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A microcontroller-based data-acquisition system for meteorological station monitoring

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ABSTRACT

This paper presents a study of feasibility of different existing methodologies linked to field's data acquisition from remote meteorological stations. The data transmission serves to collect field's meteorological information, such as temperature, humidity and radiation. In our study the experimental data is registered in a weather station located about 100 km from the University of Almeria. Various existing techniques are studied, especially Radio, GSM (global system of mobile communication) and GPRS (general packet radio service). In the result of these studies has been designed a system of field's data acquisition (herein referred as Meteologger) which we are going to present in this paper. The system is based on an ATmega 16 microcontroller, which scans 8 sensors together at any programmable intervals. This paper presents the study of the mentioned project, application and some main characteristics of the prototype system and its program. We attempt to implement the system, and subsequently present the performance of tests regarding the mentioned system. To verify its functioning some comparison of this measurement system with two others commercial data-acquisition system (Campbell and Hobo H8) has been carried out.

1. Introduction

The knowledge of the solar radiation (in a given place) is fundamental for the suitable location of solar systems, both thermal and photovoltaic. It seems to us necessary to analyse the complex of factors influencing the variability of the solar radiation as; elevation and orientation of the place and its accessibility. The latter is often limited by nearby elevations. The importance of the variability of the solar incidental radiation in the topography in certain applications is fundamental. In this study, the weather stations are located in the zone of complex topography and of difficult access. Thus, the utilisation of electronic system to automate measurements will make easier and more efficient the acquisition of meteorological data in that kind of location. Today, microprocessors are used to collect meteorological data and most of them are especially designed for solar energy applications [1]. For example, a microprocessor-based system devoted to the collection of solar radiation data was constructed by Thomas et al. [2]. More recently, Mukaro and Carelse [3,4] in 1999 also built a microcontroller-based data-acquisition system for solar and environmental monitoring. Some sort of confirmation and justification for our study we found also in the following scientific work. The rapid evolution of renewable energy sources (RESs) during the last two decades resulted in the installation of many RES power system all around the world. A disadvantage of RES systems is a fact that the installation cost is still high, so their design optimization is desirable. However, such an effort requires detailed knowledge of meteorological data of the place where the system will be installed, because the corresponding energy production is highly influenced by the climatic conditions. Thus, is essential to develop techniques that will aid in assessing the available RES potential at the area of interest resulting in minimum system cost and maximum operation reliability under intermittent energy production conditions. In many cases, meteorological data from many different locations is required in order to evaluate models describing the spatial variability of a RES resource, such as the global radiation, across an extended geographic region or to fill missing data because of measurements unavailability, leading to the development of data-collection networks. Additionally, because of the yearly variation of the climatic conditions, statistical processing of a large volume of data available from past years is required in order to derive accurate models of the RES resources. Thus, the usually applied data organization in text files is inefficient and the development of automate Database Management Systems is indispensable. Such systems typically consist of microcontroller-based unit for recording the signals of interest, while the collected data are usually transmitted to PC for storage and further processing. This type of systems is usually installed in geographically isolated areas, while the acquired data must be distributed to the several remote users. It is possible to

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Nomenclature

MBE	mean bias error	V_{in}	input voltage of the circuit
RMSE	root mean square error	V_{REF}	selected reference voltage
GSM	global system of mobile communication	EEPROM	electrically-erasable programmable read-only memory
GPRS	general packet radio service	SRAM	static random access memory
RES	renewable energy sources	kB	kilobyte
ADC	analog-to-digital converter	MB	megabyte
USART	universal synchronous and asynchronous serial receiver and transmitter		

display all of the acquired data to remote users in real-time through the Internet [5,6].

Nowadays, the classical big power plants for the production of electrical power are supported by micro-generators spread along the territory. Due to both economical and ethical aspects, the contribution to the generated power provided by renewable sources is rapidly increasing. In particular, photovoltaic (PV) panels were introduced for domestic power supplies, radio stations, street signs, water pumps, etc. Therefore, in these situations, the connection with the network of power distribution is often unpractical or even useless, the energy is locally produced and managed (stand alone plants). Hence this kind of plants are usually difficult to reach, the presence of maintenance operators should be as low as possible, also considering the moderate value of the produced energy. For these reasons, such plants need to be remotely monitored and controlled. The monitoring and control system can be functionally divided in three sub-systems:

- The PV sensor cell, providing an estimation of the radiation incident on the PV generator.
- The data-acquisition system, that measures the plant interesting quantities, characterizes the overall performances, and individuate possible problems.
- The transmission system that manages the communication from and to the monitoring and control system.

The use of the GSM standard extends the effectiveness of the system independently wherever the plants are placed, even far from the electrical distribution network and from the traditional and wired telecommunication systems. Due to the low cost and diffusion of the GSM devices, the transmission system is fairly cheap and it is expected to became cheaper and cheaper [7].

Automatic data-acquisition systems are currently used for both monitoring system performance and control of its operation. The obtained information can be used to evaluate the plant efficiency during long periods and to optimize future systems in terms of performance and reliability. Several data-acquisition systems have been developed for use in a wide variety of applications, which include measuring, acquisition and processing environmental variables [8], monitoring and evaluating the performance of PV systems, monitoring the status of batteries for water pumping PV systems [9], measuring operational parameters of hybrid photovoltaic-Diesel system, etc. A common characteristic of the mentioned data-acquisition systems is the use of data loggers or microcontrollers for measuring and acquiring the signals and transmitting them to a PC through serial port RS-232. This type of the data-acquisition system allows to measure typical environmental and system variables of PV systems (DC current, DC voltage, AC current, AC voltage, energy, power, ambient temperature, solar radiation), as well as the *I*–*V* curve of the PV plant. The data are transmitted and stored in a computer through different interfaces [10]. Summoning the above examples we wanted to prove that systems like our Meteologger have very wide applications, due to the needs of user, because its oneself creation permits to modify it, both physically and programmatic. This system is versatile and easy transportable. Mentioned advantage of our project makes us hopeful that our system will be welcomed with interest also by common users.

The principal purpose of this project is to design a system of data transmission received from the remote stations network, to facilitate significantly the reception of data and to diminish the cost of maintenance of these stations. Firstly we analyze several techniques used for collecting and sending/receiving field's data with the set goal to obtain real-time remote information and then we describe the field's data-acquisition system developed to receive the information from the sensors.

Every system of communication must have emitter, receiver and means of transmission. The emitter prepares digital information for transmission and then transmits the information down (through) the way of transmission. The receiver detects and transforms the information in order to visualize it, to file it and to analyze it. Usually optical fibre, radio transmission or cable are used for transmission [11]. In our case the conjunction of Meteologger and GSM Modem was chosen as the emitter, the GSM network as the means of transmission and another GSM Modem connected to a computer—as the receiver.

Nowadays the research in the field of microsystems is progressively directed towards smart electronic interface, which provides the ability to perform complex operations. Specially designed electronic interface for specific applications improve the performances of the microsystem and provide user-friendly environment for the control and communication with it [12].

In the present work a microcontroller-based data-acquisition system was devised. This system, described in the next sections, was designed around the 10-bit microcontroller ATmega 16 and will be applied for weather station monitoring. The specific microcontroller was selected in order to produce a fast and low cost prototype. The information from the sensors goes to the microcontroller, where it is processed and later send to an external EEPROM memory and passed to the GSM Modem every 24 h by RS 232 interface. In the case of failure of the data transmission caused by a problem of the circuit or GSM Modem remains stored in the memory which has a capacity to keep it up to 12 days. The number of sensors and the signal that these sensors provide have been taken into account during the process of designing of this circuit. Field test and comparison with two different data-acquisition systems have been performed. Preliminary results obtained during this experiment are presented as well.

2. Experimental data

In this work we use measurements of global radiation, photosynthetically activate radiation PAR, temperature of the air and relative humidity, registered in 15 weather stations. These stations are located in the north side of the Natural Park of Sierra Nevada, in Huéneja (Granada). Fig. 1 shows the location of the mentioned stations. The altitude of the stations oscillates between 1077 and

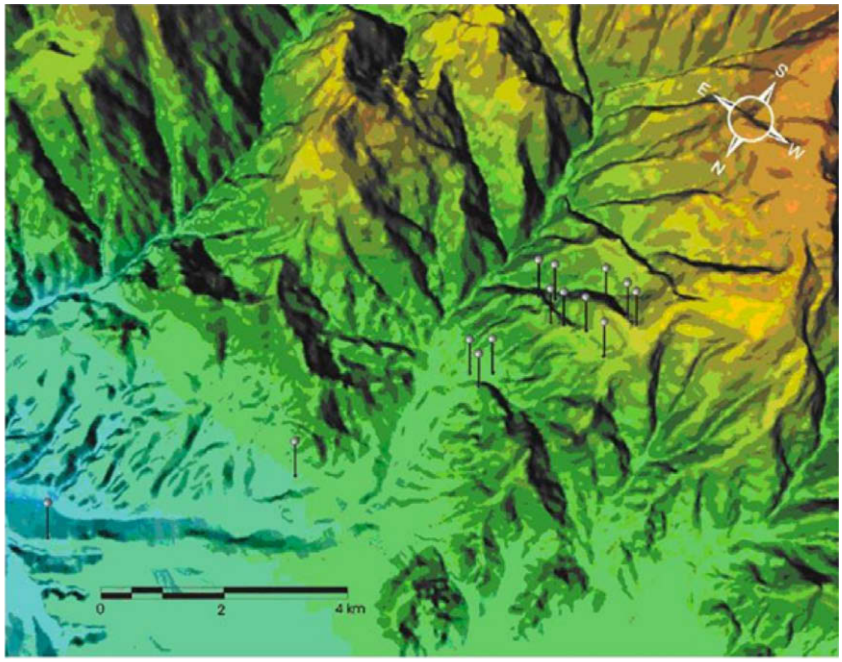

Fig. 1. The locations of the remote stations in Sierra Nevada.

1670 m, where the maximum distance between stations is of the order of 10 km. The global radiation is moderate with piranómetro LI-COR 200-SZ the PAR with piranómetro LI-COR 190, where the period of sampling is of 2.5 min, using HOBO, models: H8 and H8 PRO as system of data acquisition.

The LI-COR sensors provide a very small signal of the order of microamperes, whereas the inputs of the HOBO data-acquisition system require a signal inferior of 2.5 V. Therefore, two interfaces between sensors LI-COR and HOBO had been designed. There were used two amplifiers with the factors of amplification of 343 and 98 respectively. The above amplifiers are supplied by a battery of 6 V and 7.2 A h. The outputs of the amplifiers are connected to a data-acquisition system H8 (4–20 mA, 0–2.5 V DC, 8 bit resolution). This system has a non-volatile EEPROM memory of 32 kB and accumulates the registered measurements every 2.5 min.

2.1. Volume of transmitted information

To initiate and read field data from the metrological stations net is a demanding task, considering the great influence of the low and high temperatures in the mountain range, the capacities of the data-acquisition system of those stations as well as the importance of obtaining the field information in real-time. The volume of data to be transmitted is a key figure determining the design of the transmission system. Until now the period of registry of the measurements has amounted to 2.5 min. This interval has been chosen primarily due to the limitations of the data-acquisition systems. Considering the possibility of changes in the period of the measurements, the new monthly volume of the data collected from all stations has been calculated. Using a time of sampling of 10 s, the volume of data collected is of the order of 22 MB. For the same period, estimated time of the data collection is about 2 days which shows the importance of installing a data transmission system.

3. Methodology

In this section we are going to analyze the different systems of remote transmission in the first place. Many configurations are possible. The first design step consists in the individuation of the most suitable communication system, according to logistic (available means of communication and operation time) and economical considerations [7].

3.1. Remote data transmission

The principal systems of remote transmission are: Radio, Satellite, Phone and Wireless Network. Fig. 2 shows a general scheme of the possibilities for field data collection and its transmission to a central computer. The selection of the transmission system has to be made after considering the following: quality and coverage of the service, transmission frequency, quantity of transmitted information (in kB), type of data-acquisition system, distances between the stations, interferences, power supplies for all devices, price of installation and maintenance, license of transmission frequency (Radio), possibilities of future development. Two practical aspects which often limit the selection of the transmission system are the transmission frequency and the cost of the installed instrumentations. Bearing in mind above considerations, we are going to analyse the advantages and disadvantages of some of these systems.

The Radio has the possibility of sending and receiving a huge amount of information with reduced costs of the transmission, and it is also a good alternative in the case of the lack of telephone lines. Its main disadvantage is the difficulty in obtaining permission for the transmission frequency and the high price of its installation.

The satellite has a great spatial and temporal coverage and it is very useful in places without access to telephone lines, however it is a very expensive method. Its main disadvantage is the high cost of its installation.

As far as wireless communication techniques (WiFi and WiMax) are concerned, they provide high speed of transmission and limited coverage rank of the order 200 meters. The overwhelming advantage of the WiMax technology over WiFi lies in the fact of its greater coverage, of the order of 50 km. Nowadays use of mobile phones, especially GSM/GPRS, is being successfully implemented in the field of data transmission [13,14]. Its main advantages are the flexibility and unlimited reach, although the latter is restricted by the

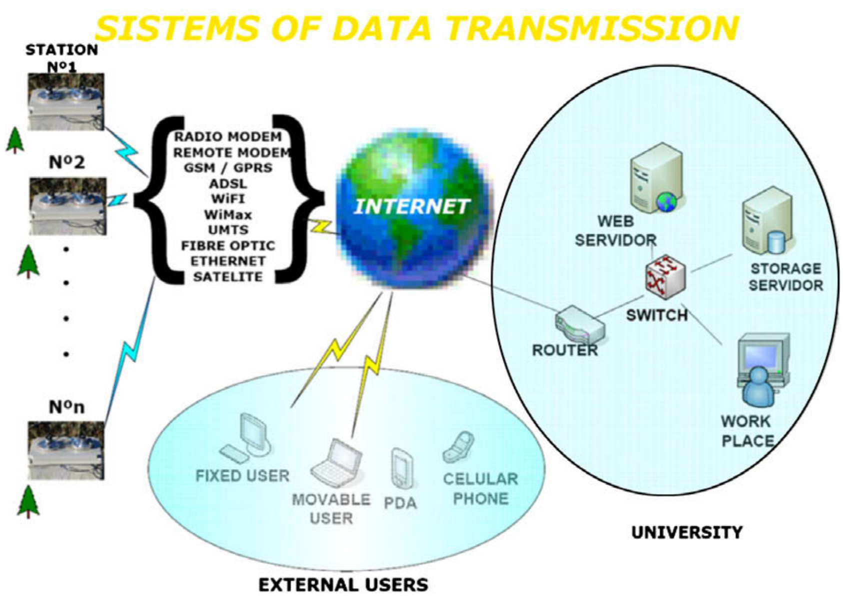

Fig. 2. Possibilities of field data transmission.

cellular phone penetration rate. Another advantage is the low cost of the amount of transmitted data, as well as the remote control of the equipment and simple power solutions.Having analyzed various techniques we suggest that the Radio and the Telephone [15] offer the most significant advantages.

3.2. Analysis of data transmission and reception system

In the last decades transmission of metrological and seismic information from remote databases has been performed by using the Radio. The telephony has not been an interesting alternative because of the price of calls, but lately with GPRS technology, the transmission through Telephone has begun to be popular. This technology opens new possibilities, which have been analysed in this work. As it was mentioned in the discussion above, we are going to use wireless communication techniques to conduct field data-collection trials from 15 remote stations located in different zones in the mountain range, where the conventional networks have no signal. In Table 1 we can see numbered meteorological stations together with their geographic coordinates, altitude and coverage of a mobile operator translated into percentage.

Table 1
The characteristics of the 15 stations

Station no.	Coordinate *x*	Coordinate *y*	Altitude (m)	Coverage (%)
1	502130	4111284	1670	60
2	502243	4111212	1647	40
3	502532	4111109	1623	20
4	502334	4111674	1562	60
5	502639	4111461	1568	40
6	502905	4111461	1537	40
7	503062	4111460	1505	20
8	503325	4111154	1460	80
9	503111	4111107	1447	20
10	503539	4112190	1301	80
11	503828	4112280	1276	80
12	503658	4112414	1299	80
13	505529	4114325	1156	100
14	508391	4116254	1077	60
15	506280	4118779	1130	100

The following is the description of systems which will be used for remote collecting and transmitting data from the metrological stations network down to the Work Place.

4. Data acquisition developed system (Meteologger)

In this section we are going to present the description of field data-acquisition system, developed to collect and transmit the information from the sensors down to the GSM Modem. We have shown the preference for this type of technology due to the limitations of the Radio Modem system. Because of the fact that they need the amplifiers to reconstruct and amplify the signal in order to transmit the information at big distances we opt for this particular technology. In the selection of this technology we also state that, in the above project, the location of some stations may change, as well as the number of the stations may be subject to alternation.

Fig. 3 shows the transmission scheme. Considering the advantages of system and the great interest that has been actually arousing in its development, the following equipment is going to be installed: Meteologger: it allows to register information and to send it across GSM/GPRS, GSM/GPRS Modem.

4.1. Meteologger

The following is the description of the field data-acquisition system developed to transmit the information from the sensors down to the GSM Modem. Fig. 4 presents the general scheme of the Data Logger. The information from the sensors goes to the microcontroller, where it is processed and later send to an external EEPROM memory and it is passed to the GSM Modem every 24 h by RS 232 interface. In the case of the data failure transmission caused by a problem of the circuit or GSM Modem, it remains stored in the

Table 2
The accuracy of the different systems of data-acquisition systems

	Reference voltage 2.5 V		
	Hobo_H8 8-bit	Meteologger 10-bit	Campbell 13-bit
Accuracy	10 mV	2.5 mV	333 μV

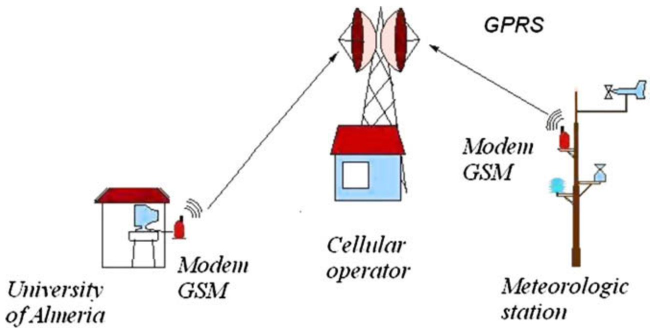

Fig. 3. Scheme of field data transmission through the GSM Modem/GPRS.

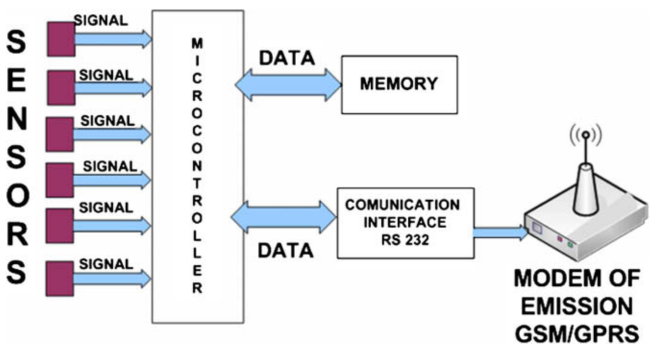

Fig. 4. Flow of the information from the sensors, across the Data Logger, down to a GSM Modem/GPRS.

memory. The number of sensors and the signal that these sensors provide have been taken into account when designing this circuit.

Fig. 5a and b show each of the components of the circuit constructed, which consists of the following elements:

- JTAG Interface "1"
- Microcontroller ATMEGA16 "2"
- Power supply "3"
- Stabilizer LM7805 "4"
- Outputs of the sensors "5"
- External EEPROM memory AT24C512 "6"
- MAX 232 DRIVERS/RECEIVERS "7"
- DB 9M connector "8"

The union "1" is used for sending the programming from a programmer (circuit designed especially for a microcontroller ATMEGA16) down to the microcontroller "2". The power source "3" provides the necessary voltage to supply the circuit. We considered the rank of the operative voltage of all circuit's elements, that was put on the stabilizer "4" that stabilizes the voltage from power supply to the circuit. The signals gathered from sensors "5" are converted to their digital form, inside of the microcontroller "2". Afterwards these digital signals are stored in 64 kB EEPROM memory AT24C512 "6". The size of the memory was chosen after considering the quantity of information obtained with the interval of measurement of 10 s as well considering its possible change. In order to send the information from the microcontroller up to a GSM Modem using the RS 232 interface, it is necessary to adapt the output voltage from the microcontroller to the input voltage of the GSM Modem. A MAX 232 Drivers/Receivers had been used previously for this task "7". Finally the Meteologger had been connected with GSM Modem through a DB9M conector "8".

After establishing the system, some performance tests in relation to clock of reference have been carried out and the necessity of the higher accuracy in the unit of time generation has been ensured. Thus, the second circuit has been designed. It contains the additional 8 MHz quartz crystal, located under the microcontroller "2", Fig. 5b. During these tests a constant deviation of time was established. It strictly depends on applied oscillator and limited possibilities of configuration of the ATmega Timer. Using optimal settings, the time deviation has been reduced to 0.3 s during one day. The auto-correction was applied to reduce this deviation and consists in adding the constant value of 0.3 s every 24 h to a current time (cf. Fig. 6).

5. Embedded developed system

In the following subsections we are going to describe the principal rules with relation to the programming of the prototype system [16]. The microcontroller and the external EEPROM memory are the essential elements for the designed circuit.

5.1. Microcontroller

In this paper we use an ATMEL high-performance, low-power microcontroller ATmega 16 and it is the most important element of the whole circuit. Continuing, we are going to describe the most

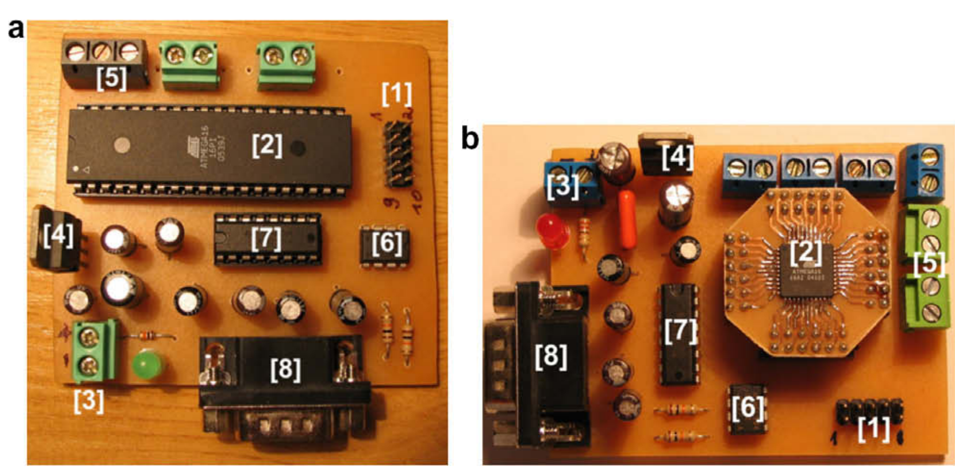

Fig. 5. (a) Aspect of the Meteologger with internal RC oscillator and (b) aspect of the New Meteologger with quartz crystal.

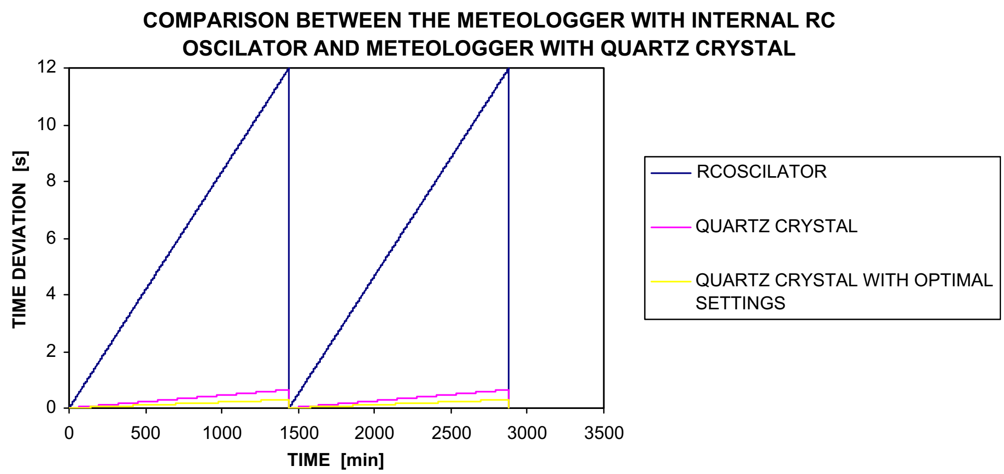

Fig. 6. The comparison between the Meteologger with an internal RC oscillator with Meteologger with quartz crystal.

important elements of the microcontroller, such as analog-to-digital converter (ADC) and the universal synchronous and asynchronous serial receiver and transmitter (USART).

5.1.1. Analog-to-digital converter (ADC)

The data transmission collects field data, such as temperature, humidity and radiation which are typically analogue and are not yet processed to be suitable for direct input to electronic systems. They must be changed to an electrical quantity—a voltage or a current—in order to interface with electronic circuits. Fig. 7 presents the basic functions of analogue to digital conversion for the temperature signal input with the amplitude in millivolt. The first step after obtaining the signals from the sensors is conditioning the signal so that its amplitude increases by over 1000 times and the output signal is now measured in volts rather than millivolts. The amplification is linear and the output is an exact reproduction of the input, just changed in respect of the amplitude.

The next step is the analog-to-digital conversion. In the basic function of analog-to-digital conversion, as shown in Fig. 7, the analog signal must be changed to a digital code so it can be recognized by a digital system that processes the information. The microcontroller used in this paper is equipped with a 10-bit Resolution ADC converter and 8 Multiplexed Single Ended Input Channels. *Resolution* is the number of bits that the converter (ADC) uses to represent the analog signal. The higher the resolution, the higher the number of divisions into which the range is broken, and

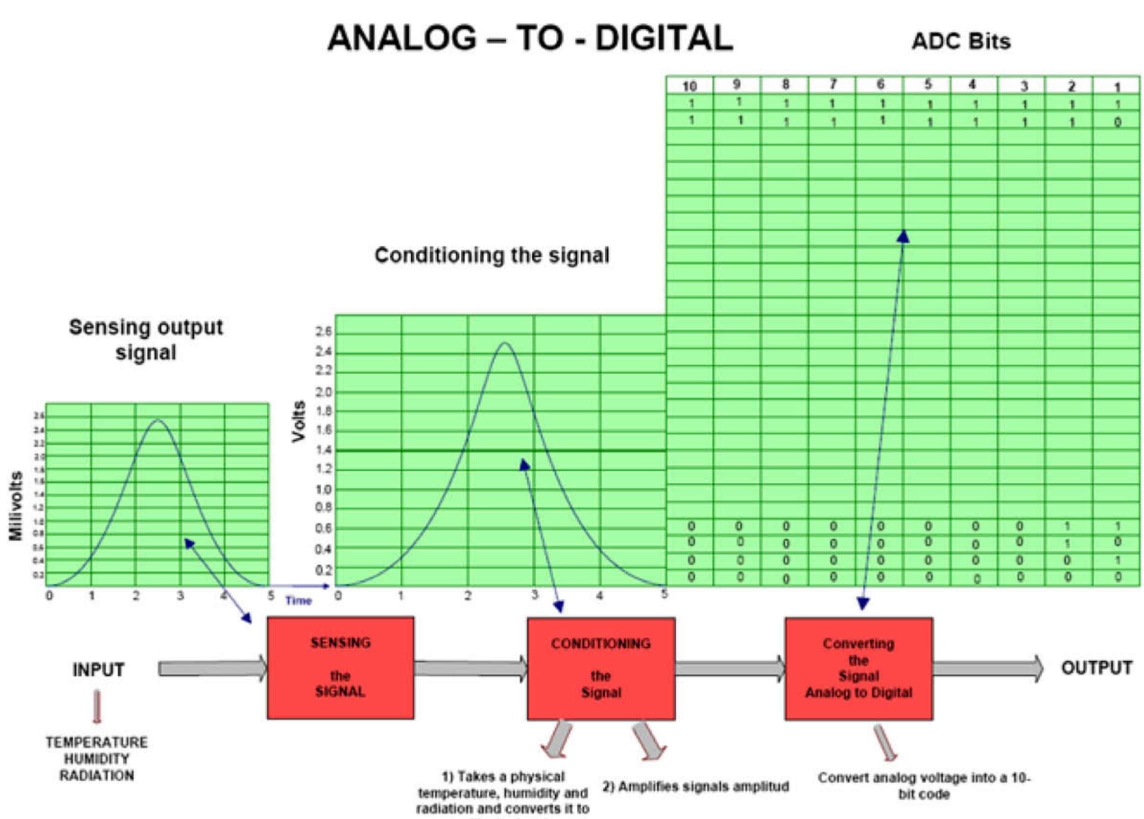

Fig. 7. The basic functions of analog-to-digital conversion.

therefore, the smaller changes of voltages can be detected. Fig. 7 demonstrates the resolution of the hypothetical 10-bit converter, which can resolve 2^{10}, or 1024 different levels. This accuracy can be maintained because digital quantities are manipulated and processed very rapidly, millions of times faster than analog signals [11].

The result of the conversion for the channel with only one input is expressed in the following equation:

$$\mathrm{ADC} = \frac{(V_{\mathrm{IN}}) \cdot 1024}{V_{\mathrm{REF}}} \tag{1}$$

where ADC—the result of the conversion, V_{IN}—the input voltage of the circuit and V_{REF}—the selected reference voltage.

Making this equation useful the smallest detectable change in the input voltage has been calculated, which is mainly determined by the resolution of the ADC converter. A 10-bit ADC converter with the reference voltage of 2.56 V detects a change of 2.5 mV.

5.1.2. The universal synchronous and asynchronous serial receiver and transmitter (USART)

Serial communication is a popular means of transmitting data between a computer and a peripheral device such as a programmable instrument or even another computer. It uses a transmitter to send data, one bit at a time, over a single communication line to a receiver. It is very useful when it is necessary to transfer data over long distances.

The USART has to be initialized before any communication can take place. The initialization process normally consists of setting the baud rate, setting frame format and enabling the Transmitter or the Receiver depending on the usage. The information is sent and received in the asynchronous way (UART).

The following step is undertaken to specify the setting frame format. Each transmitted character is packaged in a character frame that consists of a single start bit followed by the data bits, the optional parity bit, and the stop bit or bits. A *start bit* signals the beginning of each character frame. The order of transmission of data bits is imposed from least significant bit (LSB) to most significant bit (MSB). An optional *parity bit* follows the data bits in the character frame. This bit is included as a simple means of error checking. You specify in advance whether the parity of the transmission is to be even or odd. If the parity is chosen to be odd, the transmitter will then set the parity bit in such a way as to make an odd number of 1's among the data bits and the parity bit. The last part of a character frame consists of 1, 1.5, or 2 *stop bits*. The parity generator calculates the parity bit for the serial frame data. When parity bit is enabled, the transmitter control logic inserts the parity bit between the last data bit and the first stop bit of the frame that is sent.

The port series is working at the asynchronous mode and the format of data for transmission consists fundamentally of 11 bits, that is 1 bit of start, 8 bits of data, 2 bits of stop.

5.2. The external AT24C512 EEPROM memory

When programming it is necessary to plant the system of transmission and storage of the information. The mentioned microcontroller consists of a 1 kB SRAM memory and 512 B of EEPROM memory, which facilitates the organization of the information to be transmitted. Doing the calculation of the quantity of obtained information from each station, we can easily estimate the space occupied in the memory of the microcontroller. Considering that the design of the mentioned circuit leaves the possibility of using an external memory, an EEPROM AT24C512 memory has been used, which we are going to describe in the following paragraph.

The AT24C512 EEPROM memory organized as 65.536 words of 8 bits each has an endurance of a 100,000 write cycles. The size of the memory had been chosen, considering the quantity of information obtained with the interval of measurement of 10 s and its possible change.

6. Results and discussion

In this work we have presented the design, implementation and test of the data-acquisition system. The system will be used for reading and storing information from several stations, located in zones of difficult access. The designed circuit and its programming, offers an advantage because of the possibility of changing the number of placed sensors, as well as changing the frequency of its measurement. The data transmission collects field data, such as global and PAR radiation.

In this paragraph we present the results obtained when using the developed system of data acquisition. To verify its functioning some field tests and comparison of this measurement system against two others commercial data-acquisition systems has been carried out. The reference system Campbell has been chosen, as it presents the highest precision due to higher ADC resolution (13 bit). The second system Hobo H8 has been elected with the 8 bit resolution. The Meteologger was mounted outdoors on a horizontal surface alongside a Campbell and Hobo H8 (see Fig. 8). The PAR sensor LI-COR 190 was connected to three different systems of data acquisition. The same tests with the global sensor LI-COR 200-SZ were performed. Global and PAR horizontal radiation readings from these three instruments were taken simultaneously at 2-min intervals for intensity levels between 20 and 1200 mV. We have carried out the comparison of three different systems of data acquisition in mV unity voltage provided by the sensor, in order to eliminate possible errors caused by a factor of its calibration.

The three used systems acquired voltage provided by the sensor with the different precisions due to resolution of each one (see Fig. 9). Measuring a linear ramp signal for example gives the three graphs, as shown in Fig. 9. Fig. 9a shows a 8-bit discrete representation of the input ramp signal, measured without artificial noise added. The *quantization steps* are the very marked. To increase the resolution, the quantization steps need to be reduced Fig. 9b and c.

In this work an Atmel's AVR microcontroller with an 10-bit resolution analog-to-digital converter was used. In most cases 10-bit resolution is sufficient. In some cases higher accuracy is desired and if it will be necessary special signal processing techniques or an external ADC can be used to improve the resolution of the measurement. The ADCs reference voltage and the ADCs resolution

Fig. 8. Picture of data-acquisition systems used during experiments.

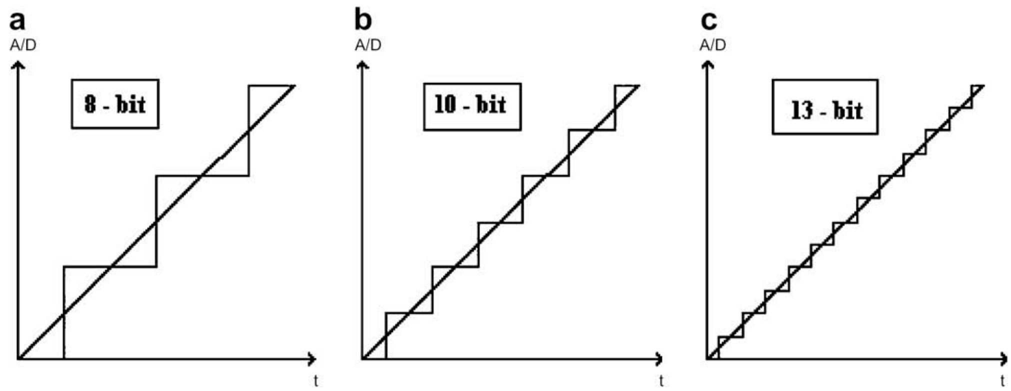

Fig. 9. Enhancing the resolution.

define the ADC step size. The ADC's reference voltage, VREF, may be selected to AVCC, an internal 2.56 V reference, or a reference voltage at the AREF pin. A lower VREF provides a higher voltage precision but minimizes the dynamic range of the input signal. If the 2.56 V VREF is selected, this will give ~2.5 mV accuracy on the conversion result for Meteologger and the highest input voltage that is measured equals 2.56 V (Eq. (1)).

Following we are also going to analyze the results in meaning of the Root Mean Square Error (RMSE) and Mean Bias Error (MBE).

The RMSE informs us about the dispersion of the experimental data and it is defined as

$$\mathrm{RMSE} = \sqrt{\frac{\sum(X_{\mathrm{estimated}} - X_{\mathrm{measured}})^2}{N}} \tag{2}$$

where $X_{\mathrm{estimated}}$—the data measured by the Campbell, X_{measured}—the data measured by the Meteologger and the Hobo H8.

The MBE informs us about the tendency above the underestimation of experimental data and it is expressed by the following equation:

$$\mathrm{MBE} = \frac{\sum(X_{\mathrm{estimated}} - X_{\mathrm{measured}})}{N} \tag{3}$$

In Tables 3 and 4 we can see the statistical results of about 7500 measurements from the different data-acquisition systems (Meteologger, Campbell and Hobo H8) for the global and PAR radiation. The RMSE error caused by the Meteologger against to the Campbell is of order 1% and it is minor than the RMSE error caused by Hobo H8. We suggest that this diminution due to resolution of data-acquisition system: Hobo H8-8 bit, Meteologger-10 bit, Campbell-13 bit (cf. Table 2). For both cases the deviation is practically null.

Figs. 10 and 11 illustrate measurements of global solar radiation registered by the Meteologger and the Hobo H8 against to the measurements registered by the Campbell, respectively. Fig. 10 shows that the majority of the experimental points are located over the perfect adjust line 1:1, illustrating the minimal dispersion. We distinguish that this behaviour is similar for all voltage range. Fig. 11

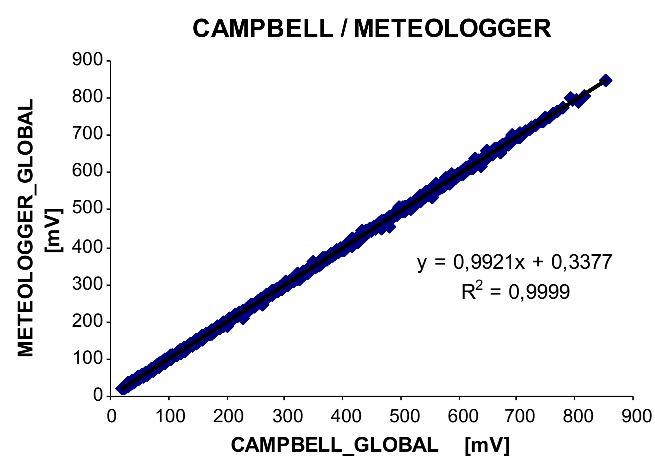

Fig. 10. The correlation between the Global radiation measured by the Meteologger and the Campbell.

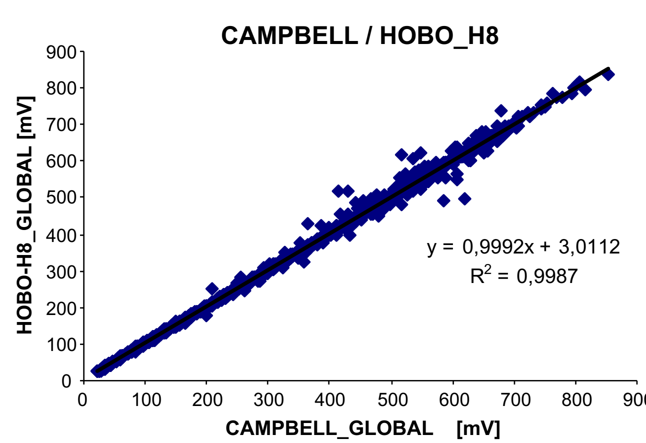

Fig. 11. The correlation between the Global radiation measured by the Hobo H8 and the Campbell.

Table 3
The correlation between the RMSE and MBE errors of PAR measured by different systems

	PAR (mV)	
	Campbell/Meteologger	Campbell/Hobo_H8
RMSE%	1.02	1.87
MBE%	0.41	−0.36

Table 4
The correlation between the RMSE and MBE errors of Global measured by different systems

	GLOBAL (mV)	
	Campbell/Meteologger	Campbell/Hobo_H8
RMSE%	1.00	1.99
MBE%	0.70	−0.69

Table 5
The content of the format of transmitted data

3 BYTES	1 BYTE	3 BYTES	2 BYTES	2 BYTES	2 BYTES	2 BYTES	2 BYTES
Date	Number of station	Measurement time	PAR radiation	GLOBAL radiation	Humidity	Temperature	Battery

Table 6
Decoding of the received message

Code	Meaning
061107	The date of the transmission 2006-11-07
1	The number of the station 1
143720	The hour of the average 2:37:20 PM
1538.34	The PAR radiation 1538.34 μmol/s m^2
927.90	The Global radiation 927.90 W/m^2
73.54	The humidity 73.54%
34.4	The temperature 34.4 °C
6.25	The state of the battery 6.25 V

illustrates the dispersion for measurements above 200 mV. For measurements of PAR radiation we obtained the similar results.

Finally we analyze the content of the format of the information measured by the Meteologger, that is essential for its future transmission. Table 5 presents the frame format that consists of the specified date of every measurement, the identification of the station, time of measurement and the data concerning radiation, humidity, temperature as well as the additional information about the power of the battery. Taking into account the huge flexibility of the prototype system and emphasizing that the programming leaves the possibility of choosing the interval of the measurement, the sampling time of which amounted to 2 min, was performed every 6 min on average. It was estimated that the monthly volume of the collected data is equal to 0.5 MB, taking into account that the size of the individual data frame is of the order of 17 B. In this work we have presented the design, implementation and test of the data-acquisition system and we have come to a main conclusion of the availability of ordering the information of each station in the following format [17]:

$$061107, 1, 143720, 1538.34, 927.90, 73.54, 34.4, 6.25$$

It is worth mentioning that the commas and points are marked only for the convenience of reading and they do not appear in the transmitted format. In Table 6 we can observe the meanings of data fragments.

7. Conclusions

In the first phase of the work we have analyzed different systems of field data transmission with their advantages and disadvantages. It has been observed the technology GSM/GPRS is the one that offers considerable advantages in transmitting the information at big distances. Favourable conditions, flexibility and the low costs allowed to develop a data-acquisition system for reading and storing information from several stations, located in zones of difficult access. In the following phase of the work we have focused on the development of data-acquisition system. A microcontroller-based circuit for data acquisition has been designed, which scans 8 sensors together at any intervals programmable. The comparison of the developed system against two others commercial data-acquisition systems (Campbell and Hobo H8) has been carried out. The measurements registered by the Meteologger present the RMSE error of order 1% and practically the null deviation. We suggest that the resolution of the data-acquisition systems is the essential influence factor for this error.

Considering obtained acceptable results, we point out that the future study in this field should focus on the transmission of information to remote area of University of Almeria.

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