A power consumption monitoring, displaying and evaluation system for home devices

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Abstract

This paper presents an implementation of a smart meter monitoring system based on Arduino platform and accessible from Android mobile devices. On the one hand, it has been developed a measure device, based on Arduino, which monitors the power consumption from each home device and sends this information to a server. On the other hand, users can see by means of their mobile devices the power consumption in real time. Also, users can know the detailed consumption from previous months. This way, the developed application is aim to satisfy two different consumer needs: improve their economy and their sustainability in the way electrical power is consumed.

Keywords: Efficiency, Power Consumption, Arduino, Mobile Applications, Smart Meter.

1. Introduction

The pursuit of energy efficiency as part of everyday life is a necessary objective, both from an economic and ecological point of view. Our standard of living is based on the consumption of electricity, a limited and costly to generate resource whose consumption has skyrocketed in recent decades. In fact, the electrical demand in Spain has doubled in the last twenty years Red Eléctrica de España, "El sistema eléctrico español en 2011," Jul. 2012.

Although at this time there has been a break in that growth as a result of the current economic situation, demand remains high and will keep rising as soon as the economic situation improves.

However, although power consumption has increased, distribution infrastructure has not been growing at the same rate. It is required to enhance transport networks, equipped with greater intelligence, which optimizes the generation, makes a proper control of demand and establishes a direct communication between production and consumption. Only thus it will be possible to get a better distribution of the energy, which is not yet able to store in an efficient manner.

This is the objective of the so-called *Smart Grid*. An abstract concept that is not well defined yet, but aims to bring new technologies to the field of distribution of electrical power. Smart Grid draws a future where there is a closer relationship between the demand curve and electrical power consumption, more reliable and with less discontinuities and losses.

On a smaller scale, at home, it is also necessary a proper supervision and use of electrical energy. In Spain residential consumption represents approximately 25% of total Red Eléctrica de España, "Guía de consumo inteligente," Nov. 2010., which makes it a very important sector where consumption should be improved.

There has been a lot of new devices lately aimed to provide household users with tools to measure their electrical consumption. These devices are under the umbrella of the *Smart Metering* term, which refers to devices that give the user more information and control about electricity consumption at home.

Possible applications in this field are immense, so their presence and usefulness will be appearing as consumer electronics include algorithms to rationalize and respond

Probes are connected to the Arduino board to measure power consumption. This information is sent to the server via Internet.

to different conditions in the power supply. While in Spain the use of a dual electricity rate is not very widespread at the household level, nor involves real benefits to consumers, in other countries dual rate is widespread and there are already for sale appliances such as washing machines and refrigerators capable of synchronizing its operation with the minimum consumption in the network. In the future, this could be based on the type dominant generation source at all times, making the washer wait, for example, for maximum production from renewable sources to start the wash cycle.

The great importance of the Smart Metering is reflected in the related work. For instance, M. G. Rodriguez, L. E. Ortiz, Y. Jia, K. Yoshii, R. Ross, and P. H. Beckman, "Wireless sensor network for data-center environmental monitoring," in Proc. of Int. Conf. on Sensing Technology (ICST), Palmerston North, New Zealand, pp. 533-537, November 2011. proposes a wireless sensor network for data-enter environmental monitoring, where the Arduino platform is used to develop the prototype sensor network. In the same vein, in C.-Y. Tu, "A power-aware cloud architecture with smart metering," in Proc. of the Int. Conf. on Parallel Processing Workshops (ICPPW), San Diego, California, USA, pp. 497-503, September 2010. Arduino is used to develop a Smart Metering system, which is part of the cloud architecture with Smart Metering proposed in that paper. Another related paper is F.-Y. Xu and Y.-N. Ma, "Impact of smart metering on energy efficiency," in Proc. of the Int. Conf. Machine Learning and Cybernetics (ICMLC), Qingdao, China, pp. 3213-3218, July 2010., which analyses the impact of Smart Metering on energy efficiency. Finally, V. Bashko, C. David, S. Kuryla, V. Perelman, and J. Schauer, "Design and prototype implementation of the WattsApp telemetry platform," in Proc. of the Int. Conf. on Green Computing and Communications (GreenCom), Besançon, France, pp. 72-78, November 2012. presents a mobile application based on Android which allows users to get information regarding their power consumption.

In this sense, this paper presents a system for monitoring electrical consumption at home. Despite the related work explained previously, this paper combines the Arduino platform with the Android operating system. The rest of the paper is structured as follows: the next section presents the system overview of the system proposed, highlighting the main technologies involved. Section 3 explains the Smart Meter developed whereas Section 4 presents the mobile application. Finally, Section 5 presents some conclusions and future work.

2. Technologies and design considerations

2.1. Introduction

This section presents the different design considerations taken into account during the development of the application. The system developed is aim to monitor, display and evaluate the power consumption of typical home devices (televisions, fridges, hairdryers…). The system includes an intuitive and simple application for mobile devices that allows consumers to identify the different consumptions, estimate the cost and calculate the amount of carbon dioxide emissions. The system allows to know, in real time, the electric power demand curve. The prototype is based on three main points: the measure device, the storage platform and the mobile application.

Regarding the measure device, the system uses power consumption monitoring devices which are connected to those home devices in which the user wants to measure the power consumption. In this sense, a power consumption measure device based on Arduino has been developed. On the other hand, it is needed to use an additional system in order to storage the information obtained from the different monitoring devices. To that extent the web platform Xively has been used.
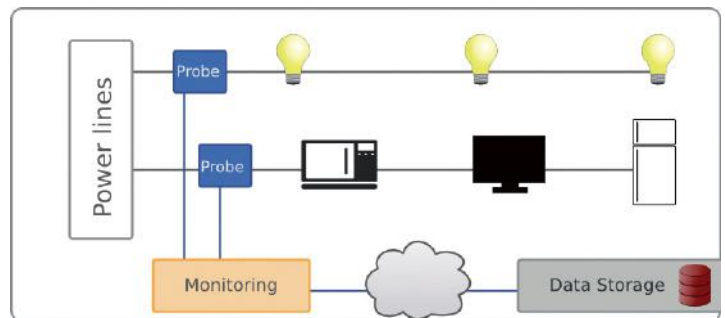

■ Figure 1. *Diagram of the measure process.*

As Fig. 1 shows, probes are connected to the Arduino board to measure power consumption. This information is sent to the server via Internet. The operations taking place within these blocks are:

- Capturing electrical performance using a current sensor connected to the power cord;
- Interpretation of values and translation of consumption parameters;
- Format compatible HTTP Xively messages and send data to the remote server through the Ethernet connection of the smart meter.

Finally, the user accesses to the information by means of a mobile device such as tablet or smartphone. The user can check the detailed power consumption at any time, thus detecting any anomaly. As Fig. 2 shows, the user can monitor, analyze and control the power consumption. The mobile application is developed in Android platform.
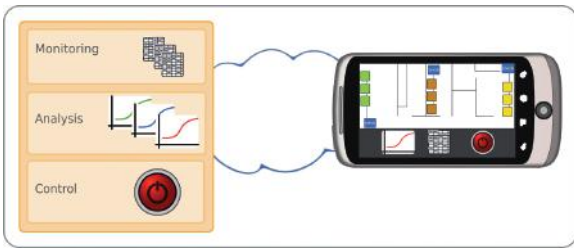
Figure 2. *Mobile application functionalities.*

Following sections explain in greater depth the three main technologies used to develop the system: Arduino, Xively and Android.
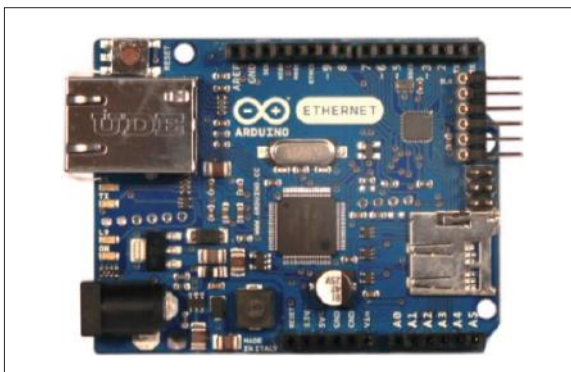
2.2. Arduino

Arduino is an open-source platform for prototyping that offers flexible hardware and software tools. It is targeted to users interested in creating objects and interactive environments. Its main usage fields are art, design and leisure. It is widely used for developing sensor platforms, motorized vehicles, illumination systems and more.

Arduino is a single-board microcontroller designed to make the process of using electronics in multidisciplinary projects more accessible. New model has been designed around a 32-bit Atmel ARM. The software consists of a standard programming language compiler and a boot loader which is executed on the microcontroller.

The system proposed in this paper is highly oriented to enable the Internet-of-things therefore the Arduino Ethernet model has been chosen as the baseboard. This Arduino model is based on the ATmega328 micro-controller and has a built-in RJ45 female connection to the 10/100 Ethernet network interface. This Arduino model contains 14 digital inputs/outputs as well as 6 analog inputs. Also, it includes ICSP (In-circuit serial programming) connection and microSD card readers. Regarding technical characteristics, this model has a clock speed of 16 MHz, an Ethernet W5100 TCP/IP controller and a FDTI serial programmer. Moreover, it contains a flash memory of 32 kB, 2kB SRAM and 1kB EEPROM.

With regards to external connections, Fig. 4 shows the ports diagram of the Arduino Ethernet board:

Figure 3. *Arduino Ethernet.*

The Arduino development environment is the software commonly used to program the Arduino platform, that is it is based on C/C++ languages and it is also open-source. It integrates the code writing, compiling and uploading to the device. The Android board is connected to the computer by the FTDI to USB interface. This interface can be also used to monitor the board and used as a logging output. The Arduino development environment has several libraries to manage common hardware as LCD screens, networking and external memory card reader.
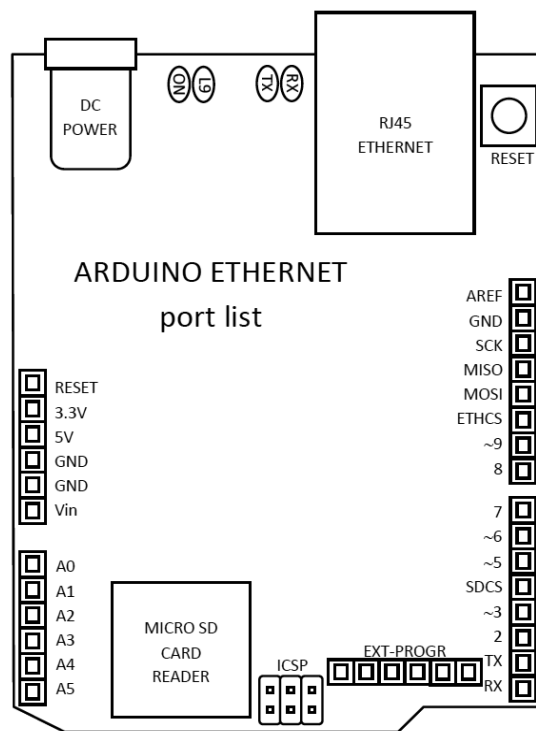
Figure 4. *Ports diagram of the Arduino Ethernet.*

2.3. Xively

Monitoring devices have not unlimited storage capacity to save all the information they generate, therefore it is necessary the use of a cloud storage service, accessible through the Internet. In this sense, Xively has been used as a web platform. Xively Xively webpage. Available at: https://xively.com. Accesed 24 May 2013. is a secure, scalable platform that connects devices and products with applications to provide real-time control and data storage. Formerly known as Pachube and then as Cosm, Xively is in an updating process, with a new image and new (commercial) functionalities. Apart from the premium version, Xively offers an open-source service. In this sense, the free version provides enough resources for any user of the system here proposed and for prototype testing issues.

> **As getting an accurate power measure is a key aspect, the input block becomes the most important block of the design.**

Xively daily manages millions of datapoints from thousands of individuals, organizations & companies around the world. Data can be pushed from the sensor end, or pulled by the Xively servers every 15 minutes, with the data feeds then made available in multiple formats at no charge.

The service allows people to embed real-time graphs & widgets in websites; analyze and process historical data pulled from any public Xively feed; send real-time alerts from any datastream to control scripts, devices and environments.

Xively is built to encourage open digital ecosystems, for example electricity meters, weather stations, building management systems, air quality stations, biosensors and Geiger counters.

There is a three-level hierarchy on the Xively data model: *feeds, datastreams* and *datapoints*. A feed is a collection of datastreams of channels, and a datastream is a collection of datapoints, which are the lowest element of the hiercharchy, made up of an uploaded value plus the timestamp given by the Xively server at the receiving time. All together build a big collection of raw values accessible with the proper HTTP request.

Also, Xively allows to interact easily with data collections, thus allowing the data introduction manually, feeds creation or to indicate the number of datastreams that conforms each feed.

On the other hand, Xively contains security mechanisms in order to manage the level of access of each user when accessing or modifying data through HTTP. Moreover, Xively data are accessed through REST web services and data can be sent/requested on JSON or XML formats.

2.4. Android
Android Android webpage. Avalailable at: www.android.com. Accesed 24 April 2013. is a Linux-based operating system designed primarily for mobile devices such as smartphones and tablet computers. Android was developed with the founding of the Open Handset Alliance: a consortium of companies devoted to advancing open standards for mobile devices. Android is open source and Google releases the code under the Apache License. The Android open source code has a permissive licensing that allows the software to be freely modified and distributed.

Android applications are written primarily in a customized version of the Java programming language. Nowadays, Android has become the most used smartphone platform Canalys webpage, "Google's Android becomes the world's leading smart phone platform," published on January 2012. As a result, despite being primarily designed for phones and tablets, it has seen additional applications on televisions, games consoles, digital cameras and other electronics. The open nature of Android has further encouraged a large community of developers and enthusiasts to use the open source code as a foundation for community-driven projects, which add new features for advanced users or bring Android to devices which were officially released running other operating systems. As mentioned, the mobile application here presented is based on Android.

3.Measure device

3.1. Introduction
This section presents the most important part of the prototype here presented, that is, the Smart Metering measure device. The block diagram of the measure device is shown in Fig. 5:
As figure depicts the measure device is composed by five blocks: three input blocks, one output block and one I/O
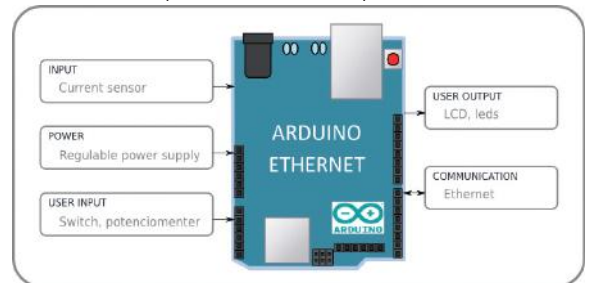
■ **Figure 5.** *Block diagram of the measure system.*

block. Following sections explain the functionalities of each block.

3.2. Input block
As getting an accurate power measure is a key aspect, the input block becomes the most important block of the design. Mainly because this functionality is not provided by the Arduino built-in capabilities and it is needed an external adaptation to transform target signals into valid Arduino ADC's inputs, plus an internal algorithm in charge of the conversion to power parameters.

Taking a look into the algorithm and assuming as base case we are working with the power consumption of a pure resistive device, in order to measure power we have to work with the voltage and current statistical RMS values present in the circuit. That is:

$$P_{RMS} = I_{RMS} \cdot V_{RMS} \qquad (1)$$

where I_{RMS} and V_{RMS} represent the average current and voltage respectively, whose calculation follows the rule:

$$I_{RMS} = \sqrt{\frac{\sum_{n=0}^{N-1} i^2(n)}{N}} \qquad (2)$$

$$V_{RMS} = \sqrt{\frac{\sum_{n=0}^{N-1} v^2(n)}{N}} \qquad (3)$$

where i and v represent the current instantaneous and the voltage respectively, and N the number of samples.

However, devices connected to the network also have some reactive component, which models the power stored as capacitance and inductance. This creates a phase shift between voltage and current signals by which at certain times the instantaneous power reaches a negative value, representing a power flow back as if a portion of the power becomes slower through the device taking longer to return to the network. We can see this relationship throught phasor representation, defining three types of power, as Fig. 6 shows.
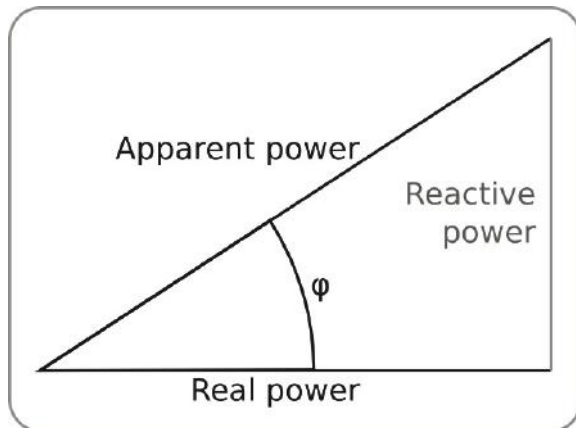

■ **Figure 6.** *Power phasor representation.*

The apparent power is the direct result of multiplying voltage and current in an instant of time, but the one we really want to know is the real (active) power. In order to calculate the real power it is needed to calculate the angle φ, known as power factor, by using the reactive power.

However, for the prototype construction we have chosen to leave out the power factor calculation, accepting the apparent power as a good approximation for the real power. With this simplification our meter only needs current acquisition and assumes a 230V constant RMS voltage value, as it is theoretically provided by the Spanish electricity system. Also it is true that making such an approximation we have introduced an error regarding the real value.

In relation to the implementation, the input block consists of the most complex part of the circuit, since it is necessary to perform an adaptation of the signal provided by the current transformer to the Arduino analog inputs, whose internal analog to digital converters have a specific margin of accepted values.
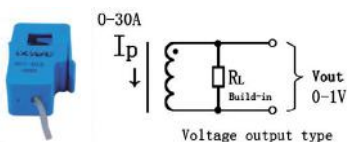
The selected current transformer model is the SCT-013-030, which generates an output voltage proportional to the current that flows through the ferrite core, has a divisible construction in order to allow a non invasive measure of the supply current wire.

It consists of a current to voltage transformer, thanks to the load R_L of 62 Ω included inside of the sensor itself. The ratio winding 1800:1 allows a linear conversion of the current margin [0, 30A] to the voltages one [0, 1V]. Then we can see that the maximum current working value is of 30 amperes, especifications enough for covering an average domestic use.

That output alternating current signal provided by the transformer, from 0 to 1V, has to be applied to one of the Arduino's ADC inputs. The board has 6 analog inputs tagged as A0 to A5 (Fig. 4), which feed an analog to digital converter of 10 bits that works based on a successive-aproximation technique. The choice of each of the internal ADCs is managed by an internal multiplexer.

Analog inputs require a positive voltage (5V as default value), and for this it is necessary an adaptation to obtain pure positive values. We will use an added DC level over the input signal. After that, this level will be removed by a code algorithm based on a FIR high pass filter. As a result, the input block looks like it is shown in the following figure:
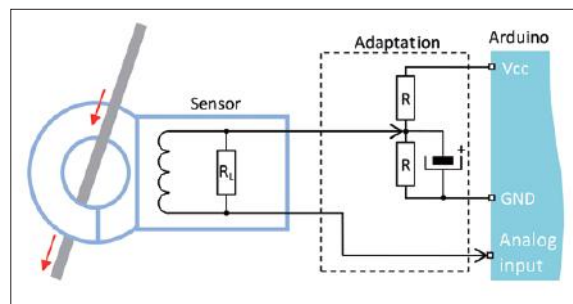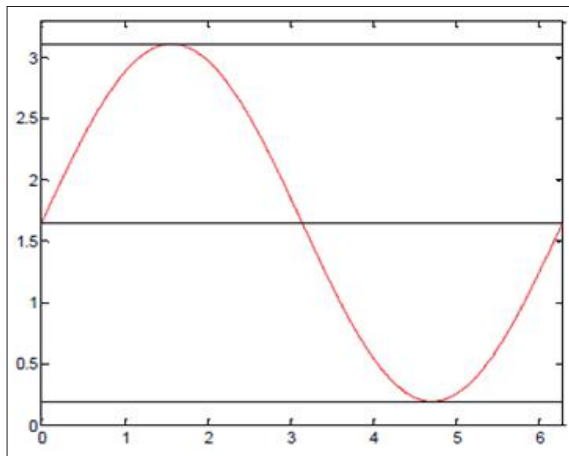

■ **Figure 8.** *Connection from the current sensor to the Arduino Ethernet board.*

Regarding the ADC, note that it is possible to change the background reference scale conversion by using the Aref pin on the Arduino board. Following it is shown the signal path from the transformer until the analog input port:
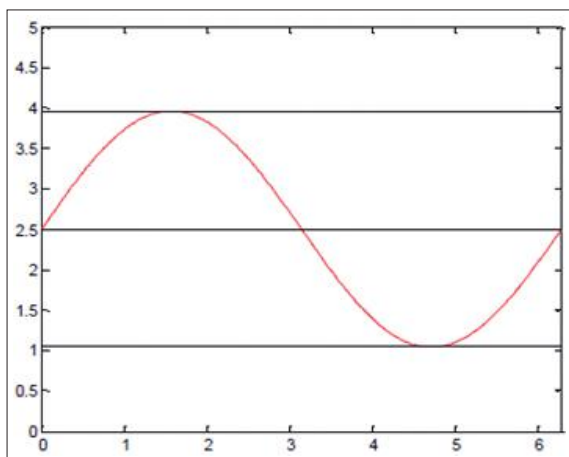
Maximum I_{rms} in the primary: 30 A

$$I_{peak} \text{ in the primary: } I_{rms}\cdot\sqrt{2}=42.426 \text{ A}$$

$$I_{peak} \text{ in the secondary (transf 1800:1): } \frac{I_{peak\ primary}}{1800}=23.57 \text{ mA}$$

$$V_{peak} \text{ in } R_L \text{ of processor } (R_L=62 \text{ Ω}): R_L\cdot I_{peak} \text{ sec}=1.461\text{V}$$

input current	output voltage	non-linearity	build-in sampling resistance (R_L)
0–30A	0–1V	±1%	62 Ω
turn ratio	resistance grade	work temperature	dielectric strength(between shell and output)
1800:1	Grade B	−25℃~+70℃	1500V AC/1min 5mA

■ **Figure 7.** *Main characteristics of SCT-013-030 current transformer.*

The ideal value for Vcc at Fig. 8 is the one that which permits the input pin signal cover the highest part of the range from 0 to Vcc, where the input signal is the sensor output signal plus the offset provided by the adaptation block. With that maximum value we get a minimum value for the ADC quantization voltage, V_q, which is equal to the full scale range divided by the number of possible digital value ADC outputs. In this case, as there are 10 analog outputs, $V_q = V_{cc}/2^{10} = 1024$ V. In order to get a better value for the V_q, it would be better to have a current to current transformer instead of the current to voltage transformer. The current-to-current transformer, as it does not have a built-in R_L, allows us to choose the best R_L value, and a full usage of the ADC input range. To facilitate the design, we will take as a possible value for that Vcc one of the two reference voltages provided by the Arduino board, which are 5 V or 3.3 V, avoiding the need for external circuitery for this purpose.

	$A_{ref} = 3.3$ V	$A_{ref} = 5$ V
V_{min}	0.189	1.039
V_{max}	3.11	3.961
N_{min}	58	212
N_{max}	966	811
ADC Range usage	88.5%	58.4%
V_q	3.22 mV	4.88 mV
P_q	15 W	23 W

■ **Table 1.** *Comparison between Aref=3.3 V and Aref=5 V.*

In addition, Table I shows a comparison between the difference values of A_{ref}. As results shown, the value of A_{ref}=3.3 V is the best choice since it occupies a larger range of the converter. A resolution input voltage from the board of 3.22 mV, which corresponds to 15 W measured by the sensor.

Finally, we have used 10 kΩ for resistor values, based on the recommendation from the creators of the library. It is a high value taking into account the energy consumption and the ability of the Arduino to provide current. However this value introduces less noise. Also, in order to prevent noise, we incorporate a capacitor, which performs a first signal filtering.
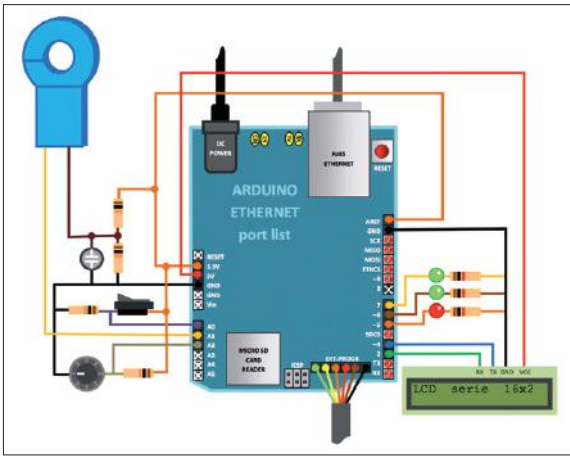
3.3. Other blocks
To power the smart meter it is used an adjustable power supply, which supports a wide range of voltages. With respect to communication, as mentioned previously, the board used to develop the prototype incorporates an Ethernet connector, thus allowing the connection to the network.
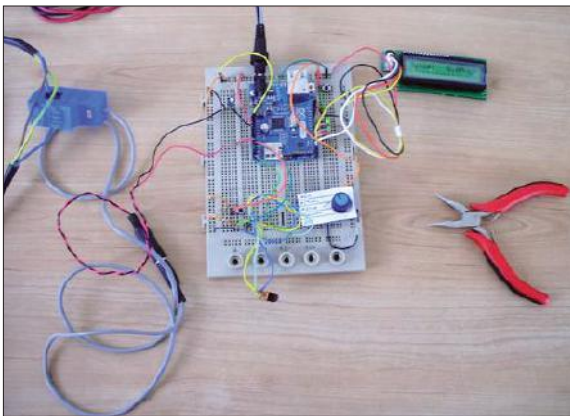
On the other hand, the smart meter include 3 LEDs and a serial LCD for status and output data to the user. The LEDs are connected to a digital output, adding a serial resistor to digital ground. The inclusion of this resistor is mandatory so as to limit the current output of the board. In this sense, given that we have incorporated an LCD to the prototype, it has become necessary to include some elements in order to control its operation. Specifically, we have used a switch that allows to work in local mode, without the need of uploading the measurements carried out to the remote server. In addition, we have used a potentiometer that allows to show the different parameters being measured. The possibilities are: power, current, maximum power consumption, latest data uploaded to the web and a reset of the local parameters.

3.4. Prototype
Finally this section shows the final connection diagram of the prototype as well as some images of the prototype developed.

a) A_{ref}=3.3 V

b) A_{ref}=5 V

■ **Figure 9.** *ADC analysis.*

Fig. 9 shows a graphical representation of the correspondent maximum signal of 30 A within the range provided by the ADC. In both cases the area within the square of the graph represents 1024 values of the ADC.

Figure 10. *Connection diagram.*

Figure 11. *Design and development phase.*

Figure 12. *Final prototype.*
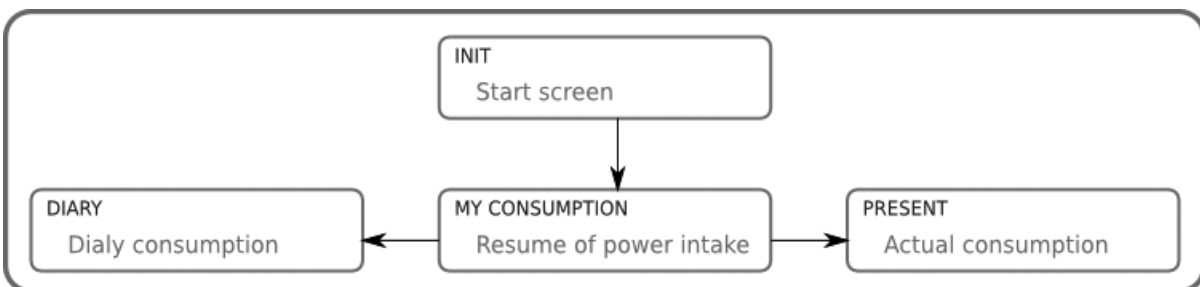
4. Mobile application

The mobile application takes advantage of the information obtained by the measure device, information which is stored in the Xively platform. The display application, installed in the mobile device, gets this information and shows it to the user in a simplified way. The mobile application contains four main screens or activities, as Fig. 13 shows.

The "Init" activity is the welcome screen of the application. This screen – Fig. 14(a) – contains information regarding the date of the latest access to the application, as well as the shortcuts to the rest of screens.

The "My consumption" activity – Fig. 14(b) – summarizes the power consumption information. To this extent three intervals are considered: day, week and month. This way, clients can rapidly consult their consumption. As figure shows, there are three values shown: power consumption (in kWh), cost (in Euros) and the estimated CO_2 emission (in kg.).

If previous screen allows to see a summary of the consumption, the "Diary" activity details the power consumption by day. Fig. 14(c) depicts how this information is shown through a list. In this case values shown are power consumption and cost. This screen allows to see the daily consumption of any month.

Finally, with the "Present" activity – Fig. 14(d) – users can know the current state of their home devices, accessing to the latest consumption data measured by the Smart Metering device and updated to the storage platform. This screen also contains a new functionality of consumption interval counter, using two buttons ("start" and "pause"). These buttons improve the interactivity with the mobile application since users can measure the power consumption of specific actions carried out at home, for instance switching on the oven or the vacuum cleaner.

Figure 13. *Activities of the mobile application.*

a) Start activity   b) My consumption activity   c) Daily activity   d) Present activity

■ **Figure 14.** *Mobile application screenshots.*

5. Conclusions and future work

The system developed allows to monitor the power consumption, with the aim of providing an intelligent energetic consumption. In the domestic environment the use of a Smart Metering provides to the user more information and control over the electricity consumed. By means of the Smart Metering prototype developed users are able to discover their consumer habits. With this information users can develop strategies to make their consumption more efficient and thus, most environmentally-friendly.

Regarding the future work, there are new development lines to monitor the different resources such as the water consumption and natural gas, or the production of solar water heating (SWH) throughout low temperature solar collectors. Moreover, other lines to highlight are electric motors (calculating the efficiency of motors using variable frequency systems) and the activity detection of computer equipment measuring fluctuations in power consumption.

Acknowledgment

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Biographies

Antoni Miquel obtained a degree in Telecommunication Engineering from the Universitat Politècnica de València (UPV) in 2012. He met Multimedia Communications research group (COMM) along his last year of studies, where he participated as assistant and joined after obtaining his degree. His area of interest is energy managing systems based on the cloud and mobile devices.

Román Belda was born in Alzira (Valencia), Spain. He received the Computer Science degree from the Universidat Politècnica de València (UPV), Valencia, Spain, in 2004. He is currently working towards the M.S. in telematics at UPV. He also currently works as a Researcher at the Multimedia Communications research group (COMM) of the Institute of Telecommunications and Multimedia Applications (iTEAM). His areas of interest are mobile applications and multimedia transmission protocols.

Ismael de Fez was born in Valencia, Spain. He received the Telecommunications Engineering degree and the M.S. degree in Telematics from the Universitat Politècnica de València (UPV), Valencia, Spain, in 2007 and 2010, respectively. Currently, he is a Researcher at the Multimedia Communications research group (COMM) of the Institute of Telecommunications and Multimedia Applications (iTEAM), UPV, where he is working toward the Ph. D. degree. His areas of interest are file transmission over unidirectional environments and file encoding.

Pau Arce was born in Valencia, Spain. He received the Telecommunications Engineering degree and the M.S. degree in Telematics from the Universitat Politècnica de València (UPV), Valencia, Spain, in 2005 and 2007, respectively. Currently, he works as a researcher at the Institute of Telecommunications and Multimedia Applications (iTEAM) UPV, where he is working toward the Ph. D. degree. His research interests include multimedia QoS, routing on wireless ad hoc networks and performance evaluation of computer systems.

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