IoT Systems for Healthy and Safe Life Environments

Martina Capuzzo*, Andrea Zanella†, Maddalena Zuccotto‡, Federico Cunico‡,
Marco Cristani‡, Alberto Castellini‡, Alessandro Farinelli‡ , Luciano Gamberini§
**Human Inspired Technologies (HIT) Research Centre*, University of Padova, capuzzom@dei.unipd.it
† *Dept. of Information Engineering*, University of Padova, zanella@dei.unipd.it
‡*Dept. of Computer Science*, University of Verona,
{maddalena.zuccotto, federico.cunico, marco.cristani, alberto.castellini, alessandro.farinelli}@univr.it
§ *Human Inspired Technologies (HIT) Research Centre*, University of Padova, luciano.gamberini@unipd.it

***Abstract*—The past two years have been sadly marked by the worldwide spread of the SARS-Cov-19 pandemic. The first line of defense against this and other pandemic threats is to respect interpersonal distances, use masks, and sanitize hands, air, and objects. Some of these countermeasures are becoming part of our daily lives, as they are now considered good practices to reduce the risk of infection and contagion. In this context, we present *Safe Place*, a modular system enabled by Internet of Things (IoT) that is designed to improve the safety and healthiness of living environments. This system combines several sensors and actuators produced by different vendors with self-regulating procedures and Artificial Intelligence (AI) algorithms to limit the spread of viruses and other pathogens, and increase the quality and comfort offered to people while minimizing the energy consumption.We discuss the main objectives of the system and its implementation, showing preliminary results that assess its potentials in enhancing the conditions of living and working spaces.**

***Index Terms*—Internet of Things, Health, COVID-19, Assisted living, Home automation**

I. INTRODUCTION

The abrupt spreading of the SARS-Cov-2 pandemic impacted our everyday lives more than expected, making it necessary to impose strict rules that limited people's movement and activities, impacting society and economy. Indeed, the limitation of human activities and the prevention of social gathering heavily affected the social relationships and people mental health, often increasing the feeling of loneliness of people and the level of anxiety [1]. On the economic side, the lockdown has affected many business sectors, reducing the production and yielding a contraction in the economic growth of many countries [2], which has also led to shortages in the supply of raw materials.

As a reaction to the emergency, a number of actions have been undertaken to limit the spreading of the virus. Common recommendations include the use of Personal Protective Equipment (PPE), avoidance of crowding and in-person meetings, and frequent sanitization of surfaces and spaces. In this scenario, technology can be instrumental not only in improving the safety of work and living environments (e.g., temperature screening, Covid-pass monitoring, and face mask detection), but also in supporting social relationships and limiting the social burden of isolation and the fear of human contacts (e.g., enabling remote video calls, online events, and smart working).

The effectiveness of these systems can be further amplified combining their functionalities in a single, multi-purpose system. Such an integration can be obtained by resorting to the Internet of Things (IoT) paradigm, which virtually enables any object to become part of the Internet, thus making it possible to develop horizontal services that build upon multiple enabling devices. Its application to sensors and actuators enables remote control and monitoring of several quantities and values, from life parameters to environmental conditions. Examples of the potential of such a paradigm are today countless, and range from Smart City applications [3], to Smart Agriculture, wild life monitoring [4], [5], and assisted living for disable people [6], just to mention a few. The IoT has then played a primary role in the fight against the SARS-Cov-2 spreading, as documented in many scientific papers (see, e.g., the surveys [7], [8]).

However, most of the available solutions target specific use cases and risk to become useless once the pandemic emergency has passed. Instead, the demand for solutions to ensure healthy, comfortable spaces and a better quality of life will be enduring. Following this principle, here we present the SAFE PLACE project, which aims at designing an IoT system capable of effectively fighting the spreading of the SARS-Cov-2 virus, while remaining a valid tool to improve the healthiness of working and living environment also in non-pandemic periods. The system allows for the interconnection of sensors and actuators and leverages Artificial Intelligence (AI) to improve the quality and comfort offered to people while minimizing the energy consumption. Contrary to other solutions fighting the SARS-Cov-2 pandemic, the value added by SAFE PLACE is that it is conceived as a *modular* "system of sub-systems", based on a *co-design* approach that actively involves the users to identify the service requirements, and that entails the *cyber-security* aspects by design. Different academic institutions and several industries take part in the project, joining research competences and industrial skills for the creation of an innovative single product, which combines in a unique solution devices that are usually presented singularly.

The rest of the paper is organized as follows. Sec. II presents the overall objectives of the project, its organization and the design principles. Sec. III details SAFE PLACE, describing the devices, the system architecture and its setup. Some preliminary

---

This work was supported by the POR FESR 2014-2020 Work Program of the Veneto Region (Action 1.1.4) through the project No. 10288513 titled "SAFE PLACE. Sistemi IoT per ambienti di vita salubri e sicuri".

results are presented in Sec. IV, as proof of concept. Finally, Sec. V draws the main conclusions and discusses the advantages of SAFE PLACE implementation.

II. THE SAFE PLACE PROJECT

The SAFE PLACE project aims at leveraging and boosting research and products to realize healthier environments. The project consortium includes three research institutes and several local companies and stakeholders, a combination that makes it possible to develop innovative solutions for practical problems, with a commercial perspective. The motivation and main action lines that guided the project are presented in Sec. II-A, followed by the description of the design principles that represent its main strengths: application of the co-design approach, system's modularity, security, and self-regulation.

A. Problem statement and action lines

The SARS-Cov-2 virus is airborne and people's infection happens through contaminated air and surfaces. The guidelines that have been internationally recognized to guarantee people's health and safety generally include the following aspects:

- Monitoring of people's flows and movements, and guarantee that rules on personal and gathering prevention are respected,
- Air salubrity,
- Spaces and objects sanitization,
- Psico-physiological support of isolated people.

In particular, for what concerns the realization of safe environments, the project consortium has identified five macro targets, which have been structured in as many lines of action, labelled with evocative names: they are summarized in Tab. I, together with the required services and possible application scenarios. The five action lines are the following.

1) Safe Path: This action line has the objective of assuring the monitoring and regulation of people's flows, and the respect of the rules to contrast the pandemic (social distancing, use of PPE). These features can be enabled through the integration of devices for the automated access control and video-surveillance systems, able to count the number of people in a given area, identify gatherings and recognize the incorrect use of PPE in real time, rising an alarm at need. Additionally, according to the current situation (e.g., reaching of the maximum number of people in the room), the access to some area can be automatically prevented. These service can be useful in places as museums and stores, where rules on the maximum room capacity may be in place and people gatherings may be prevented or discouraged.

2) Safe Air: The monitoring and improving of air quality to guarantee comfort (air temperature, humidity) and safety (absence of pollution or pathogenic elements) is the objective of this action line. The air renewal or its sanitization through suitable devices is an important feature in places where people stay for a long time, compromising the air quality, such as gyms and meeting rooms.

3) Safe Objects and Spaces: Infections can also be contracted through contaminated objects. Therefore, new technologies, as bi-polar iones and UV-C rays can be leveraged for spaces and surface sanitization. Hardware implementing these capabilities can be integrated in chandeliers, which, thanks to their raised position can light objects more homogeneously. Furthermore, chandeliers can implement *Human-Centric Lighting* solutions, i.e., providing self- or automatic- tunable light whose color and intensity can emulate the natural lights, making the space more comfortable and adapting to the human biorhythms. This particular kind of light can be employed in places with fragile people (e.g., rehabilitation gyms, rest homes, hospitals) or shops.

4) Safe Talk: Isolation may be necessary to protect fragile people from infections (e.g., old people or people with other pathologies), and long periods of quarantine are imposed to infected people, sometimes forced in environments that are not planned for long periods of staying. These situations may cause the increase of physical diseases and affect mental conditions. To mitigate this problem, a possible solution is to provide fragile people with a highly easy-to-use application, specifically designed for this user category, which includes the possibility of communicating to professional staff, as doctors or psychologists, or to beloved people, as family and friends.

5) Safe Place: The four work directions described above can be combined together to implement what we called a *Safe Place*, i.e., an environment where all the requirements previously discussed are simultaneously considered and addressed. It is therefore possible to join them in a unique, flexible and comprehensive IoT system. In this way, different services are combined and adapted to provide a more robust answer to the challenges imposed by the contrast to SARS-Cov-2, optimizing procedures and costs according to the specific use case.

B. Design principles

1) System co-design: When designing technologies that are applied to everyday use cases and that can have a social impact, it is important to consider users' preferences, to match their needs, values, habits and, generally, lifestyles. Indeed, if the services are not appropriately designed, technology becomes an additional barrier to people's well-being. In SAFE PLACE, we applied the co-design approach, which consists in actively involving the final users in shaping the requirements for the target system, by analyzing the preferences of users categories belonging to different areas to match technologies and locations for the system's deployments.

2) Modularity: SAFE PLACE is designed as a *modular* system composed by different sub-systems, each addressing a particular challenge. Hence, the number and the kind of system components can change depending on the scenario and the considered class of users.

3) System security: In its comprehensive design, SAFE PLACE also considers the *security* aspects of each individual subsystem, thus providing a solution where privacy and IoT security aspects are addressed by design. The use of a centralized architecture and the system's modularity makes

TABLE I: SAFE PLACE action lines, services and possible use cases.

Action line	**Services**						**Possible use cases**
	Automatic doors	***Monitoring radar***	***Object sanitization***	***Air purification***	***Monitoring camera***	***Mobile application***	
Safe Path	✓	✓	✗	✗	✓	✗	Stores, museums, cinemas
Safe Air	✗	✗	✗	✓	✗	✗	Gyms, classrooms, meeting rooms, restaurants
Safe Spaces and Objects	✗	✗	✓	✗	✗	✗	Gyms, shops, hospitals
Safe Talk	✗	✗	✗	✗	✗	✓	Isolated/fragile people
Safe Place	✓	✓	✓	✓	✓	✓	all

it possible to harmonize the devices' security mechanisms and protocols, and provide unique credentials to access each system's sub-module.

4) Self-regulation: Although initially configurated during the installation phase, systems that interact with the environment may suffer from variations of the original conditions, and not perform as expected. Instead, the SAFE PLACE system is conceived to be self-tunable, able to automatically adapt the devices configuration and activation to the actual operational context to ensure safe conditions and offer a comfortable space.

III. SYSTEM DESCRIPTION

In the SAFE PLACE system multiple communicating devices are connected together to implement an IoT system, allowing for monitoring and control. In the following, we describe how the system is implemented, describing devices, system's architecture and system's initial setup. Although these deployment choices have been taken specifically for the SAFE PLACE project, the constraints and limitations faced are common to many IoT deployments, especially when combining devices that are provided by different manufacturers and the system is not stand-alone. Thus, this discussion can be helpful to guide the implementation of other similar systems.

A. Devices

To implement the services described in Sec. II, new devices have been designed from scratch or existing commercial devices have been powered up with IoT communication interfaces and additional functionalities. These devices, some at the stage of prototypes, will be deployed to realize proof-of-concept installations of the SAFE PLACE system. The devices, their capabilities and limitation are described in the following.

1) Cameras and radars: Cameras for indoor and outdoor monitoring are extended with functionalities that allow (i) people tally, (ii) monitoring of social distance and gathering recognition, (iii) monitoring of the correct use of PPEs. In particular, if rules on conditions (ii) and (iii) are broken, the system rises an alarm. The radar also has the additional advantage of higher privacy preservation, since no images of the users are collected. However, according to the hardware implementation and components, radar devices may not be sufficiently performant for these applications. For example, when used in indoor spaces, the many reflections on the room walls can compromise the received signals; furthermore radar devices may struggle in the discrimination of individuals that are close in space or move in the front/back direction.

2) Automatic doors: These common devices are extended with a communication interface to enable their remote control for closing and opening operations.

3) Controlled Mechanical Ventilation (CMV) and air sanitizer: The CMV allows to exchange indoor air with the outside. The tuning of fan speed and the direction of the air flow also affect the air temperature. On the other side, the air sanitizer employs the Non Thermal Plasma (NTP) technology to reduce the presence of Volatile Organic Compound (VOC) and microorganisms (bacteria, virus) in the air, decreasing the risk of patologies transported by air in general. The air quality sensors, CMV and air sanitizer are all connected and controlled by a local gateway, which collects their measurements and status and send back to them possible commands.

4) Smart lighting system with sanitization capabilities: Smart lighting systems are combined with methods for direct/indirect air and/or surface sanitization. According to the specific prototype considered, the air sanitization can be obtained through bipolar ion technology or direct and indirect UV-C rays. The use of direct UV-C rays makes it possible to sanitize object surfaces when employed with a sufficient intensity for a specific time. However, the device can be activated only when the room is empty for safety reasons, and an additional safety mechanism is integrated to the lamps to interrupt their functioning if a movement is detected. Finally, the devices are also tunable in terms of light color and intensity which makes it suitable to implement the *Human Centric Lighting* principles.

5) BoxIO: it is a gateway that acts as the central node of the network, able to connect the different objects, collecting data transmitted by the devices, and sending them to the SAFE PLACE server through an always-open connection. This device also has the capability of working with many communication technologies (e.g., Modbus, LoRaWAN, Zigbee, WiFi, 4G LTE), and it can serve as a WiFi Access Point (AP). Thus, the BoxIO can act as a "translator", enabling the communication also between devices using different interfaces.

6) SAFE PLACE server: it is the server dedicated to the SAFE PLACE system. It stores devices credentials, system and devices configuration, data collected from the devices and control policies. It also runs AI algorithms to optimize devices' energy consumption and configuration according to the state of the system (e.g., visualizing alarms and/or activating air purification when the sensors monitor stale air or the room is crowded).

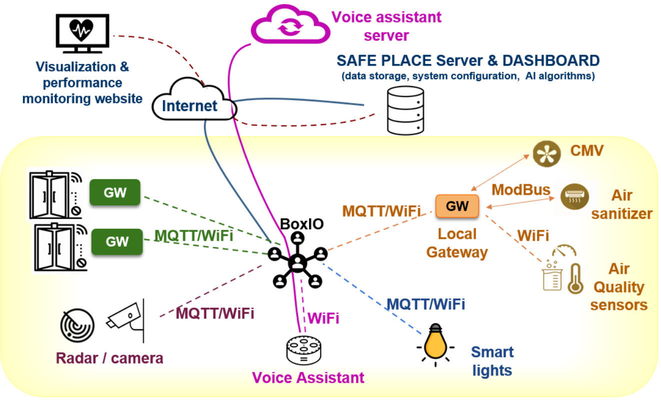

Fig. 1: SAFE PLACE system architecture for Safe Place scenario. The yellow part corresponds to the SAFE PLACE local network.

7) Software components: These elements enable the control and monitoring of the system. An application running on mobile devices (i.e., smartphones, tablets) is designed for the initial system setup, installation and rules configuration, and for the visualization of real-time and short-term data describing the status of the system. These data are collected from the devices, are temporary stored in the BoxIO, and then passed to the SAFE PLACE server for long-term storage, from where they can be retrieved for data analysis and visualization through a web interface. An additional mobile application for fragile people is specifically designed to implement the Safe Talk functionalities.

B. System architecture

The SAFE PLACE project foresees both *vertical* scenarios (Safe Path, Safe Air, Safe Space and Objects) and a *horizontal* scenario (Safe Place). The last encompasses all the components, features and services provided by the vertical scenarios. The system architecture in the vertical scenarios will be a subsystem of that in the horizontal case, since only a subset of services will be deployed, as described in Tab. I. Thus, in the following, we will focus only on the system architecture of the horizontal Safe Place scenario, which required more care for the design and definition of the interconnections between all the devices provided by different vendors.

Fig. 1 depicts the system architecture in the Safe Place scenario. A star topology is employed, where all the devices presented in Sec. III-A are connected to the BoxIO, which acts as central node and controller of the network. Some devices (smart lights, camera) have a direct connection to the BoxIO, while for others (automatic doors, air quality sensors, air sanitizer and CMV) an intermediate gateway is required to provide them with a WiFi interface. Note also that, although Low-Power Wide-Area Network (LPWAN) technologies are usually suggested for IoT networks, we do not employ any of them because the target use cases entail access to the power line and small areas (rooms or shops) so that low power and long-range features of LPWANs are not necessary. Furthermore, SAFE PLACE applications require bi-directional and low-latency communication, both for continuous monitoring of the system and for controlling the devices at any moment, features that are often not provided by LPWAN technologies. Finally, as represented in Fig. 1, voice assistant services can be integrated to the system, making it possible to control the devices through vocal commands.

Devices and BoxIO will belong to a *local* Safe Place network. However, one of the main advantages of the SAFE PLACE system is the possibility to monitor and control the system *remotely*, independently of the location of the user. To this aim, the system is connected to the Internet through the BoxIO, which can store information in the SAFE PLACE server, and download configuration files and other useful information from it. Furthermore, the web interface and mobile application are also connected to the Internet, and can, thus, access the information available in the SAFE PLACE server or in the BoxIO. The communication between devices and BoxIO occurs through the Message Queue Telemetry Transport (MQTT) protocol in its TLS secured version (MQTTS), running over WiFi.

C. System initial setup

In this section we describe the steps for the setup of SAFE PLACE, from the initial network creation to the configuration procedure, discussing implementation details and pitfalls and motivating the design choices.

1) System provisioning: This procedure is needed to register the devices in the system and provide them with certificates for security provided by the SAFE PLACES Certification Authority (CA). Each device will then employ these information to authenticate in the Safe Place network and to the MQTT broker of the BoxIO. Furthermore, in this occasion, the BoxIO will also download the system configuration (see Sec. III-C4) from the server, if available, otherwise this will be automatically done at a later time.

2) IP network configuration: To be connected to the local SAFE PLACE network, it is necessary for the devices to belong to an IP network. Because of the different vendors involved, this process is specific for each device: some provide a web interface to set the SSID and password of the WiFi AP they have to connect to, others register these credentials through a mobile proprietary application communicating to the devices through a temporary Bluetooth connection, others employ the vendors' WiFi APs to insert these credential and then switch to the WiFi network provided by the place where the system is deployed.

3) BoxIO discovery: Once connected to the Safe Place local network, devices have to identify the BoxIO and establish a connection with it. According to the specific deployment, different situations can take place:

1) An IP network is available where all the devices are able to communicate and broadcast messages are not filtered;
2) An IP network is available where all the devices are able to communicate but broadcast messages are filtered (this is often the case in large networks, as in university campus, for security reasons);

3) No available IP network is present, but it is possible to use the BoxIO as a local Wifi AP, providing connectivity to all the devices that are in range. Note, that this solution makes it possible to connect the devices in a unique local network, bit eithout Internet access, thus preventing all the services provided by the server, web interface and vocal assistants.

The BoxIO IP address can be discovered in two ways:

1) using a *zeroconf* service, where the devices send broadcast requests and the BoxIO answers to them, establishing a connection,
2) by directly setting the BoxIO IP address on each device (which requires an appropriate interface).

The use of a *zeroconf* service is possible where broadcast messages are not filtered, while, when this is not the case, the manual setting of the BoxIO IP address, or making the BoxIO work as a WiFi AP, can be backup solutions. Note that the manual entering of the BoxIO IP address requires that (i) the address is known in advance, (ii) the address is static, i.e., it is the same also in the case of system reset, which may happen with a temporary black-out or because of other events. However, IP addresses are usually dynamically assigned through the DNS protocol. To have static addresses, it is necessary to modify the configuration of the WiFi hosting network.

4) System configuration: Once all the devices are registered, it is possible to control them through the SAFE PLACE mobile application. This translates in the definition of a *configuration*, i.e., how devices should behave according to rules specified by the user. For example, it will be possible to activate some machines (e.g., start the sanitization procedure) when some thresholds are met, or at need. Once created, the configuration is saved in the SAFE PLACE server and can be downloaded by the BoxIO. According to this configuration, the BoxIO will know when to send MQTTS messages to control the devices. Another element that should be taken into account is the definition of the actions that each user is allowed to perform. This requires the identification of a users' hierarchy, where different privileges (e.g., visualization, editing) are assigned according to the role.

IV. PROOF OF CONCEPT

In this section we briefly present some preliminary results obtained in the first phase of the project, which show the effectiveness of the prototypes and first partial installations. They also provide an overview of the expected outcomes of the system (performance, data that can be collected, simulations of the functioning). In particular, we discuss results concerning the Safe Path and Safe Air scenarios.

A. Safe Path

Preliminary results are provided for the monitoring of the correct use of PPEs, specifically face masks. To this end, a classifier-based solution requires a dataset as training data, in order to learn an effective model parametrization for generalizing on unseen data. Due to the lack of a suitable dataset in the literature, we built our own by merging previously published datasets covering different specific scenarios (FMLD [9], Moxa3K [10], MMD [11], RMFRD [12]) and added synthetic data to have images of faces taken from a video surveillance point of view (camera are not frontal, but at a higher position on the floor, capturing skewed images), using a generation pipeline based on MakeHuman [13] combined with Blender [14] to obtain photo-realistic humanoid models. To test the system, an additional dataset has been created from a video sequence acquired with multiple surveillance cameras in the ICE lab of the University of Verona. As for the classification results, we trained different classifiers, namely ResNet-50, VGG19, MobileNet, EfficientNet. With these frameworks, on the test partition we reach an accuracy score on face mask classification of 0.864, 0.873, 0.857, 0.884, respectively. These results are in line with what can be found in the literature [15]. Also notice that, in the Safe Place scenarios, the wide field of view of surveillance cameras complicates the detection of the face mask, which will occupy a minimal portion of the image (approximately, 60 by 60 pixels), whereas in most of the literature it is assumed the image is close-up of the person's face, so that the face mask detection can be performed on a much higher resolution image (see, e.g., [16]–[18]).

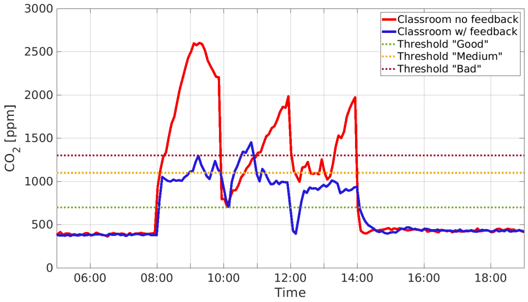

Fig. 2: Example of the efficacy of monitoring systems and feedbacks in two school classrooms.

B. Safe Air

Some first tests on the air quality considered monitoring sensors placed in two different scenarios. The first considered two school classrooms provided with sensors measuring the level of carbon dioxide (CO_2) (see Fig. 2). In the first classroom (benchmark), teachers employed the school policy that suggested to ventilate the room at the end of each lesson. The second classroom also had an additional notification system that indicated when the CO_2 level was above some threshold, both with some messages and with some acoustic signals; these are represented in the graph by the dotted lines at 700 ppm, 1100 ppm and 1300 ppm, corresponding to worsening levels of air quality. Observing the figure, we notice that the CO_2 drops every 2 hours, i.e., at 10:00, 12:00 and 14:00, which corresponds to the time when windows are opened to ventilate the room as for the school policy. Instead, high peaks are present before these events for the classroom with no feedback system (red line), which reveals the high increase of CO_2

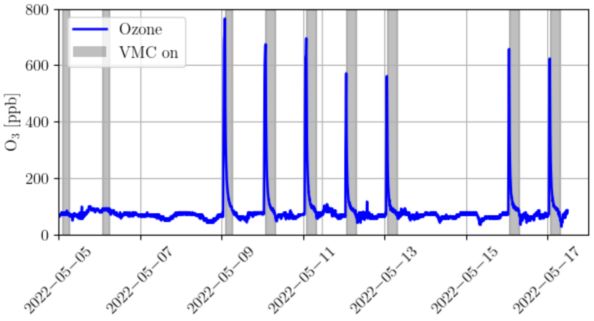

Fig. 3: Level of ozone and activity of a CMV in an office area.

due to the presence of people. Conversely, the values for the classroom where the notification system was present (blue line) are mostly inside the thresholds 700-1300 ppm, without any significant peak, proving that using a feedback system encouraged people to open windows to ventilate the room through the day. This led to a more virtuous behavior, which reflects in the average CO_2 value during the monitoring period: in the benchmark scenario, this is 1519 ppm, while it reduces to 1006 ppm when the notification system is used.

The second scenario considers devices placed in an office area. In particular, in Fig. 3 we see the level of ozone in the room: from May 9th, a machine for sanitization through ozone ran during the night, leading to peaks of ozone level. Thus, the system was configured to make a CMV machine start working afterwards, which brought back the O_3 levels to standard values. The ON states of the machines are represented by the gray-background regions, based on the outputs of the corresponding messages.

Other preliminary tests evaluated the effect of AI-based algorithms for actuator control in a simulated environments. Specifically, the problem of activating the sanitization process can be formalized as a planning problem. In this context, the use of Reinforcement Learning (RL) techniques allows to trigger actuators to improve the environmental conditions in an adaptive fashion. In the results we show, we considered a scenario of a room that can be reserved by a specific number of people (e.g., a meeting room or a school classroom), where the objective was to keep the CO_2 level below a threshold. An example is reported in Fig. 4, wherethe first row shows the number of people present in a room the classroom from 8:00 to 18:00 due to a reservation schedule. In the second row the orange line represents the value of CO_2 in the room while the pink dashed line is the threshold not to be exceeded. Finally, in the third row we show the signal produced by the system to control the actuator ('0' for OFF and '1' for ON). The evolution of the CO_2 has been modeled with a preliminary simplified linear model, which considers the current value of CO_2 and the expected number of people in the room for future prediction. Moreover, we assume values for the CO_2 in the range (0, 100) and the maximum threshold is set to 75. As we can see, the RL algorithm is able to predict how the CO_2 value will change in a specific horizon and, consequently, to decide the signal for the actuator to maintain the value of CO_2 in the room below the threshold. More precisely, we aim at avoiding activations when people are in the room and leveraging CO_2 value predictions to trigger the actuator sufficiently in advance to keep the value below the maximum threshold. For example, between 10:30 and 11:55 the system triggers the actuator when no people are in the room to maintain the CO_2 value under the threshold from 12:00 to 13:55 when 30 people are physically present in the room. Tests under investigation also focus on the adaptability of the planning strategy to the environment, which is an important problem in real world domains. The aim is to make the system adapt its initial configuration to the actual environment considering how the values of interest change over time and then to optimally plan the activation of the required processes.

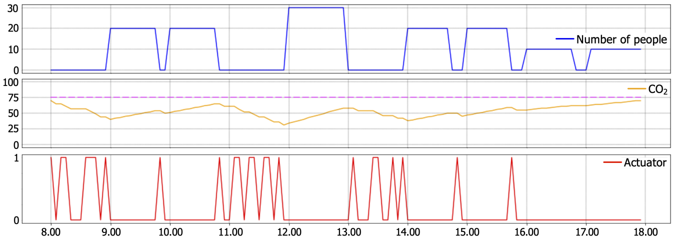

Fig. 4: Example of the effect of applying RL technique in a simulated environment.

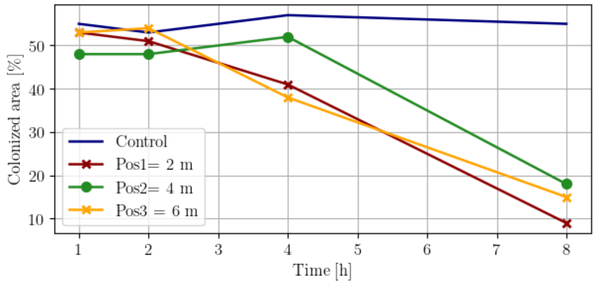

Fig. 5: Percentage of area colonized by microbacteria over time.

It is worth noting that the measured values of CO_2 and O_3 also indicate whether the air has been sufficiently changed, activity that is recommended to increase the air salubrity providing healthier environments. This has been verified when testing a prototype device for air sanitization using NTP. The tests evaluated the growth of a microbacteria colony in plates placed at different distances from the sanitization device. Fig. 5 shows the efficiency of the NTP sanitization also on surfaces: when used for some hours, the devices clearly acts as a biocide in the surrounding space. The blue line represents the results on the control plate (not exposed to sanitization), while the remaining corresponds to plates placed at the following distances from the sanitizing device. These results prove that this method of air sanitization is helpful to limit the spreading of pathologies by acting on both air and surfaces at the same time.

V. CONCLUSION

In this paper we presented the SAFE PLACE, an IoT system that aims at providing safe and healthy living environments, helping against the spreading of pandemic viruses, but also offering a solution that can be generally applied to improve the quality of the living environment and comfort to the users. We covered all the implementation aspects, from the design principles (modularity, co-design, security, system's self-regulation) to the description of the devices, to the system's architecture and configuration. This can be an inspiring discussion for other solutions that aim at providing benefits for the users and the society in different scenarios. Finally, we have showed preliminary results that demonstrate possible outcomes of the system and its efficacy in first simple demos scenarios.

ACKNOWLEDGMENTS

The authors thank GiZero Energie s.r.l. and Jonix S.p.A. for sharing the preliminary data presented in this paper.

REFERENCES

[1] E. Long, S. Patterson, K. Maxwell, C. Blake, R. B. Pérez, R. Lewis, M. McCann, J. Riddell, K. Skivington, R. Wilson-Lowe, *et al.*, "COVID-19 pandemic and its impact on social relationships and health," *Journal of Epidemiology and Community Health*, vol. 76, no. 2, pp. 128–132, 2022.

[2] U. Anand, C. Cabreros, J. Mal, F. Ballesteros Jr, M. Sillanpää, V. Tripathi, and E. Bontempi, "Novel coronavirus disease 2019 (COVID-19) pandemic: from transmission to control with an interdisciplinary vision," *Environmental research*, vol. 197, p. 111126, 2021.

[3] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of Things for Smart Cities," *Internet of Things Journal, IEEE*, vol. 1, pp. 22–32, Feb. 2014.

[4] P. Asghari, A. M. Rahmani, and H. H. S. Javadi, "Internet of Things applications: A systematic review," *Computer Networks*, vol. 148, pp. 241-261, 2019.

[5] A. Khanna and S. Kaur, "Internet of things (IoT), applications and challenges: a comprehensive review," *Wireless Personal Communications*, vol. 114, no. 2, pp. 1687–1762, 2020.

[6] D. Bacchin, P. Pluchino, A. Z. Grippaldi, D. Mapelli, A. Spagnolli, A. Zanella, and L. Gamberini, "Smart Co-housing for People With Disabilities: A Preliminary Assessment of Caregivers' Interaction With the DOMHO System," *Frontiers in psychology*, vol. 12, 2021.

[7] R. P. Singh, M. Javaid, A. Haleem, and R. Suman, "Internet of things (IoT) applications to fight against COVID-19 pandemic," *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, vol. 14, no. 4, pp. 521–524, 2020.

[8] M. Yousif, C. Hewage, and L. Nawaf, "IoT technologies during and beyond COVID-19: a comprehensive review," *Future Internet*, vol. 13, no. 5, p. 105, 2021.

[9] B. Batagelj, P. Peer, V. Štruc, and S. Dobrišek, "How to Correctly Detect Face-Masks for COVID-19 from Visual Information?," *Applied Sciences*, vol. 11, no. 5, 2021.

[10] B. Roy, S. Nandy, D. Ghosh, D. Dutta, P. Biswas, and T. Das, "Moxa: A deep learning based unmanned approach for real-time monitoring of people wearing medical masks," *Transactions of the Indian National Academy of Engineering*, vol. 5, pp. 509–518, 2020.

[11] H. in the Loop, "Medical mask dataset."

[12] Z. Wang, G. Wang, B. Huang, Z. Xiong, Q. Hong, H. Wu, P. Yi, K. Jiang, N. Wang, Y. Pei, H. Chen, Y. Miao, Z. Huang, and J. Liang, "Masked face recognition dataset and application," 2020.

[13] L. Briceno and G. Paul, "Makehuman: A review of the modelling framework," in *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018)*, (Cham), pp. 224–232, Springer International Publishing, 2019.

[14] Blender Online Community, "Blender - a 3D modelling and rendering package," 2018.

[15] A. Nowrin, S. Afroz, M. S. Rahman, I. Mahmud, and Y.-Z. Cho, "Comprehensive review on facemask detection techniques in the context of covid-19," *IEEE access*, 2021.

[16] M. Inamdar and N. Mehendale, "Real-time face mask identification using facemasknet deep learning network," *Available at SSRN 3663305*, 2020.

[17] S. V. Militante and N. V. Dionisio, "Real-time facemask recognition with alarm system using deep learning," in *2020 11th IEEE Control and System Graduate Research Colloquium (ICSGRC)*, pp. 106–110, 2020.

[18] A. Chavda, J. Dsouza, S. Badgujar, and A. Damani, "Multi-stage cnn architecture for face mask detection," in *2021 6th International Conference for Convergence in Technology (I2CT)*, pp. 1–8, 2021.

Martina Capuzzo received her PhD in Information Engineering in the University of Padova (IT) in 2022 under the supervision of Prof. Andrea Zanella. Her research interests include the design and performance analysis of IoT networks, with a particular focus on LoRaWAN and battery-less devices. She collaborated with Simula Research Center and Telenor Group, Oslo (NO), and with the IDLab research group, University of Antwerp (BE).

Andrea Zanella is Full Professor at the Dept. of Information Engineering (DEI), University of Padova. He received the Laurea degree in Computer Engineering in 1998 from the same University and the PhD in 2001. During 2000, he was visiting scholar at the University of California, Los Angeles (UCLA), within Prof. Mario Gerla's research team. Andrea Zanella long-established research activity is in the field of protocol design, optimization, and performance evaluation of wired and wireless networks. He has authored 220+ papers and has been serving in the editorial board of several top journals, such as IEEE Internet of Things Journal, IEEE Communications Surveys and Tutorials, IEEE Transactions on Cognitive Communications and Networking.

Maddalena Zuccotto is a Ph.D. student at the University of Verona focusing on probabilistic planning and reinforcement learning techniques. Her work focuses on Monte Carlo tree search based planning under uncertainty and introduction of prior knowledge in model-based reinforcement learning. Main applications are related to intelligent systems, such as cyber-physical and robotic systems.

Federico Cunico is a Ph.D. Student in Computer Science at the University of Verona under the supervision of Prof. Marco Cristani. He received his Master's degree in Computer Science and Engineering at the University of Verona in 2019. His main research interests are in deep learning and computer vision with a focus on people analysis.

Marco Cristani is full Professor at the Computer Science Department, University of Verona, Associate Member at the National Research Council (CNR), External Collaborator at the Italian Institute of Technology (IIT). His main research interests are in statistical pattern recognition and computer vision, mainly in deep learning and generative modeling, with application to social signal processing and fashion modeling. On these topics he has published more than 180 papers, including two edited volumes, 46 international journal papers, 126 conference papers and 13 book chapters. He has organized 11 international workshops, cofounded a spin-off company, Humatics, dealing with e-commerce for fashion. He is or has been P.I. of several national and international projects, including PRIN and H2020 projects. He is member of the editorial board of the Pattern Recognition and Pattern Recognition Letters journals. He is Managing Director of the Computer Science Park, a technology transfer center at the University of Verona.

Alberto Castellini is assistant professor at the University of Verona, Dept. of Computer Science, since 2018. His research interests include predictive modeling, planning under uncertainty, reinforcement learning and data analysis for intelligent systems (robotic/cyber-physical systems).

Alessandro Farinelli is full professor at University of Verona, head of the Computer Science Department. His research interests focus on developing novel methodologies for Artificial Intelligence systems applied to robotics and cyber physical systems. In particular, he focuses on multi-agent coordination, decentralized optimization, reinforcement learning and data analysis for cyber-physical systems.

Luciano Gamberini is full professor of Work and Organizational Psychology and Human-Computer Interaction at the University of Padova (Italy) since 2016. He is director of the Human Inspired Technologies Research Centre and vice-director of the doctoral program Brain, Mind and Computer Science. His research activity involves fields including Augmented and Virtual Reality, UX, Accessibility, Symbiotic Systems, and Industry 4.0. He is the author of more than 100 publications in high-impact journals (h-index 25). He is editor of the Cyberpsychology, Behavior and Social Networking Journal and he serves as a reviewer for several journals and conferences.