



Wireless sensor network development for measuring ultraviolet radiation on human health application

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reference action spectrum of the erythemal of the International Commission on Illumination (ICI) and it is normalized to 1 for the 298 nm. The referral rate is dimensionless and is defined for a horizontal surface by the following expression:

$$UVI = K_{err} \int_{250nm}^{400nm} E_{\lambda} S_{er}(\lambda) d\lambda \quad (1)$$

where:

K_{err} : Constant equal to 40 m² /W

E_{λ} : Solar spectral irradiance

$S_{er}(\lambda)$: Erythemal reference action spectrum.

The intensity of UV radiation to which people are exposed depends on the UVI levels of regions, situations or work in which they operate.

The UV Index is measured in horizontal plane in the different centers of the world in charge of giving the daily forecast of it or of doing related research. However, people exposes their body in all directions and the sun makes an apparent movement in the sky, which determines the need for UV index information at different levels in order to reconstruct the solar incidence throughout the body, as it was done manually and with a single sensor in a previous work [3]. So UVI values particularly high make it necessary to carry out several measurements in a defined area, with different angles of capture. These cases occur for example in Antarctica for the existing high reflectance, at construction sites for the amount of hours that workers are exposed to the sun, in high altitudes above the sea, or in regions where the atmosphere filters less UV radiation because of the depletion of the ozone layer. In these situations it is possible and convenient to use Intelligent Wireless Sensor Networks, "IWSN" [4], for the collection, temporary storage and transmission of the measurements. A IWSN is formed by nodes that are organized and connected together by the auto-configuration of a transmission net, in which specific techniques and algorithms are used to this functionality. In the IWSN each node can own and control one or more sensors suitable to the type of variable measured. Besides acquiring and transmitting data, the nodes perform other functions such as an efficient energy management to maximize the lifetime of the network, temporary storage of information, and local processing of data using different techniques [5]. In general, it is the specific application what will ultimately define the structure and characteristics of an IWSN and its nodes.

This paper reports a joint work by the Solar Energy Group (FCEIA - IFIR) and the Intelligent Wireless Sensor Networks Group (FCEIA) for the implementation of a network of sensors to make measurements of UVI. The aim of the work described in this paper was to investigate the feasibility of the proposed project and analyze, design and build a prototype sensor node suitable for the measurement of UVI and also as a basis for the future establishment of a network of sensors for measuring UVI in the special conditions mentioned, this is: in Argentine Antarctica, on workers exposed for long periods to sunlight and in snow sports, among others.

The rest of the publication is organized as follows, section 2 details the requirements defined for the system, Section 3 describes the design and implementation of the prototype, and Section 4 account for the operation tests performed. Finally, conclusions and future work lines are reported in Section 5.

2. Requirements defined for the system.

Applications of IWSN generally have "ad-hoc" requirements that should be taken into account. Therefore, although there are a set of techniques, communication protocols, transmission systems and technologies that are applicable specifically to the design and creation of the IWSN [6], the selection and use of these resources is defined when the particularities of each case are analyzed.

The requirements exposed in this thesis are summarized in the following basic points:

Measurements Frequency: The nodes of the IWSN can perform measurements continuously, or on periodically or triggered by environmental events demands. For our particular cases UVI data acquisition requires periodically measurements, with intervals of 10 to 30 minutes. However, there is the possibility of having to make measurements at high frequencies (30 seconds or less). So, it was defined that the structure of the network and the nodes should be flexible enough to cover this range and to allow an online reconfiguration of the detection times. However, as the network "sleep" during periods in which it does not have to measure and transmit, saving energy in this way. [7], the lifetime of the network and nodes were calculated for the case of performing measurements every minute.

Low Energy Consumption: In the IWSN the constituent nodes usually acquire the energy required for operation of internal batteries. In many cases, the sensor nodes location prevents the use of renewable energy sources and it is possible that the batteries were set in places of difficult or impossible access that makes it difficult their frequent replacement. This feature leads to propose a design that maximizes the lifetime of the network [8], minimizing the consumption of each sensor nodes. This type of restriction is necessary for a number of interesting applications, mainly those aimed at measurements in Antarctica, where it is required a minimum autonomy or nodes between 3 and 6 months.

Number of Variables to Measure: The traditional measurement for the UVI is done in vertical orientation, that is to say, this index is defined by reference to a horizontal surface at ground level integration. In this case submitted applications require the need to perform multiple simultaneous measurements with different degrees of tilt, with a minimum of five directions. In addition it is desirable to measure other key variables such as temperature. Thus, it was decided to work on a flexible design of the nodes, which allowed the acquisition of a minimum of six variables, with future possibilities of expansion, through multiplexing.

Network Topology: The relative location of the nodes in the IWSN, may acquire many different forms, with fixed or mobile nodes. From the logical point of view these networks can be structured in the classical forms: star, ring, bus, hierarchical tree or mesh [9], but in all cases the information from the network ends up being collected in a special node called commonly "sink." The implemented prototype has a small number of nodes, but future applications may require deploying a large number of these devices. Therefore, the star topology was adopted for the prototype, operating in the point-multipoint form, defining the "sink" as the direct recipient of the information sent by the nodes. It is possible that the network may migrate to a peer-to-peer topology to contemplate the applications where not all the sensor nodes can directly connect to the "sink", having to use intermediate nodes to transmit messages. It was decided that the prototype operates under the IEEE 802.15.4 protocol, which will allowed, in the future, to set up routing algorithms of higher level and complexity [10].

Deferred transmission: For some of the programmed applications it may be possible to the "sink" to be out of service or far from the scope of the entire network as a normal working mode. If this were the case, it becomes necessary to provide local storage for the measurements, for either all nodes or in some with extended functionality, in order to retain the measurements made over a long period of time and transmit them when the presence of the "sink" is detected. Although it was considered for the designs the possibility of including this temporary storage, it was not implemented in the prototype, being its addition a purpose of further work.

3. Design and Implementation of the Prototype

3.1. General description

The "sink", in charge to collect all the measurements made by the sensors, is a node operating in a coordinated manner within the 802.15.4 protocol specification.

The implementation of the prototype, both the remote and the coordinator nodes was made with the transceiver Maxstream (today DIGI Int.) XBee model [11] 802.15.4. This transceiver properly handles the reception, transmission and "sleep" cycles to maximize energy savings. It also has a digital analog converter up to 7 channels, RS-232 interface and digital outputs for remote control. It has a programmable interface suitable for its control and configuration.

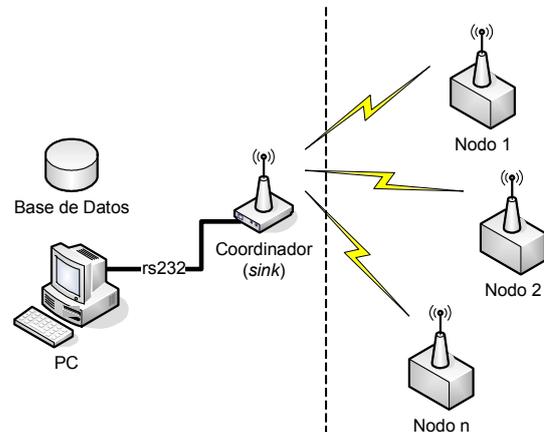


Figure 1

The distance between a remote and the coordinator node within which the link is possible, may depend on the type of module and antenna used, and of the existent clearance between them, ranging between 90 meters and 1600 meters on the outside with an external antenna and total clearance.

The coordinating node, to whom the remote nodes that contain sensors reported, includes received signal level gauges and controls of transfer / reception that allows to understand how it works. This is located at the point of collection of data and it is connected to a PC via RS-232 interface.

This PC, by means of a software specially developed for the application, administer and stores the information from the remote nodes and their sensors. Figure 1 shows a general scheme of the network.

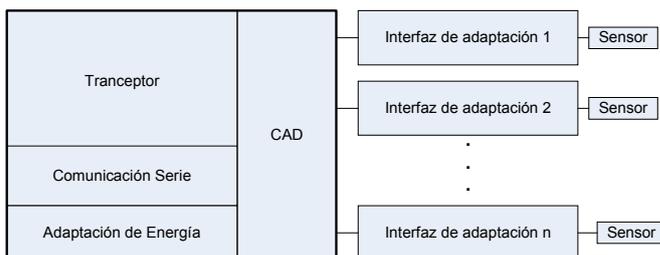


Figure 2

possible to change variables to measure and / or sensors without affecting the disposition or operation of the node. Figure 2 shows a block diagram of the remote node. This structure keeps a strict relation with the control software programming.

The remote nodes were defined in a modular way. In one module there were included components related to digital analog conversion, power adequacy and transmission. In another there were considered the components related to the amplification and adjustment of the signal levels coming from the sensors, very weak in origin. In this way, it is

4. Implementation of the Node

The remote nodes can be heterogeneous, both in type and in the number of sensors that they have. Each node was provided with the capacity of measuring up to 6 analog or digital variables, plus an exclusively digital one.

The power of the nodes in the prototype is performed by four AA alkaline batteries, which sums approximately 8000 mAH, allowing a more than six month autonomy. To reach this autonomy there were used components of very low consumption and the above-mentioned transceiver operating in the "sleep" way at every moment, except during the transmission / reception periods. Table 1 shows the distribution and calculation of the consumption considering a measuring frequency of about once per minute.

Table 1. Expected consumption.

	mode	Time	consumption	distribution
Transceiver	sleep	60 s	50uA	5,45%
	transmission	4 ms	250mA	3,64%
	idle/receive	1 s	50 mA	90,91%
Average consumption transceiver			885 uA	
UV Sensor Interfaces (5 x 3uA)			15uA	
other consumption (including temperature sensor)			65uA	
Total			965uA	

With this consumption, and even considering a general efficiency of the system of 80% or less, it is highly above the six months set for the required autonomy. These theoretical values were measured and verified on the prototype.

Analyzing the availability of tension levels supported by the transceiver and the available source power, conversion levels in the range 0 - 3V were defined. These values also match with levels possible for the interfaces described in section 3.3, for the most critical situation.

It was included in the node design a temperature sensor that was adapted directly on the main board. For control purposes, it was also included the possibility of reporting as a variable measure the level of battery voltage.

It should be noted that from the practical point of view and taking into account that both the remote nodes and the coordinator one are based on the same XBee transceiver, it was desirable to develop a single circuit to carry out both functions, defining the function role during the assembly of the node, including as appropriate the necessary components for each function.

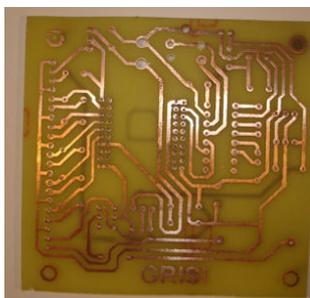


Figure 3



Figure 4

Figure 3 shows the developed form and Figure 4, a montage of it to fulfill with the function of remote node.

5. UV Sensors and Interfaces.

To determine the UVI it should be done a measurement of the ultraviolet radiation from the source Sun, from about 290 nm to 400 nm wavelength, and integrate these values enlarging them according to the curve of skin erythema. Alternatively, it can be used devices which response to ultraviolet light are equivalent to the erythematic curve.

In the prototype a photodiode developed by SGLux and manufactured in The United States for Research Inc Believes., named EryF* (EryFstar), was selected whose curve of response is showed in the figure 5 and that allows to make measurements with a precision of $\pm 0,5$ UVI.

This photodiode is based on an alloy of silicon carbide (SiC) that assures it a highly durability and can operate from -25°C to 70°C . In terms of ultraviolet light exposure it produces a current in the order of the nanoamperes, which must be amplified. For this purpose, special techniques and components were used to achieve very low power consumption. In particular, operational amplifiers (OA) responsible for the amplification of the currents delivered by the photodiodes with voltages and currents of "offset" very low, among other characteristics, and to operate as current-to-voltage converter amplifier in the first stage, were selected.

The LMC6442 AO was selected, which consumption, with two amplifiers in the chip is from about $0.95\ \mu\text{A}$ per amplifier. This selection was based on the fact that the application required a extremely low power consumption. The amplification level was calculated so that saturation does not exists even with UVI very high levels, above 20, which guarantees the possibility of measuring in regions of Argentina where there is extreme risk, as in summer in the intertropical high mountain area Puna de Atacama [13].

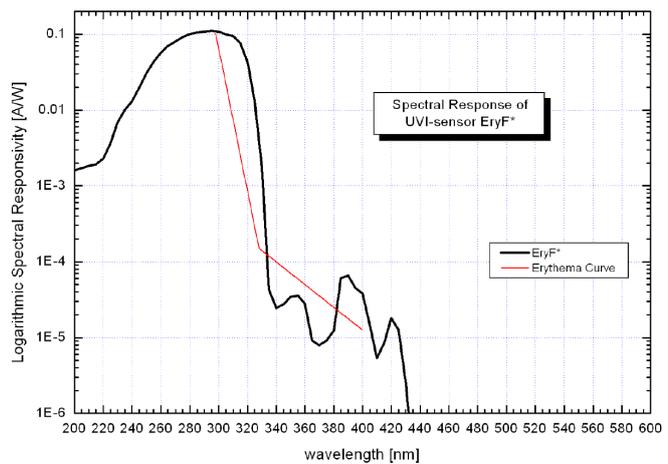


Figure 5

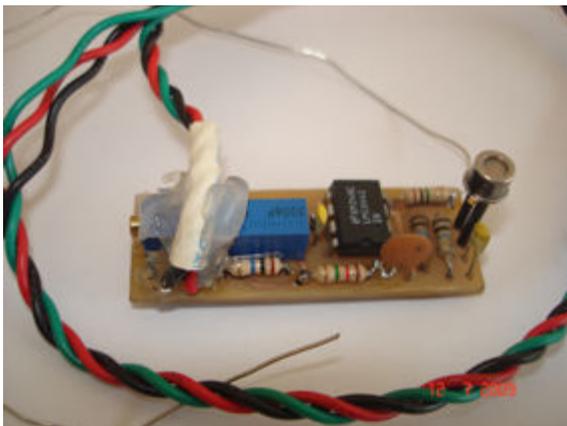


Figure 6

Some of the applications planned for the network require that nodes can be easily displaced, thus in the prototype, the circuit and size of the interface they were diminished to the minimum, although it was used, for practical reasons, the encased DIP one for AO. Physically the assembly was done on base of $15 \times 45\text{mm}$. Figure 6 shows the finished interface with the mounted sensor.

Because of the low levels of currents generated by the photodiode, the input circuit of the adapter is of very high impedance that is why it requires shielding to prevent the capture of electrical noises.

6. Constituent assembly

Two remote nodes were constructed: one with the UVI sensors described (EryF *) and the other using photodiodes of flat response in the spectrum UVB and UVC (AG32S [14] SGLux). The assembly of each one was performed placing a sensor in vertical form and other four in horizontal form, so as to test the measurement in several directions, according to the raised requirements.

The entire set was housed in a sealed box suitable for outdoor use. Figures 7 and 8 show the finished node.



Figure 8



Figure 7

7. Application Software.

The objective of the developed program is to handle communications with the nodes and to store in a database the values recorded by different variables under control. Certain facilities were also included to monitor in real time the status of communications, alerting about declines in the nodes or loss of messages. Figure 9 shows the main program interface.

Analysis tools were not included in the application software since the exportation of stored data to specific programs was assumed, so the application stores the digital values reported by sensors, after converting them to representative units of the measurable variable. Especially and taking into account the principal objective of measuring UVI values, the conversion is customizable in the form of a quadratic equation. This form was chosen from tests contrasting the values obtained with a biometric (erythemal solar irradiance meter trademark YES) used as a template, of the Solar Energy Group, located at the Astronomical Observatory of Rosario and contributed by the World Meteorological Organization, through the National Weather Service.

ESTRUCTURA: **BASICA**

Características
Nodo Coordinador

Com Num: COM1 Baudios: 9600 Paridad: N Data Bits: 8 Stop Bits: 1 Control Flujo: NO

CARACTERISTICAS NODOS FINALES

Nodo ID	Tiempo entre transm.	Cant. Lect p/Tran...	Tiempo entre Lecturas	% Max Transm. Perdida
1	20000	2	250	10
3	30000	1	150	10
5	50000	5	550	5

PINES Y TIPO DE SENSORES DE CADA NODO FINAL

Nodo ID	Id Pin	ID Tipo Sen...	Tipo Señal	Mgntd	A	B	C	Valor Max	Valor Min	% Posib Alerta
1	0	6	DI	OK	0,0	0,0	6,0	1	0	0
1	1	1	ADC	°C	0,0023	0,0	1,0	2700	10	10
1	2	2	ADC	°C	0,232	0,0	2,0	300	25	5
1	3	3	ADC	% HUMEDA	1,0	0,0	3,0	5000	50	8

Click sobre la fila del nodo para ver sus sensores

ULTIMA LECTURA REALIZADA EN CADA NODO

STATUS: S0 S1 S2 S3 S4 S5 S6 S7 S8 VALORES

Haga DobleClic sobre la fila del nodo para ver historial de lecturas

Modificar Parametros

Figure 9

8. Operational testing.

The node was tested in the laboratory showing a functioning according to the design parameters. The calibration for zero UVI (in total darkness) and measurement in clear sky in hours of the midday solar in January, produced such values that guarantee the non-saturation of the node to any natural possible condition. Later tests were conducted in the area of the Astronomical Observatory of the city of Rosario. The interfaces were calibrated and the parameters of conversion adjusted in order to obtain analogous indicators to the reported ones by a Davis meteorological station installed in the place, for the sensors located in vertical form. The consistency of the sign and a correct report of the variables and their storage were constantly verified. The prototype was delivered to the Group of Solar power for contrast and intensive testing.

9. Conclusions and Future Work

The present work allow confirming, theoretically and practically, the application of technologies and techniques related to Wireless Intelligent Networks orientated to multiple measurement of indexes ICU, even for unusual conditions and restrictions. The modular structure given to the node was verified to be effective and implemental. It turned out to be directly suitable for several of the fixed conditions of use and very simple to adapt to applications that need mobility of the nodes, replacing the interface wired contact by Bluetooth links. The selection of a photodiode of direct erythema response to sensing the ICU was determinant to reach the requirements in terms of node lifetime and network. For these reasons, the prototype achieved constitutes in a good base, sustainable for future developments.

The tests revealed an excessive directionality of the used photodiode therefore it is of foreseeing the need to incorporate diffusive screens into the node, in order to have an equal response to the pattern instruments in conditions of low elevation of the Sun. On the other hand, tests indicate that it is necessary to refine the design of the interface of adjustment, for greater immunity to temperature variations, which magnitudes turned out to be bigger than expected. This improvement will consist essentially of the addition of a two-track "offset" in the AO and in the selection of components with high precision. It is possible to foresee that this redesign will affect the size of the interfaces so it will be convenient at the appropriate time to move to a superficial assembly type.

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