HOUSEHOLD ELECTRICITY AND WATER MONITOR AND CONTROL WITH CELLULAR COMMUNICATIONS AND WEB INTERFACE

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Abstract: The availability and depletion of natural resources is increasingly punted as the limiting factor for sustainability. A lot of focus is currently placed on the role and effect of fossil fuels as well as water conservation. One way to affect prudence with these scarce resources is to generally create timely awareness of consumption thereof, and also the related cost for the consumers. Existing metering solutions for electrical energy and water are often manually read by officials, and the information difficult to digest. Moreover, billing information, which serves as feedback, lags consumption by several weeks. Smart meters address many of these challenges by enabling electronic and real-time metering, but are still prohibitively expensive. In this paper, a low-cost power meter is discussed and also a novel low-cost water flow meter is developed to integrate into a household smart metering system. Electricity supply to appliances as well as the main water supply is controlled through relays and a valve. The whole system is connected to the Trintel SMART web platform by means of cellular communications from where end-users can manage their own energy and water usage. The results demonstrate that the smart metering system provides a functional, accurate and less expensive alternative to household metering. Further improvements on the system are also suggested.

Keywords: smart meter, M2M communications, cellular communications, power meter, orifice, water flow meter.

1. INTRODUCTION

Recent advances in technology have resulted in multi-functional devices, such as laptops, tablets, cell phones, etc., being ubiquitous and pervasive. These devices are already able to control most aspects of our lives. Concurrently, the global population is growing while natural resources are withering, increasing the already intense need to save and convert to a sustainable way of living. This growing global need for centralised control and optimisation also creates various opportunities.

One approach that offers various fringe benefits is that of smart metering. Driven mostly by the recent emergence of ubiquitous wireless networking, smart metering enables autonomous metering of utilities (e.g. electricity and water usage). Two key benefits of smart metering, both of which affect savings, are the low-latency and highly visualised method of data reporting. These two factors ensure that the consumer of the utility, who is usually also the payer thereof, is aware of consumption patterns, which leads to more responsible behaviour [1], [2]. The main enabler behind the reduction in latency with smart metering is that utility suppliers do not need to manually read the meters for billing purposes, but can autonomously capture and process all the data centrally, without having to send an official to every household to read the meter readings.

Significant inroads have been made towards achieving smart metering in the energy sector [3]. Trintel is a South African company that specializes in providing wireless and machine-to-machine (M2M) solutions to customers through its self-developed SMART platform. They are currently in the testing phase of projects where customers have their household hot water cylinders (called geysers in South Africa) connected to several sensors and controlling devices which, through serial and cellular communications, provide real-time access to the SMART platform. The user can log on from any location to monitor and control the state of their hot water [2].

1.1 Contribution

This paper aims to prove the concept of enabling an end-user to monitor and control his/her household water and electricity supply on Trintel's Smart platform through cellular communications. The implementation of aa low-cost power meter is discussed, and a novel low-cost water flow meter is developed for use in a integrated household smart metering system. Relays and a valve are incorporated into the electronic unit to respectively control the electricity supply to the individual electrical circuit breakers and the main water supply into the household. The results clearly demonstrate that the smart metering system functions accordingly, and provides a promising and inexpensive alternative approach to home metering.

The rest of this paper is organised as follows:

Section 2 discusses related work done in this field, Section 3 describes the design of the different components used in this system and Section 4 discusses the results after completing and testing the system. Section 5 concludes the paper.

2. RELATED WORK

The generic configuration and hierarchical architecture of an M2M network is described in [1] and [3]. Various smart metering solutions have been discussed in literature and some limited proof-of concept designs reported [2, 3]. However, no integrated solution exists that combines utilities, water and electricity, into a smart-metering platform with a highly visualised online platform.
A key challenge faced by smart water metering is the prohibitive cost and complexities associated with electronic water flow meters [4, 5]. Moreover, the design of a flow meter is cumbersome, and usually contains moving parts to accommodate the detectability of low flow rates. Off-the-shelf products in the range of this study are expensive and seldom adhere to all of the requirements simultaneously such as the flow medium, size, measurement range, ability to integrate with a microcontroller etc. For example, one suitable off-the-shelf product is the EH Promag 10P. This product functions as an electromagnetic flow measuring system, often used in chemical or process applications, to very accurately measure flow rates with little to no effect on the water flow. However, its price of approximately R 25 000 (US$ 2 500), which eliminates it as an option for large scale household deployment, based on the criterion of affordability.

3. SYSTEM DESIGN

The proposed system can be seen in the system diagram in Figure 1. It shows all the major components and their relations to each other. The major components are discussed in the following sub-sections.

3.1 Processing

The microcontroller unit (MCU) serves as the centre of operations for this system. Most of the processing is performed by the MCU. Power meter and flow meter measurements are transmitted to the MCU to process and send to the web platform via the modem. The relays and effectively the valve are controlled by commands from the MCU. The MCU is programmed to interface with each of these components. The Arduino Mega 2560 is used as MCU platform.

3.2 Communication

The modem is the connection between the electronic unit and the online platform. It facilitates communication between the MCU and the SMART platform via GSM (Global System for Mobile Communications) networks which has extensive coverage in South Africa. ATtention (AT) commands are used to send data over the network. The modem used is the Sierra Wireless Airlink GL6110. The Sierra Wireless AirVantage software is used to set up an asset model for the modem to interface with the SMART web platform.

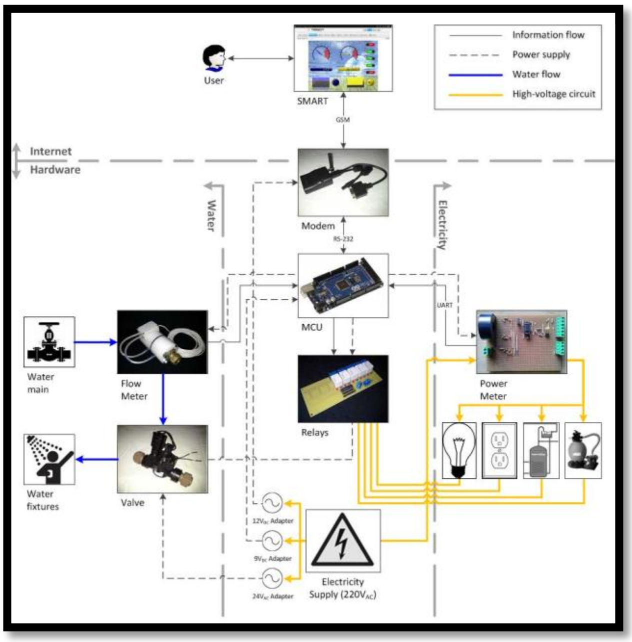


Figure 1: System diagram

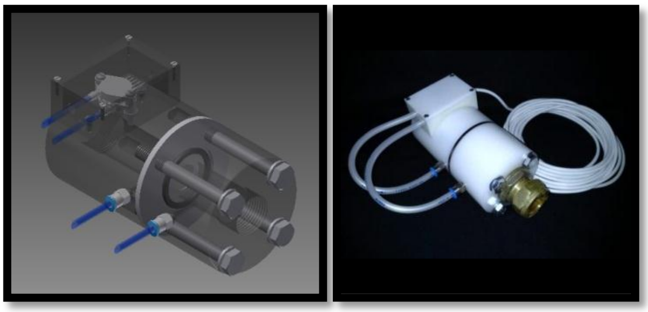
3.3 Water

A device is required to accurately measure the flow rate and thereby also the volume of water flowing into a residence. In this paper, an orifice flow meter was designed as a prototype.

The orifice flow meter utilises the Venturi effect by placing an obstruction in the line of flow, which causes a measurable pressure drop. The pressure drop is measured with a differential pressure sensor to determine the flow rate, by applying Bernoulli's equation, which states that the pressure drop is a function of the square of the flow speed. Continuous flow rate measurements can be integrated over time to account for the volume of water that flows through the obstruction.

The design and accompanying calculations for this flow meter were based on the appropriate ISO standards [6]. The design was further based on ease of use and finding the most inexpensive way to manufacture such a device while still adhering to all the necessary requirements and regulations. The CAD (computer aided design) model can be seen in Figure 2a. This design was used to manufacture the final product seen in Figure 2b.

To enable the user to effectively control water supply into the residence, a simple solenoid valve is connected to the system. This valve may be switched wirelessly from the SMART Sight dashboard.



a) b)

Figure 2: Orifice flow meter. a) CAD model. b) Manufactured flow meter.

3.4 Electricity

A device is required to accurately measure the billable kilowatt hours (kWh) of energy used by appliances in a residence for users and suppliers to keep track of energy consumption.

Off-the-shelf power meters were considered, such as the CRD5490 power meter from Cirrus Logic. These products were found to be expensive and in certain cases required specialist knowledge. Therefore, power meters were researched to produce an easy to design, affordable and safe-to-use product.

For this paper, only single phase electric power will be considered such as would be found in most residences.
When measuring the amount of power that an appliance consumes, it is known that this refers to the real power component of its consumption for which the calculation is shown in Equation 1.

$$P = \frac{1}{2} \cdot V_p \cdot I_p \cdot \cos\theta$$
$$= V_{rms} \cdot I_{rms} \cdot \cos\theta \qquad (1)$$

To find the amount of electrical energy used, the power is integrated over time, which in common practice would mean to average the power consumption over a period of time (often a quarter of an hour) and multiply this by the time as seen in Equation 2.

$$E = \int_0^t P(t)dt$$
$$= P \cdot t \qquad (2)$$

The Cirrus Logic CS5490 integrated circuit (IC) was chosen for its power calculation capabilities. The power meter design, seen in Figure 3, was obtained from the CS5490 datasheet. For this design current measurements are made by using a current transformer (CT) and voltage measurements by using voltage dividing resistances from the household main live and neutral wires.

Burden resistance values were calculated by considering the maximum expected current.
The use of scaling resistors raised a question about the isolation of such a circuit, since it requires that the resistors be connected between the live and neutral wire of a high voltage circuit. The power meter and essentially the whole electronic unit is therefore exposed to this high voltage circuit and potential high voltages differences between the local earth and neutral wires. This can be averted in future designs by using a voltage transformer instead of scaling resistances.

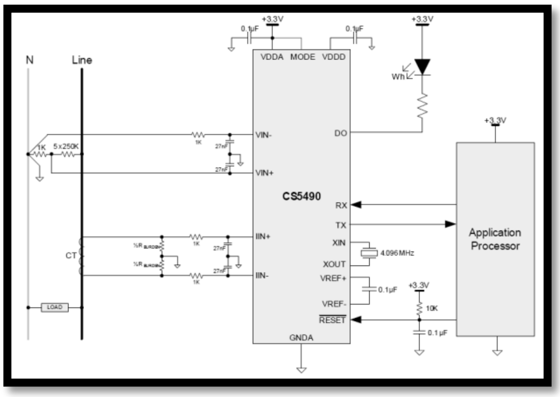


Figure 3: Power meter circuit design

The completed power meter can be seen in Figure 4.

Figure 4: Assembled power meter

To control the power supply to individual circuit breakers, relays are used. For this project solid state, printed circuit board (PCB) mounted relays were chosen with coil energising via change-over (CO) contacts and with the designation of single pole double throw (SPDT). These specific relays are rated at 250 V_{AC} and 10 A, and can be switched with 5 V_{DC}. This rating confines the use of these relays to single loads such as a kettle, heater, swimming pool pump etc. Future designs might include higher rated relays or solid state relays to switch larger loads.

The relay circuit board is connected to the MCU and each individual relay wirelessly controlled by the user from the SMART web platform.

3.5 SMART

The SMART platform is Trintel's own custom-developed M2M platform which gives their clients the ability to manage their wireless telemetry over the GSM network through a web-based portal. By accumulating and reporting on diagnostic and statistical information from devices, SMART enables enhanced maintenance, cost control, service agreements and on-billing for their clients [8]. The SMART web-based tool that is used to monitor and control the system is called SMART Sight. This tool allows clients to create a graphical user interface (GUI) for end-users, such as the one displayed in Figure 5. The dashboard has numerous possibilities for displaying information and setting up controls in the form of gadgets placed on the dashboard.

SMART Sight was used to design the final dashboard seen in Figure 5. The layout was based on user-friendliness and optimum use of the space available in one window. To the left are all of the water flow information and controls, including the flow rate in l/min, the water usage in $litres$, the flow rate history and the high flow rate set point control. In the middle are the same gadgets for the power consumption and energy usage. To the right are the controls for all of the devices connected to the relays, in this instance the water valve, plugs, lights, hot water cylinder or geyser and the swimming pool pump. The information displayed on these gadgets is from real-time data received from the modem.

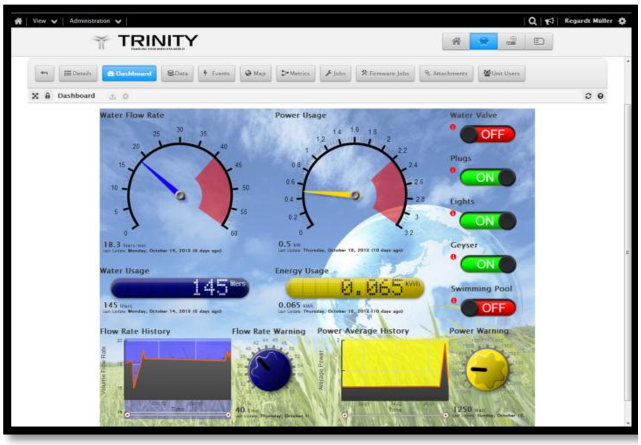


Figure 5: SMART Sight dashboard

4. RESULTS

The finished custom orifice flow meter was tested against a trusted product, the same Promag 10P named earlier [7]. From Figure 6 the water flow meter clearly matches the more complex and expensive product, providing a viable solution for household smart metering. However, future considerations should include using a Venturi flow meter design as well as refining the code for the flow meter on the MCU.

The power meter was calibrated by connecting it to a 2.2 kW heater with various settings and measuring actual readings with an oscilloscope. After calibration the power meter was tested against a commercially available power meter, the ACE9000 ISP.

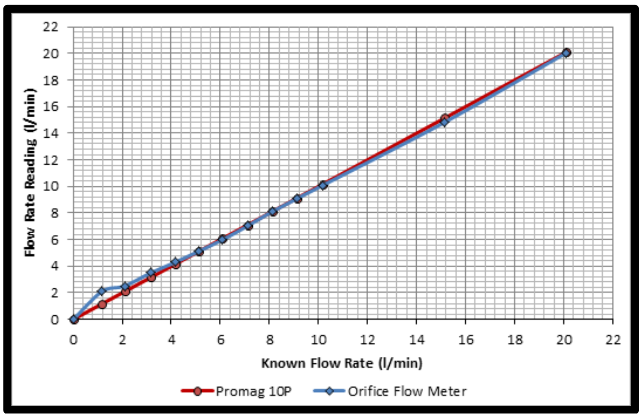


Figure 6: Flow rate reading comparison

The custom power meter kept track of the energy consumption, but eventually some inconsistencies did occur with the ACE9000 readings. The custom power meter gradually falls behind with the energy readings. After 1 kWh of energy was depleted from the ACE9000, the power meter's energy reading was approximately 6% off. This was attributed to inaccurate calibration and inaccurate (>1%) burden resistors, both of which should be easily rectifiable with further development. Overall, it is believed that the initial concept was proven to be realisable.

By integrating all of the above components, the concept of a smart household metering system was realised. The system efficiently and continuously monitors and displays electricity and water usage information to a user in a user friendly interface, and enables them to control consumption by being able to switch the electricity supply to certain appliances and the main water supply on/off.

The communication between the MCU and modem causes some errors. As stated earlier, the design of the flow meter can be improved. Improved isolation of the power meter from the main lines can be achieved.

5. CONCLUSION

The work in this paper presents the design of a smart household metering system. The system provides a low-cost alternative to existing solutions. The custom orifice flow meter has an estimated cost of 12% of the commercially available unit while the power meter parts amount up to no more than R 350 (US$ 35).

The flow meter was manufactured and tested to measure flow rates to an accuracy of within 1% for flow rates between 4 l/min and 70 l/min. It is advised that Venturi meter be considered should the product be taken into mass production, for which this design could easily be adjusted.

Trintel's SMART platform was employed to provide a highly visualised online platform.

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