SatNav E@syCare telemedicine platform in the management of Covid-19 patients: field trial results

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***Abstract*—In the framework of the Covid-19 pandemic, digital technology has played a key role in the healthcare sector, becoming essential for improving the quality of care and well-being of individuals and populations. In this scenario, telemedicine platforms have enabled remote monitoring, reducing the contacts between patients and doctors and automating health processes. In this paper, we present the experience of SatNav E@syCare, a telemedicine platform enhanced with new functionalities to respond to the outbreak. In particular, Global Navigation Satellite System technology has been added to the system to geo-tag vital parameters, together with the possibility of digitizing examinations (e.g., lung ultrasound), planning access to the territory, automatically managing patient visits and monitoring patient physical activity. The system has been used by general practitioners and doctors of continuity care in different ways according to the phase of the pandemic and the adopted model of care (patient self-measurements vs home visits). More than 2000 patients of all ages have been monitored with SatNav E@syCare. Among the doctors involved in the project, more than 90% are using the system for at least one hour per day, leading to a reduction of time spent to manage patients. Moreover, the system has simplified their daily work, thanks to the digitization of information and sharing of data with colleagues. In their opinion, in a non-pandemic future, the use of the system will introduce benefits both for patients and healthcare professionals in the monitoring of chronic conditions on the territory.**

***Index Terms*—telemedicine, covid-19, remote monitoring, questionnaires, field trial results**

I. Introduction

With the current Covid-19 pandemic, digital technologies have become crucial in everyday life. In fact, although some activities have been victim of the crisis, technology has enabled and ensured continuity in many fields which would have stopped without it during lockdowns. Some examples are retail, with e-commerce and online shopping, food and beverage, with home delivery, and education and work, which have become remote and smart, making technology ubiquitous in every home and family [1]–[4].

In this pandemic scenario, where multiple health-related problems have emerged, e.g., the overloading of hospitals and the monitoring of people treated at home, digital technology has played a key role also in the healthcare sector: the outbreak has pointed out how essential technology is in improving the quality of care and well-being of individuals and populations, while controlling costs. Even if some barriers (e.g., the need for data sharing and rigorous evaluation and ethical frameworks) remain, digital technologies have offered tools for supporting the pandemic response in management and health issues, such as contact tracing, quarantine and self-isolation, screening for infection, planning and tracking of the disease and clinical management of infected individuals, from diagnoses to monitoring and prediction of clinical outcomes [5], [6].

Among the technologies employed to respond to the emergency, telemedicine platforms have helped in solving some management problems, with the remote monitoring of vital parameters and measurements and the sharing of data among the care team members. The main benefits have been the reduction of contacts between doctors and patients, the better allocation of healthcare resources, the automation of health processes and the reduction of anxiety and depression in patients [7]–[10].

SatNav E@syCare is a telemedicine platform used in Tuscany region (Italy) for the management of Covid-19 patients. The original system, called E@syCare, designed to monitor chronic patients, e.g., heart failure ones, [11] was empowered with new functionalities to respond to doctors' requests, thus simplifying the management of the pandemic. With this platform, general practitioners (GPs) and doctors of continuity care (USCA) have had the possibility to remotely monitor infected patients, including physical activity, and organise domiciliary visits in case of medical facilities, with the possibility of digitizing examinations, such as lung ultrasound. Moreover, Global Navigation

Satellite System (GNSS) technology has enabled the geo-tagging of measurements, to provide advanced functionalities to the final users, e.g., epidemiological maps to control the spread of the virus [12], [13].

This paper presents the complete SatNav E@syCare system, highlighting the new modules added in response to the outbreak and its use and results on the territory, according to the stage of the Covid-19 pandemic and the consequent adopted model of care. At the beginning of the outbreak, in fact, doctors preferred to employ the home monitoring module, remotely monitoring the clinical status of infected patients, avoiding contacts and visits, while enabling the adoption of a therapy similar to a hospital admission and promptly identifying any sign of aggravation. Then, with the institution of USCA doctors, the employment of healthcare facilities and the introduction of vaccines, the adopted model shifted to multiple home visits and accesses per day, with the consequent employment of professional kits.

After this introduction, Section II describes the telemedicine platform, with a focus on the modules of the system and the functionalities added in response to the outbreak, and illustrates the pilot. Section III presents and discusses the results achieved on the territory, while conclusions are drawn in Section IV.

II. Materials and Methods

SatNav E@syCare telemedicine platform aims to enable remote monitoring of patient vital parameters by healthcare professionals.

The system has an overall client-server architecture and consists of three modules: i) the cloud module, accessible through an Internet browser, that performs the functions of an Electronic Medical Record (EMR) and data collection centre; ii) the home kit, composed by a tablet hosting the SatNav E@syCare Home Android application and a set of Bluetooth biomedical sensors, to support self-measurement of vital parameters by patients; and iii) the professional kit, with a tablet with the SatNav E@syCare Professional Android application installed and a set of more complex Bluetooth biomedical sensors, dedicated to the healthcare staff to acquire data during home visits. The two kinds of kits, which represent the clients distributed on the territory, automatically collect measurements from the sensors and send them to the data collection centre, enabling the healthcare staff to access data via the EMR whenever they have an Internet connection, using any device supporting an Internet browser. Also manual insertion of data is available, but it is not recommended to avoid human errors.

More specifically, the web-based EMR enables doctors to perform the following actions:

- manage patient registry and clinical diary;
- set up personalised care plans for patients, which are automatically delivered to home applications as a reminder to patients, indicating which and how many measurements, questionnaires and prescriptions to take periodically;
- set up rules for the generation of reporting events for each patient, so that the system notifies the collection of measurements that violates the threshold set by the doctor;
- consult the measurement history graphically over a customisable period;
- record results of instrumental or laboratory examinations with the possibility of uploading files associated with the examination (e.g., images and text files) and reports;
- manage the patient care team, allowing other healthcare professionals to access to all patient data, thus simplifying the sharing of patient data among colleagues;
- schedule patient accesses (home, phone or outpatient), by creating a daily to-do list, and record actions taken performing visits, e.g., acquired measurements and clinical notes (if the professional kit is used for the access, data are automatically synchronised with the EMR);
- download patient-related reports.

The home kit is associated with a single patient who does not need to enter credentials to perform operations. Through a simple Graphical User Interface (GUI), the application reminds the patient when to perform self-measurements by means of audio/visual reminders, according to the care plan set up by the doctor in the cloud. In addition, the application guides the patient through the use of the sensors and provides immediate feedback on the outcome of the measurement. Finally, it transmits the acquired data to the cloud, making them immediately available to the care team in the EMR. The patient can also use the application to take extra measurements, i.e., outside the monitoring plan, manually or automatically via Bluetooth sensors.

The professional kit is designed to support professionals during home visits or to manage patients in a healthcare facility. The Bluetooth sensors included in this kit are usually more complex than the ones in the home kit, to acquire measurements that the patient is not able to acquire by himself (e.g., spirometry and multi-lead electrocardiogram). Once logged in, the application provides the list of patients in charge and gives the possibility to perform a visit for each of them, including annotated measurements and clinical diary entries (i.e., medical history, objective examination and therapy). Data are automatically synchronised with the cloud and can be immediately consulted via the EMR.

Data between the server and the clients are exchanged via the secure web communication protocol HTTPS, assuring the identity of the parties, confidentiality and, in general, security of sensitive data required by the current regulations (i.e., GDPR).

For the purpose of the pilot, the cloud application was deployed on a Tomcat 8 application server running on a Linux-based virtual machine with 2 processors, 4 GB RAM and 80 GB disk space. Monitoring kits were assembled by installing the mobile applications (i.e., home and



Fig. 1. Home kit.

professional) on 8" tablet running Android 9 operating system and configuring the set of Bluetooth sensors. A SIM with 4G connectivity was included in all kits. Tablet with pre-configured application along with thermometer, pulseoximeter, blood pressure monitor and smartwatch (only in case of home kit) were finally placed in a bag to be delivered to the user. An assembled and configured home kit is shown in Fig. 1.

The SatNav E@sycare telemedicine system has been demonstrated in a 13-months pilot starting from November 2020. The pilot involved medical staff mainly dedicated to the out-of-hospital care of patients affected by Covid-19. Target patients were both those treated at home through self-measurements or home visits and those hosted in protected structures like dedicated hotels or elderly housing.

A total of 10 sanitary districts belonging to the Local Health Units of North-West and Central Tuscany received the monitoring kits and login credentials to enable medical staff to access the cloud application basing on their role (e.g., USCA doctors, nurses, GPs and specialists). Each district represents an isolated compartment in the system and counts from 5 to 20 healthcare professionals. Large districts were further divided into sub-compartments implementing a tree structure.

The number of enrollable patients in the pilot was unbounded and each of them was requested to provide his/her informed consent to enter the pilot.

Medical staff participating in the pilot was firstly trained on the telemedicine system with 2-hours online session. During this session, organised district by district, the main features of the system and specific use-cases of management of patients provided with home kit for self-measurement vs patients monitored during visits by medical personnel with the professional kit were presented.

Home monitoring kits were assigned and delivered to the target patients at home by the medical personnel, in order to allow the remote monitoring of their clinical status. Most critical and frail patients were the primary users of this kind of kit. At the end of the monitoring period, varying in general from one to few weeks depending on the patient condition and severity of the disease, the kit was collected and sanitised before being ready for the assignment to a new patient.

On the contrary, professional kits were used by healthcare professionals during visits to patients resting at home or hosted in dedicated structure such as sanitary hotels or elderly housing to collect vital signs and clinical diary registrations. The number of visits per patient varied according to the evolution of the disease from two to tens, especially considered the protected facilities in which patients were monitored at least once per day during the entire period of stay.

III. Results and Discussion

During the pilot, SatNav E@syCare has demonstrated to be flexible, configurable and customisable on both professional and patient sides.

The new features added to the system have allowed to better support the process of patients management by the doctors. More in detail, they have allowed the optimisation of patient management and the team periodic home visits organisation and scheduling process, resulting in the speed up of the assignment process of daily home visits to team members and, in general, of all actions that doctors have to perform during visits and the dematerialisation of some paper forms.

Final users have been almost 2,400, considering patients and healthcare professionals. More in detail, 14 GPs, 14 groups of USCA doctors, 2 specialists and 6 nurses have used SatNav E@sycare for the management of about 2,350 Covid-19 patients in Tuscany region. 53% of them are male, the other 47% are female, and their age ranges from 18 to 92 years.

At the beginning of the pilot (from November 2020 to April 2021), the preferred model was to deliver home kits to infected patients and reuse them after recovery and sanitisation for other patients. In the following period, starting from May 2021 until the end, the USCA doctors

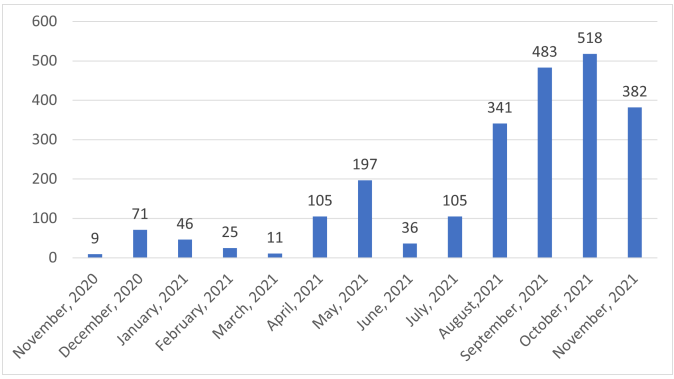


Fig. 2. Pilot patients enrolment time distribution.

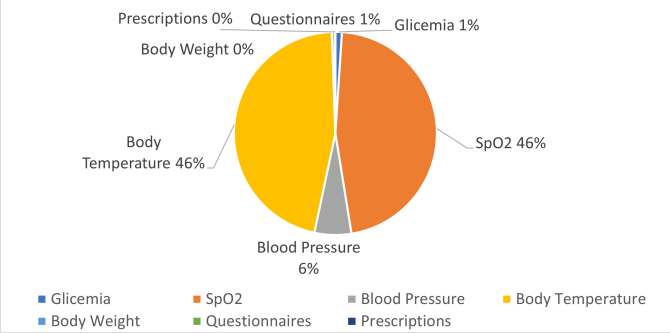


Fig. 3. Acquired measurements per type.

changed their model of care to domiciliary visits at home, in Covid-19 hotels or elderly housing, mostly employing professional kits. Fig. 2 shows the number of patients enrolled in the system per month. As expected, the number of patients managed with the platform has grown with the shift of the model of care, which allowed to manage more patients with a single professional kit and the EMR, thus enrolling more people together.

SatNav E@syCare has been used to acquire about 42,400 measurements of different types. As presented in Fig. 3, oxygen saturation (SpO_2) and body temperature are the most acquired vital parameters, reaching together the 92% of total measurements. This result is in line with the type of enrolled patients, since Covid-19 manifests itself usually with fever and affects lungs, leading to the monitoring of body temperature and SpO_2.

In addition, as a consequence of the adopted model of care and reflecting the number of patients enrolled with the home and professional modules, about the 89% of measurements have been acquired by a healthcare professional, while self-measurements represent only the 11% of total measurements.

Finally, doctors have managed about 16,800 accesses to patients through the platform. In particular, the 95% of them has been done by using professional kits, highlighting the importance of automatic synchronisation with the cloud to avoid manual transcription, errors and loss of sheets.

From the technological point of view, no episodes of data loss and unavailability online had been recorded during the pilot. The only exception was due to the deployment online of new features, which was planned and executed at night, when no user was logged in and using the system.

To evaluate the efficiency and sustainability of SatNav E@syCare for the medical staff, we have delivered a questionnaire to healthcare professionals, in order to assess the impact of the system on their work with respect to the traditional practice. The questionnaire was composed by 6 questions, regarding the amount of time the user uses the system during the day, the amount of daily time saving, the capability of the system to simplify the access to information, make it easier to share data among colleagues, optimise the work and introduce benefits to healthcare professionals and patients for chronicity monitoring and the

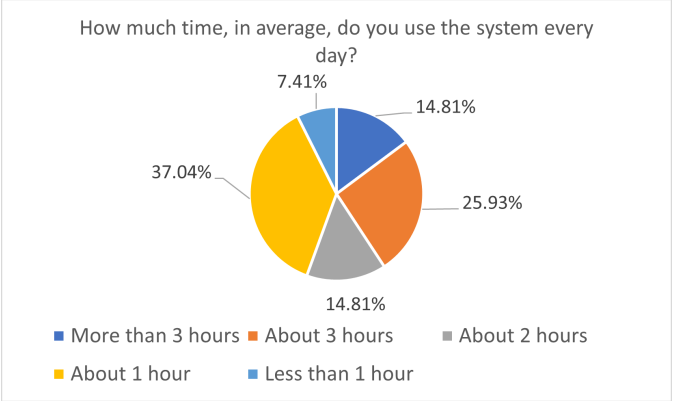


Fig. 4. Answers to the question on the usage of the system.

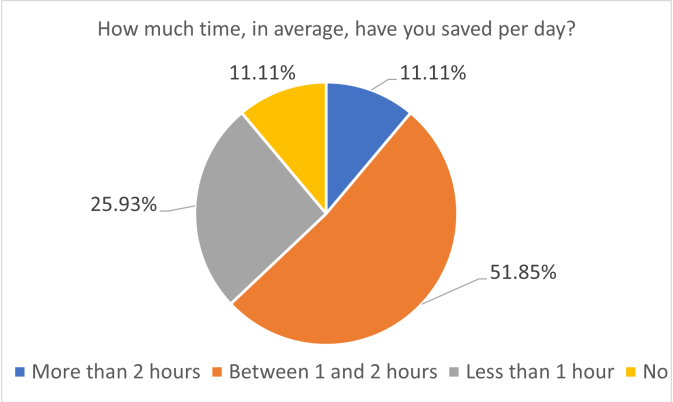


Fig. 5. Answers to the question on time saving.

willingness of the user to use the system in the future.

Results of the questionnaire are shown in Figs. 4-9. In detail, more than 90% of the users stated to use the system for at least one hour per day, and about 25% of them for at least three hours per day (Fig. 4). Moreover, it emerged that more than 60% of the users has saved more than one hour per day by using SatNav E@syCare (Fig. 5), thus achieving

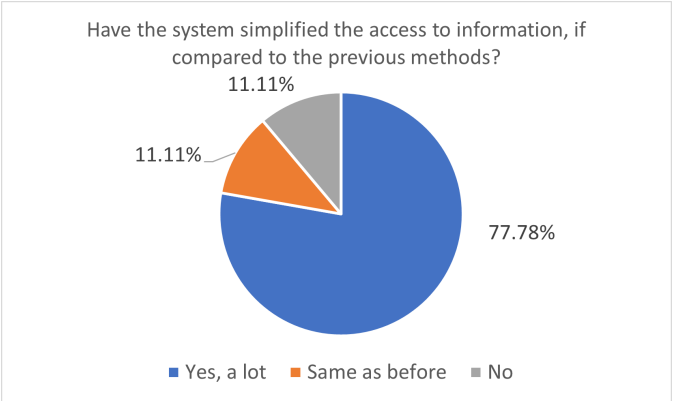


Fig. 6. Answers to the question on the capability to simplify the access to information.

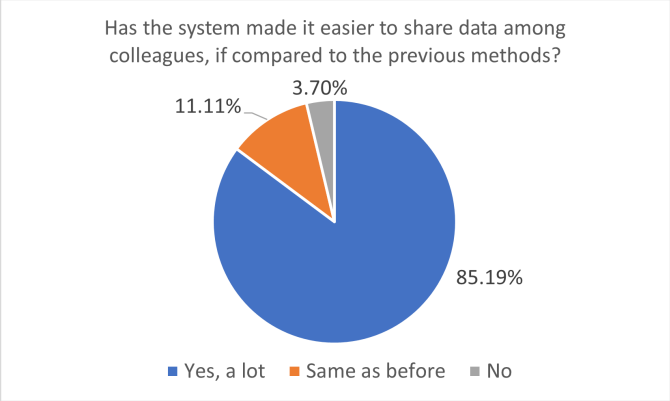


Fig. 7. Answers to the question on the capability to make it easier to share data among colleagues.

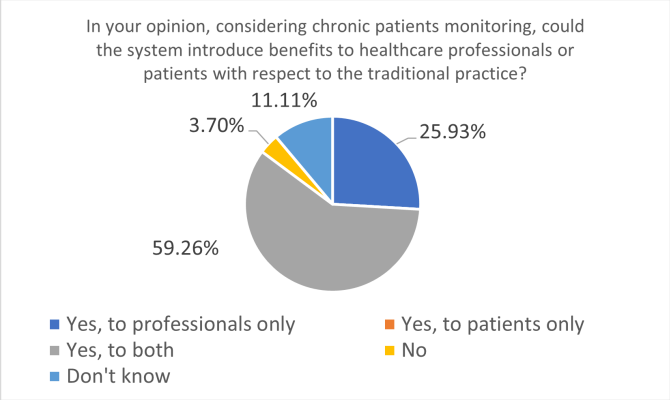


Fig. 8. Answers to the question on the capability to optimise work and introduce benefits to healthcare professionals and patients for chronicity monitoring.

good results on usability, efficiency and sustainability of the platform for healthcare professionals. More than 75% of users declared that digitising the information processed by the system has increased the ease of access, and for about 85% of users the system has made it easier to share patient data with colleagues, as reported in Fig. 6 and Fig. 7. Considering a non-pandemic use of the telemedicine platform, i.e., the monitoring of chronic patients on the territory, the majority of the users believes that SatNav E@syCare could introduce benefits both for healthcare professionals and patients (Fig. 8). At last, more than 90% of users would like to use the system again in the future if given the chance, thanks to the advantages in management brought by the system and the flexibility, configurability and customisation of the platform.

IV. Conclusion

Digital technologies in healthcare have become crucial to respond to the outbreak, highlighting how important they are to improve the well-being of individuals and populations. Among them, telemedicine platforms have enabled remote monitoring of patient vital parameters and the automation of

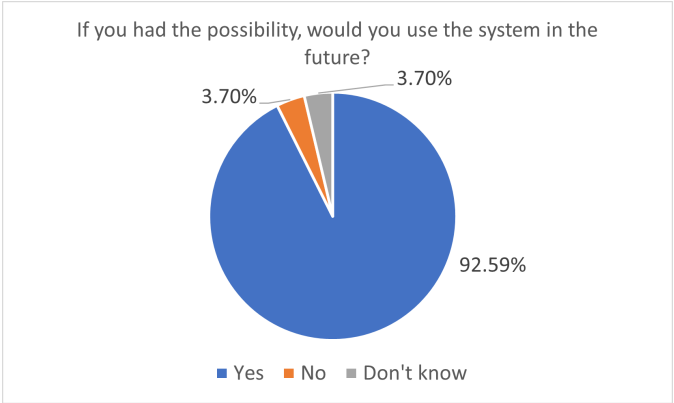


Fig. 9. Answers to the question on the willingness of the user to use the system in the future.

health processes, leading to the better allocation of healthcare resources.

This paper presents SatNav E@syCare, a telemedicine platform empowered with new features and functionalities for the management and remote monitoring of Covid-19 patients. The system is composed by the cloud module, which represents the electronic medical record, and two types of monitoring kits: the home kit for single patients to perform self-measurements and the professional kit for healthcare professionals to manage multiple patients. All measurements collected on the territory are geo-tagged by the tablet, allowing to draw customisable epidemiological maps to control the spread of the virus. Via the electronic medical record, the doctors are able to set up the personalised care plan, automatically synchronised on the home kit, plan accesses to the territory and digitise examinations.

During the 13-months pilot on the Tuscan territory, about 2,350 patients have been enrolled with home and professional kits by almost 40 groups of healthcare professionals. In total, about 42,400 measurements have been acquired, with temperature and oxygen saturation representing the most collected vital parameters. Finally, the platform has managed about 16,800 accesses to patients.

SatNav E@syCare has been evaluated by the medical staff involved in the pilot via a questionnaire. Results have shown that the system has been used for at least one hour by more than 90% of users, allowing to save more than one hour per day for the 60% of users. The telemedicine platform has simplified the daily work and the sharing of information. According to them, it will be useful to monitor chronic patients on the territory in the post-pandemic future.

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REFERENCES

[1] C. Bai, M. Quayson, and J. Sarkis, "COVID-19 pandemic digitization lessons for sustainable development of micro-and small- enterprises," *Sustainable Production and Consumption*, vol. 27, pp. 1989–2001, July 2021.

[2] P. Soto-Acosta, "COVID-19 Pandemic: Shifting Digital Transformation to a High-Speed Gear," *Information Systems Management*, vol. 37, no. 4, pp. 260–266, September 2020.

[3] S. Lopez-Ridaura, A. Sanders, L. Barba-Escoto, J. Wiegel, M. Mayorga-Cortes, C. Gonzalez-Esquivel, M. A. Lopez-Ramirez, R. M. Escoto-Masis, E. Morales-Galindo, and T. S. García-Barcena, "Immediate impact of COVID-19 pandemic on farming systems in Central America and Mexico," *Agricultural Systems*, vol. 192, p. 103178, August 2021.

[4] J. Selimović, A. Pilav-Velić, and L. Krndžija, "Digital workplace transformation in the financial service sector: Investigating the relationship between employees' expectations and intentions," *Technology in Society*, vol. 66, p. 101640, August 2021.

[5] S. Whitelaw, M. A. Mamas, E. Topol, and H. G. C. Van Spall, "Applications of digital technology in COVID-19 pandemic planning and response," *The Lancet Digital Health*, vol. 2, no. 8, pp. e435–e440, August 2020.

[6] J. Budd, B. Miller, E. Manning, V. Lampos, M. Zhuang, M. Edelstein, G. Rees, V. Emery, M. Stevens, N. Keegan, M. Short, D. Pillay, E. Manley, I. Cox, D. Heymann, A. Johnson, and R. McKendry, "Digital technologies in the public-health response to COVID-19," *Nature Medicine*, vol. 26, no. 8, pp. 1183–1192, August 2020.

[7] B. Calton, N. Abedini, and M. Fratkin, "Telemedicine in the Time of Coronavirus," *Journal of Pain and Symptom Management*, vol. 60, no. 1, pp. e12–e14, July 2020.

[8] J. Wosik, M. Fudim, B. Cameron, Z. F. Gellad, A. Cho, D. Phinney, S. Curtis, M. Roman, E. G. Poon, J. Ferranti, J. N. Katz, and J. Tcheng, "Telehealth transformation: COVID-19 and the rise of virtual care," *Journal of the American Medical Informatics Association*, vol. 27, no. 6, pp. 957–962, May 2020.

[9] D. M. Mann, J. Chen, R. Chunara, P. A. Testa, and O. Nov, "COVID-19 transforms health care through telemedicine: Evidence from the field," *Journal of the American Medical Informatics Association*, vol. 27, no. 7, pp. 1132–1135, May 2020.

[10] S. Panicacci, M. Donati, A. Lubrano, A. Vianello, A. Ruiu, L. Melani, A. Tomei, and L. Fanucci, "Telemonitoring in the Covid-19 Era: The Tuscany Region Experience," *Healthcare*, vol. 9, no. 5, April 2021.

[11] M. Donati, A. Celli, A. Ruiu, S. Saponara, and L. Fanucci, "A Telemedicine Service System Exploiting BT/BLE Wireless Sensors for Remote Management of Chronic Patients," *Technologies*, vol. 7, no. 1, p. 13, January 2019.

[12] S. Panicacci, G. Giuffrida, M. Donati, A. Lubrano, A. Ruiu, and L. Fanucci, "Empowering Home Health Monitoring of Covid-19 Patients with Smartwatch Position and Fitness Tracking," in *2021 IEEE 34th International Symposium on Computer-Based Medical Systems (CBMS)*, June 2021, pp. 348–353.

[13] S. Panicacci, G. Giuffrida, M. Donati, A. Lubrano, M. Olivelli, A. Ruiu, and L. Fanucci, "Enhancing a Telemedicine Platform with Global Navigation Satellite System Technology and Clustering Algorithms for Supporting Epidemiological Analysis," in *2021 IEEE International Conference on Electronic Technology, Communication and Information (ICETCI)*, August 2021, pp. 410–414.