An IoT system for monitoring and data collection of residential water end-use consumption

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***Abstract*—The paper presents a hardware/software platform that integrates IoT technologies for deploying a smart water network in a domestic environment. Low cost sensors and edge nodes have been deployed in a real pilot for monitoring water fixture use. A data collection platform, which can run in the Fog or in Cloud, allows for processing of raw data and monitoring. It makes available raw and intermediate data to offload the computation of complex Big Data analytic. The paper presents preliminary results according to the data available after two months of operation.**

***Index Terms*—Internet of Things, water end-use consumption, smart water meters, domestic water supply, edge analytic, edge data platform.**

I. Introduction

The spread of Internet of Things (IoT) and Cloud has brought opportunities for innovation in many application domains. IoT technologies and applications (i.e. IoT sensors, devices, systems and services) continuously generate Big Data (BD) that needed to be stored, analyzed and processed. They represent sources of information which can be exploited to develop context aware intelligent services.

Critical infrastructures are also being integrated with the IoT-cloud services in relevant domains, such as smart health, smart cities [1], [2], smart energy [3], where the technology readiness level of system and applications is already high.

On the other hand, in the field of smart water distribution networks the application of IoT technology is still backlog [4].

Just in the last years the progresses in metering and data communications technology has promoted the use of high-resolution smart water meters (SWM) [5], [6]. Water utilities are starting to install these devices in order to read, in real time or in close real time, water consumption, which was typically recorded manually on a quarterly or half-yearly basis.

The possibility to record household water usage data through SWM represents a new approach to support decision making processes with direct innovative implication on: water distribution network modelling, demand forecasting, leak detection, water monitoring, energy management, water savings, awareness campaigns, utility-customer relationship, etc.. Nevertheless, household meter level is not enough to reach a detailed understanding about *how* water is used. In fact, information of water fixtures use is needed (i.e. water use for shower, toilet, tap, etc.), so end-user measurement studies are becoming crucial for utilities water demand management and planning [7].

To this day, due to the lack of low cost and non-intrusive sensing infrastructure, SWM are installed at the water mains providing aggregate BD of water usage that need to be disaggregate in order to obtain single end-use categories [8]. Disaggregation requires punctual and high-resolution data in order to apply machine-learning techniques, as reported in [9]. At the state of art there are neither relevant experiences of metering, nor significance open data repository to investigate and validate innovative solutions for disaggregation. To this purpose, we have developed and deployed an IoT water end use monitoring system able to read real time water end-use consumption in a residential apartment. In this paper, it is presented a low-cost, not invasive and flexible IoT based sensing and monitoring system. It has been deployed in a residential apartment, where the SWM assembled have been installed on the domestic fixtures in order to detect individual water usage.

The deployment of an edge data collection platform for metering water consumption of fixtures is new in the scientific community, where water end use consumption are generally available as global values. We think it can leverage the development of original disaggregation techniques, but also can foster the development of innovative solutions which allow for a fine grain monitoring and control of water consumption.

Finally, the pilot site can be productively used also to study the so called water-energy nexus.

II. Related work

In the era of smart technologies, automated metering and monitoring system, the use of IoT solutions is becoming viral. IoT technologies for data collection in home applications are already available in the marked to the end user. The commercial solutions usually integrate low cost sensors and micro-controllers and are available to sense environmental parameters, energy consumption or allow for the remote control of user's appliances.

In the field of water, water end-use consumption analysis enable water utilities to improve their decision support system for a smart management of water distribution network and a new customers approach. However, the lack of water sub-meters or water sensor installed on house fixtures promote the

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use of non-intrusive techniques and approaches, as reported in [7], [10].

One of the most used non-intrusive techniques is disaggregation that allows for understanding how much of household water consumption belong to a single fixture in the house. It was applied in several water end-use study: Aquacraft, Trace Wizard, Hydrosense, Watersense, WaterNILM, etc., as reported, with more details in [11]–[13]. The cited application used seminal papers, consumer feedback, motion detectors and flow rate estimation to obtain trough household water disaggregation measurement of flow rate, pressure and vibration.

Moreover, the interest for water end-use consumption is related also to the identification of day and peak demand patterns to increase water service infrastructure modelling and resource-efficient initiatives to mitigate impact on climate changes, as reported in [14]. In fact, according to [15] and to [16], demand management is also correlated to energy due to digital transformation technologies that combine electricity and water BD in residential environment defining the so called water-energy nexus.

Furthermore, as reported in [17], [18] and in [19], the limit of privacy issue, cost and intrusiveness of end-use meters, highlight the necessity to produce reliable and realistic synthetic data, so appeared in the scientific communities several methodology for synthetic household and end-use data generation.

To address these issues, this paper presents an IoT solution for monitoring in real time residential water end-use consumption. It has been developed to collect significant BD, and for experimenting smart techniques aiming at the optimization of the domestic water supply and consumption.

III. Water end-user consumption monitoring and analysis

The usage of water resources at end-user level represents the way to understand how and where water is used in domestic environments [20]. The definition of users' behaviour can offer to water utilities a chance to improve water service and customer awareness.

Actually, traditional water meters detect water usage at household level and do not provide real-time water end-use consumption data able to understand users behaviours and support water utilities in a smart management of distribution systems. Despite automated meter reading innovations, SWM are not able to read fixtures level uses due to high cost and time consuming installations. Along with the recent advancement of smart technology emerge the need of monitoring and analyze water usage habits.

The main requirements pursue are linked to the necessity of obtaining a database of disaggregate end-use consumption that could be used for further analysis in order to correlate aggregate and disaggregate data.

To this purpose, it is needed to obtain water flow measure at each consuming end points able to transmit real-time BD with high resolution rate. As reported in [21], data resolution can impact on end-use disaggregation, leak detection and peak demand evaluation so, increasing data sampling resolution, at seconds rate, decrease disaggregation errors and provide more detailed information on network status and users' behaviours.

Moreover, the possibility of an on-line data monitoring system allows a timely detection of problems and improve decision-making. In addition, the presence of a centralized repository for remote BD analysis allows the application of descriptive and predictive models for water users' consumption behaviours and water demand forecasting [22].

IV. Architecture design and implementation

The conceptual architecture of the IoT water end-use monitoring system presented is shown in Fig. 1. It is composed of three main elements: a flowsensor, a micro-controller and Content Management System (CMS), which implements a data collection platform and integrates simple processing and visualization capabilities. The CMS can be deployed at the edge, in the user's household or in the Cloud, where it can handle data of different users.

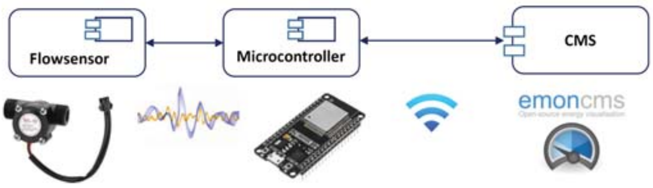

Fig. 1. Conceptual architecture of the IoT system.

The water flow sensor (WFS) used for the IoT node is the YF-S201. The choice of this device is related to cost and simplicity of use. Flow sensor YF-S201 sits in line with the water line and contains a pinwheel sensor to measure the quantity of water passing through it. There is an integrated magnetic Hall-Effect sensor that outputs an electrical pulse with every revolution. By counting the pulses from the output of the sensor, it is possible to calculate water flow (each pulse is approximately 2.25 millilitres).

The WFS comes with three wires: Red/VCC (5-24V DC Input), Black/GND (0V) and Yellow/OUT (Pulse Output) used to interface the sensor to any micro-controller. The micro-controller used for the IoT solution is the ESP 32 a low-power system on a chip (SoC) series with both Wi-Fi and Bluetooth communication interfaces. The ESP32 has been programmed to read the output pulses coming from the WFS and to upload the water flow to the CMS. An interrupt service routine is used to count the WMS pulses in time slot of 1 second. When the water flow is 0 for more than 5 seconds the micro-controller switches to stand-by mode and wakes up at the next pulse.

The CMS used for the IoT solution is EmonCMS [1], a flexible, open-source and user-friendly platform for collecting, visualizing monitored data and remote controlling of devices.

In the current deployment, water end-use consumption BD are detected real-time, processed and uploaded to a remote

[1] http://www.emoncms.org

server via HTTP. Each metering node is directly connected to the Internet through the Wi-Fi home gateway.

V. Case Study

To set up case study the system has been installed in a residential apartment located in Naples, a city in the South of Italy. The flat is inhabited by only one person and is equipped whit seven fixtures: washbasin, bidet, shower, kitchen faucet, dishwasher, washing machine, flush toilet.

In order to monitor all water end-use consumption different solutions have been selected. They are summarized in Tab. I. It specifies if a direct measure of water usage is set up and the method identified for the measurements.

TABLE I
List of fixtures and methods of measurement.

End points	*Measured Yes/No*	*Methods*
Washbasin	✓	SWM
Bidet	✓	SWM
Shower	✓	SWM
Kitchen faucet	✓	SWM
Flush toilet	x	App HTTP request shortcuts
Dishwasher	x	App HTTP request shortcuts
Washing machine	✓	SWMs

SWMs have been installed and programmed to collect high-resolution data on washbasin, bidet, shower and kitchen faucet at recording intervals of 1 seconds under operating condition and 5 seconds in case of no-use, as reported in Fig. 2.

Each SWM is identified on EmonCMS platform as a Key node able to detect water flow in milliliters per second. Each sample is processed by a pipeline of computations which store the intermediate results. In particular, we store the raw input, the total volume and the daily use of water resource. Data collected are visualized in real time on EmonCMS platform and stored as time-series in EmonCMS objects called feed.

In Fig. 3 is reported an example of the EmonCMS screen for input view and feed list of washbasin SWM.

Fig. 2. Example of SWM installation on washbasin and bidet.

For flush toilet and dishwasher, due to positional constraints, it was impossible to install the SWM. So, to register water consumption of the flush toilet the user is asked to push

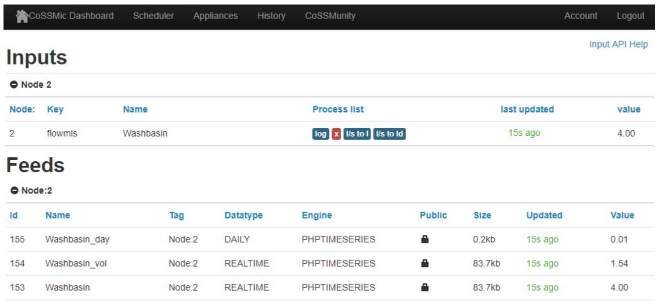

Fig. 3. EmonCMS input view and feed list for washbasin SWM.

a button on its smartphone. An open source app has been configured to send to EmonCMS flush toilet cistern capacity value and dishwasher water use per cycle. The app allows for defining buttons shortcut to invoke HTTP hyperlinks.

To evaluate the correlation between water and energy consumption of the washing machine, an energy smart-meter has been also installed. It is a Sonoff, a Wi-Fi wireless smart switch that can measure and communicate electricity consumption. The Sonoff smart meter integrates an ESP8266 micro-controller. We replaced the original firmware with the open source Espurna software[2]. Power consumption and cumulative energy consumption are transferred via the MQTT protocol to the same EmonCMS platform and stored for future analysis on this matter. In fact, as reported in [23], water-energy nexus can provide opportunity to form digital multi-utility service, reduce household water and energy consumption, promote a sustainable management and users' awareness.

The case study aimed also to obtain feedback from water users about the system and consumption. In this case, the user evaluates the system non-intrusive and easy to manage, moreover, affirms that the knowledge of fixtures daily consumption related to specific uses (shower, tooth brushing, etc.) generate more attention on water use and waste.

VI. Preliminary results

The configuration of IoT solutions for all fixture present in the residential apartment, used as pilot site, started in February 2019. Beginning from 1th March 2019 data metered at the end-use level at 1 second resolution are collected and stored by the EmonCMS platform.

Data collected are still poor and sometimes data are missing due to system failures that need to be investigated and improved. In fact, total water use obtained by adding fixtures consumption generates a 5% of error in defining global use value. The total water consumption was computed ”manually” on traditional very old household water meter that could be not calibrated. Anyway, in next weeks an innovative household smart meter will be installed.

Nevertheless, the preliminary measures enable first consideration on the method and on end-use measurements. Even if

[2]https://github.com/xoseperez/espurna/wiki/Hardware

data collection is still an on going activity, a preliminary analysis of data gathered already enables some initial evaluations.

For each end points it is possible to estimate instantaneous, daily and total end-use consumption as reported in Fig. 4, Fig. 5 and Fig. 6 with reference to washbasin use. Furthermore, some outputs of first end-use measurements analysis can be reported as:

- Percentage of water consumption at fixtures for one month of measurements. Fig. 7 shows that main consumption, during the measurement period, are related to shower and kitchen whit 30 and 33% of total use.
- Min, Max and Mean of daily volume consumption detected at fixture for one month of measurements, as reported in Tab. II. Data detection shows daily medium water consumption per person around 0.14 m^3. This value is in line with the italian daily water consumption census by the Italian National Institute of Statistics ISTAT [3] equal to 0.16m^3 (value of last census taken in the year 2015). In particular, in the case study the value of 0.14 m^3 does not take into account dishwasher and washing machine because, for just one month of measurement in the case study of 1 inhabitant, it is still not significant since it is related to few single events. Dishwasher and washing machine contributions will be considered in future work when will be available further measured data.
- Variation of daily water consumption during a week divided for fixtures. Fig. 8 shows heterogeneity of fixtures' consumption except for washbasin and bidet whose consumption is quite similar.
- Min, Max and Mean of water flow at fixtures for one month of measurements, show the measured peak of water use as reported in Tab. III. Observed data show that also water flow peak consumption for washbasin and bidet report similar values.

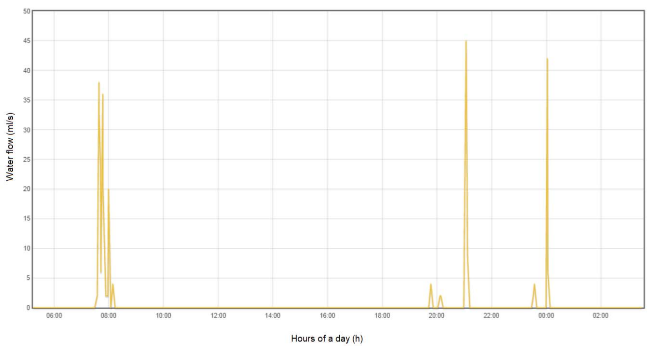

Fig. 4. Water flow detection during one day of use of washbasin.

The pilot site, whit 1 inhabitants and infrequent overlap of fixture use, may seems not a representative sample, on the other hand it is flexible and could make possible a classification of single-use events into the various water end-use categories generating overlapped uses easy to manage.

[3]http://dati.istat.it/

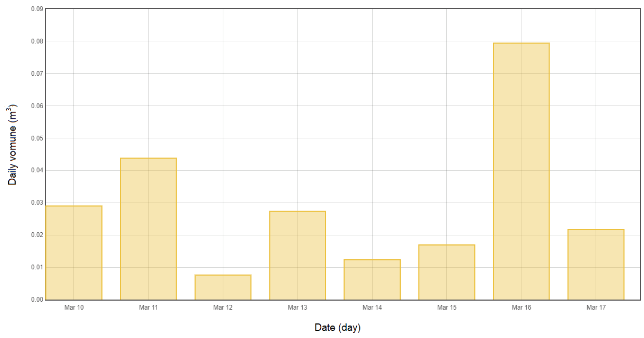

Fig. 5. Washbasin daily use from 10th to 17th March 2019.

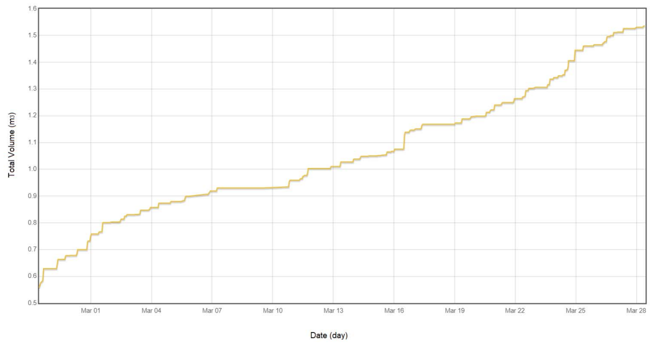

Fig. 6. Washbasin total volume from 1th to 28th March 2019.

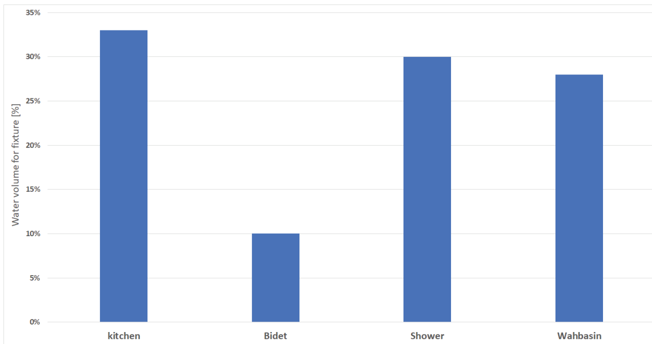

Fig. 7. Sample of percentage of total volume used for different fixture from 1th to 28th March 2019.

TABLE II
MIN, MAX AND MEAN DETECTED FOR DAILY WATER CONSUMPTION.

Daily volume			
Fixtures	***Mean [m^3]***	***Min [m^3]***	***Max [m^3]***
Washbasin	0.0321	0.010	0.100
Bidet	0.0176	0.004	0.038
Shower	0.0477	0.020	0.080
Kitchen faucet	0.0519	0.020	0.180
Flush toilet	0.0140	0.005	0.030

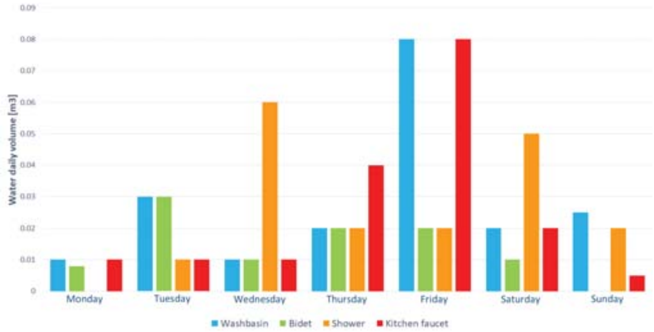

Fig. 8. Sample of water daily volume detected for different fixtures during a week.

TABLE III
MIN, MAX AND MEAN DETECTED FOR WATER FLOW.

	Water flow		
Fixtures	***Mean [ml/s]***	***Min [ml/s]***	***Max [ml/s]***
Washbasin	40	20	65
Bidet	38	22	63
Shower	64	32	96
Kitchen faucet	9	4	27

Fig. 9 shows an example of generated overlapping use between washbasin and bidet for 10 seconds of use.

Moreover, the possibility to have disaggregate water end-use consumption is crucial to apply disaggregation algorithm in order to define a correlation between single and global household water usage and define users' behaviours.

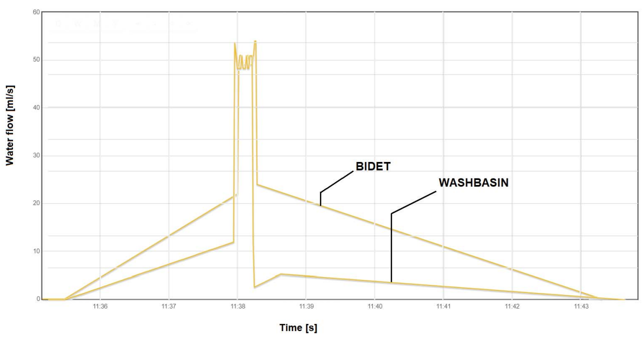

Fig. 9. Sample of overlap between washbasin and bidet use.

VII. CONCLUSIONS

The paper presented a flexible IoT based sensing and monitoring systems to detect water end-use consumption in residential apartment. The designed architecture can automatically detect, collect and store high-resolution water end-use consumption data in real time.

The main aim of this paper was to present the preliminary results of case study in order to show SWM installation on house fixtures, test IoT solutions for real time data monitoring in a residential apartment, calibrate BD collection and improve the whole system considering, specifically: installation problems, intrusiveness of system during daily use, data transmission problems, accuracy and sensitivity of measurements, etc.

This novel approach, based on real water end-use consumption brings advantages from both water utility and customers side. On water utility's side it can improve smart water management, demand forecasting, leak detection, decision making, water efficiency savings, energy saving utility-customer relationship, on customer's side it can improve users' awareness, sustainable behaviour, leak detection and personalized billing profiles. Furthermore, in broader scenarios the approach presented can essentially enhance:

- the definition and use of innovative hydraulic and economic performance indices,
- the prediction of more detailed district water balance,
- the performance of water systems through real-time pressure monitoring and management,
- the planning of ordinary and extraordinary maintenance services,
- etc.

Furthermore, the same approach could be extended integrating in the same software platform the monitoring and management of other kind of information, such as the utilization of electric appliances (heat pumps, air conditioners, water heating, etc.), the power production from renewable sources (e.g. photovoltaic panels) and environmental parameters. These data could be exploited independently or all together learning how it is possible to accomplish the users' activities optimizing the usage of utilities and renewable resources.

Monitoring and BD collection of water end-use consumption, also, allow profiling customer behaviours offering possibilities for a more detailed prediction of water demand pattern of consumption strictly related with the more general matter of water scarcity.

Moreover, thanks to water utilities smart revolution that promote the installation of SWM on their distribution network, starting from household data it is easier to identify a correlation able to predict water demand pattern, based on real water end-use data, useful in case of water crisis.

Therefore, the use of real water end-use data, collected real time for home fixtures, can open new field on disaggregation techniques, demand-side management and smart water network monitoring.

The application of the IoT solution to residential apartment whit 1 inhabitant allowed to better understand limitation of the method that can be improved for the application in different and more complex pilot site. Data collection at case study is still on going, but further development are provided. The future work planned is to collect data for almost 1 year also improving energy data collection at end-use level to work both on water end-use detection and water-energy nexus.

Starting from an apartment inhabited by one person, in the near future, the plan is to apply the IoT monitoring system developed to different residential apartment, whit different number of inhabitants, to test the IoT solution in a more complex configuration and work on customers behaviour to identify consumers profiles.

Even if data detection need to be improved because the application is still at beginning, the case study offered the possibility to apply disaggregation algorithm on real water end-use data in order to identify a correlation between household and end-use data and water-energy nexus.

Disaggregation of household water consumption to its end-use elements can identify how, where and when, water is used by users in their homes, allowing an innovative approach to water demand-side management.

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