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LOW COST SENSORS AND SYSTEMS FOR COLLECTING WATER USAGE IN THREE PILOTS

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ABSTRACT

The Waternomics project aims to reduce the water consumption of municipalities, corporations and domestic users by providing water managers and consumers alike with timely and actionable information about water usage and water availability. This paper discusses the technology for a data acquisition system for 3 different types of users to support a water information platform as they are defined in the Waternomics project. In order to create a robust sensor system for the pilots, we have started early on the project to gather the requirements for the final pilots and during this process it became apparent that we will need baseline pilots for testing the technology and to acquire baseline information for the final pilots as a reference.

Keywords: data acquisition system, sensor system, water consumption, water usage pilots

1. INTRODUCTION

Waternomics is a EU funded research project to reduce water consumption of corporate and domestic users by providing water managers and consumers with timely and actionable information about water usage and water availability. Currently the limited information available from the water services ecosystem is not interoperable or not presented effectively to stakeholders. Waternomics overcomes this problem by implementing a new level of smart meter and sensor technology and knowledge/social media based techniques to the water sector. The smart meter technology, will (1) enable the detailed and real-time measurement of water flows with state of the art as well as advanced sensor technologies, like ultrasonic flow meter, mini water meter, mass transport based MEMS sensors (2) acquire the data from the different sensor technologies using a generic platform and will include the data storage, hosting a website for visualization and have will have software to communicate data via the internet.
After evaluation of different Linux platforms, a Linux-powered single-board computer was chosen which would enable all the functions as described above. To test this platform in a real environment, a private pilot has been setup to test all the elements of the sensor system. Results of this private pilot will be presented.
After analyzing the results of the private pilot and using the detailed requirements for the pilots, the system will be demonstrated in three high impact pilots:

1. Domestic: Households in the municipality of Thermi, Greece.
2. Corporate: Operator from Linate Airport in Italy.
3. Municipal: University and public school in Galway, Ireland.

In chapter 2 we will describe the different sensor technologies and data acquisition, storage and visualization platform and in chapter 3 we will report of the private pilot that has been running since September 2014 and the three planned pilots for which we will give the basic requirements for the sensors. In Chapter 4 we will give some conclusions.

2. SENSOR SYSTEM

There are three major parts composing a real-time sensor system for water usage measurement: sensors, data acquisition platform and website. **Error! Reference source not found.**~~**Error! Reference source not found.**~~~~Figure 1~~ presents the framework of a typical sensor system.

Figure 1. Sensor system

2.1 Sensors

From the assessments of the sites for the pilots we have concluded that most likely we will need 2 types of~~for~~ sensors, the first one intended for measuring the largers flow~~s~~ present outside and in the main pipes of the building and secondly a sensor for in house which should also be easily~~easy~~ installable. This section presents the proposal for the low-cost and easily installed sensors, i.e. Ultrasonic Flow Meter and Mini Water Meter, for real-time water flow measurement. The Ultrasonic Flow Meter is typically used for flow measurement in water distribution network in buildings while the Mini

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Water Meter is more suitable for fixture-level water measurement. What's more, we also introduce our innovative flow sensors

2.1.1 Ultrasonic Flow Meter

The Waternomics project will use both off-the-shelf and project developed sensors. A benchmark of different kinds of sensors has been conducted to develop an optimal flow-sensing method. To reduce the risk in Waternomics project as much as possible, the targeted sensor should be of high cost effectiveness, interoperability with existing systems and easy installation. VTEC Ultrasonic Flow Meter (see Figure 2~~Figure 2Figure 2~~) will be highly recommended due to its cost effectiveness (three times lower than market price) and easy installation as highlights. The pair of transducers is clamp-on type so it is unnecessary to make any penetration on the pipe. And the main controller is well-designed for data collection.

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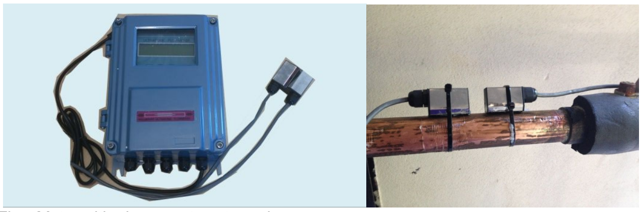

Figure 2. VTEC Ultrasonic Flow Meter with clamp-on type transducers

The measuring principle of this flow meter is based on the difference of the transit time of ultrasonic signals. The ultrasonic signals are transmitted between two transducers which work as both a sound transmitter and a sound receiver. The difference of transit time occurs when the fluid moves and is directly proportional to the flow velocity. The performance of this flow meter can reach the accuracy of ±1% at flow rate greater than 0.2m/s. It is also equipped with several outputs including RS485 serial port and 4-20mA standard output. The pipe size ranges from DN15-DN700mm for most pipe material for quite broad applications. With these advantages, it is highly recommend in the water usage (cold and hot) pilots especially for corporate and public buildings.

2.1.2 Mini Water meter

Mini water meter (see Figure 3~~Figure 3Figure 3~~) as a hall sensor inside which can output a pulse signal. The main features of this mini water meter are small size and simple data collection for the residential and commercial water network. What's more, if needed, the function of temperature measurement can also be added to this mini water meter. It can also perfectly fit with our regular residential hose (1/2") which shows an obvious advantage in installation. The flow rate of the water meter ranges from 1 to 30L/min with ±2% accuracy. In this way, it is cable of measuring on a detailed level of water usage.

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Figure 3. Mini water meter is fully compatible with regular residential hose (1/2")

2.1.3 Innovative flow sensor

In the Waternomics projects we will develop mass transport based flow sensors. These sensor are based on clean room processing technologies and have the potential to become very low cost. We are evaluating to possibilities for these sensors: 1) T~~t~~he first method is based on a MEMS sensor based on strain gages applied on the surface of a LCP substrate. The flow is measured by means of a resistance of strain gages based on the friction force of the water with the sensor surface, the output of these sensors will be analog.~~, and,~~ 2) T~~t~~his sensor is based on photonic crystals and works based on the cooling of the chip mounted on the tip of an optical fiber. The photonic crystal has a specific refractive index pattern and emits light with specific resonances when the crystal is excited by a laser. This laser excitation also results in a higher temperature of the photonic crystal. Change of temperature will result in a shift of this wavelength and the depending of the water flow the chip will obtain a lower temperature. The resulting wavelength reading can be given as an analog or digital signal.

2.2 Data Acquisition Platform

2.2.1 Hardware

We have evaluated and tested several Linux-powered single-board computers(SBCs) and made a comparison which shows in Table 1~~Table 1Table 1~~. The conclusion is BeagleBone Black is the most suitable one in the light of its performance.

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BeagleBone Black comes packed with flash memory and an operating system already installed, which means that out of the box it's already fully operational. If you want to run in headless mode (i.e. without a monitor), it's easy to do, and you don't need extra hardware to set it up like you have to do with the Raspberry Pi. The big advantage of BeagleBone Black is that it has a really good set of general purpose Input/Output(GPIO) pins (69 GPIO pins compared to the Raspberry Pi's 8) which can interface with exterior electronics easily.

In the pilots, we use this low-cost BeagleBone Black to collect data from the Ultrasonic Flow Meter, store the data internally for back up and host a website to visualise the data. Data can be transferred to the cloud and remote control of sensor settings is possible. The data acquisition platform developed with BBB is shown in Figure 4~~Figure 4Figure 4~~.

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Table 1. Comparison of most popular Linux-powered single-board computers.

	ARDUINO UNO	RASPBERRY PI(MODEL B)	BEAGLEBONE BLACK
PROCESSOR	ATMega 328	Arm 11	AM335x
SPEED	16MHz	700MHz	1GHz
RAM	2Kbyte	512MB	512MB
USB	n/a	2	1
AUDIO	n/a	HDMI, Analog	HDMI
VIDEO	n/a	HDMI, Analog	Mini-HDMI
ETHERNET	n/a	10/100	10/100
I/O	14 GPIO,6 10 bit analog	8 GPIO	69 GPIO, LCD, GPMC, MMC1, MMC2, 7 AIN, 4 Times, 4 Serial Ports, CAN0
SIZE	2.95” x 2.1”	3.37”x 2.215”	3.4” x 2.1”
OPERATING SYSTEM	n/a	Linux	Android, Linux, Windows, Cloud9, CE, etc.
DEV ENVIRONMENTS/TOOLKITS	Aruino IDE	Linux, IDLE, OpenEmbedded, QEMU, Scratchbox, Eclipse	Python, Scratch, Linux, Eclipse, Android ADK
COST	$29.95	$35	$45

2.2.2 Software

The software stack contains all the software and applications to enable a standalone operation of the system. The different components of the stack are explained below.

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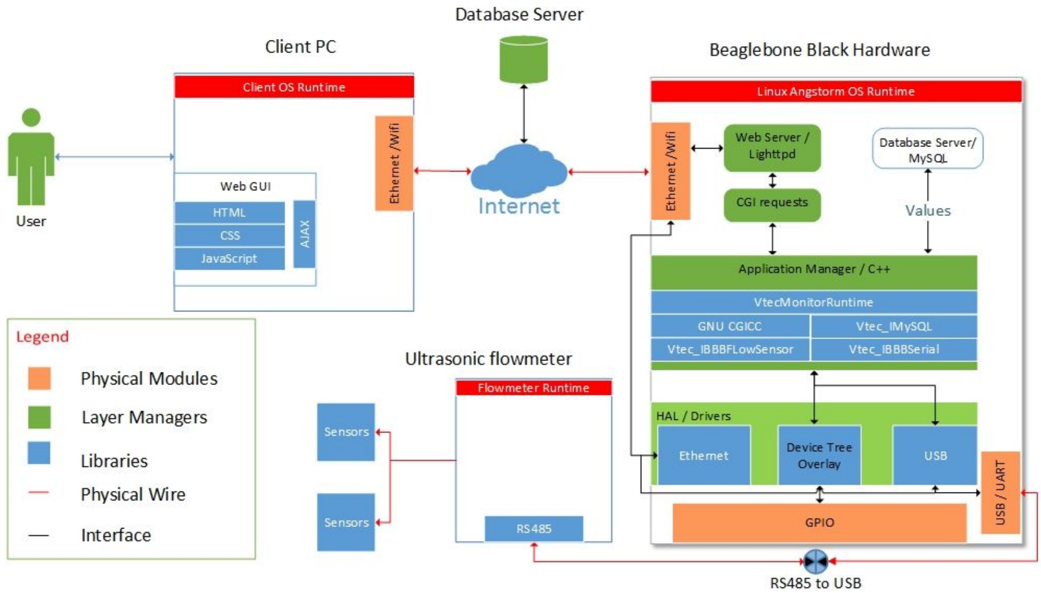

Figure 4. VTEC Data acquisition platform (BeagleBone Black)

We define the components as follows:
Client PC: This is a guest machine that can successfully run a web interface i.e. computers, smartphones, tablets etc. This will display the GUI provided via the BeagleBone Web Server.
The Web GUI: Uses various web programming elements HTML, CSS, Javascript to dynamically create an interface that a user can interact with.
Global Database Server: This is the global database that requests for data from various pilots.
Webserver: This is a Lighttpd server running on the BeagleBone that handles the CGI requests that are made.
CGI: Common Gateway Interface provides a client- server communication interface.
Application Manager: This is the heart of the acquisition system that is in charge of binding all software modules together. It is written in C++, C and uses various in-house, external and standard libraries. It is responsible to understand various client side requests, read and write to the hardware peripherals, log data to database and provide appropriate feedback to the user.
Local Database Server: This is the local MySql database server residing in the BeagleBone Black, and will hold various databases.
Hal/Drivers: Hardware abastaction layer that holds drivers to interact with the hardware.

2.3 Website

To realize real-time monitoring of water consumption and an intuitive way to present the results of water consumption activities, we design a website which is hosted in BeagleBone Black. VTEC Engineering set a completely new website for monitoring and tracking water usage. We present the water usage in the form of graph and pie chart. In the graph, there are two parameters, flow and velocity, displayed with an acquisition time of 1 second. Below the graph, a pie chart shows an overview of water consumption in the morning, afternoon, evening and night of a day. With these real time sensor data, we could even make some patterns for water usage activities.

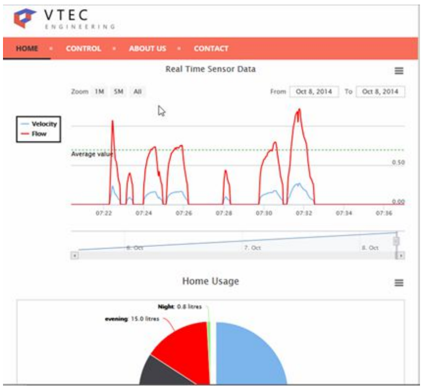

Figure 5. Example of VTEC real-time water flow website

3. PILOTS

3.1 Private Pilot

Our private pilot is a big office building, called Videolab, containing about 300 small companies distributed in 7 floors, located at Strijp-S in Eindhoven. This pilot is conducted based on the analysis of the initial requirements from all the pilots in Waternomics project. We present how we use our low-cost sensors and system to collect water usage in our private pilot. We installed the Ultrasonic Flow Meter in the main pipe of the whole water supply system of this building.

Figure 6

~~Figure 6~~Figure 6 shows an image of the Ultrasonic Flow Meter installed in the technical room of this building, in series with the original billing water meter, which can also be used for comparison and reference for the purpose of calibration.

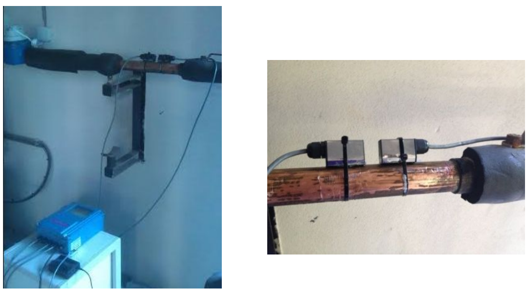

Figure 6. Private pilot in Strijp-S in Eindhoven, NL

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Besides simple water usage data recording, we also conducted some experiments on the water usage pattern in the office building. To get a clear effect of the water usage pattern, an early arrival and testing are needed. Figure 7 shows a normal toilet in a lady's room and the water usage pattern of one flush for such kind of toilet. Figure 8 presents the pattern of flush several times of urinals. And Figure 9 gives a image of the pattern for a regular hand washing. More data processing and technical research could be exploited based on the water usage patterns.

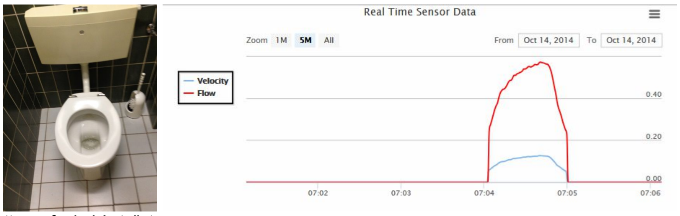

Figure 7. Water usage pattern of a lady's toilet

Figure 8. Water usage pattern of urinals

Figure 9. Water usage pattern of one hand washing with a sink

3.2 Pilots in Waternomics

3.2.1 Pilot in Italy

The pilot in Italy is Linate Airport in Milan which is a large-scale commercial site to deploy the Waternomics Platform. The airport provides a unique opportunity given the varied nature of water use on site (from washing activities, toilets, restaurants, irrigation etc.) and its role as a large-scale consumer. Linate Airport is equipped with autonomous supply and distribution networks. After field visit and technical meeting, the proposal we made is to install some Ultrasonic Flow Meters for main buildings to get a baseline in the first place. Since we have finished our own private pilot, we also could apply the sensor system in this pilot. Figure 10 presents the proposed sensor system for a baseline pilot at Linate Airport. An Ultrasonic Flow Meter connects with BeagleBone Black, with which the client can store the local database as well as communicate with a client device via internet. BeagleBone Black can both use wireless network (Wi-Fi) and wired network (Ethernet).

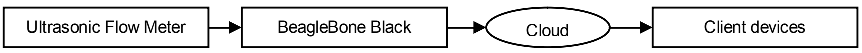

Figure 10. Overview of proposed sensor system for a baseline pilot of Linate Airport in Italy

3.2.2 Pilot in Greece

The pilot in Greece is in Thermi, a semi-urban municipality and the main users are residential. The purpose of this pilot is to validate the Waternomics methodology at a mostly residential demonstration in Greece. The WATERNOMICS Platform will be installed and commissioned for a representative sample of users. Field investigation was carried out in local home users in Thermi. To know about the current water use and home water network, 4 volunteer households in three types were engaged in the field investigation. For home water consumers, they live in different types of houses, such as apartment, duplex apartment and house. The structure of the house matters the deployment of the sensors. Table 2 shows a proposed solution. Considering the actual situation, in this pilot, we may also use GPRS for data transmission

Table 2. Proposed solution for Thermi

FLAT WITH CENTRALIZED WATER PIPING SYSTEM	FLAT WITH DECENTRALIZED WATER PIPING SYSTEM	HOUSE WITH SPECIAL WATER PIPING SYSTEM
Normal water meter for main inlet Mini water meters for break-down Data acquisition device and Wi-Fi	Normal water meter for main inlet Mini water meters for break-downs Data acquisition device and Wi-Fi/GPRS	Normal water meter for main inlet Mini water meters for break-downs Data acquisition device and Wi-Fi

3.2.3 Pilot in Ireland

The pilot in Ireland is a New Engineering Building (NEB), an advanced mixed using building which was completed in 2011. It has an existing basic water monitoring system called Building Management System (BMS) and a rain water harvesting system. The NEB comprises a café, laboratory facilities, office space, changing facilities and toilets and showers. It has installed a lot of meters with electrical outputs in the piping system but not all of them are connected with remote reading system. In this demonstration the WATERNOMICS Platform will be required to increase user awareness within public spaces in particular targeting a younger audience. Significant reductions in water consumption can be made through awareness of water consumption, leak detection, and also fault detection on mechanical equipment – indeed such detection can also increase awareness of end-user habits. So for this pilot, we will integrate the existed sensor system into Waternomics Platform. Figure 11~~Figure 11Figure 11~~ proposes a solution for this pilot.

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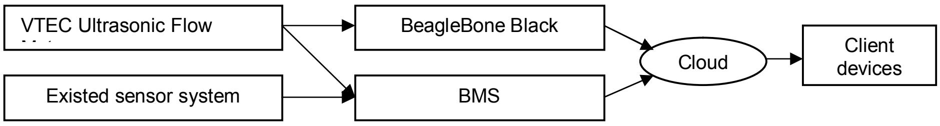

Figure 11. Overview of proposed sensor system

4. CONCLUSIONS

In this paper we have presented the pilots and its preliminary requirements, the sensors and the data acquisition system that we propose. The proposed sensor system has been tested in a private pilot where we have shown that we can measure the flow real-time, show cumulative data and are able to detect very small flows. Conclusion is that we have developed and tested a low cost water flow sensor based system for collecting water information for three pilots.

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