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# Development of a Measurement System based on IoT technologies, Artificial Intelligence and Virtual Reality for Personalized Care of Vulnerable Individuals

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**Abstract**— The continuous monitoring of clinical parameters, daily routines, and behavioural activities of older and fragile individuals has become essential to ensure their safety, support autonomy, and enable timely intervention in both domestic and residential care settings. Despite advancements in this context, integrating these technologies into existing healthcare facilities remains a challenge, requiring a balance between technological innovation, personalized care, and operational feasibility. The METASALUTE project addresses this challenge by developing new technology-assisted service models to integrate social and healthcare services. The solution combines Virtual Reality (VR) serious games to stimulate cognitive activity, IoT-based sensors for non-invasive monitoring of physiological and environmental parameters, Artificial Intelligence (AI) techniques for data analysis and a social assistive robot to support daily activities. Implemented across five specialized facilities catering to individuals with varying levels of cognitive and motor impairments, METASALUTE focuses on real-time monitoring of residents physiological parameters, environmental conditions, and the detection of accidental events. Additionally, it supports the social and cognitive well-being of users, aiming to improve their overall quality of life and promote active participation in social settings.

**Keywords**— *personalized care, vulnerable individuals, IoT technology, Virtual Reality, Artificial Intelligence*

## I. INTRODUCTION

As the global population continues to age, the need for effective and scalable strategies to monitor activities and parameters of older and fragile individuals, whether they live

independently at home or in multi-resident environments such as nursing homes, has become an urgent need. Ensuring safety, early detection of health issues, and promoting autonomy requires continuous monitoring of both physiological parameters and daily activities. In this context a key challenge is the design of non-intrusive, reliable, and ethically acceptable solutions that can operate effectively in real-world care settings [1]. To address this, the concept of Ambient Assisted Living (AAL) has emerged as a multidisciplinary approach combining engineering, healthcare, and human factors to enable aging in place with dignity and safety [2]. AAL systems typically integrate non-invasive technologies as physiological monitoring systems, environmental sensors and vision-based systems [3]. Technologies to monitor physiological parameters often consist of wearable devices equipped with accelerometers and gyroscopes. These devices are designed to measure parameters such as heart rate (HR), heart rate variability (HRV), and body motion. They are commonly used for activity recognition, fall detection, and general health status assessment [4]. However, their effectiveness can be limited by the need for active participation from users, which may pose challenges for older individuals with cognitive impairments or physical limitations [5]. Vision-Based Systems, such as RGB-D cameras, are increasingly used for activity recognition and anomaly detection when combined with Machine Learning (ML) techniques [6] [7]. These systems can detect falls, abnormal movements, or social withdrawal. However, despite their technical advantages,

privacy concerns represent a major barrier to their acceptance, especially in personal spaces such as bedrooms and bathrooms [8]. For this reason, environmental sensors are preferred to monitor senior and fragile people. They are passively embedded into the living environment and can monitor both behavioural activity and environmental conditions. For example, PIR and ultrasonic sensors are widely used for indoor localization and activity recognition for their affordability, non-invasiveness, low power consumption and high accuracy [9] [10]. Other sensors monitor temperature, humidity, and light to assess environmental risks. Recent research in the AAL-RESILIENT-T project has demonstrated how the combined use of home monitoring and wearable sensors can support the self-management of older adults with cognitive impairments, enabling early identification of critical changes in behaviour and health conditions through integrated sensor data and personalized interventions [11]. Similarly, the Health@Home [12] project is focused on the development of a platform which integrates biomedical, wearable, and unobtrusive sensors for monitoring users physiological parameters, along with home automation sensors to assess environmental conditions, providing a comprehensive framework for continuous, non-invasive health monitoring in domestic settings.

One of the major limitations is lack of integration between medical monitoring and social interaction. To address this gap, Socially Assistive Robotics (SAR) and Virtual Reality (VR) technologies have emerged as complementary tools within smart care environments. SAR platforms are designed to engage users socially while providing assistance, reminders, or companionship. They have shown positive results in supporting daily routines, reducing stress, and even improving adherence to therapy [13], [14], [15]. SARs can also collect valuable qualitative feedback from caregivers through structured interviews or interactive questionnaires, helping to train Machine Learning models with human insights. Likewise, VR-based serious games offer promising opportunities to promote cognitive engagement, especially in individuals with mild cognitive impairment or early-stage dementia. VR allows users to participate in immersive tasks aimed at stimulating memory, attention, or motor coordination. Studies have shown that VR can increase motivation, reduce anxiety, and enhance mood, offering a powerful tool for elderly care [16] [17]. However, despite these advances, the challenge remains in effectively integrating these technologies into existing healthcare facilities, ensuring an approach that combines technological innovation, personalized care, and operability [18]. The METASALUTE project is positioned within this context, aiming to define and implement new technology-assisted service models to promote the integration of social and healthcare services. The proposed solution goes beyond traditional AAL approaches by combining real-time monitoring of physiological and environmental parameters with social and cognitive support technologies, thereby addressing both medical and psychosocial needs. This solution is based on the implementation of IoT-based sensors for non-invasive monitoring of physiological and environmental parameters, and Artificial Intelligence (AI) techniques for data analysis, serious games in Virtual Reality (VR) to stimulate cognitive activity and the use of a social

assistive robot to support daily activities and collect contextual information from caregivers. METASALUTE seeks to contribute to the development of sustainable and scalable solutions for assisting vulnerable individuals, promoting their autonomy and active participation in social life, while also improving their overall health and well-being.

## II. MATERIALS AND METHODS

### A. Project implementation sites

The METASALUTE project will be implemented through a field experimentation phase across five facilities provided by LABIRINTO, a social cooperative located in Pesaro Urbino (PU) with over a decade of experience in aiding vulnerable individuals. Each selected structure caters to different groups of fragile individuals with varying levels of cognitive and motor impairments.

“Santa Colomba” is a long-term residential healthcare facility dedicated to seniors with cognitive and motor impairments. The area involved in the project is the north-western wing of the structure. It consists of 10 double rooms aligned along a hallway and a dedicated nurse station. Each room is equipped with several electrical outlets near the beds and one above the door. There are two shared bathrooms in the same wing, each including separate cubicles and a vestibule, with limited electrical access.

“Casa Giona” is three-story building for individuals with medium-level disabilities. The area involved in the METASALUTE project includes the first and second floors. The ground floor serves as a common area. The first floor consists of one double room and three single rooms, served by two external shared bathrooms. The second floor has the same layout but includes an additional single room with a private bathroom. In total, the facility includes two double rooms, seven single rooms, and five bathrooms (four shared and one private).

“Prove di volo” is a home-like environment supporting semi-autonomous users. The area involved in the project is a single apartment composed of two bedrooms, one shared bathroom, a kitchen, and a living/dining area.

“Dopo di Noi” is composed of two identical apartments for adults with mild disabilities. Each apartment is located on the ground floor of two separate but adjacent buildings. The apartments are equipped with modern electrical infrastructure, including outlets in all functional areas.

“Centro Margherita” is a facility for individuals with severe Alzheimer’s disease. Due to the cognitive conditions of the patients, no smart home or assistive monitoring devices will be installed in this structure. Instead, users will be monitored exclusively through wearable devices, such as smartwatches.

### B. Use cases definition

The selection of sensor technologies was driven by the specific needs expressed by the facility managers and workers. Project partners conducted site visits to ensure a thorough understanding of the user requirements and the structural characteristics of each facility. Based on these insights, the main use cases and corresponding sensor technologies were defined. Use cases include:

1. Monitoring of physiological parameters: for this purpose, wearable devices like smartwatches will be used

alongside a telemonitoring station equipped with a tablet, wireless sphygmomanometer and pulse oximeter. Given that nighttime is often a critical period when medical staff may not always be present, a sleep monitor belt will be included to assess sleep quality.

2. Monitoring of environmental factors and detection of accidental events: motion detectors and home automation technologies such as door and window sensors are deployed to identify falls or unsupervised exits. In environments like Santa Colomba, special attention was required for hallways and bathrooms, where power supply limitations led to the inclusion of new sockets or repeaters
3. Social and cognitive support through VR engagement: immersive virtual reality applications are employed to promote cognitive stimulation and encourage social interaction. These systems are particularly suited for facilities like Prove di Volo and Casa Giona, where users maintain a moderate level of autonomy.

Each structure was analysed through in-person site visits conducted by the project partners using a portable testing kit including a tablet, and a gateway, a door/window sensor, and a motion detection sensor. These inspections aimed to assess the compatibility between the preliminary project design and real-world structural conditions. Specific checks were carried out to evaluate Wi-Fi coverage, availability and positioning of power sockets, and the potential for signal interference due to architectural features such as reinforced walls, partitions, or false ceilings.

The insights collected during the visits were critical in finalizing the technological layout. In some cases, adjustments were made to the planned installation points, for example by elevating devices beyond residents reach or using wall-mounted shelves. Where electrical outlets were insufficient or absent, as in certain hallways and bathrooms at Santa Colomba, new sockets or channelling systems were proposed in collaboration with facility maintenance teams. Facilities like Casa Giona and Dopo di Noi presented a total lack of Wi-Fi connectivity, on the upper floors in the former and throughout the structure in the latter. This required the implementation of contingency strategies to ensure continuity in data acquisition.

Each use case was carefully aligned with the user profiles and structural conditions of the respective facilities. This context-aware configuration ensured that each solution is not only technologically effective but also aligned with the daily routines and clinical priorities of the involved care environments.

The sensor configuration was tailored per facility. These on-site visits ensured that the final system design was both technologically sound and practically feasible in the context of the specific environmental and infrastructural limitations encountered.

### III. IMPLEMENTATION DETAILS

The METASALUTE project aims to develop an integrated platform composed of three cooperative software modules, shown in Fig.1, each designed to address specific aspects of care and support for vulnerable individuals. The first module, Digital Care Insights, aims to create a more connected and responsive care environment, improving communication and coordination between healthcare professionals and caregivers

by leveraging real-time data from various sensor technologies. The second module, Cyber Home, is focused on ensuring the safety, autonomy, and well-being of individuals through the development and implementation of algorithms that correlate physiological parameters with environmental and domestic situations. Lastly, the module VR-CARE aims to engage users in cognitive training through immersive games designed to stimulate memory, language skills, and psychomotor functions. These games are expected to slow down the progression of cognitive decline, providing a valuable tool for maintaining mental health and improving quality of life for users. Together, these modules work synergistically to provide personalized, proactive, and supportive care, helping vulnerable individuals maintain their independence and well-being while ensuring they receive the necessary attention and support.

#### A. Sensor network definition

The following section presents the sensor network configurations proposed for two facilities within the METASALUTE project: Santa Colomba and Dopo di Noi. These cases were selected to highlight the differences in sensor layout and technological strategy between a structured residential healthcare environment and a home-like, semi-autonomous living setting. The configurations were defined during site inspections and adapted to the architectural and operational characteristics of each facility.

##### 1. Santa Colomba

In the context of the METASALUTE project, a detailed sensor network design was developed for the north-western wing of the Santa Colomba facility, based on findings from the on-site inspection. The configuration was tailored to the specific architectural and functional features of the structure, which includes 10 double rooms, 2 shared bathrooms, and a central corridor. The proposed sensor network includes:

- In each patient room: a gateway and SilverBox tablet (to be wall-mounted at approximately 2 meters height); two presence/fall detection sensors (Presence HE-02 by Domethics), one for each bed; two bed occupancy bands (Sleep Monitor Belt by Domethics); a night light for ambient monitoring and orientation.
- In the shared bathrooms: motion sensors and door/window sensors (DoorWin NE-04) placed in each cubicle and vestibule area; night lights to serve both safety and signal relay purposes.
- Control point: room 11 (nurse station) will host the centralized tablet (Silver Big Box 24.5" by Domethics)



Fig. 1 - METASALUTE cooperative software modules.

and gateway (Adriano by Domethics) for coordinating bathroom and corridor monitoring.

- Along the corridor: presence/fall detection sensors (Presence HE-02 by Domethics), spaced at regular intervals; wall-mounted night lights positioned near existing cable ducts.

An additional Lenovo M10 tablet will be provided to staff for receiving real-time alerts.

During the field inspection, the proposed layout was tested using a portable evaluation kit. The tests confirmed the feasibility of the network design, while identifying areas (e.g., bathrooms) where signal stability might require reinforcement through the strategic use of repeater devices.

## 2. *Dopo di Noi*

The sensor network defined for the Dopo di Noi apartments reflects the structure's residential nature and the greater degree of autonomy of its users.

The planned configuration includes:

- In two bedrooms: one presence/fall detection sensor (Presence HE-02 by Domethics), per occupied room; one bed occupancy band per resident.
- Common areas (kitchen and living room): one door opening sensor (DoorWin NE-04) on the main entrance; two night lights (one in the kitchen, one in the living room) for ambient orientation and as potential signal repeaters; telemedicine station equipped with a pulse oximeter (SB210 by Rossmax) and a sphygmomanometer (Parr X5 by Rossmax).
- Control point: a 24-inch tablet with an integrated gateway will be installed in the kitchen to collect and process data from all connected devices.

Users will be equipped with either a smartwatch (Simplo Quadrant by Domethics) or a smart band, both featuring fall detection functionality. Smartwatches, which include integrated GPS, will be assigned to residents capable of autonomous movement outside the apartment. In contrast, Bluetooth-enabled smart bands without GPS will be provided to those who are not allowed to move independently beyond the facility. Fig. 2 shows the floorplan and sensor layout of one of the apartments at "Dopo di noi". The characteristics of part of the selected devices are reported in Table 1.

Table 1. Technical characteristics of part of the selected devices.

Sensor type	Model	Specifications
Presence sensor	Presence HE-02 by Domethics	Detecting angle: 90° Detecting distance < 10m Working temperature: 10°C-50°C Working humidity < 95% RH
Door/Window sensors	DoorWin NE-04 by Domethics	Working Temperature: 0°C- 40°C (32°F-104°F) Working humidity: 20%-85%
Pulse oximeter	SB210 by Rossmax	SpO2 measurement range: 35%-99%
Sphygmomanometer	Parr X5 by Rossmax	Pressure measurement range: 30-260 mmHg Pulse measurement range: 40-199 beats/minute
Tablet	Silver Big Box 24.5"	Dimension: 24.5" Resolution: 1920x1080 RAM + ROM: 8 GB + 64 GB CPU: RK3588S-D
Gateway	Adriano	Wireless protocols: Wi-Fi, Bluetooth 5, Zigbee, Z-Wave

## B. Virtual reality

As part of the METASALUTE project, Virtual Reality (VR) technology was integrated with the goal of supporting cognitive and emotional well-being, particularly in users affected by neurodegenerative conditions such as Alzheimer disease. Although VR cannot slow down the biological progression of neurodegeneration, it can offer concrete and measurable benefits in early and moderate stages, especially in stimulating memory, spatial orientation, attention, and emotional engagement. Three types of VR-based interventions were developed and tested during the project. The first is a set of VR 360° immersive videos, featuring natural environments such as landscapes, forests, or beaches. These environments are enriched with ambient sounds, relaxing music, and guided narration. The aim is to reduce anxiety and agitation, while promoting calm and engagement. The second category involves the creation of serious games in VR, built with simplified user interaction models. These interactive activities are designed to stimulate cognitive functions such as memory, recognition, and planning, offering users the opportunity to navigate through accessible,

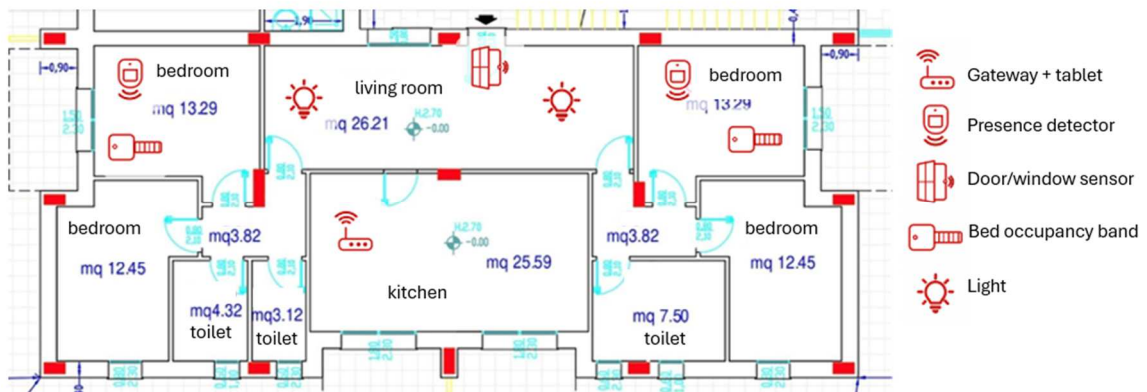


Fig. 2- Floor plan of the "Dopo di Noi" apartment with sensor layout.

low-complexity games tailored to their cognitive levels. The third tool includes 2D video tutorials for tablets and smartphones, presenting common daily routines (e.g., preparing coffee, setting the table, using a washing machine). These interactive scenarios allow users to make simple choices and are intended to train procedural memory and functional skills, especially for semi-autonomous individuals. All VR content was designed by the project partners with strong input from clinical professionals, including psychologists, to ensure therapeutic coherence. The experiences were deliberately simplified to reduce risks of disorientation or overstimulation, especially in immersive 360° environments. The software stack for VR development included Unity (for the integration and programming of interactive experiences), Blender (for 3D modelling), and Final Cut Pro (for video and audio editing). For hardware, a combination of Oculus Meta Quest 3 headsets, Insta360 X4 8K cameras, and dedicated workstations (Mac and Dell) will be used to ensure high video quality, fast performance, and cost-effectiveness. The adoption of VR in METASALUTE is not only technical but also therapeutic. By promoting cognitive stimulation, emotional regulation, and user engagement, VR represents a meaningful addition to the platform ecosystem. These tools are especially valuable in supporting personalized care strategies, complementing physiological and behavioural monitoring, and enhancing the overall quality of life of fragile users.

### C. Assistant Robot

As part of the METASALUTE project, an assistive robotic solution based on the Temi robot platform [19] will be deployed within selected care facilities. Temi will serve as a multifunctional interface supporting both caregivers and residents through interactive functionalities. One of the main roles of the robot is the administration of structured questionnaires to caregivers at the end of their working day. These questionnaires are designed to gather qualitative insights into daily events, including falls, unusual behaviours, or deviations from routine that may not be automatically detected by the sensor infrastructure. Moreover, the questionnaires include a section to investigate user acceptability of the technology proposed. This self-reported information will be crucial for the training and validation of ML algorithms, which will analyse sensor-generated data to identify patterns associated with critical events. In addition to caregiver interaction, the robot will also provide multimedia content to residents. This includes tutorials on daily living activities, which can support users in performing tasks such as hygiene routines, medication management, or safe mobility practices. These video-based materials aim to reinforce autonomy and confidence in semi-independent individuals. To apply this functionality, a dedicated app called “Patrol App” has been developed. This app enables Temi to autonomously patrol predefined areas within a facility and initiate interaction upon detecting the wake word “Temi” or through the face recognition capability of the robot. Users are prompted to choose between predefined tasks: direct navigation to a specific point, launching a web-based app, opening multimedia applications or an external application.

### D. Caregiver dashboard

The system includes a dedicated dashboard for caregivers, designed to monitor the entire sensor infrastructure deployed within each facility. The dashboard is accessible via mobile devices, tablets, and PCs, allowing flexible usage according to the operational needs of the care staff. The platform allows caregivers to:

- Monitor environmental sensor data collected by the gateways (e.g., door opening, motion, light levels)
- Track data from individual sensors such as bed occupancy bands and wearable devices
- View health parameters recorded via the telemedicine station (e.g., pulse oximeter, sphygmomanometer, thermometer)
- Receive real-time notifications of specific events (e.g., falls, abnormal vital signs, door openings at night)

Environmental sensors are configured to generate event-based alerts when a state change occurs, for instance door opening or a detected fall. Personal devices, on the other hand, also collect continuous data streams that can be used to assess trends over time. In both cases, the system is capable of sending alerts when abnormal readings are detected. The dashboard also allows for the configuration of customized notification rules. These can be tailored per facility or per staff member based on their shift schedules. For example, caregivers may configure a door sensor to trigger alerts only during nighttime hours or define specific threshold ranges for physiological measurements. All collected data are aggregated to build an individualized profile for each monitored user. As an example, screenshots of the dashboard from a facility are presented in Fig. 3.

## IV. CONCLUSION

This study presents the methodology and early implementation of the METASALUTE project, which aims to promote the integration of social and healthcare services through the use of advanced technologies. The proposed approach combines non-invasive IoT sensor networks, Artificial Intelligence (AI) techniques, Socially Assistive Robotics (SAR), and Virtual Reality (VR) to monitor and support the physical and cognitive well-being of older and fragile individuals. The project is currently being deployed across five care facilities, each serving users with different levels of cognitive and physical impairment. This diversity ensures that the solution is both scalable and adaptable to real-world care contexts. The use cases, defined following a user centered approach and considering the structural characteristics of each facility, lead to the definition of the sensor network. Non-invasive monitoring systems including environmental and wearable sensors are used to monitor activities and well-being of older and fragile people. The Temi robot plays a dual role in the system: it acts as a tool for administering questionnaires to caregivers, collecting valuable insights on critical events and unusual behaviours that may not be captured by sensors alone. These reports are then used to train ML models for improved event detection and behavioural analysis. Additionally, the robot contributes to the social engagement and autonomy of residents by delivering interactive multimedia content, including video tutorials on daily routines such as hygiene, mobility and home tasks. Future work will focus on long-term data collection, user feedback evaluation, and the development of AI-powered

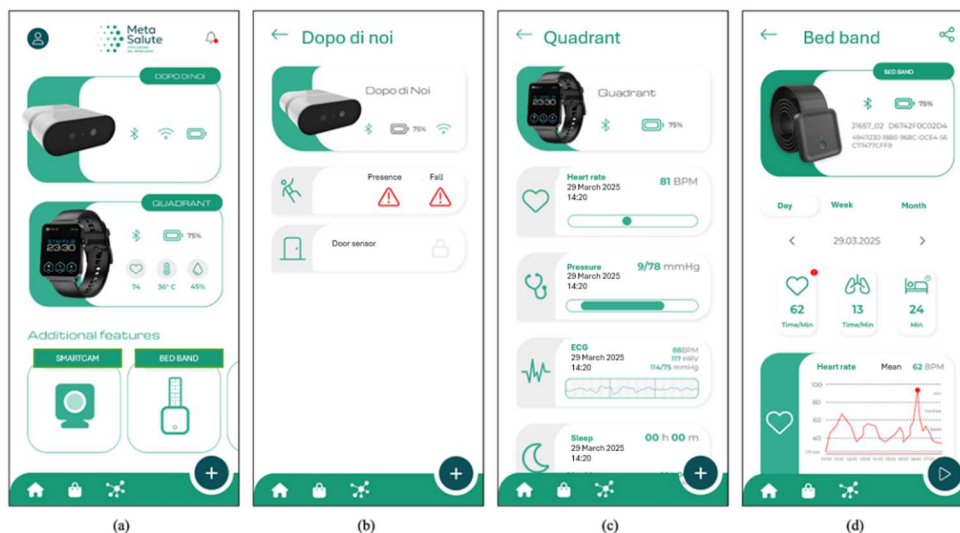


Fig. 3 - Examples of caregiver dashboard interfaces for the “Dopo di Noi” facility: (a) list of active sensors; (b) environmental event notifications (e.g., presence, fall, door); (c) overview of physiological parameters acquired via smartwatch; (d) weekly graph of heart rate trends recorded by the bed occupancy sensor.

predictive models to enable more personalized and proactive care strategies. Through its integrative, flexible, and ethically mindful design, METASALUTE lays the foundation for a new generation of technology-assisted care services, capable of improving both clinical outcomes and quality of life for vulnerable population

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