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Emergency management in Smart Campus: Case Studies and Future Directions

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Abstract

Disaster management plays a crucial role in ensuring the safety and well-being of individuals and infrastructure during emergencies. The rapid advancement of Internet of Things (IoT) technologies offers innovative solutions for disaster management in various domains, including smart campuses. A smart campus integrates IoT devices, sensors, and data analytics to create an intelligent environment that can efficiently respond to and mitigate the impact of disasters. In this paper, we describe some scenarios for the management of emergencies in the context of a Smart Campus. The Smart Campus under consideration has a people counting system able to detect and count the number of people in the classrooms and in the laboratories. Several emergencies are considered, including fires, earthquakes, and floods. In the end, we present the potentialities and the main limitations of such a system in the management of emergencies.

Keywords: smart campus, emergency management, people counting system, internet of things

1 Introduction

Disaster management plays a crucial role in ensuring the safety and well-being of individuals and infrastructure during emergencies [1, 2]. The rapid advancement of Internet of Things (IoT) technology offers innovative solutions for disaster management in various domains, including smart campuses [3–5]. A smart campus integrates IoT devices, sensors, and data analytics to create an intelligent environment that can efficiently respond to and mitigate the impact of disasters [6]. In fact, such a sensing environment can be exploited for early detection and warning systems continuously monitoring various environmental parameters, including temperature, humidity, air quality, and seismic activity. In this way, potential disasters can be identified at an early stage, triggering automated alerts and notifications to relevant stakeholders. This proactive approach can enhance the preparedness and response capabilities of the smart campus.

IoT-based communication systems facilitate effective coordination and communication during emergencies [7]. Connected devices like wearable devices, smartphones, and smart signage enable seamless information exchange between individuals, emergency responders, and campus authorities [8]. This connectivity ensures the timely dissemination of critical information, such as evacuation routes, safe zones, and emergency protocols. Furthermore, IoT devices can assist in tracking and locating individuals within the campus, ensuring their safety and enabling efficient rescue operations [9].

Moreover, IoT-driven data analytics and predictive modeling enhance decision-making processes in disaster management [10, 11]. The vast amount of data collected from IoT devices can be analyzed to identify patterns, trends, and potential risks [12, 13]. Machine learning algorithms can be employed to develop predictive models that forecast the likelihood and severity of disasters, enabling proactive measures to be taken [14, 15]. Additionally, data analytics can provide valuable insights into post-disaster analysis, aiding in the formulation of strategies for future mitigation and recovery efforts [16].

Furthermore, the integration of IoT devices with existing infrastructure and emergency management systems improves the overall resilience of the smart campus [17]. By connecting critical systems such as fire alarms, access control, and surveillance cameras, IoT technology enables real-time monitoring and automated responses. For example, in the event of a fire, IoT devices can trigger fire suppression systems, alert emergency services, and guide individuals to safe exits. This integration creates a comprehensive ecosystem that enhances the effectiveness of disaster management efforts.

Hence, disaster management in a smart campus using IoT holds immense potential for enhancing safety, response, and recovery capabilities [18]. The seamless integration of IoT devices, sensors, and data analytics enables early detection, efficient communication, informed decision-making, and improved resilience. However, challenges such as data privacy, cybersecurity, and interoperability need to be addressed to fully leverage the benefits of IoT in disaster management. With proper implementation and continuous advancements, IoT-driven disaster management can significantly contribute to creating safer and more resilient smart campuses.

Given the described context, in this paper, we discuss how a people-counting system installed within a smart campus could be employed to improve the process of emergency management. The paper describes how it can support the management of general emergencies, such as fires, earthquakes, or floods. Then, it discusses how it can support the management of pandemics, such as the CoVid-19 one. Finally, it presents the critical issues of the current people counting system that have to be addressed or mitigated, if such a system has to be effectively used in emergency management.

The remainder of the paper is structured as follows. Section 2 presents some related works in the context of emergency management with IoT or in the specific context of smart campuses. Then, Section 3 summarizes the main functionalities of the current people counting system while Section 4 details the scenarios in which such a system could be effectively used in supporting emergency management. Finally, Section 5 concludes the paper, highlighting some final remarks and future works.

2 Background and Related Work

In several works, the use of IoT systems in the context of emergency management has been investigated. In [19], the authors reported the results of the First International Workshop on Internet of Things for Emergency Management (2020), which specifically envisions solutions for using smart connected systems to handle disasters. Its main goals were to introduce IoT methods, techniques, and tools that can support the design of smart disaster management systems, to discuss real-life implementations, and to identify challenges and promising IoT solutions. The main challenges that emerged during the discussion session among the participants and the paper presenters of the workshop were: i) IoT resources and their installation and coverage; ii) Environmental context and its impact on detection; iii) Satisfying the real-time requirement. Jia and Wu [20] proposed an intelligent evaluation system of government emergency management based on an IoT environment. Such a system takes advantage of a neural network to avoid the interference of human factors in the emergency loop. The model analyzes the data collected by the sensors to determine the presence of an emergency. The system has been deployed in a province and the evaluation phase demonstrated that it can objectively evaluate and analyze the government emergency management. Liu and Wang focused on urban emergencies, with particular attention on traffic emergency response [21]. They proposed a system to support the urban emergency management system by collecting data from several sources and devising the working programs for command management, personnel evacuation, and disaster disposal in case of emergency Finally, Yang et al. [22], instead, focused on a smart emergency response system for individuals. A WiFi-enabled microcontroller is interfaced with an accelerometer, pulse sensors, ambient temperature and humidity, and a GPS module. Such a set of sensors can monitor the user's health condition and generate an alert if an emergency is detected.

Within the specific context of smart campuses, several works investigated the role of ICT systems in emergency management. Zhang et al. [23] presented a systematic review of smart campus technologies and applications, with the aim of classifying them into different domains to let the current research pattern emerge. The review has been driven by two main research questions: i) what are the key technologies that enable campus smartness? and ii) what are the application domains in smart campus? Finally, they also presented a case study where, following the human-centered principle of smart campus development, they evaluate its consistency and adherence to current research trends to the stakeholders' needs and interests. Bukar et al. [24] addresses the problem of emergency in smart campuses using social media. Starting from ongoing research on the assessment of crisis communication theories and models published in the scientific literature, they presented state-of-the-art opportunities and challenges facing universities and educational establishments in crisis. The findings highlight the significance of social media as part of the crisis communication plan and suggest that future research should focus on the integration of communication via social media during emergencies and on social media communication strategies. Always with a focus on social media, there is work presented by Ramirez et al. [25]. In particular, considering users as participants assets through their social media activities, they proposed a system for detecting emergency events for the National Polytechnic Institute Zacatenco. Such a system analyzed messages (tweets) from Twitter users near the area of interest. They evaluated three different machine learning models Bayes Multinomial, Support Vector Machines, and k-Nearest Neighbors, to classify tweets in four categories: mobility, fire, health, and none. Finally, Narendrakumar and Pillai [26] described the deployment and exploitation of smart city technologies and services within a university campus. They developed an Android application, called Campus Info, which guarantees fast and reliable delivery of information at run-time. Among the several functionalities proposed, such as a real-time water monitoring system, smart temperature monitoring system, and route map there is also a feature of emergency management that consists of emergency contacts. Once an emergency occurs, a user can call for help an ambulance, the security service, or a university contact just by clicking on the relative button in the mobile app.

3 Smart Campus People Counting System

The smart campus considered as the case study for this work is the one presented in [11, 27–31], where the overall system is described in detail. It is located in Cesena and belongs to the Univerisity of Bologna. Just to summarize how such a system works, this Section presents some information about the people counting system approach and its relative web application.

The overall architecture of the people counting system is depicted in Figure 1. As shown, it is composed of three main layers. The first one is the data acquisition layer, which exploits Intel RealSense D415 Depth cameras. They are connected to a Raspberry Pi 4 model B via the USB interface and acquire 1280 x 720 pixel images every five minutes. It is important to notice that this time interval was set to better support the storing operations but can be easily changed based on other requirements. The prediction layer is the second one. It retrieves data from the cameras and taking advantage of a custom model based on YOLOv3, it detects the number of people present in the location in a given moment by dividing the image into regions and determining the bounding boxes for each entity recognized together with the confidence interval. The model has been fine-tuned by exploiting transfer learning. The output of the model, associated with the relative timestamp, is temporally stored in a CSV file. The third and final layer is the API layer. It is mainly composed of an HTTP server, which returns the information stored in the CSV file once it receives a request. The three-layer architecture is hence based on a fat client-thin server architecture and has several main advantages: higher scalability, working semi-offline, higher availability, and privacy compliance. The current people counting model achieves an average accuracy greater than 91% depending on the room layout.

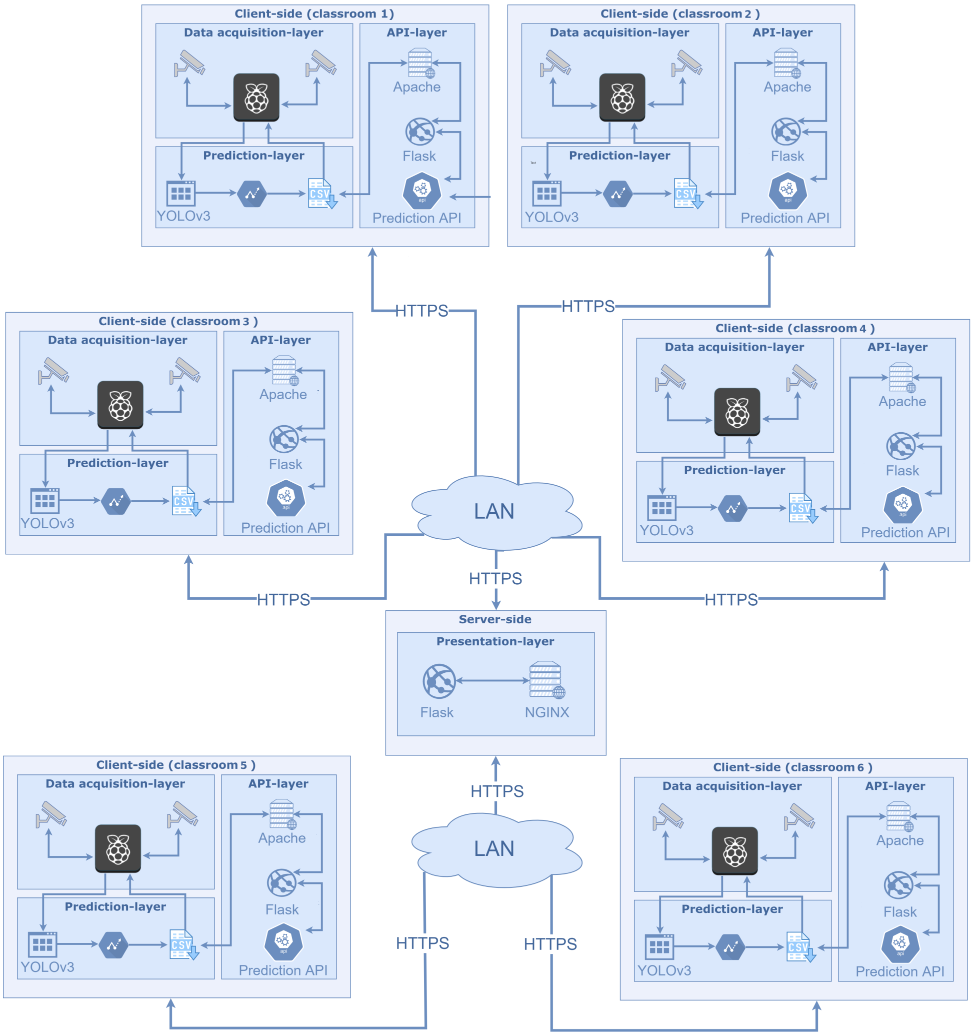

Fig. 1 System Architecture: Overview.

With regards to the web application devoted to data visualization, it was designed and developed always based on a client-server architecture. The User Interface was developed using standard web-based languages, like HTML5 and CSS3 while the application logic was implemented client-side using Angular, employing Typescript. The User Interface was designed to be responsive, hence enjoyable both from smartphones and tablets and larger screens (e.g., personal computers).

Four main Graphic Interfaces were developed:

- Lessons. It is depicted in Figure 2. It lists all the classrooms on the campus showing the following information: the current lesson (if present), the capacity, the students enrolled in the course of the lesson that is taking place, and the number of people identified. Moreover, it is possible to look for a specific classroom or laboratory and change the date and time to access historical information.
- Classroom usage. For each classroom and laboratory, it shows the lessons scheduled inside, and for those that already took place, it displayed the information about the occupancy. It also allows to compare two classrooms, displaying the trends of the number of lessons, hours, and percentage of room occupation, as shown in Figure 3.
- Teachings. It displays the information about each individual teaching: name of the lecturer, course of study, the relative lessons, and the information about the number of students attending its lessons compared to the room occupancy.
- Courses of study. It summarizes the information relative to each course of study that takes place in the Cesena Campus, displaying every teaching belonging to the selected course and a series of graphs to represent the usage of the booked classrooms or laboratories.

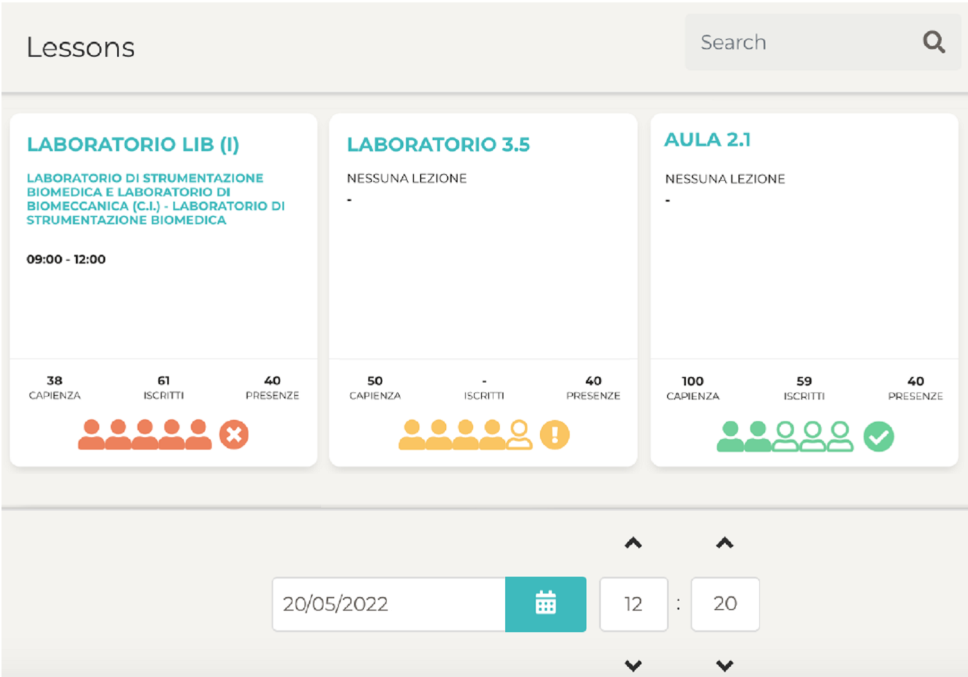

Fig. 2 Lessons User Interface of the web application.

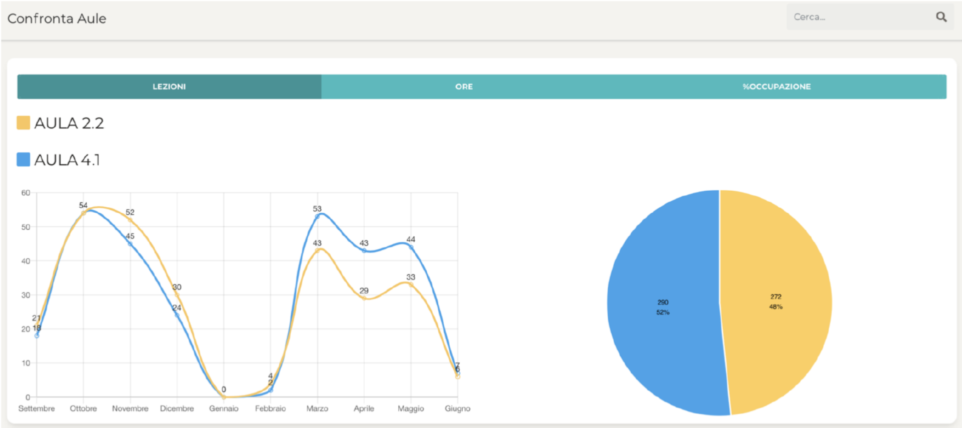

Fig. 3 Classrooms Comparison User Interface of the web application.

4 Usage scenarios for emergency management

This Section presents some scenarios in which the people counting system could be effectively employed in supporting the management of a general emergency or a pandemic, presenting some critical issues of the current system.

4.1 General support for emergency management

Regardless of the emergency that occurs, be it fire, earthquake, or flood, the people counting system of the smart campus could be employed in the following ways.

Early Detection and Alert. The people counting system continuously monitors the occupancy of classrooms in real-time using the cameras installed in the classrooms and in the laboratories. In case of emergency, the detectors (fire detectors, smoke detectors, water level sensors, and earthquake detectors) are triggered, alerting the system about the emergency situation. The system can be integrated with the campus's emergency detection and alarm systems to receive immediate notifications.

Evacuation Assistance and Planning. The administrative staff, emergency responders, and occupants can access the web application to obtain real-time information on the number of people present in each classroom. Based on such information, emergency responders can quickly assess which classrooms need immediate evacuation. They can prioritize their response based on the number of people present in each room. This enables efficient resource allocation, ensuring that rescue efforts are focused on areas with a higher concentration of occupants.

Emergency Response Coordination. The system can integrate with the campus's emergency response protocols. Authorities can use the system's data to coordinate the evacuation process, guiding occupants to safe assembly points or evacuation routes. Based on the information of the sensors, emergency responders can assess which areas are at risk of emergency (such as flooding or fire) and update evacuation routes accordingly. The system's web application can display maps of the campus, indicating safe zones. These safe zones can be designated areas that are structurally reinforced or located in areas less prone to earthquake damage or flooding. It should also highlight areas that should be avoided during an emergency.

Real-time Monitoring. As the emergency occurs, the system continuously updates the occupancy status of each classroom. Emergency responders can monitor the evacuation progress in real-time through the web application. This allows them to track the movement of individuals and ensure everyone is safely evacuated.

Assistance for Vulnerable Individuals. The system could also help in identifying and tracking classrooms with individuals who may require special assistance, such as people with disabilities or mobility issues. In this way, emergency responders can prioritize their efforts to ensure the safe evacuation of these individuals, providing them with the necessary support and resources.

Post-Emergency Analysis. After the emergency has been resolved, the system's data can be used for post-emergency analysis and evaluation. The information collected, including occupancy patterns, evacuation times, and response effectiveness, can assist in refining emergency protocols and improving future emergency management strategies.

4.2 Support for the management of a pandemic

During a pandemic, like the recent one of CoVid-19, the people counting system within a smart campus can be an invaluable tool for managing and mitigating the spread of infectious diseases. By leveraging it, the campus administration can effectively monitor and manage the campus environment, ensure compliance with safety measures, facilitate contact tracing efforts, and promote a culture of health and well-being among students, faculty, and staff. The system's real-time data and analytics enable timely decision-making, proactive interventions, and a safer campus experience for all. Here's a list of cases in which it can be effectively employed in the context of a pandemic.

Social Distancing Compliance. The people counting system monitors and tracks the density of people in different locations, evaluating the number of people detected with respect to the locations' capacities. Hence, it can help ensure compliance with social distancing guidelines. If a certain area becomes crowded and exceeds the recommended capacity, the system can send alerts. Since it is privacy-compliant and it not detect individuals, the information is transmitted to the administrative staff who is in charge of enforcing social distancing, reminding people to maintain a safe distance from each other.

Crowd Management. The system can assist in managing crowds in common areas such as entrances, cafeterias, libraries, and student unions. By monitoring and analyzing the occupancy levels and cross-referencing the data relating to the timetable of the lessons in the various classrooms, it can identify areas that are prone to congestion. Campus staff can receive alerts and take proactive measures to disperse crowds or redirect individuals to less crowded areas, ensuring a safer environment for everyone.

Occupancy-Based Scheduling. The system can integrate with scheduling platforms and campus management systems to optimize the use of shared spaces and facilities. By considering real-time occupancy data, it can help manage and allocate time slots for classes, meetings, and other activities. This ensures that areas are not overcrowded, enabling social distancing measures to be maintained effectively, and at the same time, it avoids the use of oversized classrooms.

Enhanced Cleaning and Sanitization. The people counting system can provide insights into the frequency and intensity of space utilization. This data can be used to optimize cleaning and sanitization schedules. Areas with high foot traffic can be identified and prioritized for more frequent cleaning, reducing the risk of surface transmission and promoting a safer campus environment.

Communication and Public Awareness. The system's web application can also serve as a communication platform to disseminate important health and safety information. It can provide real-time updates on campus policies, guidelines, and health advisories related to the pandemic. Additionally, the system can deliver personalized notifications to individuals, reminding them to follow hygiene practices, wear masks, and adhere to social distancing measures.

4.3 Critical Issues

During an emergency like the one described above, the people counting system may face several critical issues that can impact its functionality and effectiveness in the management of an emergency. This is mainly due to the fact that it has been designed as a low-cost solution for counting people in the context of a smart campus to monitor the classrooms and laboratories occupancy. Here are some key challenges to consider in the context of emergency management.

System Disruption. Currently, the system employs the infrastructures already available on the campus, in terms of power supply and network connectivity. It is powered by the electricity network and the cameras send information on the number of students present in the classroom via the university wifi. In the event of a fire, flooding, or earthquake, such infrastructure including the added physical components like cameras and sensors, may be damaged or disrupted. This can result in the system being temporarily or permanently non-functional, hindering its ability to accurately count and track people. Hence, the redundancy of these resources (power or connectivity) could be managed by providing, for example, the Raspberry that manages the individual cameras with auxiliary batteries or with a backup system for communication, for example, one based on LoRa. In both cases, the system could then report the lack of one of these two resources.

Evacuation Procedures. During an emergency, regardless of its nature, the primary focus is on ensuring the safety and evacuation of individuals. The people counting system may not prioritize accurate counting during such situations, as the immediate goal is to guide people to designated evacuation routes and safe areas. Furthermore, people may act unpredictably and panic, leading to overcrowding, congestion, and rapid movements. Hence, the system may face challenges in accurately accounting for individuals in chaotic and high-stress evacuation scenarios, because of the dynamic nature of human behavior. It is important to notice that currently, the system was able to count the number of people in classrooms with a maximum mean absolute error of 1.23[28] while students are sitting in the classroom while following the lesson. The system must be also tested in a dynamic environment as the one during an emergency situation.

System Integration with Emergency Protocols. The people counting system needs to be integrated with the overall emergency protocols and communication systems on the smart campus. This includes coordination with emergency alarms, public address systems, and emergency response teams. The system should provide real-time data and notifications to support emergency response efforts effectively. Furthermore, additional information regarding emergency management should be integrated into the current user interface.

Environmental Factors: Fires and earthquakes can cause environmental conditions that affect the performance of the people counting system. For example, smoke, dust, debris, or structural damage may obstruct camera views or disrupt sensor functionality, leading to inaccurate or incomplete data. Adverse environmental conditions can hamper the system's ability to provide reliable and real-time occupancy information.

Error Reporting System. Currently, the system does not provide any "alarm" mechanism in case one of the node of the system (i.e., a camera inside a classroom or a lab) does not send information relating to the number of people currently present in the location. The system could be improved to have the system notify the administrative staff that the classroom is no longer sending information. In this way, the personnel in charge can change the order of the classrooms to be monitored, giving priority to those for which no updates are received.

Camera Field of View. Being the system designed for student counting, all its cameras deployed in the classrooms and laboratories are only oriented towards all the areas where students can sit. Consequently, there are two major blind spots. The former is the area near the desk, where the lectures are, and above which the cameras are usually mounted. The latter concerns people who may find themselves stretched out or huddled between the various rows of benches because they are intent on sheltering themselves from the earthquake or to avoid breathing the smoke deriving from a fire. To mitigate this critical issue, additional cameras could be installed to eliminate blind spots. However, this eventuality must be carefully considered as it goes against one of the initial principles that guided the first phases of the design process, and that was that the system had to be low-cost.

Lack of a notification system. A notification system could be integrated into the current system to notify different users of the system of the occurrence of certain events, related to the emergency occurrences and management.

To address all the presented critical issues, it is essential to have contingency plans and alternative methods for evacuation and headcount during emergencies. This may include manual headcounts, emergency roll call procedures, and direct communication with emergency responders. The people counting system should be designed and implemented with robustness, redundancy, and adaptability to withstand emergency situations and support effective emergency response and management. In fact, as already anticipated, the people counting system could be used as a further tool to better manage emergencies.

It is worth mentioning that the current system architecture could be improved by employing containers, to allow portability on different devices, and cluster virtualization techniques to allow the scalability of the server side.

5 Conclusions and Future Works

In this paper, we discuss the use of a people-counting system installed on a smart campus in supporting the process of emergency management. We discussed scenarios with emergencies such as fires, floods, earthquakes, and pandemics, also highlighting the critical issues deriving from the use of such a system during emergencies.

There are plenty of future works. First, the critical issues highlighted in the previous Section need to be addressed or somehow mitigated. Secondly, the current system architecture could be improved by employing containers and virtualization mechanisms [31].

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