Empowering Home Health Monitoring of Covid-19 Patients with Smartwatch Position and Fitness Tracking

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Abstract—**The current Covid-19 pandemic has limited direct contacts among people, since the virus is usually widespread by the drops of saliva. Then, this world outbreak has brought the need to track patients' positions, especially to verify the respect of quarantine regulations for infected people and for their strict contacts. Moreover, the conditions of elderly and high risk patients should be continuously monitored, minimising, at the same time, the exposure of general practitioners. Among the several solutions available on the market, telemedicine seems to be an optimal support for remote monitoring, limiting the contacts between doctors and patients, and fast reaction to worsening of clinical conditions. Telemedicine platforms can also integrate Global Navigation Satellite System technology embedded in wrist devices, to add new functionalities, useful even when the pandemic is over. In this paper, we present the smartwatch integration in the already consolidated E@syCare telemedicine platform, with the aim of tracking patients' positions and monitoring outdoor and indoor fitness sessions. The smartwatch, equipped with WearOS, should have GPS receiver, heart rate sensor and accelerometer and the developed application installed. It randomly collects positions, for patients subjected to quarantine regulations, generating an alarm in case of violation. From the GUI, the user can start fitness sessions, independently or according to the care plan. Positions and fitness sessions are downloaded by the handheld device, and become available for further analysis by the doctors. Nowadays, the platform has been already delivered to 60 patients with the support of European Space Agency (ESA).**

Index Terms—**telemedicine platform, smartwatch, remote monitoring, position tracking, fitness monitoring, covid-19**

I. Introduction

During the first phase of the Covid-19 outbreak, started in Italy at the end of February 2020 [1], and also during the current phase, the administrators and health authorities are facing with multiple management problems. First of all, how to track the position and check movement restrictions of i) infected people left at home, ii) patients early discharged from hospital but potentially always contagious, iii) people subjected to preventive quarantine due to strict contact with infected ones, and in general iv) elderly and people at risk due to exiting diseases, with the aim of detecting unauthorised movements. Another problem regards the monitoring of the clinical status of the target people treated at home, to promptly detect any sign of aggravation before they become irreversible and lead to inevitably hospitalisations, also ensuring the minimal exposure of the medical staff to potentially contagious people [2].

With the remote monitoring of patients, through telemedicine platforms, early signs of infection can be identified, allowing prompt treatment and reducing the number of hospitalised people [3], [4]. In fact, the prognosis-base triage is carried out directly at home for suspected patients, avoiding the risk of spreading the infection given by the people who voluntarily go to hospitals and reducing the risk of infection the medical personnel is exposed, being also able to monitor tens of patients directly from their office/medical department [5], [6].

Considering the IngeniArs S.r.l. E@syCare telemedicine platform [7], it was created to cope with generic chronic illnesses. It meets all the requirements of the traditional Chronic Care Model (CCM), allowing the monitoring of multiple vital parameters (i.e., heart rate (HR), blood pressure, oxygen saturation, body mass, sugar level and ECG) [8]. Similarly to chronic diseases monitoring, the clinical conditions of Covid-19 infected patients may be remotely detected and promptly treated adequately with the same platform, with the addition of body temperature.

Moreover, during the Covid-19 pandemic, it becomes important to track movements of people who present mild symptoms or have been infected by the virus. From this follows the integration of the Global Navigation Satellite System (GNSS) [9] technology embedded in a wearable device, such as a smartwatch. The smartwatch will also

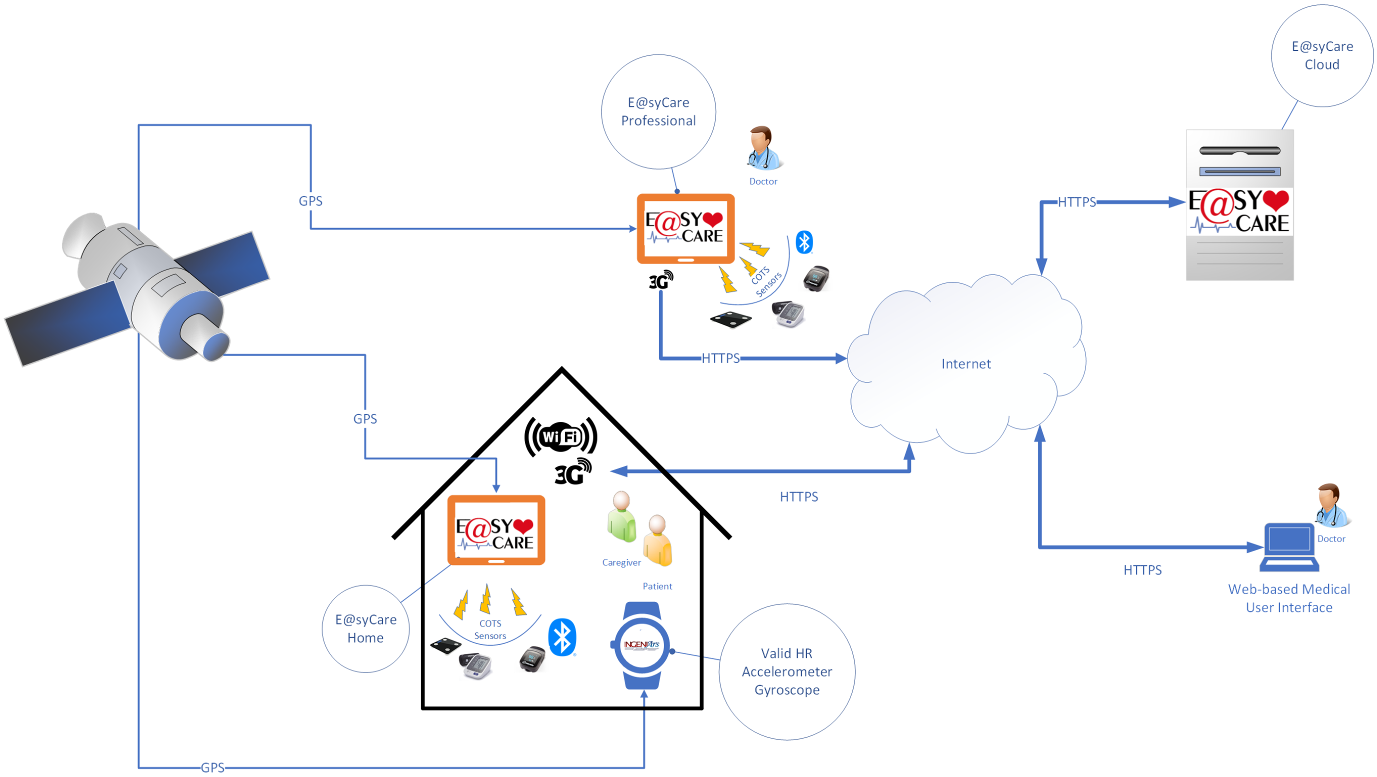

Fig. 1. System architecture.

allow the monitoring of physical activity, prescribed by doctors to enrolled patients to verify, with the other vital parameters, the worsening of the patient's clinical conditions. This feature will be useful also when pandemic is over, to prescribe more subjective exercises.

SatNav E@syCare represents the evolution of the standard E@syCare suite with the integration of a commercial smartwatch featuring as minimum a GNSS receiver, a HR sensor and an accelerometer. The integrated wrist-worn device allows position tracking of people who have been prescribed with restrictive measures, generating an alarm if the smartwatch is not worn or if the user violates the prescription. The positions collected by the system help in controlling the virus spread, through customisable epidemiological maps. In addition, the smartwatch allows fitness monitoring, giving the doctors the opportunity to monitor patients at 360 degrees with a single product.

This paper presents the role and the integration of the smartwatch in the SatNav E@syCare platform. In particular, after this introduction, Section II describes the overall architecture of the telemedicine platform, underlying where the smartwatch is added. Section III details the features and aim of the smartwatch in the system, Section IV highlights the technological challenges we faced, while the software architecture of the developed application for the wearable device is presented in Section V. Section VI shows how collected data are analysed on the cloud. Finally, conclusions are drawn in Section VII.

II. Overall System Architecture

The SatnNav E@syCare system has an overall client-server architecture [7], [10]. It consists of several monitoring kits distributed on the territory, at patients' homes (E@syCare Home) or assigned to medical personnel (E@syCare Professional), and a centralised server software application with storage capabilities (E@syCare Cloud), installed in the service provider facility. Two-way communication between these sub-systems passes through the Internet, using broadband communication technologies (i.e., 3G, 4G, 5G, or WiFi connection).

Considering the two kinds of monitoring kits, E@syCare Home and E@syCare Professional, they include a set of non-invasive Bluetooth (BT) or Bluetooth Low Energy (BLE) biomedical sensors and a gateway (i.e., tablet or smartphone), where an Android application is installed. It has multiple tasks: managing acquisition, local storage and transmission of physiological data and lifestyle parameters collected automatically from the sensor or manually inserted by the user. All the observations of vital parameters are geo-tagged through the GPS receiver on-board the gateway. The two kits differ in the version of the gateway software application and usually in the set of sensors included in the kit, that depends on the target user and the specific disease to monitor.

The smartwatch is included only in the set of sensors of E@syCare Home, dedicated to self-monitoring: it measures activity level (i.e., steps count, physical activity and calories consumption) and tracks the position of the single user over the time. Communication with the gateway and acquisition of interesting measures are managed through a dedicated application installed in the smartwatch. The wrist-worn device integrated in the platform is a TicWatch C2 [11]. However, any other smartwatch equipped with WearOS 2.x [12], accelerometer, HR sensor and GPS and with the developed application installed can be used.

A high-level block diagram of the system showing the key building blocks with their relative attributes and the main interfaces and communication protocols is provided in Fig. 1.

III. The Role of the Smartwatch

The smartwatch is one of the sensors of the monitoring kit of SatNav E@syCare Home. Its aim in the telemedicine platform is twofold:

1) track daily movements of patients who are subjected to quarantine regulations due to Covid-19 (position tracking);
2) monitor physical activity of patients both indoor and outdoor, according to the personalised care plan decided by the doctor or independently (fitness monitoring).

Regarding position tracking, using a smartwatch with GNSS support improves quality and reliability of position estimation during the day, since it is supposed that the smartwatch is always worn. Nevertheless, the position given by GNSS is validated to verify that the device is effectively on wrist, checking whenever a patient removes the smartwatch, potentially violating quarantine. Hence, positions are acquired randomly, in windows of 30 minutes, and each acquired position is validated with HR: if a valid HR measure is acquired, the position is considered valid, otherwise the position is marked as non-valid. In both cases, data are saved on a local file, available for synchronisation with the gateway. So, position tracking is transparent to the user even if the functionality is explicitly shown in the Graphical User Interface (GUI) of the application.

Fitness monitoring, which could be used also at the end of the pandemic, requires the interaction with the user. In fact, according to the doctor's suggestions or independently, the user can start an indoor or outdoor fitness session (according to the current local regulations). During the session, HR and step count are continuously acquired, while GPS positions are acquired only in case of outdoor activities. When the user stops the fitness session, all data are saved in a local file, which will be read and deleted after the gateway has downloaded it. In addition to the HR profile, number of steps and route (if outdoor), also calories and distance are calculated and saved at the end of the fitness session. Calories are derived from the number of steps and weight in kg ($kCal = steps \cdot weight \cdot 0.0005$) [13]. Distance, in case of outdoor fitness sessions, is computed by making the difference between consecutive positions; instead, in case of indoor fitness sessions, it is derived from the number of steps and height in cm ($km = steps \cdot height \cdot 0.414/100000$) [14].

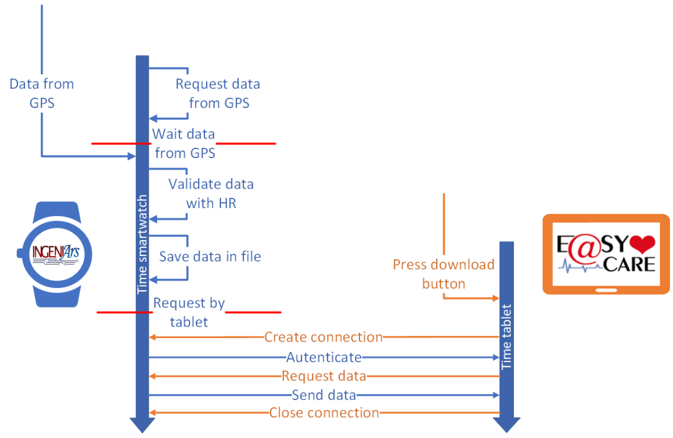

Fig. 2. Example of acquisition flow of the smartwatch and communication with the tablet application.

Data between the tablet and the smartwatch are exchanged via BLE connectivity. To improve the user's privacy, data are not shared with third-party applications, exploiting only the native connection available between Android and WearOS. Once a day, the gateway application reminds the user to download data from the smartwatch, like a standard activity (e.g. temperature measurement). Then, through a guided procedure on the handheld device, the download starts and data saved in local files (GPS and fitness) are sent from the smartwatch to the tablet.

An example of acquisition flow of the smartwatch during position tracking and communication with the SatNav E@syCare Home mobile application is shown in Fig. 2.

Coming to a use case of fitness monitoring, it enables the possibility to correlate the physical activity with the oxygen saturation. Indeed, the general practitioner could plan some physical indoor exercises per day, asking to the patient to take oxygen saturation measurement before and after the physical activity. The measurements can be visualised by the general practitioner, as shown in Fig. 3, to check if patient's conditions

Fig. 3. Example of indoor fitness session visualisation for a general practitioner: oxygen saturation before and after and details of the fitness session (e.g. HR profile).

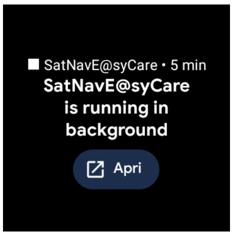

Fig. 4. Notification of the application running in background.

are worsening, and eventually decide for hospitalisation.

IV. Technological Challenges

Smartwatches are embedded devices with limited battery life and reduced computational efficiency. In particular, always-on GPS for position tracking consumes a lot of energy, causing the smartwatch to run out of battery in few hours. For this reason, implementing a continuous position monitoring during the day is not a viable solution. To overcome this issue, the smartwatch in SatNav E@syCare activates the GNSS receiver at most once every 30 minutes, having an almost good accuracy for position tracking during the day while reducing battery consumption. Moreover, since measurements are randomly acquired within windows of 30 minutes, the user cannot foresee the exact moment of acquisition and consequently remove the smartwatch from the wrist. Considering the TicWatch C2 specifications available on the website of the producer [11], the battery lasts up to 2 days, depending on usage. With our application running in background with position tracking enabled on the smartwatch, we are able to achieve up to 36 hours of activity. In this way, the user can charge the smartwatch at night, without losing hours of acquisition.

Since position tracking, if activated, is transparent to the user, the application must not be started by the user himself: most of users can forget or voluntarily avoid to launch it. Then, the application starts at the power on of the wrist-worn device, runs in background and cannot be closed. This behaviour is notified to the user in the notification panel of WearOS (Fig. 4).

The privacy issue due to the acquisition of data for a telemedicine platform opens a challenge in the management of these data. First, all the users have to sign an informed consent to collect medical data and, eventually, activate position tracking. Then, in SatNav E@syCare sensible data are sent over a secure BLE connection, voluntarily avoiding the use of WiFi communication system, by also increasing battery life. In addition, measurements are never sent together with the identification code of the patient. In this way, even if data would be stolen, they cannot be associated with any person. All the files saved in the smartwatch can be read and written only by the application itself, preventing the access by external applications and services. Finally, integrating a WearOS smartwatch allows to send data directly to the handheld device, avoiding to share information with third-party software.

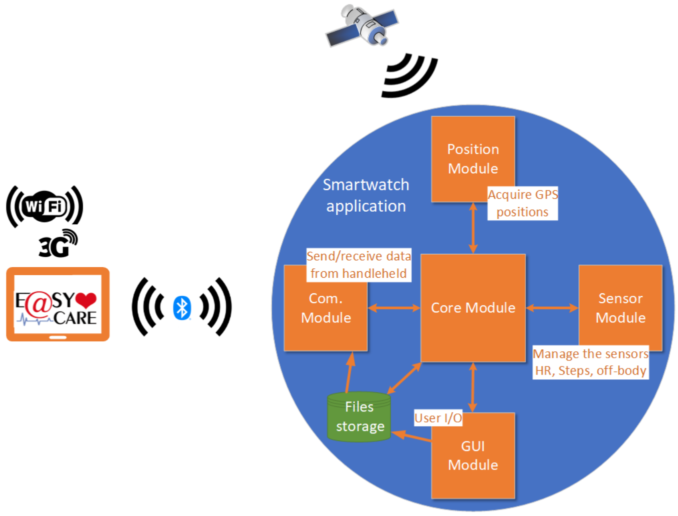

Fig. 5. Software architecture of the smartwatch application.

V. Smartwatch Software Architecture

The software application developed and installed in the smartwatch is based on Android WearOS 2.x. It exploits the standard APIs to improve portability and integration with the existing system. It is compiled using the SDK 30, but it is also compatible for SDK down to 28.

The smartwatch application was developed to perform position tracking and fitness monitoring, as described in the previous sections. Since the first task is transparent to the user, as anticipated in Section IV, a background service starts at the power on of the wrist-worn device launching the application. However, the user can interact with the application to start and stop fitness sessions or to modify settings (i.e., weight and height) through a user-friendly GUI.

The architecture of the smartwatch software application is modular, as shown in Fig. 5, where each module is in charge of specific operations. The modules, described in detail in the following sections, are sensor module, position module, communication module, GUI module, and core module.

A. Position Module

The position module is in charge of the management of the GPS sensor inside the smartwatch. In particular, it activates and deactivates GPS and gets the actual position, if available, or the last available position, if there is no GPS connection. It exploits the Fused Location API to reduce battery consumption: in case of connection with handheld device, the wearable asks the handheld position, if available, avoiding to activate its GPS. This is also needed because in case of in home use, the smartwatch GPS is not able to retrieve new positions without the tablet.

GPS is activated through the Location Provider after a core module request, with high accuracy and minimum displacement equal to 0.5 meters, when tracking is active and it is time to collect a new position, or when an outdoor fitness activity has started. In the first case, GPS is deactivated after 60 seconds, otherwise it is deactivated at the end of the fitness session.

B. Sensor Module

The sensor module is in charge to activate and retrieve the values from step, HR, and low latency off-body sensors. For each sensor, the Sensor Manager inside the module subscribes a listener which sends the updated values to the core module through a callback.

Thanks to their low power nature, steps and low latency off-body sensors are activated together with the start of the application. On the contrary, to reduce the battery consumption, the subscription of the HR sensor is activated only in two scenarios:

- to validate the GPS position, subscribing a listener for the HR sensor until a valid HR is measured for 60 seconds maximum;
- when the user starts a fitness session, subscribing a listener for the HR sensor from the start to the end of the fitness session.

C. Communication Module

The communication module manages the communication with the handheld Android device. It is implemented through a Wearable Listener Service, called Message Service, always active to receive requests from the tablet.

More in detail, this module executes different operations according to the message received from the tablet:

- in case a configuration message is received, the Message Service notifies the core module of the change of the tracking configuration and the latter provides to activate/deactivate tracking according to the configuration received. The Message Service sends an ACK to the tablet for confirmation;
- when information about tracking, number of steps of the day or battery level are required, the communication module sends the requested value to the tablet;
- if a GPS request is received, the Message Service reads the file where GPS data are saved by the core module and, if the file is empty, it sends a NACK, otherwise sends an ACK followed by as many messages as the lines in the file (each message corresponds to a file line and contains a String with a position). At the end of the file, an ACK is sent to the tablet. If another ACK is received, the GPS file is deleted, since all the positions have been received correctly on the gateway side;
- if a download fitness request is received, the communication module checks if there are some fitness files, saved by the core module (each fitness file corresponds to a fitness session). If there are no, a NACK is sent to the tablet; otherwise, the oldest file is read and completely sent to the gateway. Then, if an ACK is received, the already sent fitness file is deleted and the next one, in time order, is read and sent, until there are no more fitness files. At the end, the Message Service sends a stop signal to the handheld device.

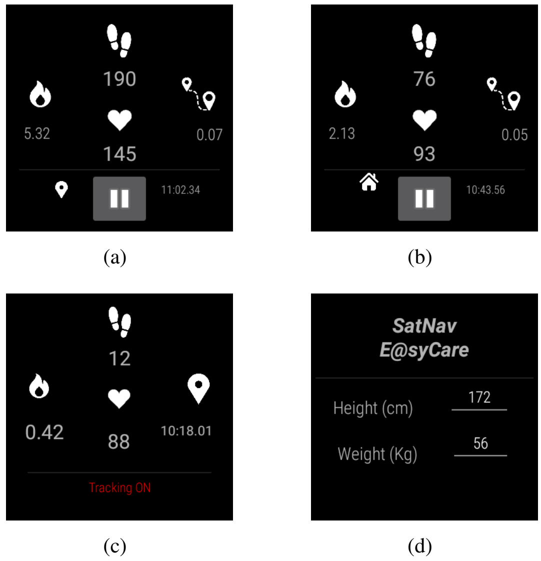

Fig. 6. Screenshots of the application GUI: (a) fitness fragment during outdoor session; (b) fitness fragment during indoor session; (c) overview fragment; (d) setting fragment.

D. GUI Module

The GUI is composed of one main activity and three fragments that fill the main activity when requested by the user. The user can interact with the application to start and stop outdoor or indoor fitness sessions (Fig. 6(a) and Fig. 6(b), respectively), to check a daily report of steps, distance, calories and mean HR (Fig. 6(c)), reset at midnight every day, and to set weight and height (Fig. 6(d)).

E. Core Module

The core module is the heart of the entire application. It executes the cross-validation of the sensors data and stores the user's positions and fitness tracking on files. It also runs the operations related to the user's inputs, while lively updating the daily report. It manages all the other modules, coordinating them, sending requests and receiving values.

When tracking is activated, the core module retrieves and validates the user's position. The GPS position is sent to the core module by the position module and is locally saved waiting for the validation, performed by checking if the user is actually wearing the smartwatch with HR.

Instead, when the user starts a fitness session from the GUI module, the core module retrieves the value of the low latency off-body sensor and, if the smartwatch is worn, activates HR sensor through the sensor module. Moreover, if the fitness session is outdoor, it sends a request for activating GPS to the position module. At the end of the session, the core module requests to power off HR sensor and GPS to the relative modules and it computes calories and distance, saving all the collected values in a new fitness file.

VI. Data Analysis

Thanks to GNSS receiver mounted on the smartwatch and to geo-localisation of the measurements stored on SatNav

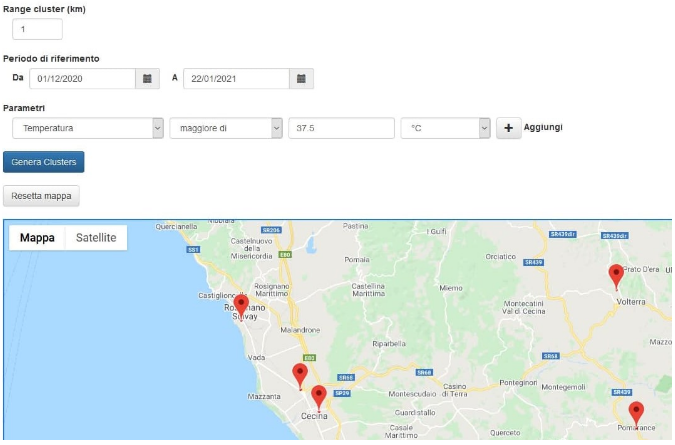

Fig. 7. Example of an epidemiological map generated by SatNav E@syCare Cloud, with cluster radius 1 km and patients with temperature greater than 37.5°C in the period 2020/12/01-2021/01/22.

E@syCare Cloud, it is possible to draw customised epidemiological maps with clusters of patients with respect to certain vital parameters, e.g., temperature, oxygen saturation and blood pressure.

As shown in Fig. 7, a dedicated web page of SatNav E@syCare telemedicine platform allows general practitioners or other members of the healthcare staff to filter patients, setting conditions on their collected measurements in a period of time, such as patients with temperature greater than 37.5°C in the last month. Furthermore, to increase customisation, they have also to select the maximum radius of each cluster. Once extracted the patients and their positions from the platform, clustering is done in two phases: first the number of clusters is generated based on the selected maximum radius; then clusters of patients, based on the location where the measurements are collected, are computed and drawn in the map.

VII. Conclusion

Through the addition of a smartwatch with GPS, heart rate sensor and accelerometer in the list of the available devices of E@syCare Home kit, the SatNav E@syCare platform aims to slow down the rapid spread of Covid-19 pandemic that is affecting the world, integrating the Global Navigation Satellite System technology. The developed smartwatch application is mainly conceived to track the position of patients under quarantine regulations, exploiting the embedded sensors to check if the smartwatch is worn. Furthermore, the application can give a complete picture of the patients' health status, also at the end of the pandemic, by monitoring their indoor and outdoor fitness sessions.

The wearable application is based on Android WearOS and communicates directly with the handheld device, based on Android OS, avoiding to share sensible information to third-party applications. It stores the information about positions, heart rate, steps, distance and calories inside files saved inside the smartwatch. These files are then downloaded on the SatNav E@syCare platform via the handheld device supplied with the Home kit.

To the present day, the SatNav E@syCare platform has passed laboratory tests and has been employed in the territorial healthcare system. In particular, 60 SatNav E@syCare Home kits, including the smartwatch, thermometer, pulsoximeter, scale and blood pressure monitor, have been delivered to patients of the Local Health Unit of North-West Tuscany for remote monitoring, after signed an informed consent.

The SatNav E@syCare project won the ”Space in response to Covid-19 outbreak” Invitation To Tender launched by European Space Agency (ESA) at the beginning of July.

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