ICT-56-2020 "Next Generation Internet of Things"
Grant Agreement number: 957218

IntellIoT

Deliverable D3.7
Human in the loop in Intelligent IoT environments (final version)

Deliverable release date	22/03/2023
Authors	1. Diana Cojocaru, Marko Djikic (PHILIPS) 2. Clayton Gordy, Nour Fendri (HOLO) 3. Panos Athanasiadis, Alexis Fourlis (VIDAVO) 4. Sumudu Samarakoon (UOULU)
Editor	Diana Cojocaru, Marko Djikic (PHILIPS)
Reviewer	Jérôme Härri (EURECOM), Clayton Gordy (HOLO)
Approved by	PTC Members: (Vivek Kulkarni, Konstantinos Fysarakis, Sumudu Samarakoon, Beatriz Soret, Arne Bröring, Maren Lesche) PCC Members: (Vivek Kulkarni, Jérôme Härri, Beatriz Soret, Mehdi Bennis, Martijn Rooker, Sotiris Ioannidis, Anca Bucur, Georgios Spanoudakis, Simon Mayer, Filippo Leddi, Holger Burkhardt, Maren Lesche, Georgios Kochiadakis)
Status of the Document	Final
Version	1.0
Dissemination level	Public

Table of Contents

1 INTRODUCTION

This deliverable is the final version output of Task 3.3 Human-in-the-loop in Intelligent IoT environments. The human-in-the-loop is the central actor which the IntellIoT framework and components seek to support. In this deliverable, the HIL enablers that make this possible as well as the connection between the enablers and the role of the human-in-the-loop in each of the use cases are described. Moreover, the collection of data and its workflow through the framework and the performance of the Global and Local AI components are detailed in this deliverable.

The Human-in-the-Loop (HIL) enablers handle the reactive approach of interaction, which enables human oversight and intervention when necessary. This is important not only from a practical perspective (e.g., when the machines do not know how to handle a situation), but also from a trustworthiness perspective, as human agency and oversight is one of the key requirements towards Trustworthy AI [1].

Within the IntellIoT Use Cases, the HIL enablers must interact with one another in order to achieve the Use Case (UC) goals and to support the human-in-the-loop. Section 2 shows the HIL enablers and the connections between them, as is explained in this document. The following paragraphs describe the human-in-the-loop corresponding to each use case, their role, and how they interact with the IntellIoT system and the HIL enablers.

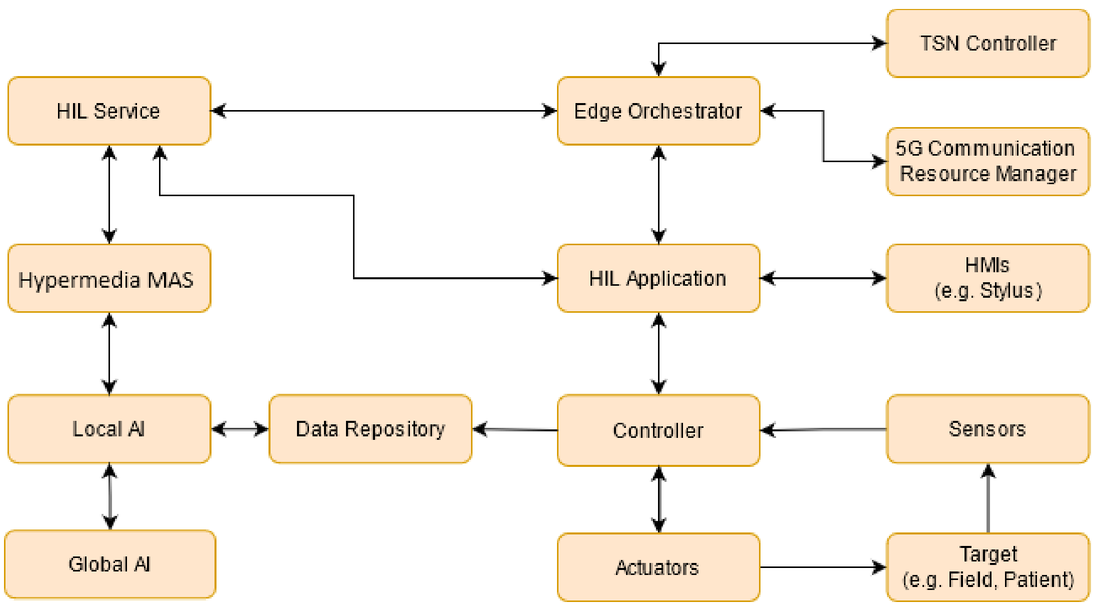

Figure 1. Human-in-the-loop enablers.

Use Case 1 (UC1) – Agriculture

In UC1, an intelligent agricultural IoT environment is aided through a human-in-the-loop intervention by a remote operator. In this use case, an operator becomes situationally aware of a semi-autonomous tractor and its immediate environment in a virtual reality (VR) setting. This awareness is leveraged to assist the tractor by interacting directly with it, enabling remote control of its movement. The specific enablers of this UC1 human-in-the-loop will be discussed below in detail, but in general consist of VR client device and VR controllers, which act as a human-machine-interface (HMI) into the human-in-the-loop (HIL) application. Real time video streams are fed into the HIL Application, which in turn permit visualization of the immediate tractor environment on the VR device. By way of the VR controller input reaching the HIL Application, the human operator can initiate actuator commands through this application to the tractor controller which allow the human to intervene with the operation of the AI-driven tractor in the event it cannot make an appropriate action. The latter situation is intended to be communicated by an escalation by the AI to the HIL Service brokered by an intermediate Agent to the VR device directly. In addition to such intervention ability, control commands are also provided to a Data Repository, which can used by the local AI of the tractor as substrate for training toward future AI autonomous control of the tractor.

Use Case 2 (UC2) - Healthcare

In UC2 Healthcare, the physician will have the possibility to send interventions to patients and allow the outcomes of AI models to be presented to patients. A password-protected web interface will be the HMI. It will be accessible through a laptop or mobile device and will show possible interventions from which the physician can select which one to send to a patient. Some of the interventions will be produced by the base or pretrained Healthcare Artificial Intelligence (AI) Models, which are hosted in the Global AI and also initially in the Local AI. Once the Local AI has trained the Healthcare AI Models on local datasets specific to a patient, some interventions can be personalized for that patient. The local datasets are produced by Sensors that take different measurements of a patient, such as body temperature, body weight, blood pressure, blood oxygen saturation, and heart rate. In addition, the human-in-the-loop and the IntellIoT framework will make it possible to use the selected intervention to train the AI models further with this new labelled dataset, which is otherwise extremely scarce and difficult to obtain. Consequently, the AI models will improve each time the physician intervenes to adapt and further personalize interventions for a patient. Moreover, an alerting system based on predefined thresholds and algorithms, defined by project's physicians, provide guidelines to patients on how to proceed with their care plan and physical activity sessions.

Use Case 3 (UC3) – Manufacturing

In an analogous fashion to UC1, this manufacturing use case utilizes HMI to remotely interact and control an intelligent semi-autonomous target. Here, such a target is a robot performing a manufacturing task. Live video feed from the camera mounted on the robot provides visual input to the human-in-the-loop through the HIL application when the robot local AI indicates an incident which it cannot overcome. The HMI client devices used here are an Augmented Reality (AR) headset, which allows the virtual content to be superimposed upon the real world, and a pen-like AR input device, the Holo-Stylus. In this use case, rather than VR controllers, control of the robot is mediated through the Holo-Stylus device. Control of the robot is mediated by the Holo-Stylus input into the HIL Application which feeds into the robot controller for subsequent actuation control. Informing the human-in-the-loop about the need to help the robot is the HIL service and intermediate Agent, as described above. Movement commands are also stored in the Data Repository which the AI can use to continue its learning for future use.

1.1 Modifications compared to deliverable D3.3

Considering the delta to the previous version of the deliverable, D3.3 - "Human in the loop in Intelligent IoT environments (first version)", the new content presented within this final deliverable includes:

- The Introduction section contains a new subchapter (1.1) which presents the overall WP3 process and changes that occurred since the last D3.3.
- Section 2 is updated with respect to descriptions of the HIL enablers and their respective connectivity along with the role of the human-in-the-loop. This update reflects adjustments or modifications which have occurred since the earlier iteration of this deliverable. Particularly, for UC2 new technologies were introduced by Vidavo, the winner of Open Call 1.
- Sections 3 and 4 switched places so that the whole exposition in the Deliverable flows more naturally. Both sections are updated to reflect the changes introduced in cycle 2.
- Annex section is updated with a new subsection containing the figures pertaining to UC2.

2 HIL ENABLERS

This section describes the interfaces that each of the human-in-the-loop in the different use cases use to directly interact with the IntellIoT system. Section 2.1 describes the HIL Application. Previously this component was only pertinent to UC1 and UC3. With Vidavo's technologies enabling HIL interfaces for UC2, this component is now present in the UC2 architecture as well, thus making it a key component for the HMIs across the use cases. Sections 2.2, 2.3, and 2.4 describe in detail the HMIs corresponding to UC1, UC2, and UC3, respectively. Section 2.5 describes the HIL Service which, when needed, enables the connection between the Local AI and the human-in-the-loop. We also refer the reader to the GitLab repo https://gitlab.eurecom.fr/intelliot/. In the future, open-source components developed in the IntellIoT project, including those from the group of HIL Enablers, will be hosted on this repo.

2.1 HIL Application and HMIs

2.1.1 DESCRIPTION

The HIL Application receives information about the Target through the Controller. In Figure 1, the Target is the starting point. Manipulating it in some manner is the IntellIoT framework's end goal. Whether it is a field that a tractor must autonomously navigate and use its tools on, a patient's health status which is to be monitored and improved if necessary, or a wooden workpiece that needs to be engraved. In practice, the information about the Target is provided by Sensors. These can be in the form of cameras, biometric devices, or something similar. For example, in UC3 a camera is used as the sensor, mounted on the head of the robot.

All human interventions take place through the use of HMIs which are connected to the HIL Application. As mentioned, these HMIs will vary depending on the use case. The VR and AR headsets are connected to the HIL Application and exchange information (derived from e.g., their respective VR/AR input devices) directly with them. In UC2, the physician communicates with the HIL Application and through it sends relevant input to the target, i.e., the patient.

The HIL Application has an additional important role when the HMIs utilize the VR and the AR headsets (used in UC1 and UC3, respectively). An important limiting factor for these devices is in their processing power. The processors located in these devices are restricted in their computational ability, which has a direct impact on the ability of the device to render and visualize high resolution and complex three-dimensional holographic models. This is particularly important for end-users operating as a human-in-the-loop, as high-quality three-dimensional content is needed to ensure that human decisions are being made with up-to-date information on the position and situational context of the targets and their environment. Low processing power on these local devices can also negatively impact latency of AR/VR experiences, which impacts the ability of the human-in-the-loop to operate efficiently. Additionally, interfacing directly with these devices is often made difficult, such as e.g., with the HoloLens 2, as some libraries are restricted or unable to interface with the UWP computing platform. In this IntellIoT project, these limitations are entirely bypassed by offloading the computationally heavy rendering demands to a nearby device with high-performance capabilities. The HIL Application is hosted on this device. As a result, all image rendering and information being processed in the HIL Application are remote from the VR/AR devices. The HIL Application and therefore AR/VR content is then streamed to the VR/AR headset devices. This remote rendering and streaming approach ensure a high quality of VR/AR content and experience for users and allows precise interfaces with the IntellIoT system. Amongst these include e.g., receiving video streams and information from the human-in-the-loop targets as well as the transmission of controls for these targets and associated metadata. The HIL Application is one component of a two-component solution. On one side, the HIL Application must connect with the Controller with a dedicated interface. Meanwhile, the HMIs connect to the HIL Application with a dedicated client application installed on the HMI devices (see below). In the case of UC2 the HMI connects to the HIL Application via the second component – the client, a REST Application Programming Interface (API) is used through an SSL channel. Additionally, in UC3 Manufacturing the HIL Application integrates with the Stylus Software Development Kit (SDK) for the Holo-Stylus. In terms of HMI connectivity, the Oculus Quest 2 in UC1 only supports Wi-Fi, whereas the HoloLens 2 in UC3 supports Wi-Fi and 5G, if connected via USB-C cable to a 5G capable Smartphone. Given the 5G IntellIoT environment, the HoloLens 2 in UC3 will connect with 5G in this environment, whereas the Oculus Quest 2 is currently being investigated to permit 5G connectivity with the HIL Application.

HMI components that support the human-in-the-loop are divided in two parts, Human to Machine, and Machine to Human. In case of UC2, both parts are handled by the web application facing the physician. Through this application, which connects to the HIL Application, the physician receives notifications regarding patients' conditions as measured by the sensors (Machine to Human), but also uses it to send instructions to the HIL Application containing e.g., care plan updates, approval of AI outcomes, and recommendations (Human to Machine).

In UC1 and UC3 these parts are as follows:

Human to Machine: In this part, human-to-machine workflows allow the human to visualize and interact within a virtual environment which also allows the sending of control commands to the HIL Application. As mentioned above, facilitating this are the VR/AR input devices, namely the Holo-Stylus for the AR Application used in UC3 Manufacturing, and the VR Controllers for the VR Application used in UC1 Agriculture. Such commands executed in AR/VR space permit the human to directly intervene with the robot and tractor, respectively.

Machine to Human: In this part, human-to-machine workflows are responsible for the visualization and display of the virtual/augmented reality elements as well as relevant user interface elements with which humans can interact with. As mentioned previously, the hardware which visualize this information are the Oculus Quest 2 and HoloLens 2 for VR and AR Applications, respectively. The VR/AR applications which are streamed to these VR and AR devices in the individual use cases are developed using the software framework Unity3D and form the HIL Application. In terms of connectivity to the HIL Application, various interfaces with IntellIoT architectural elements allow this machine-to-human transmission. For example, the HIL Application receives video streams via WebRTC from the robot cameras in UC3, or from the NVIDIA Jetson TTC Motion after conversion from RTC to WebRTC in UC1. In UC3, the joint positions from the robot are fed into the HIL Application via TCP/IP from the robot controller. Streaming of the HIL Application is mediated by a connection between respective HMIs and the HIL Application. The server where the HIL Application is hosted is pingable and reachable by a public (for the HMI) IP Address on Port 9999. The entire application, including the various data streams are then sent through WebRTC to the HMIs for the human to view. This streaming via WebRTC is mediated by a specific SDK on the HIL Application, as described below.

2.2 UC1 Agriculture HMIs

The HMIs used in UC1 consist of a VR headset and VR controllers which connect with the HIL application. These components will be discussed in more detail below.

2.2.1 HARDWARE COMPONENTS

2.2.1.1 OCULUS QUEST 2

The Oculus Quest 2 is a fully immersive virtual reality headset. End-users (I.e., human-in-the-loop) are able to fully visualize the surroundings derived from video stream footage from tractor-mounted cameras. In addition, a virtual dashboard is present which provides a variety of situational information (e.g., fuel levels, speed). Video stream visualization is provided by pixel stream to the HIL application derived from dedicated software interfaces (described below). By providing a fully virtual environment, the Oculus Quest 2 allows the human-in-the-loop to be fully immersed into the agricultural environment.

2.2.1.2 VR CONTROLLERS

Facilitating the remote control of movement by the human-in-the-loop are dedicated VR controllers. These handheld devices provide the interface component of the HMI by allowing physical movement of a joystick to be translated into movement of the tractor. The VR controllers are a component of the Oculus Quest 2, which connect with VR headset by Bluetooth. Movement of the VR controllers and motion of the joystick on the controllers is tracked cameras on the headset and Bluetooth signalling. This information is then sent to the HIL Application.

2.2.2 SOFTWARE INTERFACES

2.2.2.1 OCULUS QUEST 2 – HIL APPLICATION

Pixel streams originally from the tractor cameras are provided to the Oculus Quest 2 through the Interactive Streaming for Augmented Reality (ISAR) enabled HIL Application. An ISAR client installed on the Oculus Quest 2 permits the receival of these application streams from the HIL Application device, which are based on WebRTC. Information from the VR Controllers, which pass to the VR headset via Bluetooth, are sent from the ISAR client to the HIL Application device, along with other data such as e.g., head pose sensor data. As mentioned, streaming from the HIL Application to the Oculus Quest 2 also permits the visualization of the digital tractor dashboard.

2.2.2.2 OCULUS QUEST 2 - HIL SERVICE

No connection currently exists between the HIL Service and the Oculus Quest 2. Envisioned to be developed in the future is an additional client device application installed on the Oculus Quest 2, which would receive through a publish subscribe method messages from the HIL Service about the local tractor AI raising an incident and needing help from human-in-the-loop. Subscribing to this topic would allow the Oculus Quest 2 to receive a message when a human-in-the-loop is needed. Confirmation through a user interface (UI) element that a human-in-the-loop can assist the tractor would then be passed by API to the HIL Service. Following, this same client application then would receive information on how to connect with the tractor. Such connectivity and features are currently being developed.

2.3 UC2 Healthcare HMIs

We begin this part by describing the Vida24© application provided by Vidavo.

2.3.1 VIDA24

Vida24© connected care suite is a secure modular cloud application (HMI), where healthcare professionals can monitor patients, progress based on assigned care plans, enjoy personalization tools, effective time management, and flexible UXs. Also, patients have access to their medical data through Vida24© mobile application (HIL application) where smart sensors and medical devices are connected to provide continuous monitoring of a patients' condition and engagement. Vida24© is CE0653 Class IIa certified according to EU Medical Devices Regulation (MDR 2017/745). Vida24© cloud application is based on Laravel framework and REST APIs to exchange data with the Vida24© mobile application. Vida24© mobile application is based on Google Flutter and the BLE interface that collects data from smart sensors and medical devices is developed on Google Flutter, Java, and Swift. Interaction with these applications is encrypted with AES-256 algorithm and protected by SSL and HTTPS protocols to ensure data protection. Also, anonymization techniques and data segregation into sensitive personal data will be applied to enhance privacy. Vida24© will allow the continuous monitoring of patients' vitals, symptoms, and physical activity to ensure that patients are engaged with their treatment plans by following physicians' guidelines and approved by the physicians' IntellIoT machine learning (ML) models outcomes.

2.3.2 HARDWARE COMPONENTS

The HMI, which in UC2 is the Vida24© cloud application, will be hosted on third parties cloud servers located in Germany. The physician can use a computer or mobile device that is connected to the Internet to access the HMI. Therefore, no other extra hardware is necessary for the end user (physician) to have, except from what they already own, which is a personal computer, a smartphone, or a work computer. The physician using any one of these devices is able to monitor patients' progress. Likewise, patients need to own a smartphone where they can install the Vida24© mobile app which connects to five smart devices (a smartwatch, a weight scale, a thermometer, an oximeter, and a blood pressure monitor). These devices are used as sensors to monitor patients and collect measurements. The smart devices sync the collected data to the Edge device, a smartphone where the Local AI can train Healthcare AI models on local datasets.

2.3.3 SOFTWARE INTERFACES - CLOUD APPLICATION

The software interface that is utilized in UC2, as mentioned above, is comprised of the Vida24© web platform and the mobile app. Vida24© web platform which plays the role of the HMI in UC2 informs the physician about patients' conditions as measured by the sensors (Machine to Human), but also enables them to send instructions to the HIL Application containing e.g., care plan updates, or recommendations (Human to Machine). On the web platform, clinicians are able to see patients' physical activity and provide relevant insights. Figure 2 shows an overview of a patient's physical activity including steps, sleep, and heart rate data, whereas figure 3 shows the visualization of these 3 measurements in more detail. Figure 23 Vida24© can support a variety of medical exams that are important for each use case. In IntellIoT these include blood pressure, oximetry, body measurements, and temperature. Figure 5 shows how one can add and/or see these data for a selected patient, with a more detailed view of blood pressure measurements in Figure 6.

Apart from the medical exams, measurements, questionnaires, and the care plan, the physician can also use the Vida24© web platform to access patients' profile with important information about the patients as well as write down relevant comments for each case, as show in Figure 7. Furthermore, in the sub-section Care plan under the tab "History" the physician can create and assign a care plan for the patient as well as mark the result (success/fail) upon completion (Figure 8). Using these features and many more the web platform has to offer, the physician is able not only to monitor the patient's condition and progress but to intervene by adapting the care plan, providing insights acting as human-in-the-loop.

2.3.4 SOFTWARE INTERFACES – MOBILE APPLICATION

In UC2 the HIL service is provided by Vida24© mobile app. The mobile app is installed on the patient's smartphone, and it acts as a gateway that connects a patient with their doctor. The mobile app, thanks to connected smart IoT devices and a wrist wearable, collects important data about the patient that reflect their health status as well as their progress regarding the care plan that has been assigned to them.

In the mobile app, patients can see an overview as well as detailed graphs about various measurements such as steps, sleep, heart rate, oximetry, and more. Some of these measurements are available through a wearable that patients use which synchronizes these data with Google fit. Afterwards, Vida24© mobile app fetches this data and displays it as shown in Figure 9. Moreover, patients through the mobile app receive warnings whenever a value is considered to be off limits according to their individual health condition (Figure 9).

Furthermore, the mobile app gives patients access to their care plan that has been assigned to them (Figure 1110). The mobile app here acts as a HIL application allowing the doctor to fine-tune the care plan for each patient using the Viad24 web platform which, as explained before, is the HMI in UC2. Finally, patients can use the mobile app to upload measurements from connected smart devices such as a scale.

2.4 UC3 Manufacturing HMIs

The HMIs used in UC3 are an AR client device and a pen-like input device called the Holo-Stylus. Similar to the HMI in UC1, these devices connect with the HIL application. The AR device also receive messages from and interface with the HIL service.

2.4.1 HARDWARE COMPONENTS

2.4.1.1 HOLOLENS 2

The HoloLens 2 is an AR headset device which allows visualization and interaction with three-dimensional holographic content. Unlike the VR device used in UC1, the AR environment provided by the HoloLens 2 superimposes holographic content on the real world (i.e., not fully immersive). Here, a three-dimensional twin of the manufacturing robot and its immediate surroundings are visualized on the HoloLens 2. Such AR content gives the human-in-the-loop access to all needed information to be aware of the robot and its actionable environment in order to intervene and control it when needed.

2.4.1.2 HOLO-STYLUS

The Holo-Stylus is a handheld input device with a pen-like structure. This device is high precision instrument, which allows highly precise movements to be captured in real time. In this use case, movements with the Holo- Stylus will be tracked and used to control movements of the robot in real time. In terms of data flow, cameras located on a head mounted unit (HMU) installed on the HoloLens 2 track the movement of the Holo-Stylus, and in turn relay this information to the HoloLens 2 via Bluetooth. Buttons along the Holo-Stylus add an additional layer of control, where a button press is needed to move the robot, which is mediated by Bluetooth signalling. Movements in space with the Holo-Stylus are reflected as specific three-dimensional movements of the robot and move it in real time.

2.4.2 SOFTWARE INTERFACES

2.4.2.1 HOLOLENS 2 – HIL APPLICATION

The HoloLens2 to HIL Application connection is mediated by WebRTC ISAR pixel streams as described in UC1 (see above), which includes streaming video feeds of the robot to the HoloLens 2 and sending back sensor data to the HIL application as done with the Oculus Quest 2. An ISAR client installed on the HoloLens 2 mediates this and allows the device to receive all streamed content while also passing back to the HIL Application information from the HMU which receives event and motion information from the Holo-Stylus.

2.4.2.2 HOLOLENS 2 – HIL SERVICE

The HoloLens 2 interfaces with the HIL Service. A client application installed on the HoloLens 2 receives through a publish subscribe method messages from the HIL Service when the local robot AI raises an incident and needs help. The human-in-the-loop can confirm through a user interface (UI) element that they will help, which is passed by API to the HIL Service. Following, same client application receives information on how to connect with the robot (IP details).

2.5 HIL Service

2.5.1 DESCRIPTION

The role of the HIL Service is to connect the Local AI (e.g., on the robot or on the tractor) when it needs support to an entity that is able to provide support, such as the human-in-the-loop. The HIL Service sends information about service APIs (some of which relate to devices) in the form of W3C Thing Descriptions or TD Templates that should be used by agents in the Hypermedia MAS (Hyper MAS). The HIL Service is an Edge application and as such is suitable for deployment on Edge devices.

2.5.2 COMMUNICATION WITH INTELLIOT SYSTEM

The HIL Service is triggered through an escalation by the Local AI that is brokered by an Agent. This Agent is running in the Hyper MAS infrastructure and has been programmed by the user of the Web-based IDE for Hyper MAS to handle HIL escalation requests and invoke the HIL Service, which requires that the functional description (i.e., the W3C WoT Thing Description) of the HIL Service is available to the Hyper MAS. To enable this brokerage, the HIL Service maintains knowledge about availability, reachability, and relevant properties of available HIL Applications. Upon receiving a support request, it contacts one or more available HIL Applications. The connection is established through accepting the request by the human-in-the-loop. Only one human-in-the-loop can establish this connection. Where stringent requirements on timing apply, it initiates the reservation of communication services. Therefore, it contacts the Edge Orchestrator to update the traffic demand for the HIL Service, which further resources at the TSN Controller and the 5G Communication Resource Manager. The Edge Orchestrator also takes care that the availability constraints of the HIL Application are met. Therefore, it continuously considers starting and terminating HIL Application instances.

2.5.3 NOTE ON UC2 HEALTHCARE

While the above holds for UC1 and UC3, in the UC2 Healthcare, due to the sensitivity of the application, a less automated approach is followed. In this use case a more asynchronous and active involvement from the human (i.e., clinician) is needed. Namely, actions of the Actuators towards the Target which are initiated by the Local AI may be potentially harmful for the Target (i.e., patient), due to, for example, erroneous predictions. That is why every such action is communicated via HIL Application to the web platform accessible by the clinician and awaits the approval (or rejection) by the clinician before being communicated to the target.

3 DATA COLLECTION WORKFLOWS

In this section, we discuss the data collection workflows through the IntellIoT system and HIL enablers to support the human-in-the-loop.

3.1 Sources of Data

In this section, we discuss the sources used to collect data, namely sensors and human input, and the storage of this data within the IntellIoT architecture.

3.1.1 SENSORS

3.1.1.1 UC1 AGRICULTURE

Sensor data from tractor derives from cameras mounted on it. RTP streams from the cameras are converted into WebRTC on the NVIDIA Jetson TTC Motion and sent to the HIL Application. This sensor data is then provided to the Oculus Quest 2 by HIL Application streaming.

3.1.1.2 UC2 HEALTHCARE

Medical devices and wearable sensors will take measurements of a patient such as blood pressure, body temperature, blood oxygenation, body weight, and heart rate. The sensors in UC2 are a smartwatch (Samsung Galaxy Watch4), a blood pressure monitor (Omron M7), a thermometer (Beurer FT95), a pulse oximeter (Beurer PO60), and a weight scale (Beurer BF600). This data will sync to an Edge device (patients smartphone running Vida24© mobile application) where the Local AI (inference and training) is executed. The Local AI will use these local datasets to train the Healthcare AI Models, which will enable, for example, the personalization of models to that patient. It will also produce interventions requiring human input (outcome approval from the physician) as described in Section 4.2.

More specifically, the data from the smart devices will be collected through the Vida24© app. Vida24© app will manage the interaction with the smart devices through a Bluetooth Low Energy (BLE) connection. The Vida24© app extracts corresponding measurements from each of the smart devices (blood pressure monitor, thermometer, pulse oximeter, weight scale, and smartwatch) as well as useful information like available device functionality, measurement type, and measurement unit.

3.1.1.3 UC3 MANUFACTURING

As in UC1, sensor data derives from cameras mounted on the robot. WebRTC video feed is sent to the HIL Application and then streamed to the HoloLens 2 for the human-in-the-loop to visualize. In addition to video camera feed, sensor data consisting of information about the joint position of the robot is sent to the HIL Application, mediated by the TCP/IP interface with the robot controller.

3.1.2 HUMAN INPUT

3.1.2.1 UC1 AGRICULTURE

The human-in-the-loop operator is being investigated to interact with the tractor through a 5G connection. Irrespective of the connection type, Control commands from the HIL Application, which as mentioned previously originate from the VR Controllers from the human, are sent to the tractor controller. Additionally, these commands are also stored in the Data Repository. The tractor local AI Models are then able to will use this new movement data in future training to learn and potentially avoid a similar situation in the future. Commands from the HIL Application are provided to the controller via AVL API.

3.1.2.2 UC2 HEALTHCARE

The physician will have the possibility to send interventions to patients. Some of the interventions will be produced by the base or pretrained Healthcare AI Models, which are hosted in the Global AI and also initially in the Local AI. The HMI will show the possible interventions from which the physician can select and approve to decide which one to send to a patient. The human-in-the-loop within the IntellIoT framework will make it possible to use the selected intervention to train the AI models further with this new labelled dataset, which is otherwise extremely scarce and difficult to obtain. Specifically, human's input (outcome's approval or not) validates AI models outcomes and can be used for re training.

3.1.2.3 UC3 MANUFACTURING

Human-in-the-loop operators can directly interact with the robot in this use case. The HIL Application, enabled by the HIL Service and Agent, allow this human input to be incorporated. Movement commands are sent from the HIL Application, which originate from the Holo-Stylus, to the controller of the robot by a TCP/IP connection. These commands instruct the robot how to move and are also sent into the Data Repository to aid the robotic local AI for future training.

3.1.3 STORAGE

3.1.3.1 UC1 AGRICULTURE

In the event of human interventions in terms of an expert taking over the control of the eTractor, the control decisions (velocity components) and sensory data (video frames) are stored on the local storage, i.e., storage on the eTractor. Each file is named with the following convention:

[timestamp]-lm-[linear velocity component]-rm-[angular velocity component].jpg

This data will be used to retrain the obstacle bypassing AI model under HIL.

3.1.3.2 UC2 HEALTHCARE

The data that will support the human-in-the-loop will be stored in the Data Repository. This component will be an application backend and database and will store only a subset of measurements (patient data) that are required for making the reports and the recommendations that need to be sent to a physician. Since some of the recommendations produced by the Local AI will require the intervention of the human-in-the-loop, the physician will make a selection by using the HMI. As mentioned, this component will be a password-protected web interface and will have an interface to the Data Repository. The option selected by the physician will be stored as new labelled data in the Data Repository and is eventually used by the Local AI in new training rounds.

3.1.3.3 UC3 MANUFACTURING

In UC3, the supervised training is used for the crosshair marker detection, which is a prerequisite for both Area and Grab Spot Detection AI models. In the events of failure to identify crosshair markers, a human operator captures an image from the camera having the top view of the machine/workplace storage and stores in the storage at the edge along with a label corresponding to crosshair markers, which are then used for retraining the Crosshair Marker Detection AI model.

3.2 Data Curation, Annotation, and Validation

Within each use cases a wide range of data types are collected from several sources. For each use case the data is used in the training phase to develop AI models and in the deployment (evaluation) phase to derive inference or prediction. In both project phases, we need to ensure that the data is of the required quality and that it is transformed to a structure and semantics that are suitable for the ingestion in the project tools, including for model development, model execution, and visualisation.

Several key aspects need to be considered:

•The selection standards for structure and semantics of the data, to be used for data representation.

•Create ground truth data to support AI training tasks.

•Ensure at all steps in the process that data quality is preserved and detects issues that occur.

For data representation, we need to select relevant standards when those are available, both for the structure and semantics of the data. This approach enables us to harmonize all the collected data, both from hospital systems (standard of care) and from the deployed devices during the pilot. Other benefits of harmonizing the data to established standards are potentially for future reuse of the collected data beyond the end of the project and the integration of relevant external data sources that could enhance our use cases. A standards-based approach enables us to evaluate the use of existing (open) tools for needed data processing, e.g., for curation, annotation, and user-driven validation.

In the healthcare use case, the chosen standard is HL7 FHIR [2] (due to its high adoption) and ontologies such as SNOMED-CT [3] and LOINC [4] (as per the standard specifications).

4 SYSTEM AND AI MODEL PERFORMANCE

In this section we explain how human-in-the-loop interacts with, and potentially improves, the performance of the Global and Local AI components. Due to a diverse nature of the use cases in this project, we will split the discussion per use case. However, the motif which is present in all the use cases is that the human-in-the-loop by their actions provide additional data to the AI models, and thus continuously improve their performance.

4.1 Use Case 1 (UC1) – Agriculture

The role of the HIL is to provide the expert control decisions when the AI model fails to infer the control decisions related to obstacle bypassing. During the human takeover, an expert will drive the eTractor remotely by issuing the control decisions, linear, and angular velocities. These control decisions are stored along the video frames following the convention given in Section 3.1.3.1. The purpose of such a data collection is to enrich the training dataset including unseen samples as well as confounders.

Upon the accumulation of 50 – 100 of new data, the Obstacle Bypassing AI model is retrained to incorporate with the situations where it has been failed. This repetitive task ensures the continuous improvements in the AI model. This improvement is measured in terms of reductions in the need of human interventions during the inference. In this view, with an AI model after n retraining rounds, the fraction of interventions is given by,

$$f(n) = \frac{\text{Number of interventions}}{\text{Number of inferences}} = \frac{\text{Number of failed inferences}}{\text{Number of successful inferences} + \text{Number of failed inferences}}.$$

The rate of reductions in interventions are then characterized with two parameters a and b via a logarithmic regression that holds $f(n) = a \cdot \exp(-b \cdot n)$. Note that higher the value of b, the lesser the number of interventions is required after each retraining. For UC1, due to the difficulties on data generation, the characterization of (a, b) is to be obtained in future after a considerable usage of the AI model.

4.2 Use Case 2 (UC2) – Healthcare

As previously explained, in the terminology of Figure 1, Targets of UC2 are cardio-vascular patients which are being monitored remotely, while the AI components make decisions regarding patients' conditions based on Sensor measurements and health-related data. ML algorithms developed for UC2 include regression and classification algorithms which predict clinically relevant parameters for the patients. Those parameters can refer to the patient's condition during an exercise (maximal heart rate, or whether the exercise session will be successful or not) or general patient's condition (for example, heart rate at rest).

These ML algorithms will be trained in a federated learning setting, while the base algorithms initially distributed by the coordinator (Global AI) to the workers (Local AI) will be pre-trained on a baseline dataset. The baseline dataset will also be used in the decision-making process by the coordinator when considering whether to include updates of a specific edge worker.

The role of the human-in-the-loop in the interaction with the AI components of the IntellIoT system is twofold. The first role is to safeguard the target from potentially harmful actions initiated by the Local AI. Namely, no AI system is perfect, and there is always a possibility that it produces erroneous predictions or recommendations. This is why every recommendation is first examined by the clinician before being propagated to the patient.

The second role of the human-in-the-loop is in producing information, i.e., data points, that can be used to train the base model in the Global AI component, but more importantly, to further personalize the ML models by training them in the Local AI setting. To elaborate this further, note first that in order to train the AI models we first need to collect data. While sensors give us data, it is clinician's input which gives meaning to these data and annotates the data. For annotating the data, we use already implemented notification system inside the HIL Application, which is based on rule-based algorithms where rules are defined by the clinician. For example, in Vida24© application there is a rule-based algorithm implemented for checking whether an exercise session performed by a patient was successful. Notifications initiated by these rules are exactly the data annotations needed by the ML algorithms to learn patterns and predict whether a future exercise will be successful before the exercise being performed. Apart from clinician's annotation of data in this automatic manner, which can be captured by rule-based algorithms, clinicians help with additional annotations when they inspect the outputs of already trained ML models. Namely, clinicians mark certain predictions as unreliable, and Local AI can use that information when re-training the model by giving special attention to such erroneous examples. In this way clinician's input helps with improving the performance of the Local AI, and by extension, also the performance of the Global AI which aggregates the models from all the patients.

4.3 Use Case 3 (UC3) - Manufacturing

In the Manufacturing use case, the AI is composed of two tasks with a combination of both supervised and unsupervised learning. The supervised training relates to the crosshair marker detection, which is a prerequisite for both Area and Grab Spot Detection AI models. The crosshair marker detection model is used to identify the crosshair markers given the camera image that provides the top view of the storage table/machines. The model is trained with images as the inputs and masking images isolating crosshair markers as labels. In the events of extreme lighting conditions (direct sunlight causing high exposure, harsh shadows, shadows due to multiple light sources), the AI model is likely to fail in detecting crosshair markers. In such events, a human expert captures the image and provides the corresponding label, which are then used to retrain the model similar to the Agriculture use case setting described in Section 4.1.

Upon the accumulation of few new data (5 – 10) and augmenting new data on top of these new samples, the crosshair detection model is retrained to incorporate with the situations where it has been failed. This repetitive task ensures the continuous improvements in the AI model. This improvement is measured in terms of reductions in the need of human interventions during the inference similar to the metrics given in Section 4.1.

5 CONCLUSIONS

This is the final deliverable of Task 3.3 *Human-in-the-loop in Intelligent IoT environments*, and it describes the final results of the work performed in this task, updating the previous version (D3.3), and integrating feedback from the first cycle of IntellIoT's development and integration activities. Therefore, we focus on the links established between the IntellIoT system and the human actors. We give description of the components of the IntellIoT system which support the HIL and describe in more detail the role that the HIL has when interacting with the IntellIoT system.

Interaction of the HIL with the IntellIoT system is realized through the HIL Enablers components. Although the interfaces that HIL uses to directly interact with the IntellIoT system differ per use case, general architectural principles are the same across the project. Specifically, all human interventions take place using human-machine interfaces (HMI) components which are connected to the HIL Application. In this deliverable, HMIs and HIL Application are described in detail. Moreover, with the technologies provided by the Open Call 1 winner Vidavo, which enable HIL interfaces for the UC2 Healthcare use case, the HIL Application is now present in the UC2 architecture as well, which was not the case in Cycle 1.

A notable role that the HIL has in the IntellIoT system is the interaction with the AI components. On one side, HIL helps the AI components in situations of uncertainty, or in those potentially harmful towards the targets. On the other side, HIL interactions feed into the AI models to enable model refinement and prevent degradation in model performance. In this deliverable we describe per use case how HIL interacts with, and potentially improves, the performance of the Global and Local AI components. We also give a description of the data flows pertaining to this process.

In terms of next steps, this deliverable will guide further efforts within Cycle 2 of the project, including the final integration, demonstration, and validation efforts which will be carried out within WP5.

6 ANNEX

6.1 Acronyms and Definitions

Acronym	Definition
API	Application Programming Interface
AI	Artificial Intelligence
AR	Augmented Reality
BLE	Bluetooth Low Energy
HIL	Human-in-the-Loop
HMI	Human Machine Interface
HMU	Head Mounted Unit
Hyper MAS	Hypermedia Multi-agent System
ISAR	Interactive Streaming for Augmented Reality
ML	Machine Learning
REST	Representational State Transfer
SDK	Software Development Kit
UC	Use Case
UI	User Interface
VR	Virtual Reality

6.2 UC2 figures

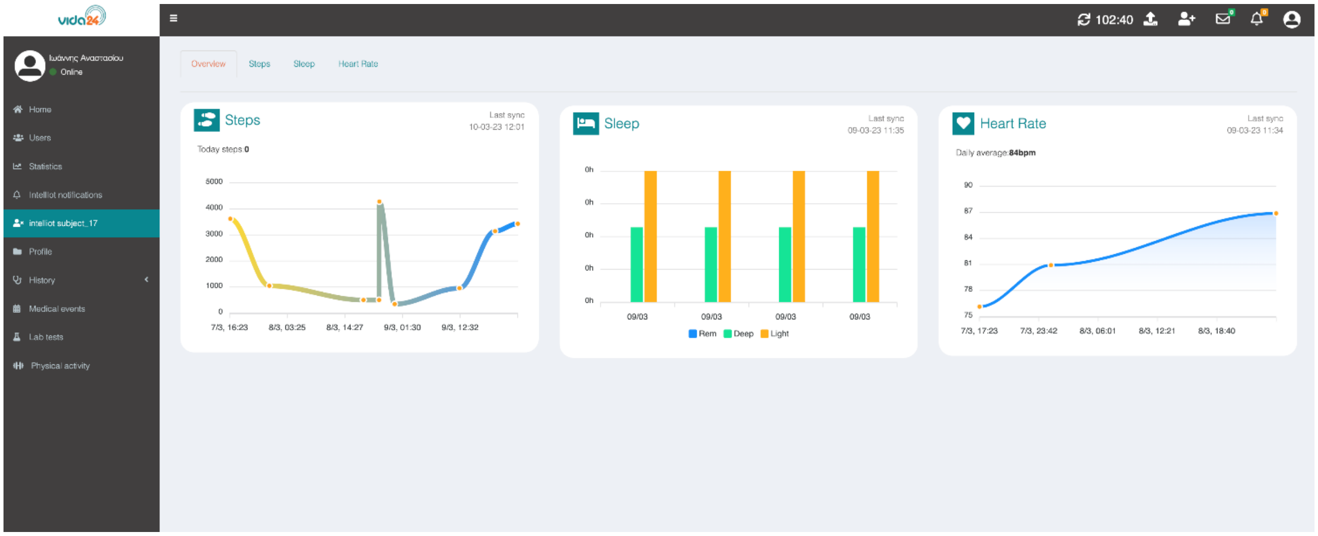

Figure 2. Vida24© web platform patient progress overview.

3

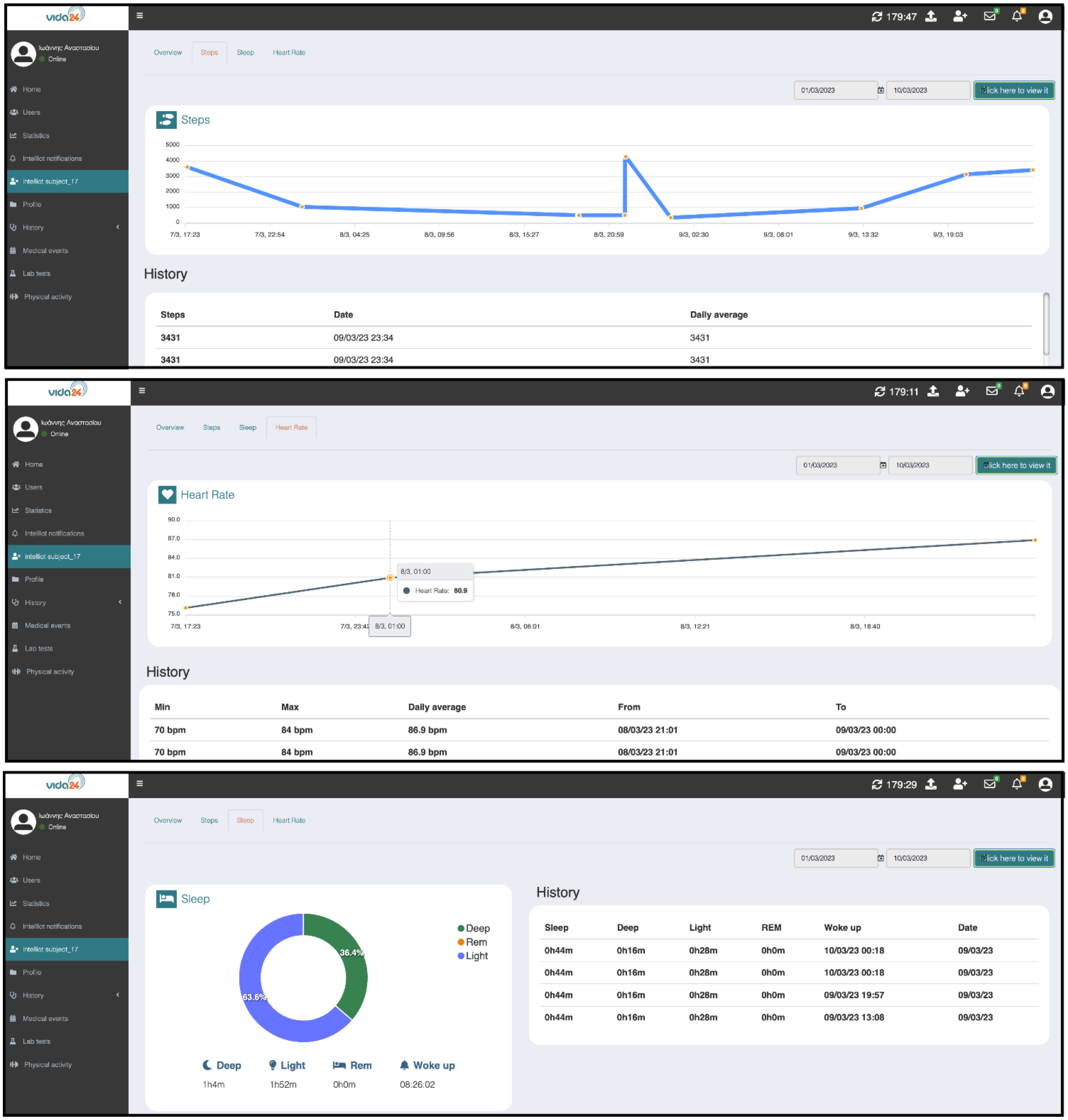

Figure 4. Real data representation for steps, heart rate and sleep.

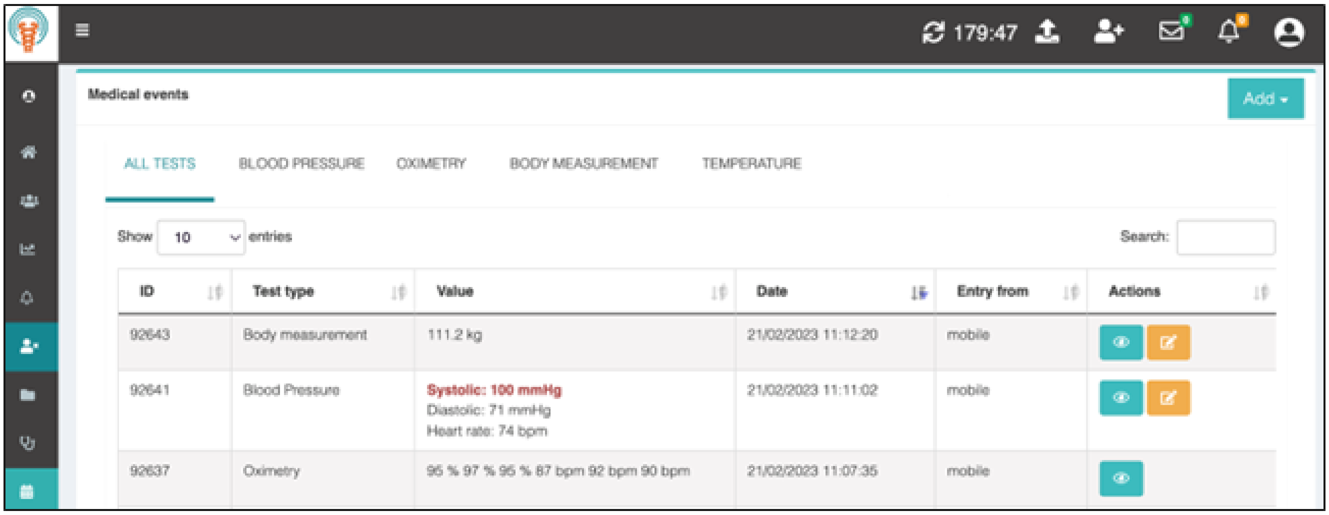

Figure 5. Patient's reported medical events

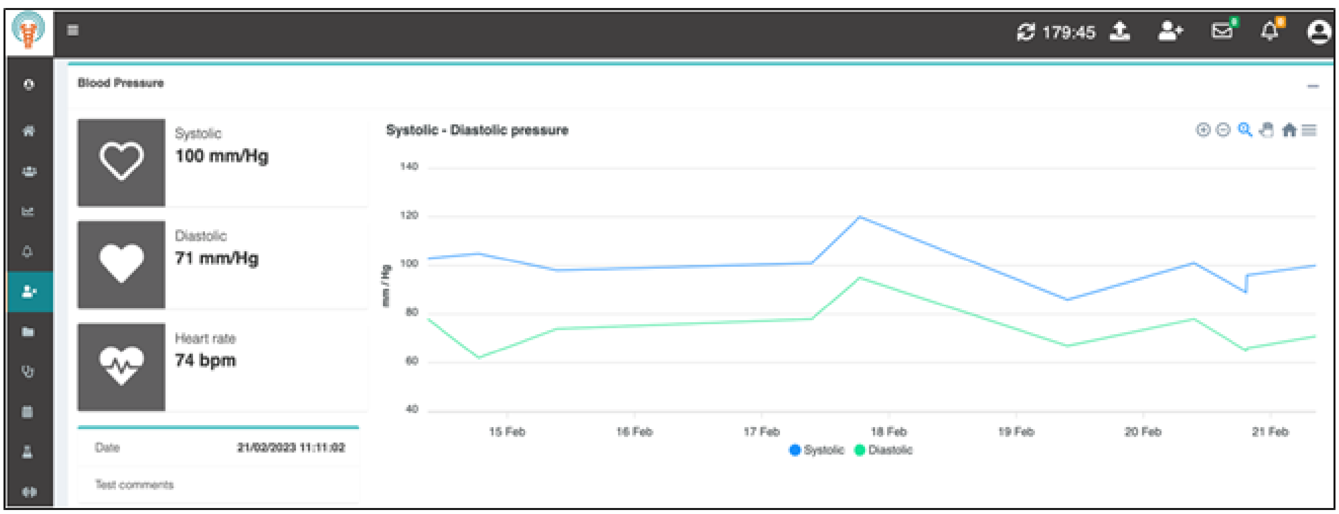

Figure 6. Patient's blood pressure representation

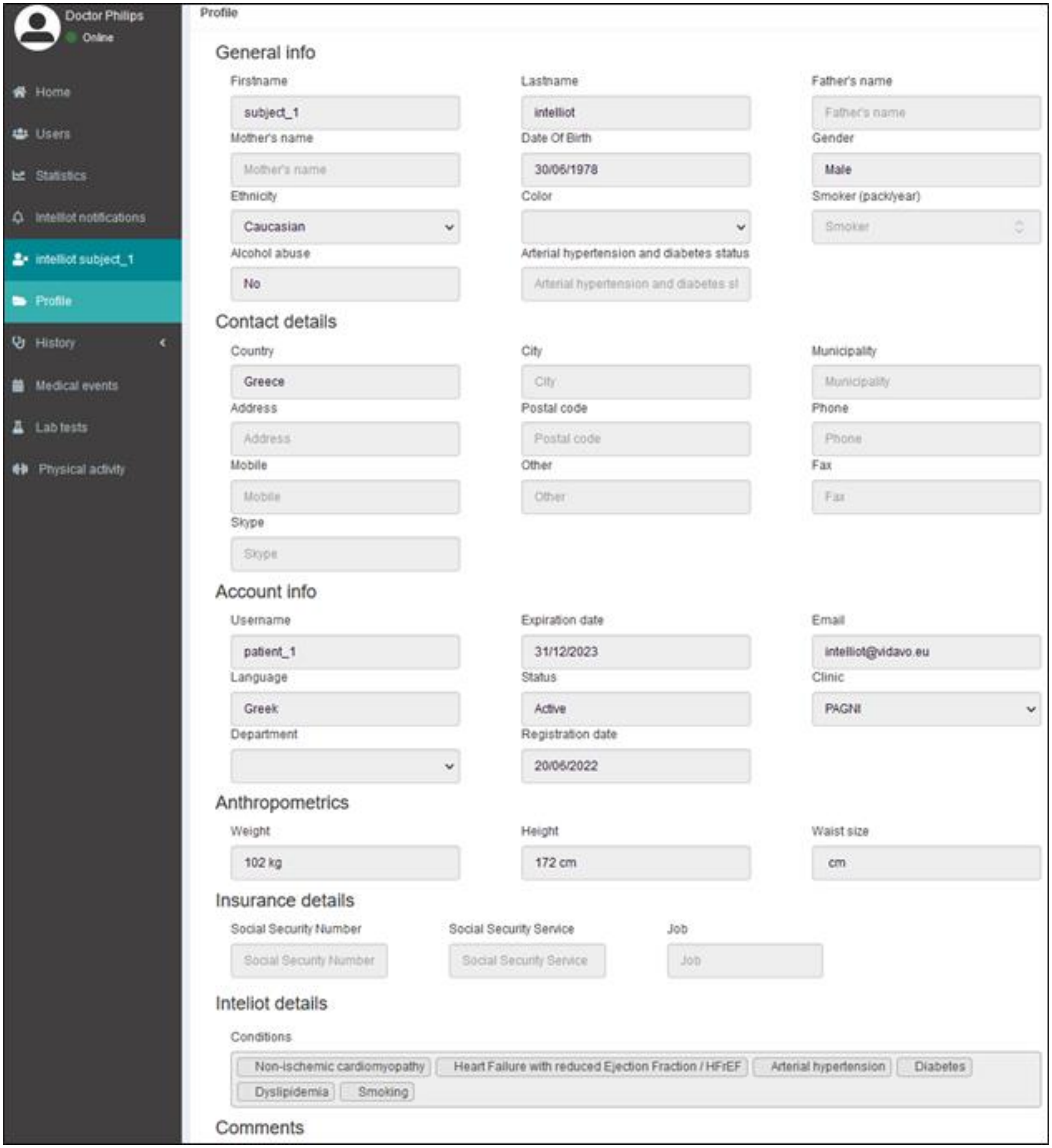

Figure 7. Patient profile page

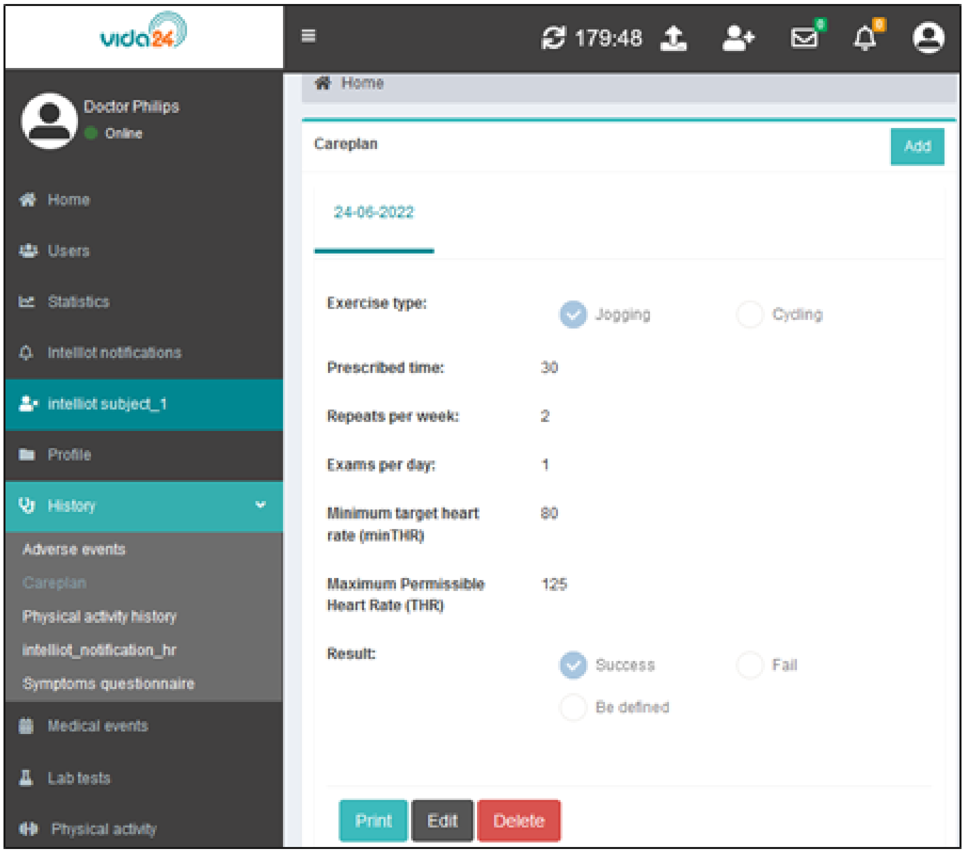

Figure 8. Patient's care plan

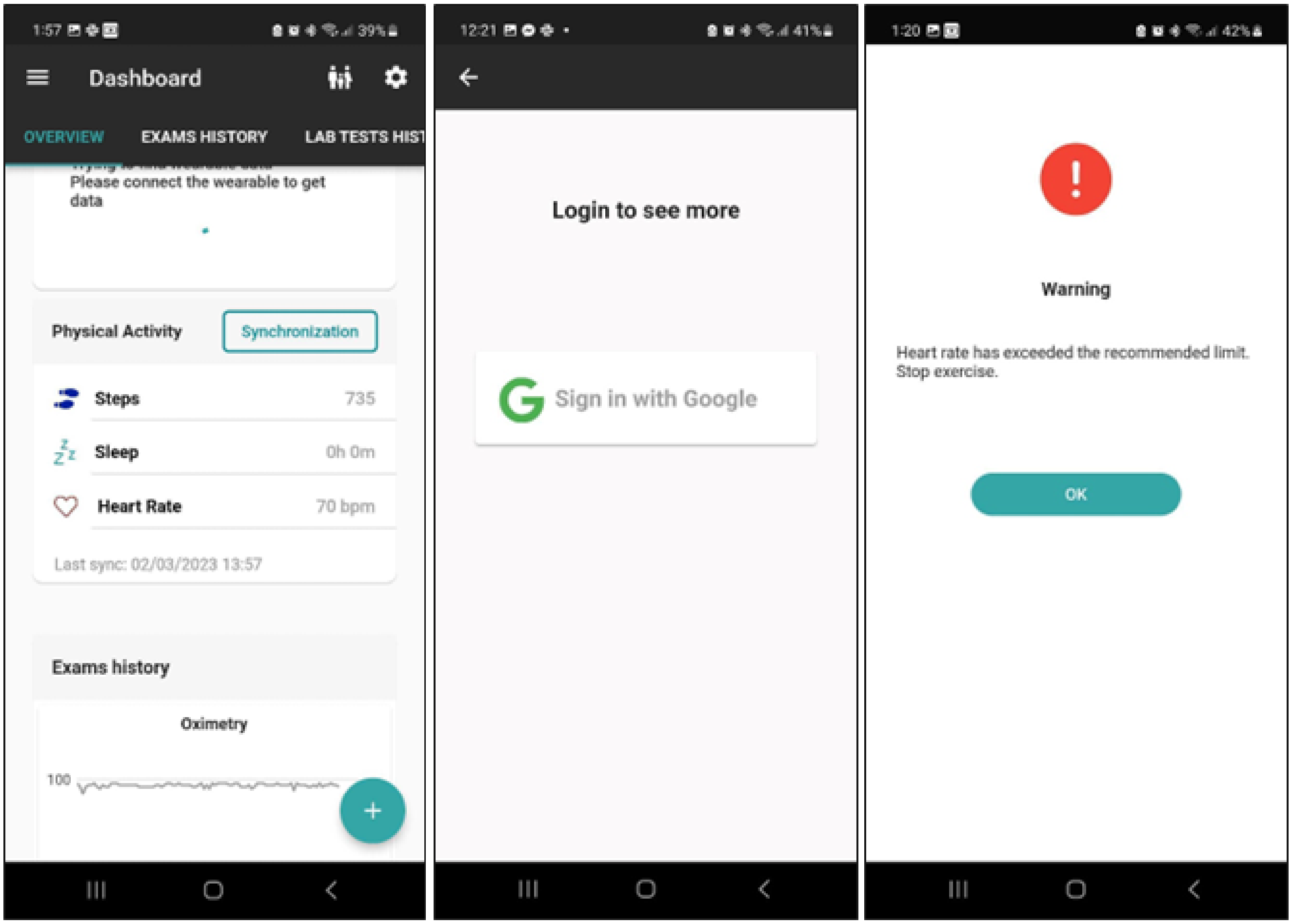

Figure 9. Vida24© mobile app dashboard

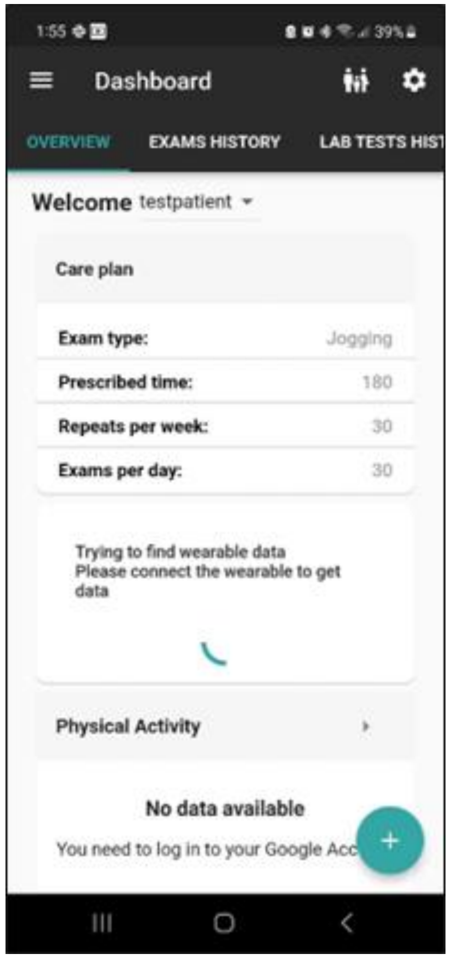

Figure 10. Vida24© mobile app care plan

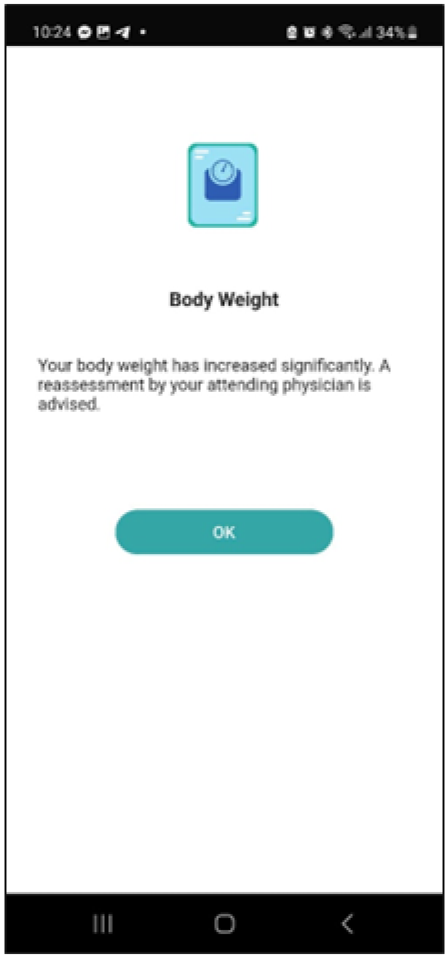

Figure 1110. Connected smart devices

7 REFERENCES

[1] European Commission, Independent High-Level Expert Group on Artificial Intelligence, "Ethics Guidelines For Trustworthy AI", Apr. 2019. https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai.

[2] Health Level Seven (HL7), "Introducing HL7 FHIR", Nov. 2019. https://www.hl7.org/fhir/summary.html.

[3] SNOMED International, "SNOMED-CT: a five-step briefing", 2021. https://www.snomed.org/snomed-ct/five-step-briefing.

[4] Logical Observation Identifiers Names and Codes (LOINC), "What LOINC is", 2021. https://loinc.org/get-started/what-loinc-is/