The Post-pandemic Effects on IoT for Safety: The SAFE PLACE Project

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***Abstract*—COVID-19 had substantial effects on the IoT community which designs systems for safety: the urge to face masks worn by everyone, the analysis of crowds to avoid the spread of the disease, and the sanitization of public environments has led to exceptional research acceleration and fast engineering of the related solutions. Now that the pandemic is losing power, some applications are becoming less important, while others are proving to be useful regardless of the criticality of COVID-19. The SAFE PLACE project is a prime example of this situation (DATE23 MPP category: *final stage*). SAFE PLACE is an Italian 3M euro regional industrial/academic project, financed by European funds, created to ensure a multidisciplinary choral reaction to COVID-19 in critical environments such as rest homes and public places. SAFE PLACE consortium was able to understand what is no longer useful in this post-pandemic period, and what instead is potentially attractive for the market. For example, the detection of face masks has little importance, while sanitization does have much. This paper shares such analysis, which emerged through a co-design process of three public SAFE PLACE project demonstrators, involving heterogeneous figures spanning from scientists to lawyers.**

***Index Terms*—Internet of Things, Smart Building, Real-Time Systems, COVID-19, Assisted Living**

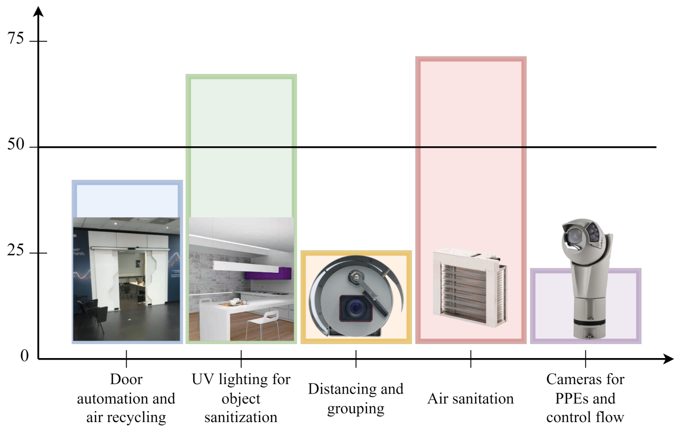

Fig. 1. Types of technologies hosted in the SAFE PLACE project, and how much potential they have felt in the post-COVID-19 era thanks to a co-design process. The percentages shown here expressed how many users among 75 participants would like to have a particular SAFE PLACE technology in their working environment.

I. INTRODUCTION

At the moment of writing, Europe and the United States are in the endemic stage of the COVID-19 outbreak: the virus is widespread, it is significantly less fatal than it was in 2020, and it seems to be becoming less and less aggressive.

Since the first appearance of COVID-19, the IoT community has promptly reacted, through ideas that became demonstrators in unprecedented short times. From social distance analysis systems [1] and the analysis of the correct use of Personal Protective Equipment (PPE), air monitoring control, systems aim at assisting elderly and impaired people [2], to disinfection systems, specific research directions have been started or boosted, leading to theoretical and technological advances and promoting further research *in some cases*.

In fact, some of these research directions seem nowadays to be losing importance in the same way that COVID-19 is winding down, such as the detection of face masks. Other directions instead, such as air sanitization, are considered as potential beyond sanitary urges: this is because they are also concerned with environmental sustainability issues that will be fundamental today and in the near future. Our technical analysis is based on a user-centered approach; we gathered explicit opinions of how promising the SAFE PLACE technologies of the various scenarios were, 75 participants belonging to heterogeneous sectors (*i.e.*, large distribution, catering, tourism, public education, and health), were interviewed between January and March 2021. The percentages reported in Fig. 1 reflect

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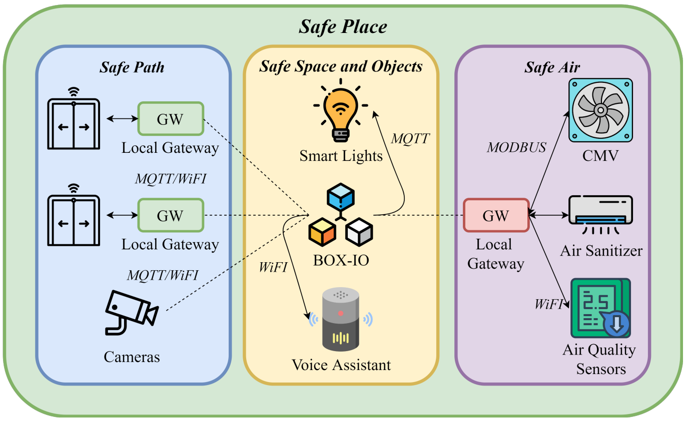

Fig. 2. The scenarios and modules of the SAFE PLACE project. The SAFE PLACE project foresees both vertical scenarios (*Safe Path*, *Safe Air*, *Safe Space and Objects*) and a horizontal scenario (*Safe Place*). Different devices are used in specific scenarios, while the general architecture is shared among them.

participants' willingness to have in their working environments the SAFE PLACE systems for sanitizing air and surfaces (*i.e.*, direct/indirect UV lighting), instead of technologies for monitoring the presence/absence of face masks or social distancing.

This paper analyzes SAFE PLACE [3], a 3M euro ICT Italian research project (POR FESR 2014-2020) started in late 2019 and ending in March 2023, in which these aspects of birth, decline, and continuation of specific research directions have clearly emerged since they co-exist for the very first time in a single multidisciplinary framework. Specifically, we present the study that analyzes why SAFE PLACE and its modules are unique by highlighting the genuine advancements in the state-of-the-art that the project has brought. At the same time, we share our impressions about the potentialities that will go with these advancements, beyond the pandemic emergency

The SAFE PLACE project was aimed at leveraging and promoting heterogeneous research and products to realize healthier environments to cope with the pandemics' emergency. SAFE PLACE implements a *modular system of sub-systems*, where its IoT-oriented sub-systems cope with the following aspects[1]:

- People flow monitoring to prevent gathering and unsafe behaviors (dubbed *Safe Path*);
- Space and object sanitation (*Safe Space and Objects*);
- Air quality and thermal comfort monitoring and control (*Safe Air*).

II. THE SAFE PLACE PROJECT

Fig. 2 depicts the system architecture in the SAFE PLACE scenario. A star topology is employed, where all the devices are connected to an orchestrator which acts as the central node and controller of the network. Some devices (smart lights and cameras) have a direct connection to the BOX-IO controller, while for others (automatic doors based on [4], air quality sensors, air sanitizer, and controlled mechanical ventilation), an intermediate gateway is required to provide them a WiFi interface.

In the SAFE PLACE system, multiple devices are connected to implement the SAFE PLACE scenarios, namely *Safe Path*, *Safe Space and Objects*, and *Safe Air*. Some devices are brand-new and will be described in the following. The other (standard) devices, like PTZ cameras and automatic doors, will be mentioned in the scenarios descriptions.

Air sanitizer devices employ Non-Thermal Plasma (NTP) technology to reduce the presence of Volatile Organic Compounds (VOCs) and microorganisms (*e.g.*, bacteria, and viruses) in the air, decreasing the risk of airborne diseases. We started from the JONIX CUBE, a device designed for 24/7 sanitization, even in the presence of people. A custom-developed IoT board (JONIX IoT) has been added to monitor air quality which uses Reinforcement Learning methods to decide when to activate it.

In addition, Controlled Mechanical Ventilation (CMV) devices allow exchanging indoor air with the outside, expelling polluted substances and improving indoor air quality. We designed a new CMV device (dubbed CMV plug&play) engineered to be smaller and designed to optimize energy consumption, and make more efficient external air filtration. CMV plug&play and JONIX IoT have been connected together in a system by a custom PCB Indoor Air Quality Monitor device, a Smart Display, by means of an IoT Box.

Finally, we have also implemented: *i)* an integrated multi-sensor for ozone, carbon dioxide (CO_2), PM2.5, PM10, temperature, and humidity; *ii)* a gateway and local actuator for management of the controlled mechanical ventilation unit and the sanitizer based on NTP technology according to the air quality level indoor and outdoor; and *iii)* a planner based on AI algorithms (reinforcement learning tools) for optimizing the control of the air quality, thermal comfort, and energy consumption considering future states of the system (*e.g.*, weather forecasting, space occupancy).

III. THE SAFE PLACE SCENARIOS

The SAFE PLACE project foresees both vertical scenarios (*Safe Path*, *Safe Space and Objects*, and *Safe Air*) and a horizontal scenario (*Safe Place*), as described in Fig. 2.

All the installations are currently ongoing and will be definitive at the end of 2022. Therefore, so far all the technologies and scenarios have been tested and validated in simulations and in temporary installations. In all these tests the systems performed very well, achieving state-of-the-art performances on several tasks. Quantitative results are reported in [5].

In the following, for each vertical scenario, their peculiarities are discussed in order to comply with the DATE community and to cope with the main aim of the paper. In particular, will be considered the uniqueness, the outcomes for the community, lacks, and the post-covid outcomes that emerge from the scenarios.

A. *Safe Path*

In this scenario, the objective is to monitor people's flow, identify gatherings, and assure the correct usage of PPE (*e.g.*, face masks) in real-time, raising an alarm in case of violation or

[1]The project also involved modules of psychological support, which here we prefer to omit for the sake of space.

automatically restricting access to some areas. Such a system can be useful in places like museums or stores, *i.e.*, public locations with rules on maximum room capacity and where it makes sense to prevent or discourage people gatherings.

The analysis of face masks in real-time is a challenging computer vision task: for several reasons: *i)* it considers the detection of small objects on distant faces; *ii)* masks can have colors that generate camouflage effects with the skin; *iii)* the scarcity of annotated datasets does not allow for proper training of a classifier in a supervised setting. In this regard, the project contributed to the guided creation of a dataset in which data from multiple sources have been aggregated and augmented with synthetic data using a visualization technique to understand if there were missing data [6].

Crowd detection for anti-covid purposes differs from classic crowd surveillance [1] in that it becomes crucial to capture the distance at which people are from each other, trying to avoid the formation of gatherings of people standing at a distance of less than 2m. However, all this represents a minor challenge at a technological level, given that calibration systems for the mapping of moving objects on the plane are rich and the problem can be said to be solved.

In case of violation, the incident is reported to a security operator, preventing more people or the person not wearing a face mask to enter the room. This latter decision logic represents the first case in which video analysis is strictly mandatory and cannot be replaced with other more privacy-preserving methods. On the one hand, the General Data Protection Regulation (GDPR) must always be taken into consideration; on the other hand, we find ourselves in the condition of carrying out high-resolution analyses of the human face, which would facilitate the improper use of personal data.

The *Safe Path* scenario is the heaviest in computational terms. Indeed, it was deployed on a high computing platform which is expensive in terms of power consumption. Nevertheless, we have evidence that such a fine-grained monitoring operation can be automatically achieved, thus it is worth investigating how the models can be compressed to be deployed to embedded devices (*e.g.*, relying on [7]). The DATE community can offer hints to make the system scalable.

The easing of social and health tensions on the COVID-19 problem, due to its weakening has essentially declassified the mask detection module to a purely technical exercise. Besides, after having consulted the managers of the various sites hosting the SAFE PLACE scenarios, none of them appeared interested in this feature of the system.

On the other hand, the detection of masks requires a series of crucial skills that are very similar to those required for other applications appearing in the literature.

Finally, the problem of analyzing distances between people, which can be performed effectively, allows us to address interesting issues of social signal processing. This last involves the computational coding of social cues, such as nonverbal behavior during face-to-face interactions. It is known that the distance maintained between two individuals, or proxemics is indicative of the existing social relationship [1]. Therefore, the emphasis on measuring distances between people can promote a new type of profiling of crowds, and understand, for example, if one is in front of couples or people close by chance; whether there are larger or smaller groups.

B. Safe Space and Objects

For this scenario, we developed devices for the sanitization of air and surfaces using UV lamps and ionic systems using advanced materials for the production of lighting fixtures capable of triggering indirect UV sanitization. Air sanitization systems using UV and ions have been in use for years for the reduction of viral loads in the air and effectiveness against the SARS-CoV-2 virus has been demonstrated in lab tests.

The SAFE PLACE project pushed the integration of UV/ion sources in luminaires, integrating the two functions of lighting and sanitization in a single fixture. In addition, the lighting function required specialization through the application of the HCL paradigm to support people during lockdown periods. Well-known chromotherapy functions have been integrated via 5-channel dimmers (3 RGB channels + 2 Tunable White channels) for a precise selection of the chromatic coordinates. Finally, the validation tests on the ability to reduce the viral load, conducted by the Microbiology laboratory of the University of Padua, allowed us to evaluate the efficacy in reducing the SARS-CoV-2 viral load for luminaires based on photoactive technology and for lamps based on inactivation technology. The experiments lead to an estimate of the inactivation time and the abatement of the viral charge.

The implementation of this scenario is the result of a close collaboration between several companies and research centers. The ion generation system produced by one company partner has been integrated into lighting fixtures produced by other companies of the Consortium, creating devices capable of performing a double sanitizing action through the combined use of ions and UV (both direct and confined).

C. Safe Air

In this scenario, the goal is to guarantee appropriate air quality levels and thermal comfort using smart technologies, such as sensors, actuators, and AI algorithms.The novelty relies on the sensors/actuators adopted and on automated planning based on AI algorithms (reinforcement learning tools) for optimizing the control of air quality, thermal comfort, and energy consumption considering also future states of the system (*e.g.*, weather forecasting and space occupancy).

The planner developed in the project uses recent techniques based on Monte Carlo Tree Search (MCTS), recently used in the scientific literature to learn strategies for game playing (such as in the popular AlphaGo). These techniques have been applied to the air quality control problem, in which uncertainty is a key ingredient of the living contexts different from game environments in which the dynamics are completely known and deterministic. The application of MCTS planning to the Safe Air context represented a significant contribution to the state-of-the-art since it guarantees optimality conditions under regimes of uncertainty well beyond ad-hoc manual rules.

A final point of interest is related to the possibility to implement the tool on embedded platforms. The MCTS approach also allows parallelization hence the optimization of the tool on multi-processors embedded platforms could be considered in future work.

The approach for air replacement and sanitization has been recognized as crucial for pandemic management and yet it is easy to be convinced that this technology will be useful in the post-pandemic. In particular, designing an energy-efficient device ensures its future use. Especially in Europe, energy efficiency has become an essential criterion in all architectural planning.

IV. Scenarios in everyday life

The *Safe Path* vertical scenario is particularly interesting for environments with crowded situations. Possible use cases include stores, museums, and cinemas. For this reason, the trial is being deployed in the public library and cultural center *"A. Mantegna" of Piazzola sul Brenta (Padua, Italy)*.

The installation consists of one smart camera, a server connected to the camera for processing gatherings and face mask detection, one BOX-IO, and the smart door. The smart automatic door has been installed at the entrance of the building, while a smart PTZ camera monitors the entrance and the reception desk from an elevated point of view inside the building. The camera and the door are connected to the same network: the camera is cabled and the door is in WiFi. The smart camera is independent and monitors the area detecting the formation of gatherings, as well as the correct usage of face masks. As previously mentioned, in case of a violation in gatherings (either in the number of people and spatial distance) and/or in wearing face masks the automatic door does not allow any further entrance, and the alarm state is notified to the security operator.

The vertical setup for *Safe Space and Objects* and *Safe Air* has been implemented in the ice cream shop *"Chocolat" (Mestre, Venice, Italy)*, in a space of over 500m^2. The capabilities of sanitation using intelligent sensors and the technologies of air purification are the core of this installation.

In the areas the sanitation of surfaces with UV lights is performed, both automatically (with no people in the area) and with manual activation. Depending on the area sanitation may be performed with ions. Sanitization is scheduled to be automatically performed after the closure of the shop, before the opening, and every two hours. The air quality is also verified periodically in terms of ozone, CO_2, VOC, PM2.5 e PM10, temperature, and humidity. Finally, during the day the color of the lights is changed following the circadian cycle.

V. The Safe Place Scenario: Work in Progress

In the Safe Place scenario, the joint application of all the vertical setups *Safe Path Safe Air* and *Safe Object and Space* is required. The place of installation is in the *"Fenice" Green Energy Park (Padua, Italy)*.

This park is a reduced version of a smart city. It hosts several structures including two multipurpose classrooms and one hall with over 80 seats, used for high school education purposes and dissemination on green and ecological technologies, all located in a building with the most efficient energy class. Also, the park offers a bike station (both electric and not) and a youth hostel with 23 beds. As of this writing, the final installation of the Safe Place integrated system has just finished, and field tests are in progress. This environment is large enough to allow the co-presence of all the scenarios. This is not a mere collection of independent entities, but a coexistence in which the features seen previously are aware of and exploit each other. Specifically, the presence of people to activate/deactivate the object sanitization can be carried out by camera sensors to have redundant monitoring. The full assessment of this scenario is expected at the end of February 2023.

After that, there will be a further interview session, to gather the end users' and stakeholders' impressions and observe whether the findings of the co-design phase remain the same.

VI. Conclusions

This paper presented Safe Place, a choral industrial-academic experience with more than 50 engineers, professors, psychologists, entrepreneurs, and professionals working together for around 2 years and a half (*i.e.*, 24 months). This is an *unicum* in the panorama of the standard EU projects, made possible by the proximity of the various partners. This type of project allowed us to get an honest insight into the effectiveness of the proposed technology against the pandemics, but also important feedback about its potential when the pandemics will definitely end.

The take-home message collected so far speaks loud: anything that could affect privacy, such as visual analysis for the detection of masks and gatherings, is postponed in importance compared to technologies that are privacy by design. This is surprising because it is well known that the correct use of masks and social distancing are essential for the containment of the virus. It is therefore very plausible that these technologies will be abandoned from an industrial point of view after the end of the pandemic.

References

[1] M. Cristani, A. Del Bue, V. Murino, F. Setti, and A. Vinciarelli, "The visual social distancing problem," *Ieee Access*, vol. 8, pp. 126876–126886, 2020.

[2] G. Skenderi, A. Bozzini, L. Capogrosso, E. C. Agrillo, G. Perbellini, F. Fummi, and M. Cristani, "Dohmo: Embedded computer vision in co-housing scenarios," in *2021 Forum on specification & Design Languages (FDL)*, pp. 01–08, IEEE, 2021.

[3] L. Gamberini, P. Pluchino, D. Bacchin, A. Zanella, V. Orso, S. Anna, and D. Mapelli, "Iot as non-phaarmaceutical interventions for the safety of living environments in covid-19 pandemic age," *Frontiers in Computer Science*, 2021.

[4] L. Capogrosso, G. Skenderi, F. Girella, F. Fummi, and M. Cristani, "Toward smart doors: A position paper," *arXiv preprint arXiv:2209.11770*, 2022.

[5] M. Capuzzo, A. Zanella, M. Zuccollo, F. Cunico, M. Cristani, A. Castellini, A. Farinelli, and L. Gamberini, "Iot systems for healthy and safe life environments," in *2022 IEEE 7th Forum on Research and Technologies for Society and Industry Innovation (RTSI)*, pp. 31–37, IEEE, 2022.

[6] F. Cunico, A. Toaiari, and M. Cristani, "A masked face classification benchmark," *arXiv preprint arXiv:2211.13061*, 2022.

[7] F. Cunico, L. Capogrosso, F. Setti, D. Carra, F. Fummi, and M. Cristani, "I-split: Deep network interpretability for split computing," in *2022 26th International Conference on Pattern Recognition (ICPR)*, pp. 2575–2581, IEEE, 2022.