Monitoring city water incidents via an Internet of Things-based sensor network

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Abstract

This research aims to prove that an inexpensive Internet of Things-based sensor network can be used to deliver information about current ground-level humidity & soil conductivity, as well as notifications about sudden changes in these measures, which would indicate flooding or soil erosion. The platform uses an open API, which can be accessed by both utility companies and NGOs and be a part of their decision-making process. This paper builds on previous research with water & electricity management in the free and open-source platform Home Assistant, which can be used in conjunction with a time series database such as InfluxDB & a visualization platform like Grafana to highlight sudden pattern changes in humidity and soil conductivity and notify interested parties via Telegram or any other such real-time alerting platforms. A case study was made, which set up an inexpensive combination of Bluetooth Low Energy sensors with Raspberry Pi local servers that transmitted their data to a central database. Data was collected both outdoors with results of normal rainfall, as well as in a lab environment with simulated flooding and soil movement caused by it. Results showed that sudden changes in humidity and soil conductivity correctly triggered real-time notifications via Telegram and that a backup battery and 4G internet connection for the local servers could mitigate the effects of potential blackouts and loss of internet access caused by severe weather events. Implications of the study for smart city practitioners are that authorities can be quickly notified of severe water & soil-related events so that measures can be taken, while long-term analytics can be used to predict (perhaps via an AI machine-learning model) when and where such events are most likely to occur in the future. The value of this paper is that it shows how a combination of open-source software and inexpensive sensors & servers can be used at city level (especially in developing cities which do not have major infrastructure in this sense) to combat the effects of climate change and both react to and predict severe water & soil issues.

Keywords: IoT, Water Incidents, Grafana.

1. Introduction

Due to population growth and climate change, it has become an ever more important requirement to create smart, resilient cities that are well-prepared to deal with natural and man-made water and soil incidents.

Whereas in the past such analyses were the domain of complex infrastructure such as the Sentinel-1/2 satellites [1], nowadays local problems can be identified and acted upon with much more readily available hardware and software, due to the proliferation of inexpensive Internet of Things devices [2] and their easy scalability to cover large areas or numerous communities.

Such devices can be used for round-the-clock monitoring of key areas in the city, which are either prone to flooding or located near sensitive infrastructure or densely populated regions.

Custom soil humidity and conductivity monitoring sensors for specific projects were not overly complex to create in the past [3], but mass production of such sensors by companies like Xiaomi has enabled standardization and ever lower costs.

Meanwhile, an easily accessible open-source API for integration with centralized monitoring nodes (such as the one provided by Home Assistant) has allowed these systems to communicate more efficiently amongst each other and with other relevant parties, including interested members of the public or NGOs.

Sustainability is a key component of any smart city architecture [4] and legislation must take into account the social and infrastructure realities of the implementation space.
Thus, the lower the barrier to entry for such monitoring and analytics systems, the wider their scope can become, while communities which did not have access to their benefits before can quickly have such systems up and running, with minimal maintenance costs in future years.

Given that water scarcity is projected to affect 50% of urban dwellers by the year 2050 [5], it is more important than ever to properly manage the water cycle in large urban areas, which are also being affected by developments that increase land cover, thus not allowing natural soil permeability to be used properly and creating the potential for flash-flooding.
Smart water systems are considered to be one of the main drivers of smart city development [6] and incident monitoring and notifications are the logical endpoint of any public water management program.

2. Methodology

This case study used a combination of open-source software (Grafana, Home Assistant, InfluxDB), a commercial but free notification system (Telegram, also used for earthquake notifications for the general public by the Romanian National Institute for Earth Physics) and off-the-shelf hardware (a Raspberry Pi 4 server in a rugged case, Mi Flora Bluetooth Low Energy sensors, a ZTE MF833 4G USB modem and a VARTA Fast Energy backup power bank).

While initial setup is quite technical, post-implementation maintenance needs are low.

2.1. Case Study Hardware Setup

The sensors used for this case study are the Mi Flora Bluetooth Low Energy sensors from Xiaomi (Fig. 1), which provide soil moisture, soil nutrient, temperature and light monitoring.

The sensor also has an IPX-5 rating, which translates as being protected from a low-pressure water stream from any angle. Depending on the needs of its placement, more rugged models can be used, but this particular model provides good value and can work for a year before its battery needs to be replaced.

There is also the option of creating purpose-built sensors with boards like the ESP32 and associated software such as ESPHome.

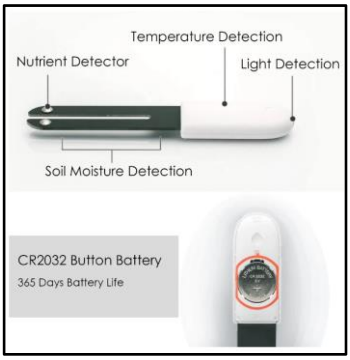

Fig. 1. Xiaomi Mi Flora sensor
Source: www.aliexpress.com

The Raspberry Pi 4 single-board-computer (Fig. 2) can be used as a local server for monitored points in the city, connecting via Bluetooth Low Energy to Mi Flora sensors up to 15m away and via WiFi or 4G to the wider Internet.

Other single-board computers can also be used for such purposes, but the Raspberry Pi 4 is unique in its level of software support and computing power available for its price, despite current supply chain issues which have limited its availability.

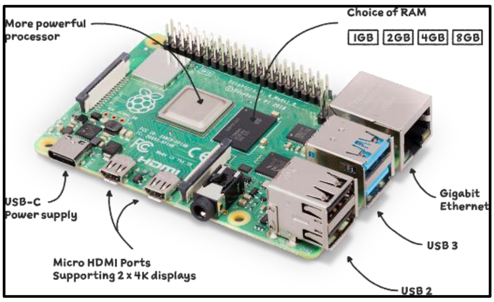

Fig. 2. Raspberry Pi 4 board layout
Source: www.raspberrypi.com

The case selected for the Raspberry Pi was an aluminum model from Flirc (Fig. 3), which provides shock protection as well as passive cooling (with no moving parts like fans, which can break in time).

Fig. 3. Raspberry Pi case
Source: www.flirc.tv

In the event of a loss of power or WiFi Internet access, the Raspberry Pi was outfitted with a 4G USB internet stick from ZTE & a 20000mAh backup power bank (Fig. 4), capable of providing the 5V/3A output required by the Pi.

The power bank can be used as a passthrough device and in the event of a power loss can keep the Raspberry Pi running for 12 hours or even more, depending on the performance load.

Fig. 4. Raspberry Pi backup Internet & power
Source: www.aliexpress.com & www.varta-ag.com

2.2. Case Study Software Setup

In terms of software setup, the sensors use the Home Assistant Bluetooth communications stack and Xiaomi integration to connect to the Raspberry Pi, which acts as a bridge device to the wider Internet.

The Raspberry Pi devices run Home Assistant OS (based on Linux) and each of the nodes can either stream their data to a centralized InfluxDB instance or, if power and traffic demands are such that this is impractical, the historical data can be sent in batches at less frequent intervals (every hour, or daily), with only emergency notifications having real-time priority.

The notifications can be automated to instantly transmit any of the sensor data attached to the Telegram notification message if certain thresholds are reached and there is also the possibility to have actionable notifications, which would allow authorities to deploy a one-click mitigation for certain issues.

For example, in the code in Fig. 5 the sensor is set to detect changes of greater than 10% in 10 samples over 5 minutes and, if this is the case, a notification is immediately sent to the operators notifying of a flood in that sensor's area. These parameters can be tweaked, in order not to generate false-positive notifications.

Further customization can be done to the notification text, which would map sensors to specific areas and make the notification more user-friendly, i.e. by mapping Soil Sensor 1 to the street it is on and sending a notification of the form "Flooding is occurring on _____ Street"

```
#Template for monitoring sudden shifts in Soil Humidity Sensor #1

  - platform: soil_humidity
    sensors:
      soil_humidity_1:
        max_samples: 10
        entity_id: sensor.soil_humidity_1
        sample_duration: 300
        min_gradient: 0.033333

#Notification after flood detection

alias: Soil Sensor 1 Flood
initial_state: "on"
trigger:
  - platform: state
    entity_id: sensor.soil_humidity_1
    to: "on"
action:
  - service: notify.telegram_operator
    data:
      title:
      message: Flooding is occurring in the area of Soil Sensor 1
```

Fig. 5. Sample code for detection of sudden humidity shifts and sending a notification
Source: author's testing

3. Results

3.1. Water incident monitoring results

As can be seen in Fig. 6 (which has been exported from a 6-month Grafana dashboard of one of the sensors), the highlighted sudden increase in soil humidity from less than 40% to more than 60% when flooding was simulated is an easy indicator of an incident which can trigger a notification.

By comparison, in the last third of the graph one can notice the much more gradual increase in humidity caused by autumn rains over a longer period of time, which would not trigger notifications.

Fig. 6. Flooding incident as registered in Grafana
Source: author's testing

3.2. Soil conductivity monitoring results

The electrolytic conductivity in the soil that is measured by the Mi Flora sensor is another interesting indicator of the effects of water and other factors and can be combined with soil type data to extrapolate salinity issues (Fig. 7).

This is an especially important factor given the modern salinization dangers to soil fertility and the costs involved in artificial fertilization.

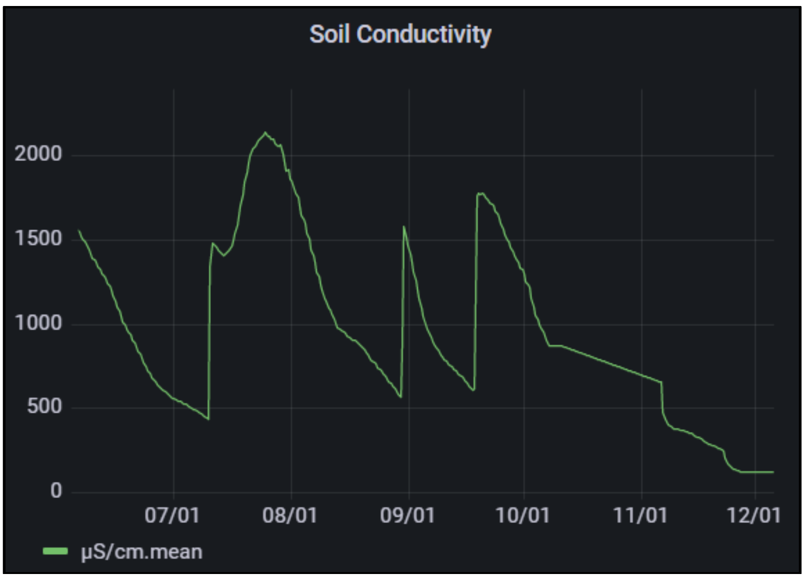

Fig. 7. Soil conductivity trends as registered in Grafana
Source: author's testing

4. Discussions

4.1 Applicability

The sensor network is able to monitor various locations within a city 24/7 and can automatically send notifications either via Telegram or through an accessible web socket to relevant emergency service human operators or APIs.

If other city service APIs are integrated with this network, automatic triggers can be created to enable the opening of runoff channels or the notification of nearby residents via the emergency SMS broadcast system. NGOs can also use the API information to create their own applications that make use of the provided data.

The cost of one entire monitoring node is less than 200 EUR (with one sensor, but it can accommodate multiple sensors within a 15-meter range), so scaling up such an infrastructure can be done in a very cost-effective manner.

Meanwhile, being in the coverage area of city-provided WiFi or at least a 4G mobile data connection negates the need for any hard-wired dedicated infrastructure except for an electricity source.

The low power consumption of the Raspberry Pi also means that it can be permanently connected to a solar power source, which would make it more useful in remote or low-infrastructure areas.

4.2. Limitations of case study

This case study was performed on a sample city street in Bucharest, Romania with both exterior and lab conditions, with reliability tested on wired, WiFi and 4G networks, as well as with failover to 4G & portable power after simulated power grid & wired Internet access failures.

Charging the emergency battery power supply with a portable 10W solar panel was also attempted, which had satisfactory results in an environment with either enough daily sun or less than 12 hours of continuous power outage, although both of these limitations can be overcome with the added cost of a more powerful solar panel system and/or larger battery pack.

5. Conclusions

Flash-flooding, soil erosion & salinization are major problems for both cities and outlying areas at present. They endanger the fresh water supply, damage buildings and infrastructure and increase upkeep costs for urban green areas.

The case study has shown that with low cost and a high level of scalability, an IoT-based soil humidity & conductivity sensor network can immediately alert authorities of emergency events, as well as show trends over time which can then be included in a Machine Learning model for predictive analysis.

In the past year, usage of Home Assistant has risen from 500.000 to nearly 700.000 worldwide operators, with easily retainable long-term statistics for water, power & gas constituting one of its main drivers of growth. As a platform for both off-the-shelf and custom sensors, it can enable amateur and professional operators to gain access to real-time information and act upon it, either automatically or on demand.

Especially for developing areas, such early warning or proactive solutions can be the difference between an easily controllable incident and a large-scale problem which would require a much more complex reactive solution.

The experimental results have demonstrated that even a minimal implementation of such a sensor network can quickly reap benefits for the communities being monitored, thus achieving the objectives of the study.

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