RnMonitor: An IoT-Enabled Platform for Radon Risk Management in Public Buildings

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Abstract. Radon is a naturally occurring radioactive gas that can easily accumulate in indoor environments, being classified by the World Health Organization (WHO) as the second most important cause of lung cancer after tobacco, negatively impacting public health. The presence of this gas indoors tends to increase in regions were the subsoil presents a higher granitic prevalence, such as the northern and central interior regions of Portugal. The paper introduces RnMonitor, a Cyber-Physical System (CPS) with humans-in-the-loop specifically designed for online monitoring and active mitigation of radon risk in public buildings. The system takes advantage of an IoT device specifically designed to acquire radon concentration and other relevant Indoor Air Quality (IAQ) and consequently transmit the collected data, using a low-power wide-area network (LPWAN), to a cloud-engine for reasoning and therefore trigger specific mitigation actions, e.g. manual ventilation.

Keywords: Cyber-Physical Systems · IoT · Radon

1 Introduction

Radon is a naturally occurring radioactive gas classified by the World Health Organization (WHO) as the second most important cause of lung cancer after tobacco [1,2]. Its presence tends to increase in regions where the subsoil has granitic prevalence, such as the northern and central interior regions of Portugal. In poorly ventilated indoor environments it can easily accumulate, which negatively impacts the Indoor Air Quality (IAQ). Recently, several studies have been carried out in the Minho region, northwest of Portugal, and evidences that the Portuguese Legal limit was being largely exceeded, have been found in several samples, cf. [3–6]. In order to mitigate the associated human exposure risk, the design and development of the RnMonitor platform, hereby presented,

H. Santos et al. (Eds.): SmartCity 360 2019, LNICST 323, pp. 49–55, 2020.
https://doi.org/10.1007/978-3-030-51005-3_6

was put forward in late 2017 with the main goal of designing a Cyber-Physical System (CPS) with humans-in-the-loop to enable online monitoring and active mitigation of radon risk in public buildings. The developed system includes an IoT edge device specifically designed to collect several IAQ parameters and a LoRaWAN radio link to transmit the data to a cloud-engine for reasoning and to trigger specific mitigation actions.

2 Architecture Design and Implementation

The RnMonitor system's conceptual design can be inferred through the observation of Fig. 1. The figure depicts the three main blocks along with one use case example that includes buildings with regular human occupation. The RnMonitor platform is composed of three main building blocks: 1) IoT Edge Devices and LoRaWAN, 2) Cloud/Analytics Engine and 3) Client App/Dashboard, that will be described in more detail in the following subsections.

Conceptually, the proposed system takes advantage of IoT-based devices installed in several rooms of distinct buildings. These IoT-based devices were designed to measure, not only, the radon gas concentration, but also, other relevant IAQ parameters, such as CO_2, temperature, relative humidity and atmospheric pressure.

In the illustrated use case example, several rooms in distinct buildings are equipped with IoT-based devices that include long range and low power connectivity by means of using the LoRaWAN communications network technology. This use case contains three main events:

- **Event 1)** a specific room of Building 2 has been identified with a poor indoor air quality for a given occupation profile in a specific time interval;
- **Event 2)** following Event 1, and based on the overall building management context, the analytics engine dispatches an alarm notification to the Building Administrator;
- **Event 3)** since Building 3 has no HVAC and no active ventilation system installed, a manual ventilation action is carried out by the building administrator.

2.1 IoT Edge Devices and LoRaWAN

The IoT edge device is shown in Fig. 2a, having been designed to measure IAQ parameters, such as CO_2, temperature, relative humidity, atmospheric pressure and radon gas concentrations, cf. [7,8]. Connectivity is made available through LoRa, a Sub-GHz technology that can be used with the LoRaWAN stack to enable long range and low power networking. Moreover, by using LoRaWAN we are not depending on local and specific infrastructures, such as Wi-Fi or Ethernet, that due to security issues are normally closed for third party applications. Figure 2b illustrates estimated LoRaWAN coverage in Viana do Castelo, the city where this technology demonstrator is being put forward.

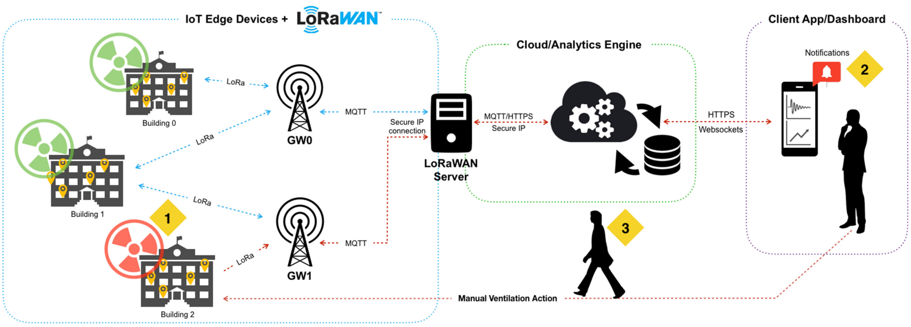
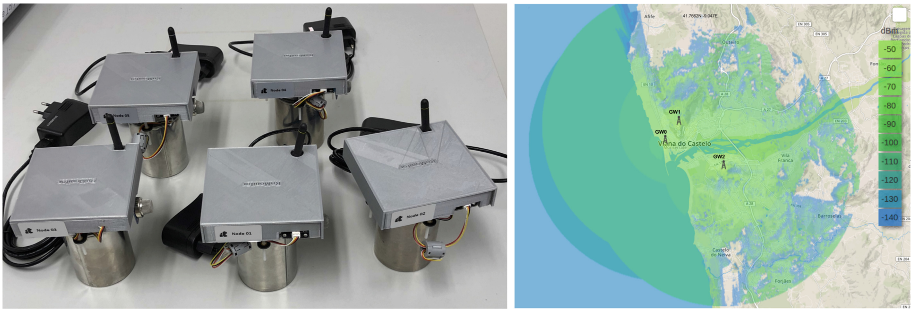


Fig. 1. Concept specification with three events: ***Event 1)*** a specific room of Building 2 has been identified with poor indoor air quality for given occupation profile in a specific time interval; ***Event 2)*** following Event 1, an alarm notification is sent to the Building Administrator; ***Event 3)*** since the building has no HVAC and no active ventilation system installed, a manual ventilation action is carried out by the building administrator. Image from [9].



(a) IoT-edge devices. (b) LoRaWAN estimated Coverage.

Fig. 2. IoT Edge Devices and LoRaWAN estimated Coverage in Viana do Castelo [9].

2.2 Cloud/Analytics Engine

This block stores the data collected by the IoT edge devices. It is responsible for the reasoning and data analytical processing, implemented by an Extract, Transform and Load (ETL) process that computes a set of metrics and indicators for distinct time periods: Real-Time (last hour), Very-Short-Term (last day), Short-Term (last 7 days) and Long-Term (last year), based on a specific building/compartment occupancy profile.

The usage of Occupation Profiles provides a better Radon Risk Assessment in metrics computation because it only uses radon concentration data that are inside the time periods associated with the occupancy profile. It also provides the system API and notification services. To generate the dashboard for an easy user interface, Grafana as-a-service was used, which is directly connected to the time-series database.

The GIS services are available via Geoserver with the integration of the geospatial collections of the MongoDB, which contain a "2dsphere" index that calculate geometries on an earth-like shape. Detailed information of the platform architecture can be found in [9].

2.3 ClientApp/Dashboard

RnMonitor is a web-based application designed for high-level building management. The main purpose of the ClientApp is to provide data visualization that allow users to quickly view dashboards and receive real-time notifications. The application is map-centered and has GIS techonolgies integrated, i.e. OpenLayers and Geoserver, which provide a better visual data analysis enabling the establishment of native and geo-referenced hierarchies between entities, cf. Fig. 3, which can be buildings, rooms or devices. Selecting an entity will render a customized dashboard, showing metrics and indicators that were previously defined for radon management according to the occupation profile.

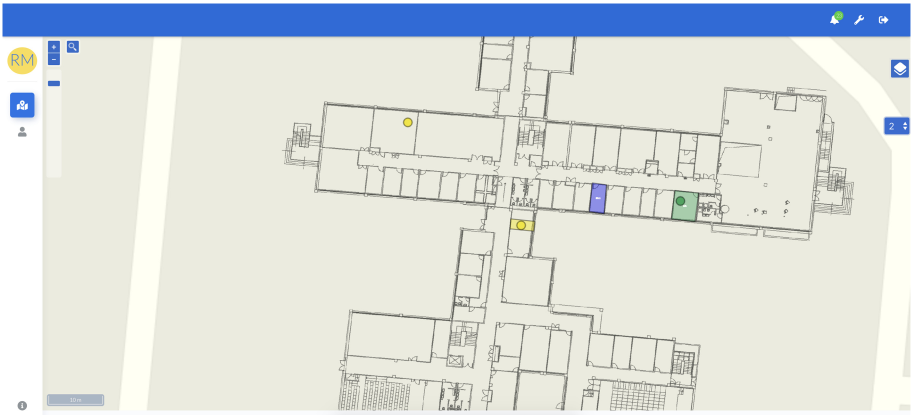
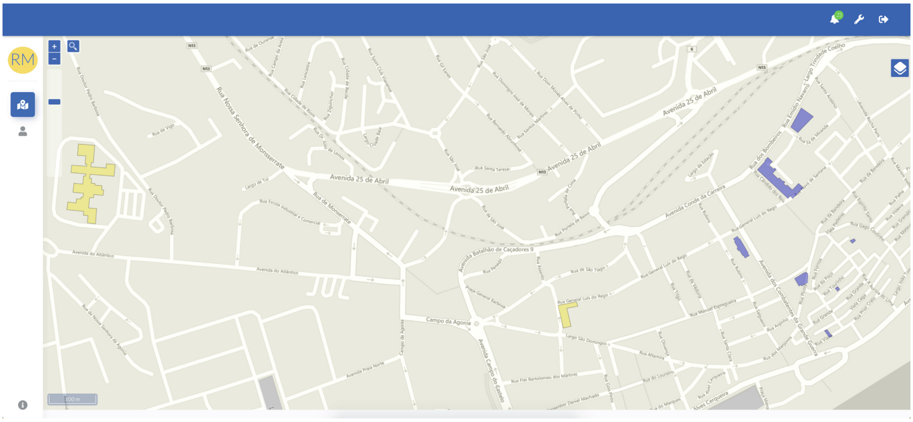


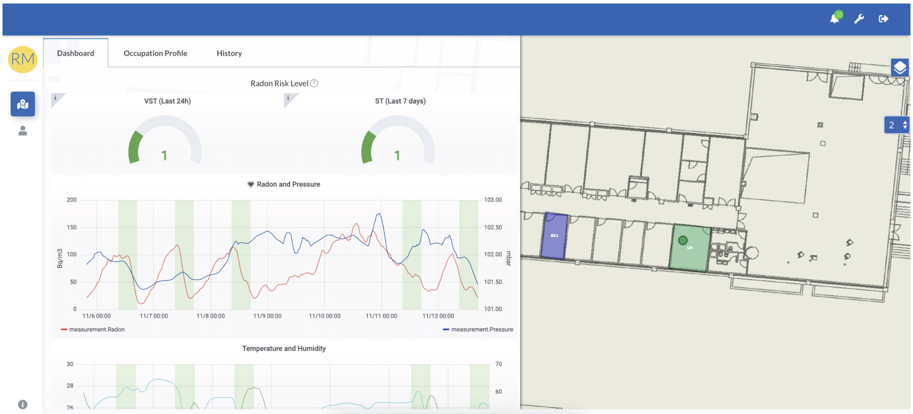
Fig. 3. Building view with distinct compartments identified.

3 Case Study - Demonstration

Figure 4a shows the map-centered interface. This is what the user is prompted after he logs in. The map changes the zoom and centroid based on the polygons that the user is managing. The map has two types of features defined as layers - Sensor and Polygon. Each feature is represented by a color which is associated with the Radon Risk Indicator, in case of polygons, and by the radon legal limit, in case of a sensor. The colors go from a range of Green - Safe, to Yellow - Warning, Orange - Alert, and Red - Critical, which change in real-time, triggering notification alerts to the sensor/polygon owner.



(a) City view with distinct buildings identified.



(b) Compartment view with dashboard.

Fig. 4. Client application views. a) City level and b) specific building/compartment with dashboard. (Color figure online)

If the user selects a feature, a new tab opens up as shown in Figure 4b, displaying three tabs corresponding to Dashboard, Occupation Profile and History. In the Dashboard tab, charts are displayed with data of 7 days and indicators corresponding to three periods of data range - Very-Short-Term (VST) for periods of 24 h, Short-Term (ST) for periods of 1 week to 3 months and Long-Term (LT) for periods higher then 3 months.

The Occupation Profile tab displays a form with data from the occupancy period of the polygon. For example, a public building has an occupation period of Monday to Friday, from 9 a.m. to 5 p.m. Using occupancy profiles, the system is able to compute effective Radon Risk Indicators. The History tab allows the user to search and view data on a specific time-range.

4 Conclusions and Future Work

This paper presents the RnMonitor platform, part of a Cyber-Physical System (CPS) with humans-in-the-loop specifically designed for online monitoring and active mitigation of radon risk in public buildings, with focus on its main features and functionalities. Future work will include the expansion of LoRaWAN network coverage and the long-term evaluation of the proposed platform with several IoT edge devices deployed in a set of potential problematic buildings in the Minho region in Portugal.

Acknowledgements. This contribution has been developed in the context of the Project "RnMonitor - Online Monitoring Infrastructure and Active Mitigation Strategies for Indoor Radon Gas in Public Buildings on the Northern Region of Portugal (Ref. POCI-01- 0145-FEDER-023997)" funded by FEDER (Fundo Europeu de Desenvolvimento Regional) through Operational Programme for Competitiveness and Internationalization (POCI).

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