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Development of a cloud-based system for remote monitoring of a PVT panel

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Abstract: The paper presents a monitoring system developed for an energy conversion system based on the sun and known as thermophotovoltaic panel (PVT). The project was implemented using two embedded microcontrollers platforms (arduino Leonardo and arduino yún), wireless transmission systems (WI-FI and XBEE) and net computing, commonly known as cloud (Google cloud). The main objective of the project is to provide remote access and real-time data monitoring (like: electrical current, electrical voltage, input fluid temperature, output fluid temperature, backward fluid temperature, up PV glass temperature, down PV glass temperature, ambient temperature, solar radiation, wind speed, wind direction and fluid mass flow). This project demonstrates the feasibility of using inexpensive microcontroller’s platforms and free internet service in the Web, to support the remote study of renewable energy systems, eliminating the acquisition of dedicated systems typically more expensive and limited in the kind of processing proposed.

Keywords: PVT; Embedded systems; Wireless transmission; Cloud computing

1 Introduction

Almost all engineering systems need to be monitored and controlled in order to optimize their operation and increase aspects like efficiency and reliability. To address these issues electronic systems using sensors able to get information in real time and controllers able to process that information are required. Sometimes the information also needs to be stored for a long period of time and, for that, data loggers are normally applied. The information associated with physical variables is mainly analog and its transmission is usually done in this form with cables. However, this transmission type is limited in range and prone to noisy environments. These limitations are surpassed using digital transmission systems which are more robust, although some quantization errors are introduced on the analog-to-digital conversion process. With digitalization, microcomputers have become a basic tool to build new monitoring systems, and with the increasing integration of electronics it is now possible to have access to low cost embedded microcontroller systems, where many functions like analog to digital conversion and storage are easily implemented. On the other hand, computers interoperation have led to the development of the internet network, firstly on a cabling basis, but now increasingly in a wireless form using Wi-FI protocol (www.wifi.org). The increasing capacity of this network has created the new paradigm of cloud computing, where processing tasks can be performed on remote servers, far from users. The advantages of wireless connections over cabling, led also to the development of others protocols like Bluetooth (www.bluetooth.com) and Zigbee (www.zigbee.org), applied for communication between low end electronic devices, including sensors, or even for other devices like wearables. This also introduced the new concept of internet of things. This paper presents the development of a monitoring system for a renewable energy converter, known as thermophotovoltaic solar panel (or simply PVT) [1], integrating these new technologies and concepts. The application of those technologies is gaining increase interest in the field of monitoring and control of re-
renewable energy systems, that are many times placed in remote areas where there is a need to get and store many physical variables associated with their operation, [2–7]. On the basis of this study there was also the intention to replace an all-cable measuring system, by using hardware and software systems of open source type and without any operational costs. The chosen solutions were the Arduino platform (www.arduino.cc/en/main/products) and Google Drive, due to their universal widespread. The Arduino platform has become such a success story that even important computing tools, such as the well-known MATLAB program, has developed an application for interconnection of the two systems (www.mathworks.com/hardware-support/arduino-matlab.html) and a very dynamic worldwide Arduino community is present on the web.

2 Hardware system

At the CISE (Electromechatronic Systems Research Centre) facilities, located at the Politecnico Institute of Guarda (IPG), a research station in renewable energies is being developed, and a pilot plant has been built for the study of PVTs. This system has, as a central element, one PVT with the main characteristics of Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV cell technology</td>
<td>Monocrystalline</td>
</tr>
<tr>
<td>STC PV Efficiency</td>
<td>14.88%</td>
</tr>
<tr>
<td>Maximum power</td>
<td>190 W</td>
</tr>
<tr>
<td>Short-circuit current</td>
<td>5.6 A</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>45.2 V</td>
</tr>
<tr>
<td>Fluid volume</td>
<td>1.2 l</td>
</tr>
</tbody>
</table>

The connections of the PVT system, including its hydraulic part, main electrical power circuit and sensing devices are shown in Figure 1. For initial purpose tests, the electrical load used is a resistor, with a value corresponding to the maximum power point at Standard Test Condi-

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**Figure 1:** PVT main system.

**Figure 2:** PVT conditioning and transmission subsystem.

**Table 1:** PVT parameters (http://www.solimpeks.com/pv-t-hybrid-solar-collectors).
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Figure 3: Flowchart for cloud logging.

As measuring elements the system has a small weather station consisting of a pyranometer, an anemometer, a weathervane and an ambient temperature sensor. The monitoring of the electrical quantities involves reading the electrical current and voltage and is based on two Hall effect sensors. For the thermal part, five temperatures are monitored, the upper and lower temperatures of the glass, the inlet and outlet temperatures of the hydraulic fluid and the temperature of the rear surface of the PVT. Finally a turbine flowmeter is used for the measurement of the fluid mass flow rate.

The conditioning and transmission system is designed around two Arduino boards (uC1, uC2) in accordance with the scheme shown in Figure 2.

To minimize the errors in final measurements, for each of these sensors, it was necessary to create a system for signal conditioning able to adjust the level and type of signal to the analog to digital conversion system that makes up the Arduino platform, which works at 5 V. In the case of the flowmeter and the anemometer, the conditioning circuit is based on a frequency to voltage converter, followed by an amplifier. In these two cases, for low physical values, the measurements errors tend to increase. For the other cases only amplification was needed. For the pyranometer and temperatures (measured using PT100 sensors), differential instrumentation amplifiers were used to minimize errors, due to the small electrical variations associated with the physical quantities to be measured.

The transmission system is based on all-wireless technologies, from the PVT to the cloud, where the data logging is performed. On the field, the Arduino uC1 is near the PVT and the uC2 is 30 m far from the PVT. Although it was possible to implement a simpler wireless transmission based on GSM/GPRS communication, this would imply usage costs, associated with data transmission over the cell phone network, which, mentioned on the introduction, was not desired. Given that the pilot system is in the IPG campus, where a Wi-Fi network is available, this technology has been adopted for the solution without transmission costs. However, it was found that the signal power available at the location of the pilot system was weak and irregular and does not guarantee a permanent connection; so it was necessary to work around using ZigBee wireless transmission, to communicate between the PVT outside plant and the inside of the nearest building with appropriate Wi-Fi signal. Taking into account the already wide diversified range of Arduino platforms and signal acquisition needs, Arduino Leonardo board, with ZigBee module, was selected as outside platform and Arduino Yun, also with ZigBee module, as inside platform. The Zigbee communication protocol is becoming popular for IoT. The Yun includes two processors, one running a Linux operating system, responsible for Wi-Fi communication, and a SD card slot, which also gives additional storage capacity. Due to these characteristics, the Yun is already used in cloud monitoring systems, with some cloud services like Temboo (https://temboo.com/arduino). All the analog inputs in Leonardo were used for the complete monitoring system. In the case of Yun it was necessary only to use a pair of digital inputs to operate them as a virtual serial port between the ZigBee module and the processor. Besides monitoring, hereafter the Leonardo will also have a function of managing the power extracted from the PVT.

3 Software system

For the code development, it was taken as the initial goal to get a data storage with the lowest sample time possi-
Figure 4: Print screen of results in spreadsheet format.

Figure 5: Print screen of the graph for solar radiation.
ble and its real-time data display. In the case of the acquisition times for Leonardo, they are reduced (the maximum ADC conversion time according with its datasheet is 260 us). To minimize the effects of punctual acquisition errors, each variable is acquired consecutively three times, retaining its mean value. The data is processed in accordance with the voltage reading and the calibration curves obtained for each sensor, building after that a vector with values and the desired measurement units for the physical variables. To increase the reliability of the data transmission, in the message to be sent the vector starts with character ‘*’ followed by the number of characters to be sent and is finished with ‘#’. The message is sent from uC1 to uC2 using the rate of 9600 baud, because it was the one in which there was no transmitting errors. In the receiver, the message is checked for start/end message characters and the number of characters, to validate the information received, reconstructing then the original array. Before it is sent to the cloud, the current time is determined through Yun and used as the value of the acquisition time. In reality, there is a delay (of some ms) between this time and the acquisition, but it can be neglected taking into account the PVT time constants. Sending data to the cloud is then done by using an appropriate cURL Linux command executed through Arduino. It was found that the time lapse between Yun sending and Google data receiving was highly variable with the message size to be sent, similarly to what presented in [8]. Even with code optimization, for the twelve variables, a mean value of 11658 ms was measured. With the additional processing times, like those associated to Zigbee transmission, it was verified that a sampling time around 30 seconds was necessary to maintain the reliability of information. This time was introduced in the Yun code as a delay and synchronized with Leonardo to avoid it from sending information that will only overload the Yun serial buffer. To prevent the acquisition and processing data by both platforms, when this is not intended an hardware interruption in Yun was used (using a digital port) allowing a change of its state, putting the Leonardo in a kind of listening mode only. The data in the cloud is introduced in a temporary Google spreadsheet, in which a script runs showing the evolution of all the variables over time in a table and allowing a chart visualization for individual variables. Due to the amount of information collected, it was decided to aggregate the information on a daily basis by creating a new file at the end of each day, saving it in a dedicated directory. The acquisition time interval can also be limited in Yun (for the tests in summer the limits cho-

Figure 6: Print screen of graph for electrical current.
sen were 7 am and 10 pm). Figure 3 presents a flowchart showing the operation of the software developed for cloud logging.

Figure 4 presents a screenshot of the table with the results obtained for the 25th June 2015. At the top of the table we can see the identification of the variables, being the first one the time. At the bottom we can see the separators that allow seeing the charts. This was a typical summer day, as it can be observed looking at the graph for solar radiation presented in Figure 5. It can be see that the maximum value registered was 1001 W/m² with a dip at 12.56 pm. Figure 6 shows the output current from the panel with a maximum of 4.9 A and with the corresponding dip at 12.56 pm, which indicates that a cloud must have passed at that time. The accuracy of these results was confirmed with occasional readings made with portable measuring meters, like Green Test FTV-100 from Chauvin Arnoux.

The steps visible in Figure 6 for the current are associated with the use of only one decimal point for this variable. This single decimal was imposed to limit the string’s values sent to the Google Cloud, and so the time transmission.

To analyze the limitation of the 30 second sampling time on the information acquired, a comparison between the new acquisition and wireless transmission system and the original cabling system was done. For that, a Pentium 4 laptop running Matlab V7 with a DaqCard (6062E from National Instruments) with a 1 second sampling time was used. Figure 7 presents that comparison, showing a zoom of the solar radiation around the dip visualized in Figure 5. The noisy curve is for the lower sampling time. As seen, the values are in good agreement, even considering that the analog to digital conversion converters are not the same.

4 Conclusions

A monitoring system using mainly open hardware and open software was developed to allow the monitoring of a renewable energy device. The system was developed to replace a conventional cable transmission system with wireless technologies, and to use the new concept of cloud computing to create a data logger with remote access through the web. It was proved that with the availability of new low cost embedded electronic systems and the universal cloud services it is possible to build an acquisition and data logging system with good characteristics, adapted to the particular needs of the system to be monitored remotely. The main drawback of this system is the delay time associated with the posts on the cloud that limits the sampling time. However, in the future this drawback can be reduced as the speed of digital electronics and digital transmission systems continues to increase.

References


