Reducing city household water consumption with internet of things devices

Ioan Florin VOICU,
ING Tech, Bucharest, Romania

ioan-florin.voicu@ing.com

Daniel Constantin DIACONU,
Dr., Faculty of Geography - University of Bucharest, Bucharest, Romania

daniel.diaconu@unibuc.ro

Abstract

This research aims to prove that inexpensive Internet of Things devices can be used to monitor domestic water consumption, thus lowering water usage, educating consumers about better water habits and preventing or detecting leaks. Such devices can also expose their information to the local water utility company, which can then use these data points in their decision-making.

This paper is built on direct experience and research with Home Assistant, a free and open-source Internet of Things device management system, which allows for detailed statistics to be compiled at database level about water consumption, including the effects of optimizing daily usage.

The main method employed was a case study comparing household water consumption before and after sensors and valves were implemented, with 4 stages: 1 - no sensor info, 2 - with sensors but no changes made to habits, 3 - sensor info analysis, 4 - changes made to habits based on the previous analysis, 5 - before/after result comparison.

Key results included: 20% water consumption reduction after daily habit changes; broken pipe smartphone notification while residents were away, alongside automatic water closure to the household; detection of leaks which were too small to be visible at water meter level, but nevertheless existed.

Implications of the study for smart city practitioners are that even inexpensive water sensors and valves can significantly reduce water usage and prevent incidents, quickly paying for themselves and allowing for a more sustainable level of water consumption at city level.

The value of this paper is that it shows how a combination of off-the-shelf sensors and valves and free software can be used at household or even city level to bring intelligent water management to communities which might be suffering from the effects of climate change or other causes of water scarcity.

Keywords: *IoT, Water Management, Home Assistant*.

1. Introduction

The growth in the number of inhabitants of urban environments requires measures which can ensure needed energy, water and food. An urban area that allows sustainable economic growth and provides high quality of life in essential areas, such as the environment, mobility, the economy and governance, can be called a smart city.

A smart city needs the foundation provided by an infrastructure based on standards for Information Technology, this aspect supporting a large array of requirements and being adaptable to new technology, such as advanced Internet of Things sensors, analysis and measurement instruments and solutions led by machine learning and artificial intelligence (Camero, 2019; Costache et al, 2020).

Building a smart city is a gigantic task, because of the multiple structural issues and components involved. Building such an urban space from the ground up is difficult, albeit not impossible, as has been proven by cities like Songdo – Korea or Neom – Saudi Arabia (https://www.kpf.com/projects/new-songdo-city; https://www.neom.com/en-us/regions/ whatistheline).

Obviously, other, existing cities, which we may call "traditional cities" have also reached certain targets proposed by the concept of a smart city. Most of their achievements have had to do with transportation or carbon emissions management (Singapore, Dubai, Oslo, Copenhagen, etc.).

The current challenge is in transforming classic cities into smart cities.

Intelligent development of a city is a process which is constantly evolving, with transformations taking place at a slower or quicker pace depending on the volume of investment and legislation created in this sense. Standardization of measures and techniques being applied in development and increase of intelligence of component systems of cities can lead to their eventual interconnection (ISO/TR 37150:2014; ISO/TS 37151:2015).

The European Commission defines the concept of a smart city as "a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business. A smart city goes beyond the use of ICT for better resource use and less emissions. It means smarter urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings. It also means a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population" (https://ec.europa.eu/info/eu-regional-and-urban-development/topics/cities-and-urban-development/city-initiatives/smart-cities_en).

There are also alternatives to the “smart city” concept, such as the Japanese “smart community” (Japan Smart Community Alliance Smart Community Development - available online: https://www.smartjapan.org/english/). Analyzing the definition of this notion we realize that there are many similar points being made: “A smart community is a community where various next-generation technologies and advanced social systems are effectively integrated and utilized, including the efficient use of energy, utilization of heat and unused energy sources, improvement of local transportation systems and transformation of the everyday lives of citizens”.

As part of smart cities, smart water systems employ IoT-enabled sensors to collate real-time data. With precise and reliable data, smart water systems can drive great transformations in water sector transparency and accountability (https://www.hitachi.eu/en-gb/social-innovationstories/communities/smart-water-smart-cities; Hope et al., 2011).

Smart water metering refers to a system that measures water consumption or abstraction and communicates that information in an automated fashion for monitoring and billing purposes.

Smart meters differ from conventional meters in that they measure consumption in greater detail and transmit that information back to the service provider without the need for manual readings (Ng, K. S., et al., 2017).

Smart metering systems can be configured in many ways, and when broadly defined, the term includes both Automated Meter Reading (AMR) and Advanced Metering Infrastructure (AMI) systems. AMR refers to any system that allows automated collection of meter reads (usually by radio transmission), without the need for physical inspection. AMI is used to describe a system that involves two-way communication with a water meter. Smart water metering is experiencing strong growth throughout the industrialized world with annual growth projections varying between 8% and 13% until 2016 (Hope et al., 2011).

Most researchers present macro-structural approaches of the smart city and smart water concepts. Our research, however, wishes to highlight a micro approach, of one of the components of a smart water system.

Although water loss can be attributed to a variety of reasons, pipeline leakage is the main cause of world water loss, about 48.6 billion cubic meters (Thornton, R. Stunn and G. Kunkel, 2008).

Many studies have suggested automated intelligent methods to detect and predict leaks to reduce the workload of human detectors.

The chosen approach allows for a better understanding of the concept, as well as horizontal integration of the mechanisms needed for large-scale implementation. Not least, reducing water waste generates lower costs, protection of water resources and creates the premise for sustainable growth.

2. Methodology

This case study used a combination of open-source software (Home Assistant) and off-the-shelf hardware in order to create a water-monitoring and alerting solution that can be made available to any user, even though initial setup is relatively technical.

An important aspect, is that, although some IT technical knowledge is required, this approach can be implemented without requiring any structural changes to the home's water system.

2.1. Case study hardware setup

For this case study there were several aspects to be considered at hardware level:

1) Water consumption monitoring, which would enable data points that could be used for habit modification, as well as provide abnormal consumption information that could be used for detecting leaks that would not yet be considered an actual flood.

For this there are online providers of devices that clamp on to water meters (Figure 1), record the consumption and transmit it via Wi-Fi and an open API to a receiver. In this case, a Home Assistant server.

Fig. 1. Example Water Meter Monitoring Kit setup
Source: www.watermeterkit.nl

2) Leak detection in the case of sudden in-house pipe ruptures which could cause extensive damage to property.

For this use case Zigbee flood sensors are an effective solution, as the low-power Zigbee radio enables 12+ months of constant wireless operation with just one Li-Ion battery (Figure 2).

Fig. 2. Zigbee Flood Sensor
Source: www.xiaomi.com

They are also the lowest-cost sensors on the market, which would enable more of them to be placed within the household, depending on the number of areas which need to be protected.

Once the sensor detects water on the house or apartment floor, it can send a Telegram notification to the users, as well as initiate mitigation via an automation.

3) A flood mitigation system, which can be activated automatically via a flood sensor. The extent of this system depends on the number of areas in the household which would need to be protected. It can typically be installed either at each tap in the household, or just made to stop the water supply outside the household, thus shutting water off completely, regardless of the area in which the leak is occurring.

The system relies on a leak sensor, which starts a software automation in the Home Assistant server that can trigger a smart power plug, which can be set to turn on and thus shut off water via a 220V solenoid valve connected to the water pipe (Figure 3). This system is fully "local", which means that even with Internet access down, the automation will run and the solenoid valve (Figure 4) will protect the household from a leak (as long as electric power is still functioning).

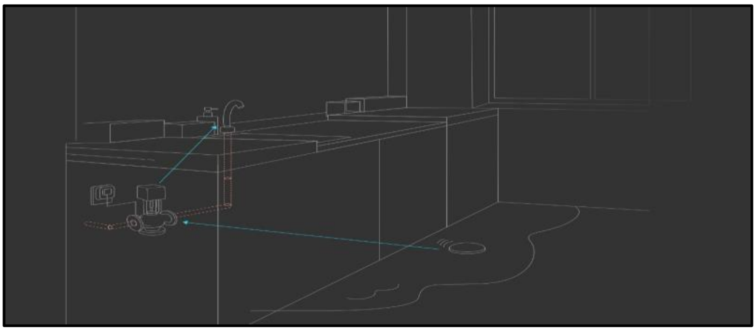

Fig. 3. Water leak detection system
Source: www.xiaomi.com

This approach eliminates two major drawbacks that such systems that are connected to the "cloud" have, namely that lack of Internet access can cause the automation not to run and that if the provider of the hardware has a business reason to turn off their cloud servers (such as a re-focus on other products or even bankruptcy), the system can still run indefinitely. Notifications of a leak sent to a user's phone are still dependent on the existence of household Internet access, though.

The smart plug can be connected via Zigbee radio, much like the leak sensor, but since constantly powered devices don't have the same low-power needs as battery-powered sensors, a Wi-Fi smart plug (Figure 5) can be considered as a more cost-effective device for such uses.

It would however add another point of failure to the system (the Wi-Fi router to which the plug would connect), so depending on the stability of Wi-Fi in the target household, Zigbee might be preferable.

Fig. 4. 220V solenoid valve for shutting off water supply
Source: www.fluid24.eu

Fig. 5. Wi-Fi Smart Plug
Source: www.xiaomi.com

4) The smart home server that acts as a controlling hub for all the other devices.

Home Assistant is open-source software that can run on everything from a low-power Raspberry Pi device to a virtual machine on a multi-purpose server, but for this case study the choice was made to use first-party hardware, the Home Assistant Yellow device (Figure 6).

Fig. 6. Home Assistant Yellow smart home server
Source: www.home-assistant.io

This choice allowed for maximum flexibility and cost-savings compared to a more traditional server setup, as the Zigbee radio module included on the motherboard can connect to Zigbee devices from any brand (as opposed to other such radios, like the one included in the Xiaomi Aqara gateway, which are limited to the manufacturer's own-brand devices).

The Home Assistant Yellow also features built-in support for the future Matter wireless standard, which promises to unite multiple disparate Internet of Things standards into a common one.

Also, the usage of a Raspberry Pi Compute Model 4 as the main processing hardware in the unit allows for future upgrades as new modules become available and household needs increase.

The presence of wired Gigabit Ethernet instead of Wi-Fi also ensures that the server is constantly connected to the home network and the Internet with minimum latency, which is a very desirable feature in a system that is supposed to send critical notifications to the users.

2.2. Case study software setup

In terms of software setup, the Home Assistant server has a custom Linux-based operating system, with many configurable options.

This allows for data to be collected from any sensor in the home and that data can trigger automations, which are coded in YAML. By using such a standard Markup language, automations can be shared between user communities, with only the affected sensor entities needing to be changed, as they pertain to each household's setup.

The code below is such an example, which takes the data from a flood sensor and sends the user a Telegram notification when the sensor indicates the presence of water (Figure 7):

```yaml
- alias: Small Bathroom Flooded Florin
  initial_state: 'on'
  trigger:
    platform: state
    entity_id: binary_sensor.small_bathroom_flood_sensor
    to: 'on'
  action:
  - delay:
      seconds: 7
  - service: notify.telegram_florin
    data:
      title: FLOOD
      message: Your small bathroom is being flooded!
```

Fig. 7. Setup for flood notifications to phone via Telegram
Source: Author's personal server

Sensor data can also be used for graphing purposes, showing trends that can be helpful for user habit modification, as well as abnormal longer-term usage which can highlight hidden problems with the water system.

3. Results

3.1. Water consumption results

After viewing real-time data about household water consumption, especially during water-intensive activities like showers, laundry & outdoor watering, a decision was made to limit this consumption, by:

- adding weather information to the Home Assistant server in order to prevent automatic outdoor watering on rainy days
- making sure the washing machine is always running at full load instead of performing more cycles (which also led to a decrease in power consumption)
- adding a bathroom smart speaker notification when showers exceeded a certain number of minutes

The results of this habit modification are presented in Table 1.

Table 1. Household water consumption for Q2 2021 (post-sensor install) & Q3 2021 (post-habit modification)

Month	04.2021	05.2021	06.2021	07.2021	08.2021	09.2021
Consumption (m^3)	10	11	11	9	9	8

Source: Author's personal household water consumption data

3.2. Disaster prevention results

During the case study period, the water measurement sensors set up at building and apartment level exposed two issues:

- Light water consumption at apartment level with all inside taps shut & central heating off, which was revealed to be caused by an in-wall pipe which had burst and was slowly leaking water into the wall (also leading to the appearance of mold in a non-directly visible part of the apartment).
- Heavy water consumption at building level, which was due to a crack in the main underground pipe leading to the building (Figure 9). Because this issue was between the outdoor water source and the apartment water meters, it would have been undetectable at apartment water meter level, as the soil was absorbing all the excess water. It was however detected by the outdoor water meter sensor, which showed abnormally high water consumption via the daily history graph in Home Assistant, thus enabling rapid fixing of the problem.

Fig. 8. Outdoor main building water pipe rupture
Source: Author's personal household

4. Discussions

4.1 Applicability

The water pipeline leakage detection device is able to monitor the water pipeline 24/7 without the presence of a human leak detector.

The relative low cost (starting at 250 EUR and increasing depending on the number of areas which need to be monitored) of the system in the case study can allow for scaling at neighborhood or even city level. Compared with other leak analysis methods such as the μPAD system for colorimetry, it is technically simple to implement (Zodidi G. et al., 2011).

The presence of an open API also allows for the data to be shared to interested parties, although privacy considerations do need to be made. For example, Mashford et al. uses the Support Vector Machine (SVM) to classify the data in the EPANET hydraulic modeling system to improve water leak prediction (J. Mashford, et al., 2009). Leu et al. used the Bayesian learning process to optimize the water leak prediction accuracy (S. Leu and Q. Bui, 2016.).

4.2. Limitations of case study

This case study was performed on a single household & multiple-apartment building, with a constant power supply and reliable Internet.

In areas where either power or Internet access (or both) are intermittent, for maximum reliability of the system there would need to be further investment in hardware like an uninterruptible power supply for the server and a failover Internet connection via the mobile network. This would ensure that even in the event of a power or Internet outage, the user would at least get a notification of the problem.

5. Conclusions

Leaks in water pipes are a major problem of many cities at present. Not only do they waste valuable natural resources, they also create huge economic losses.

The main conclusion that can be drawn from the case study is that, with minimum investment, not only can flooding disasters be prevented, but water consumption can be significantly decreased without noticeable effects on quality of life or major changes in lifestyle.

Decreases of 20-28% in household water consumption as recorded here would have huge effects at global level and cities like Las Vegas or Cape Town have shown that, when dealing with water scarcity, even heavy-consuming users can be helped and convinced to change habits and use water in more efficient ways.

Sensor data can also be provided via an open API to water utility companies, which can use this information to forecast trends in water consumption, as well as take action if multiple consecutive days of unusual consumption are detected, which would be an indicator that the user is not present during an incident and should trigger a valve shut-off by the water utility company.

Overall, such systems are already under increasing use, with even DIY solutions like Home Assistant featuring more than 500.000 users across most countries worldwide.

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