IoT Based Experimental Study to Modify Water Consumption Behavior of Domestic Users

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Abstract. In this paper, we present the results of a small experimental study to understand and quantify the impact of real time feedback on water consumption behavior inside buildings. We develop a low cost water monitoring node, which can be conveniently installed without plumbing requirements on water fixtures found in typical households and commercial buildings. In our experiment, we installed the developed Internet of Things (IoT) node on a kitchen sink in a commercial building. The sink was used primarily for washing mugs, plates, and making tea & coffee. We collected, analyzed and compared the data of different users for different activities (e.g., washing mugs and plates) to understand their water consumption pattern. Then, we provided real time feedback for three weeks to two major water consumers after every activity about potential water wastage. We observed a significant improvement in the water consumption behavior of these users (water wastage reduction up to 50%). This study clearly demonstrates the utility of low cost IoT based solutions and real time feedback in modifying water consumption behavior of domestic users.

Keywords: Internet of Things · Consumer behaviour · Feedback
Water conservation

1 Introduction

Water is perceived to be abundantly available and is provided at a nominal cost (often free of charge) to domestic consumers, but they do not consume it with due care and prudence. Empirical evidence suggests that even conservationist consumers, who claim to possess a positive attitude towards water management and climate change issues, also fail to reliably translate their noble intentions into concrete actions. This lack of prudence often leads to lot of water wastage. Unfortunately, many consumers remain unaware of the water wastage that results from their own actions [1].

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According to the psychological literature, human behavior can be influenced by the 'availability bias' [2,3]. In nutshell, availability bias suggests that consumers resort to mental shortcuts and draw on readily available information. Resources are not used with due care because often their conservation is not at the forefront of our consciousness. Consumers can be made to think and act more rationally if feedback and information is provided to them about their consumption habits and any wastage resulting from their actions. This, however, requires a better understanding of their existing resource consumption pattern, i.e., how, when and where the resources are being consumed by different users.

Internet of Things (IoT) platforms have gained tremendous popularity and research interest in recent years. However, in most buildings, sensing and control capabilities are very limited, and it is considerably hard to monitor real time resource utilization. A variety of IoT systems using wireless sensor networks for monitoring domestic usages of water have been proposed and developed in recent years [4–8]. In [4], a case study was presented in which a global household water consumption monitoring system was developed across two countries that showed remote, near real-time monitoring of water consumption in different households. Several systems have also been proposed to provide feedback and induce resource conservation behavior in the consumers [5–8]. [5,6] used android and web applications to show water consumption by users in terms of graphs. [7] developed a system that included automatic billing as a way of intervention to change consumer resource consumption pattern, while the system in [8] focused on providing real time alerts in the form of alarms when the consumer crossed some previously defined threshold on consumption.

In this paper, we also develop a low cost IoT based system to monitor and change the water consumption behavior of domestic consumers. Contrary to previous works, our paper disintegrates the water consumption data according to the activities performed by each user. In the proposed system model, the sensor nodes, which can be retrofitted on faucets and fixtures monitor the water consumption pattern of consumers. The data collected from the nodes is transmitted to a central gateway and then to a remote servers where the data is stored and processed to understand the consumer behavior. We performed an experiment where the system was deployed to monitor the water consumption pattern of kitchen sink users in a commercial building. The collected data was used to identify water wastage in different activities performed by two major water consumers in our study. These users were then provided real time feedback for three weeks after every activity about the potential water wastage. The results showed promising reduction in water wastage (up to 50%), which indicates the potential of low cost IoT platforms in modifying consumer behavior.

The rest of the paper is organized as follows. In Sect. 2 we describe an IoT based system model for water monitoring in buildings, in Sect. 3, we discuss our experimental water monitoring setup, in Sect. 4 we describe the results of our experimental study, while the paper is concluded in Sect. 5.

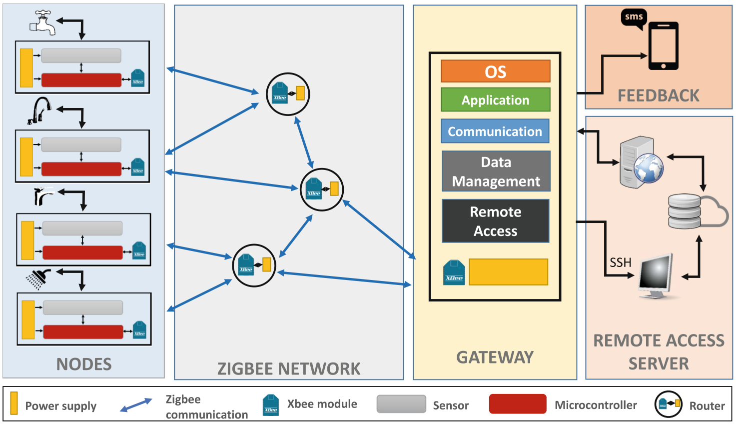

Fig. 1. IoT based system model for water monitoring

2 IoT Based System Model for Water Monitoring

An IoT based system model for water monitoring is shown in Fig. 1. There are four distinct components of the system. The sensor nodes monitor the water flow at different types of faucets and pass the data to a central gateway using a Zigbee network. The gateway aggregates and processes the data and sends it to a web server where the data is uploaded onto a database. The server can be remotely accessed to perform data analysis and the feedback is generated for the consumers. The gateway then communicates the feedback to the consumers. Further details of these modules are explained in the following subsections.

2.1 Water Monitoring Node

The most important module in this system is the node designed to fit on the faucet where the water usage needs to be monitored. To install a sensor, consideration of pipe size and its dimensions is of fundamental importance. Water pressure is also important for sensors that fit inline or somewhere in the piping infrastructure because high pressure can damage the sensor. Water pressure for domestic faucets and fixtures is at most 150Psi [9]. Flow rate of every faucet varies and the sensing module must have a reasonable measuring accuracy and sensitivity within that range. Moreover, the issues of additional plumbing requirements, such as, whether the sensor needs to be mounted inside the piping infrastructure vertically or horizontally and whether the sensor needs additional instrumentation for its deployment are also important.

The most commonly used sensors to monitor the water flow at the faucets are Hall-effect sensors [10]. These type of sensors can be easily interfaced with any microcontroller. As the water flows through the sensor, the magnetic rotor spins at a rate proportional to the flow of the water passing through the sensor. The rotor provides for the magnetic field to the sensor and a series of voltage pulses are generated whose frequency is proportional to the water flow rate.

2.2 Radio Communication Network

A low-energy radio, like Zigbee, could be used to transmit the data to a central gateway. Zigbee can form any network topology based on the number of nodes and the distances between the nodes. Zigbee has three device types: coordinator, router and end device [11]. Different routers should be placed by doing experimentation to determine the Received Signal Strengths (RSSI) of the Zigbees in Non-line of sight (NLOS) and Line of Sight (LOS) locations [12].

2.3 IoT Gateway

Gateway acts as an edge device which connects the sensor nodes to the internet. A gateway can play multiple roles as it collects the data coming in from all the sensor nodes, and then standardizes the formats of all the data so that it can be easily processed and stored. Some key features of the software stack of the gateway include operating system, application container, communication & connectivity, data management and remote management [13]. Raspberry Pi has all the key features and therefore it is often a popular choice to build a gateway in IoT based systems [14].

3 Experimental Low Cost Water Monitoring Setup

To test the performance of our water monitoring system and to study the impact of real time feedback in modifying consumer behavior, we built a low cost water monitoring system based on the model discussed in the previous section. We conducted an experiment by installing our water monitoring node on a kitchen sink in a commercial building. A significant amount of water is used at our targeted node for various activities; the most common being, washing dishes and mugs, making tea and coffee for the staff (almost 50 persons). The setup of our node is shown in Fig. 2.

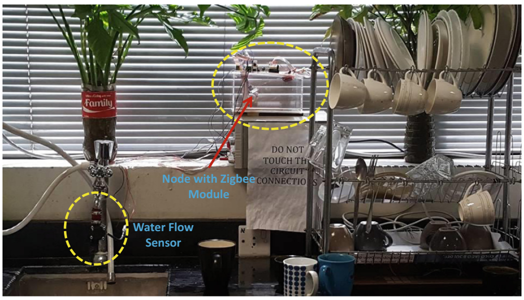

Fig. 2. Experimental setup

3.1 Development of Water Sensing Node

We selected **YF-S201** Hall-effect sensor to develop our water sensing nodes [15]. The sensor does not have any plumbing or retrofitting requirements and it can be easily installed at the exterior of the faucet with minimal intrusions and obstructions. With proper calibration, this sensor also provides reasonable accuracy (85%–90%). Furthermore, it can measure water flow rate of up to 0.5 l/s, which falls in the range of the domestic faucets. This sensor can be fitted inline (both in horizontal and vertical mounting) or to the exterior of a faucet and piping infrastructure according to the application requirements. Moreover, this sensor is readily available in the market and can be purchased off the shelf.

A microcontroller is required to process the signals coming from this sensor. We used Arduino because it can be easily interfaced with both the sensor and the Zigbee modules [16]. Whenever the faucet turns on, an interrupt is generated and the voltage pulse produced by the sensor is detected by the Arduino. Arduino then disables the interrupt and calculates the flow rate and the total water consumption. The calculated data is then sent to the gateway using Zigbee network.

3.2 Zigbee Radio Network

Xbee is an embedded wireless communication module that is built on Zigbee standard [17]. To form a wireless network, we used Xbee S2C Pro models [11]. The Xbee at the gateway was configured as a coordinator and the one at the node was configured as an end device. The Xbees in between the coordinator and the end device were configured as routers. We placed two routers between the node and the gateway at distances where the RSSI value dropped below −70 dBm [12]. The exact router locations were determined by performing experiments for RSSI values in line of sight and non-line of sight paths.

3.3 Raspberry Pi Based Gateway

To build a gateway, we used Raspberry Pi 2, model B [14] as it supports all inbound and outbound communication protocols required for a typical IoT gateway. We used Xbee for the inbound communication, which is the data coming from the sensor node over the network formed and for the outbound communication we used Ethernet which connected our Raspberry Pi to the internet. The default operating system for the Raspberry Pi is Linux, specifically Raspbian, and it also runs Apache, as the web server; MySQL, as a database; and PHP, for server-side scripting [18]. Raspberry Pi is also capable of acting as a local web server [19]. The packets of flow rate, current flow, and total water consumed were separated and uploaded on the database table corresponding to the time-stamp using a python application. This gateway could be accessed through Secure Shell (SSH), which is a network protocol that provides administrators with a secure way to access a remote computer [20].

4 Experimental Study

In this section, we describe and discuss the results of our experimental study. The collected data was stored in a database along with the time-stamps. To associate water usage with individual consumers, we also attached a camera with the Raspberry pi and as soon as the faucet was turned on, the camera took a series of snapshots with time-stamps. Passive Wi-Fi tracking techniques [21] can also be used to distinguish the users using the faucet. In this method, the MAC addresses of the smart phones can be scanned and RSSI values can be used to find out the users near the faucet at the time of water consumption activity. This method will be further explored in future work.

The experiment was divided into two phases. In the first phase, we simply observed the activities and corresponding water consumption of all the users and logged them for five working days (1 week). We analyzed this data and selected the consumers who used the maximum amount of water during the experiment. In the second phase of the experiments, real time feedback was provided to the selected users and the impact of our feedback was observed in their water consumption behavior.

4.1 Phase I: Monitoring

The water consumption of all the users was monitored. The consumption patterns and disaggregation of data was done for only those users who contributed significantly or were involved in major activities at the node. The main activities observed were washing plates, mugs or hands.

Figure 3 shows the percentage of water consumed by different users. The three most frequent users are indicated as users X, Y and Z. Together, these users accounted for 66% of the total water consumption at the node. User X was found to be the highest water consumer, followed by user Y, and then user Z.

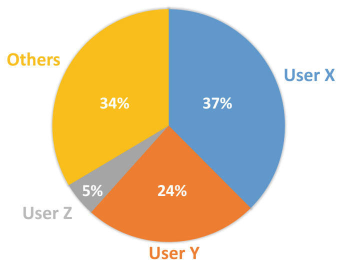

Fig. 3. Percentage water consumption by different users

We further analyzed the water consumption pattern of only the three main users. Table 1 shows their mean daily water consumption and variance. It can be observed that user X has the highest mean of 38.32 l. The mean daily water consumption by user Y is relatively less than user X but the variance is very high. High variance shows the inconsistency in the amount of water consumed by user Y for his activities. User Z has the lowest mean daily water consumption and is also relatively consistent. Therefore, for further analysis and feedback we also dropped user Z.

Table 1. Mean and variance of daily water consumption by users X, Y and Z

Users	Mean (*liters*)	Variance
X	38.32	29.90
Y	24.40	56.59
Z	4.89	1.56

The major daily activities of users X and Y were washing mugs and plates. However, the number of washed items varied for both the users. Due to this variation in the number of activities performed by the two users, we computed the average water consumption of washing a mug or a plate in that particular day. All the further analysis was done using the averaged value of the activity.

4.2 Phase II: Real-Time Feedback

The second phase of our experiment was aimed at providing feedback to users X and Y in our study. We initially briefed these consumers about their water usage pattern as observed in the monitoring phase and also reminded them about the importance of water conservation. Then after every activity that was performed by user X or Y, we notified them about the water (in liters) that was consumed. The feedback was provided for three consecutive weeks (5 days per week).

In Figs. 4 and 5 we plot the average water consumption of user X and user Y respectively to wash one mug and one plate for the complete experimentation period. The first 5 days (day 1 till day 5) in these two graphs indicate the pre-feedback period, while the remaining 15 days (day 6 till day 20) indicate the post-feedback period. It can be observed that during the pre-feedback week, the total water consumed to perform an activity was the highest for both the users. However, as the feedback process started, it can be observed that the water consumption of user X decreased drastically. The water consumption stayed almost constant in the second week and by the third week it began to increase slightly. On the other hand, the response of user Y to the feedback was very effective. As can be seen from Fig. 5, during the pre-feedback period, the consumption of water by user Y was very high, but during the feedback period the consumption rate significantly dropped. This indicates that the impact of feedback on user Y was relatively high as compared to user X.

To further understand the impact of feedback on consumer behavior, in Fig. 6, we plot the average weekly water consumption for both the activities by users

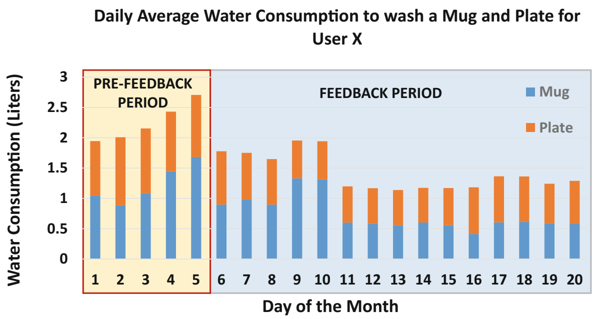

Fig. 4. Daily average water consumption by user X to wash 1 mug and 1 plate for the complete experimentation period

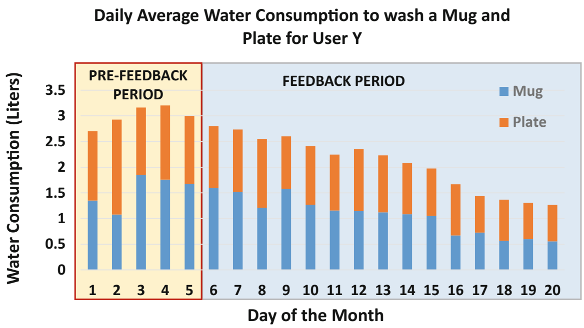

Fig. 5. Daily average water consumption by user Y to wash 1 mug and 1 plate for the complete experimentation period

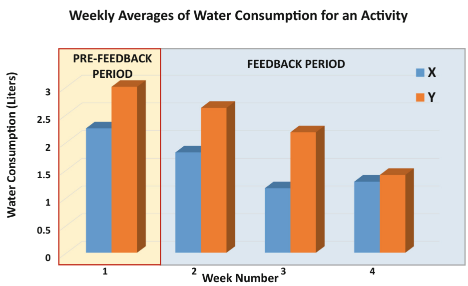

Fig. 6. Average weekly water consumption by users X and Y for washing mugs and plates

X and Y. From this figure, we deduce that the water consumption of user X was reduced by 42% from the pre-feedback week till the last week of the feedback. While user Y's water consumption was reduced by 53%. It can also be observed that the water consumption of user Y for the same set of activities was always higher than that of user X throughout the four weeks of our experiments. This also leads to the conclusion that despite large reduction in water consumption, user Y still wasted water and further improvement in his behavior could be achieved by continued feedback.

5 Conclusions and Future Work

The aim of this paper is to present our work towards the development of a low cost IoT based system, which could be effectively used to monitor the water consumption pattern of domestic consumers and then design consumer behavior change interventions. We successfully developed and deployed a water monitoring system for a kitchen sink node in a commercial building. With the help of the data collected by our system, we can easily identify the water consumption patterns of different users. In our experimental study, we identified two major water consumers and provided them real time feedback about potential water wastage. We observed tremendous positive impact of feedback on the water consumption pattern of these two users.

The impact of providing incentives along with feedback is an interesting area to be explored in future. The consumers using the faucet could be categorized as green and non-green users and a points based system could be devised to promote pro-conservation behavior. The overall points gained by various same faucet users could also be shared among each other in order to create a competition. Moreover, the water consumption behavior of the users once feedback is discontinued would also be evaluated in future.

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