment transport in a predefined span of time. Similarly, if using a wider number of sensor nodes arranged in a grid layout, it will be possible to estimate the morphological variations of a whole portion of a sand dune, which would be of great help for coastal managers given the crucial role coastal dunes play for ecological and economical purposes.

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