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[1]L = legal agreement, O = other, P = plan, PR = prototype, R = report, U = user scenario

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9	Comtrade Digital Services	CTR	Large enterprise	Slovenia
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Contents

Chapter 1

Introduction

As an age segment, senior adults have become the fastest growing in society due to the ever-advancing technology – in the form of improved medical devices and cloud services – and the individualised care.

Integrated devices with Assisted Living solutions and assistive technologies can have positive impacts on different dimensions of health and quality of life and can be used as facilitators for operational optimization of care services. Therefore an integrated platform for promoting active ageing, person-centered and event-driven applications running on top of the operators platform, for active ageing and independent living, providing social networking services as well as services for communication with clinical personnel, in a manner that reflects the elderly patient's lifestyle, needs, usual habits, preferences, cultural and social orientations, and circumstances is increasingly becoming a great daily need for senior adults. To this end this report described the way that the different components (from end user to system and vice-versa) that will be engaged in the communication, interaction and exploitation of the required data and will be inter-operating over a specific middleware. The proposed middleware integrates the different devices interactions and exposes and creates interactions with the sensed data. In turn, the sensed data will be used to construct personalized condition-monitoring patient models of the patient, which will further be used to evaluate context against a set of potential life-threatening events. The realization of a high-quality dementia monitoring system requires a sound model of the assisted people with a precise notion for critical situations and emergency cases. Such a model, will allow personalizing the service, i.e., customizing it by taking into account the existing memory problems associated with each person. The vINCI technology will also offer the possibility of identifying the user's context data (i.e. location) with the usage of specific devices (i.e. smart watches). In the case that a user has been detected to an unexpected behaviour and he/she is unable to call for help or if the user is disoriented, then the designed system will be able to detect such behaviour and act accordingly for each one of the cases/situations. In the following sections the different use-cases/scenarios are being described with the related proposed frameworks in order to effectively assess and evaluate the related parameters, that the Vinci architecture contributes. The latter will effectively measure and critically assess the parameters in relation to the clinical validation and the QoL.

Chapter 2

Defining the scenario

2.1 Technology links to the architecture

Four main inputs are foreseen for the proposed vINCI architecture: a static profile of the patient; the outcomes of a questionnaire on the perceived Quality of Life (QoL) by the patient; data generated by sensing devices (smartwatch, smart shoes, depth sensor); and clinical data provided by the medical staff in charge of the patient.

About the data input by sensing devices, the following applies to the smart shoes and the depth sensor.

One of the shoes (for each pair) is equipped with Force Sensing Resistors (FSRs) providing a variable resistance according to the force applied on the active area of the sensor. A proper algorithm, implemented and executed onboard the embedded electronics, gathers the resistance values from the sensors and identifies different activity conditions, namely: standing, walking, running, and non-contact (meaning the shoes are not worn, or the foot is not laying on the ground). Each state is identified by a different numerical label, which is sent to the remote server through a wireless communication interface at a state change. When the shoe is worn by the subject, an initial time interval is used to set the proper condition label; from that moment on, every time the condition changes (e.g. from standing to walking, and back to standing) a corresponding packet is sent to the remote server. Here, by collecting the data packets transmitted over a given amount of time, and checking the timestamps applied by the server, it can be possible to draw the timeline of the physical activity performed by the subject, i.e. how much time has been spent in each state over the whole observation duration.

Data provided by the depth sensor depend on the configuration according to which the sensor is used. In a top-view configuration (that fits the project's requirements), with the sensor physically located on the ceiling, it is possible to recognize the subject and track it, by properly processing the raw depth frames generated by the sensor. Once the tracking is active, the depth sensing system will transmit to the remote server the list of spatial coordinates in the top-view plane, occupied by the subject. At the remote server, it can be possible to recover the information about how much time has been spent by the subject in a given area, among those covered by the depth sensor, in its field of view.

If the depth sensor is used in front view with respect to the subject, it is possible to extract the so-called body joints' coordinates, i.e. the spatial coordinates of a number of specific points typically associated to the body Repere points. By collecting these coordinates and processing them, it is possible to obtain an objective representation of a movement performed by the subject, and compare the way the movement is executed, in different moments. This aspect may be addressed under a research perspective.

The smartwatch will send information to Connected Medical Devices Platform and Connected Medical Devices will export in the form of a JSON the following data for each smartwatch:

- GPS Location/time;
- Number of steps;
- Battery;
- Times the watch exits the defined zone;
- Times that the watch was taken down from the hand.

These informations are sent encrypted to the VINCI platform in order to be interpreted.

2.2 Clinical links to the architecture - the clinical procedures

According to the United Nation's analysis, in 2017, older persons aged 60 or over accounted for 13 per cent of the world's population [1]. Survival rates and longevity are expected to persistently increase around the world. As life expectancy increases and fertility declines, population aging is a globally occurring phenomenon. By 2030 the world's older population is projected to be 1.4 billion, while a quarter of the world's older population is currently living in Europe [1].

As world's population longevity has grown and medical sciences dramatically progressed, the understanding of older adults has changed from the old negative archetype as a decline in all areas of life (health, social, financial) to concepts such as "active ageing", "successful ageing". The old age can be regarded as a natural component of the life span [2], liberated from the burden of employment and parenting, a time to explore areas of personal realization and to rejoice one's life achievements [3]. The shift of the world's population age structure, the increasing need for health and social services and their cost-effectiveness, the rising expectations of elderly to be healthy and independent have boosted the interest in quality of life and well-being in old age as well as health promotion and education. In light of the demographic changes more emphasis is put on investing efforts to maintain good health and preserve independence, quality of life and well-being in older age.

The central dimension of the quality of life in older age is related to health status. People are and will be living longer, healthier lives, but they are also exposed to risk factors and chronic diseases for a longer period of time. In order to maintain and improve health and well-being in older age we need to identify factors that limit independence and take appropriate preventative measures by employing coordinated health care practices and public health policies.

The major causes of death for persons aged 65 and over are ischemic heart diseases and cerebrovascular diseases as reported by the Eurostat data [4]. Sedentary behaviour or inadequate physical activity levels is one of the most important modifiable risk factor for chronic cardiovascular disorders. Physical inactivity and low physical activity account for 7-9% or premature deaths [5]. There is strong evidence that an optimal level of physical activity in older age is linked to lower rates of coronary heart disease, high blood pressure, stroke, diabetes, cancers, mood disorders and disability [6]. Physical activity is associated with a higher level of respiratory and muscular fitness as well as functional health [6]. Physical exercise is the only intervention unfailingly demonstrated to attenuate functional decline among seniors [7, 8, 9]. It has been demonstrated that physical activity has many other benefits in older age such as protective effects on cognitive function [10, 11] positive effects on well-being and quality of life and is negatively correlated with depressive symptoms [12, 13, 14]. Higher levels of physical activity in elderly reduce the fear of falling and improve balance [15, 16, 17] and actively prevent fractures by increasing muscle strength, balance and bone mineral density [18]. However, The Eurobarometer and other studies reported that the majority of both the adult and elderly populations are insufficiently active for optimal health benefits [19, 20].

Approximately 10% of people aged over 65 years and a quarter to a half of those aged over 85 years are frail [21]. Frailty is considered a geriatric syndrome and is described as a health state in older age when multiple body systems progressively lose their functional reserves and the patient is in a state of increased vulnerability and functional impairment [22]. The main feature of frailty is loss of muscle mass and strength along with other cumulative declines in energy and exercise tolerance, cognitive function and physiological reserve, ultimately leading to reduced ability to recover from an acute stress induced by illness and poor prognosis and outcomes [22]. Early identification of frail patients or patients at risk of frailty is crucial for preventive and rehabilitation interventions [23].

New insights into lifestyle, psychological, and other environmental influences on health promise to have a profound impact on the ability of older adults to remain physically healthy and cognitively, emotionally, and socially vital into very advanced ages, optimally, for as long as they live [24]. The field of cognitive aging has evolved from a focus on cataloging age-related declines of brain and mind in healthy older people to a focus on interventions aimed at limiting those declines.

Mood disorders are frequent in old age and their prevalence is increasing with population aging. Because of its severe consequences, late-life mood disorders may be regarded as an important public health problem [25]. In older adults, depression may present with more sleep disturbance, fatigue, psychomotor retardation, and hopelessness. Other very common presentations in elderly with depression are complaints of poor memory and concentration, slower cognitive processing speed, and executive dysfunction confounding with dementia, called pseudodementia [26]. Neurological comorbidities may be associated with depression in the elderly, for example, Parkinson's disease and stroke, which may account for differences in the clinical presentation of symptoms. Depression in Parkinson's disease is usually milder and with less anhedonia than depression in otherwise healthy geriatric patients [27]. Poststroke depression is frequently associated with severe vegetative symptoms [28].

Along with population aging, many age-related conditions (mood disorders included) steadily increase over time, necessitating the need for specific diagnostic tools and treatment approaches. Frequently severe illnesses that impair functionality reduce quality of life and increase mortality. There is still limited evidence on how to specifically deal with mood disorders in late life, particularly considering the high rate of comorbidities and association with neurocognitive and degenerative outcomes [29]. The translation of basic findings and cutting-edge technological breakthroughs into practical applications improve health and well-being at older ages [24].

Quality of Life was widely recognized as a health related issue associated with the WHO's definition of health been not only the absence of disease but a complete mental, social, and physical well-being. The WHO definition above supports an emerging consensus that QOL is a multidimensional construct conceptualized as separate domains and sub-domains relating to all areas of life [30].

The needs of the elderly population are diverse and complex due to growing health concerns in the older years. With the growing elderly population and extension of the life span, it is very important to understand the factors which affect the quality of life (QoL) of the elderly population. The analyse of the multidimensional profiles of mental well-being includes emotional, psychological, and social well-being. It should be recognized that QoL encompasses general well-being phenomena (satisfactions), social phenomena (e.g., social support, work, interpersonal relationships), and health-related phenomena (e.g., functionality), but that the overarching dimension of the QoL concept is psychological well-being [31].

In our days technology plays a major role in our everyday lives transforming our lifestyles and offering easy and instant access to a wide range of information. Technology has an enormous potential to benefit the lives of older people, enabling them to live independently and providing the support to implement preventive health care, health education and promotion measures. Problematically, older adults often lack the skills and knowledge necessary to use computers and access online information and disability, sensory and cognitive function impairments, chronic disease, or handicaps can make technology difficult to use. The vINCI technology could offer a feasible opportunity for seniors to independently evaluate their quality of life and health status and receive a direct feedback which would enable them to take appropriate measures to improve their health status and prevent future negative events.

2.2.1 Pathway

The vINCI technology will be constructed to offer a platform for early identification of health related problems in a stepwise manner. The most important feature of the vINCI technology is the user will be able to independently identify his/hers health risks by receiving a direct feedback with specific recommendations.

On an active screen tablet, seniors will be able to self-complete a questionnaire that assesses their quality of life (QoL) across multiple domains. The scoring algorithm will generate a direct feedback that will be visually displayed on the tablet's screen. If their quality of life is optimal the received feedback will read: *"Congratulations! Your quality of life is very good! You can take this test again after 6 months or any time your health status changes"*. If their quality of life scores below the optimal level, evaluation of their psychological well-being and subjective and objective assessment of their physical activity level will be offered in a stepwise process.

Because mood disorders and also the user's mood at the time of completion can influence the QoL score, the next step will be evaluation of psychological well-being. When the QoL and the psychological assessment results are sub-optimal, the user will be invited to further proceed with assessment of physical activity.

The **World Health Organization Quality of Life Instrument, Short Form** (WHOQOL-BREF) questionnaire[1] is a commonly utilized generic measure of quality of life that is used to measure quality of life in healthy people and in different groups of patients. The WHOQOL-BREF questionnaire is available in many languages, and has been translated into Romanian. The short-form version of the World Health Organization's Quality of Life measurement tools (WHOQOL-BREF) is a 26-item questionnaire that assesses quality of life on physical, psychological, social, and environmental domains [32].

The WHOQOL-BREF self-assessment is completed, together with socio-demographic and health status questions. Analyses of internal consistency, item–total correlations, discriminant validity and construct validity through confirmatory factor analysis, indicate that the WHOQOL-BREF has good to excellent psychometric properties of reliability and performs well in preliminary tests of validity. These results indicate that overall, the WHOQOL-BREF is a sound, cross-culturally valid assessment of QOL, as reflected by its four domains.

Visual analogue scales (see Figure 2.1) have been widely used in psychiatric research as brief measures of subjective distress (e.g. dysphoria, pain). Typically, these scales involve a 100 mm horizontal or vertical line with written descriptors at either side of the line (e.g. *"not at all sad"* versus *"very sad"*). For example, in the study by Stern and Bachman (1991), a single bipolar Visual Analogue Dysphoria Scale (VADS) was used [33]. The scale involved a 100 mm vertical line with a simple schematic *"happy face"* at the top pole and a *"sad face"* at the bottom; corresponding words (i.e. *"happy"* and *"sad"*) appeared above and below the two faces. The patients were instructed, either with words or gesture, to place a mark on the line at the point that represented their degree of sadness. The scale is scored from 0 to 100, based on the number of millimetres from the *"happy"* pole.

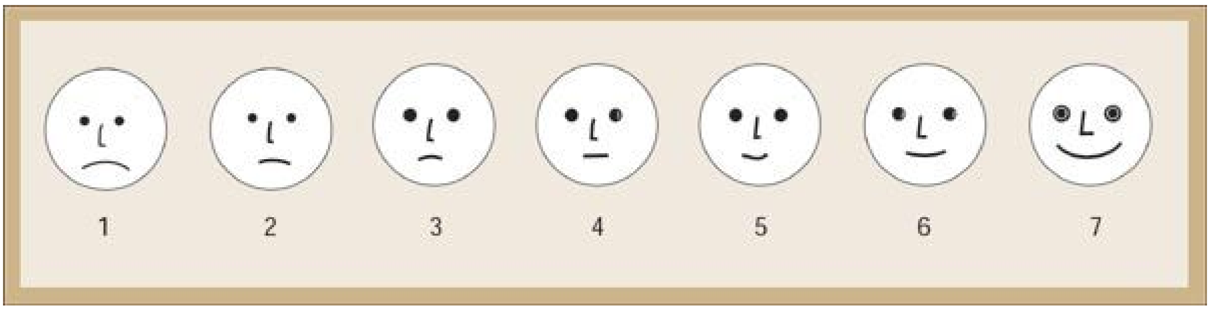


Figure 2.1: Eg. of 'smiley' faces series ranging from glumness to happy (from [33]).

The **Dynamic Visual Analogue Mood Scales** (D-VAMS[2]) are based on the Circumplex Model of

[1]http://www.who.int/mental_health/media/en/76.pdf
[2]http://dvams.com/dvams/menu_home_dvams.htm

Affect, and consist of seven bipolar scales: Miserable-Satisfied, Sad-Happy, Distressed-Peaceful, Bored-Excited, Afraid-Calm, Angry-Peaceful and Sleepy-Alert. The scales comprise images of human faces whose expressions change according to the position of a slider. The design of D-VAMS was based on analyses of ratings of posed facial expressions in three studies and scaling data by a non-clinical sample. Initial validity findings in a sample of stroke survivors indicate that the D-VAMS is a valid and reliable measure of pleasantness of mood on a scale of 0–100, and is suitable for use with stroke patients with aphasia [34]. D-VAMS (or "Emotiscope") is a brief, nonverbal mood assessment instrument designed for stroke patients with communication difficulties due to aphasia. It consists of sliders controlling transitions between facial expressions on seven scales.

The physical activity level will be subjectively evaluated with the **International Physical Activity Questionnaire** (IPAQ[3]). Users will be able to complete the IPAQ on the tablet and receive a feedback with regard to their physical activity level and recommended subsequent actions. Sedentary behaviour will additionally be evaluated with the smart camera which will record time spent sitting. The feedback will be constructed on an algorithm based on current physical activity scientific guidelines with the aim of reaching the recommended targets.

The physical activity will be objectively evaluated with the smart shoes which will measure the daily number of steps as well as a median gait speed. The gait speed is a simple yet very important parameter for early identification of functional decline. When the gait speed falls below a predefined value, the user will receive a specific feedback, also on the tablet screen.

The vINCI technology will also offer the possibility of identifying the user's exact location with the smart watch. If the user has fallen and/or is unable to call for help or if the user is disoriented, the next of kin can be notified of the situation.

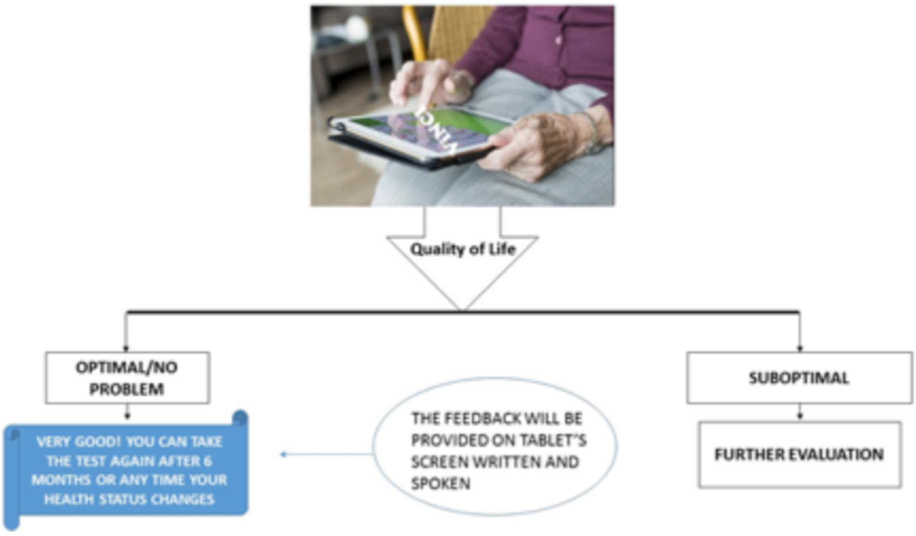


Figure 2.2: Step 1. The user completes the WHOQOL-BREF questionnaire.

2.2.2 Clinical Validation

The vINCI technology will be tested in a clinical validation study on a total number of 50 users 65 years of age and older, who will agree to participate in the study and will sign the informed consent.

The validation study will consist of correlating the vINCI data with data obtained by specialized multidimensional geriatric assessment.

[3]http://www.sdp.univ.fvg.it/sites/default/files/IPAQ_English_self-admin_long.pdf

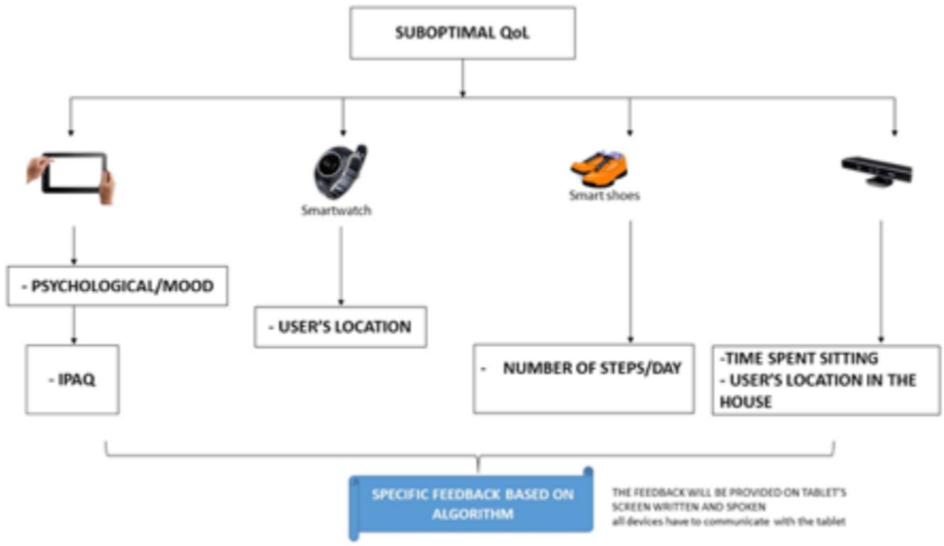


Figure 2.3: Step 2. Next he periodically fills in the D-VAMS and IPAQ questionnaires, wears the watch, shoes, and is monitored in-door (the vINCI Kits).

Clinical multidimensional geriatric assessment:

- medical history, anamnesis;
- ECG, AV;
- Geriatric Depression Scale (GDS-30);
- Montreal – Cognitive Assessment (MoCA);
- ADL (Nottingham Extended test);
- Frailty Index (Prisma 7 Questionnaire), Timed-up-and-go test.

2.2.3 Evaluating the impact on Quality of Life (QoL)

The evaluation of the impact of technology on QoL will be carried out after the clinical validation is completed. The WHOQOL-Bref, the DVAMS mood scale and the IPAQ physical exercise questionnaires will be completed by participants before using the technology. After the use of technology for a period of six months, the three above mentioned questionnaires will be completed again in order to identity any changes in the scores which can be linked with the use of technology.

2.3 A working scenario

After carefully analyzing the technology updates compared to the proposal writing moment, we came to the conclusion that a small and improved update on the scenario is clearly needed. In the proposal we explained that, for monitoring the older adult, we will primarily use several tools: the DHL One smartwatch, the smart shoes, depth cameras. In addition, the monitored adult will first be clinically screened using a battery of QoL questionnaires (to be decided), and this clinical assessment will be repeated using a clinical methodology.

Here, our analysis led to the following four different inputs for monitoring:

Step 1 – The static profile of the patient is established via clinical questionnaires. When enrolling into vINCI, the patient (or his family will, if his condition does not allow for direct input) is presented first with a Smart Tablet, where the *vINCI Digital Caregiver* runs. He first enters his Personal Data (for registration, see Figure 2.4). For this step, he will be using a personal laptop, or we will offer also the alternative to use a mobile tablet (this will be a Web-based form, accessible from various devices).

The personal data to be included in the Registration process includes Name, Age, known prior Clinical Conditions. This is the kind of base data for us, to construct the first profile of the patient (to report the clinical progress against).

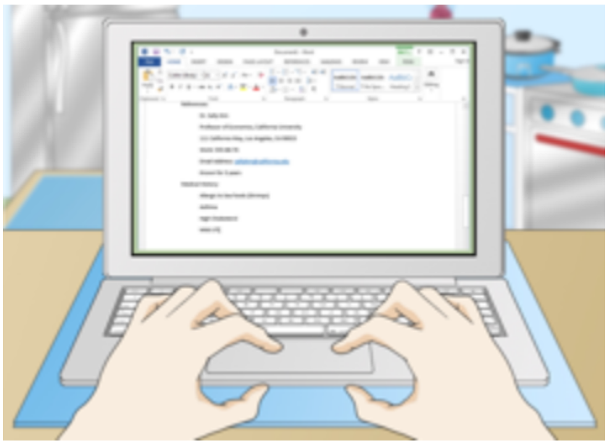


Figure 2.4: Illustration of the patient responding to the Registration process (enrolment in vINCI will require the monitored older adult to first register).

Step 2 – Next, the patient will be presented with the Questionnaire to determine his perceived Quality of Life index (chosen and indicated by Clinical partners, the WHOQOL-Bref). An example of how this questionnaire should be built, using Smileys, is presented in Figure 2.5.

This questionnaire will be supplied in an Web-based mobile form that will be available (and this is quite important to us) from a mobile tablet. The form will need to be repeated periodically throughout time, to continuously re-evaluate the clinical status of the patient (and adjust the scales for vINCI monitoring and alert triggering accordingly). The way to interpret the data entered by the patient will be established by clinical partners in the project. It's important that the entries make little use of visual texts, and we intend to use smileys to map psychological data into the questionnaire (see Figure 2.6)

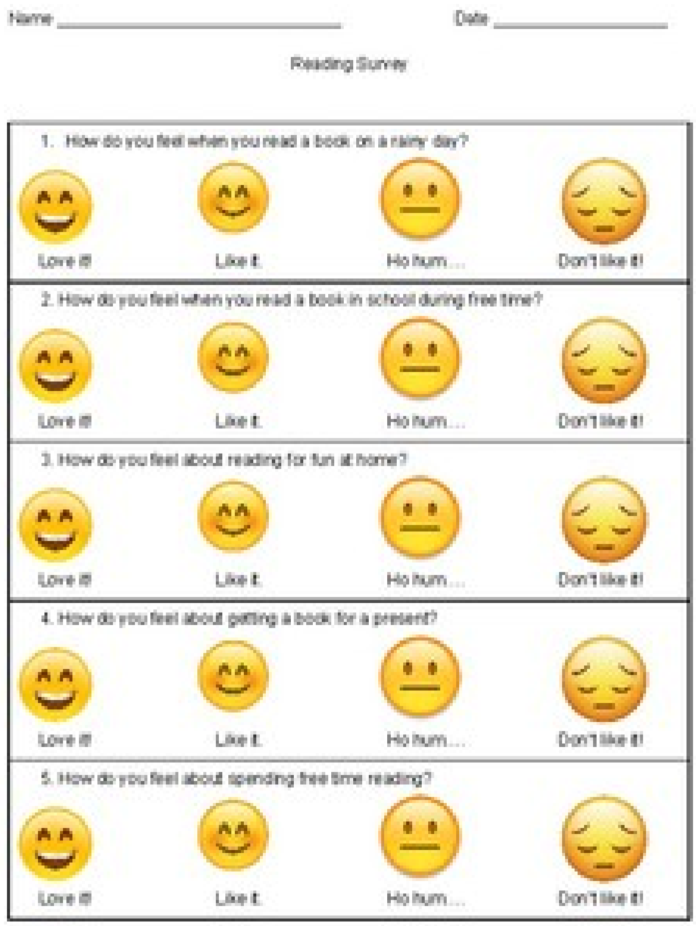
Step 3 – From this point on, the patient will wear the CMD One smartwatch (right part in Figure 2.7) and the smart shoes (left part in Figure 2.7).

Within the house, the patient is being monitored by depth and stereo cameras (see Figure 2.8). First we start with algorithm to track the person while in-house, to monitor the activity level. Next, we aim to extend this research towards detecting also frailty problems, by asking the person to perform certain exercises and measuring mobility in arms and/or legs.

Periodically, the person is also asked to fill in the D-VAMS and IPAQ questionnaires, to get his sense of activity/social levels (see Figure 2.9).

Step 4 – The cameras, watch, shoes, questionnaires, all these serve to get data related to the patient. However, in order to correctly interpret that data, we need to have appropriate clinically-validated models. For these models, in the clinical pilots we will use alternative medical methods (see Figure 2.10) to get the actual clinical facts for the patient (how the patient is filling). These facts will then be mapped against the sensed data we get from our sensor, to construct supervised ML models.

From this moment on, the patient is continuously monitored via the smart watch and the smart shoes. Every day, the patient has to visit a specially-designed room, where he needs to perform some activities



Name ____________________ Date ______________

Reading Survey

1. How do you feel when you read a book on a rainy day?

Love it! Like it. Ho hum… Don't like it!

2. How do you feel when you read a book in school during free time?

Love it! Like it. Ho hum… Don't like it!

3. How do you feel about reading for fun at home?

Love it! Like it. Ho hum… Don't like it!

4. How do you feel about getting a book for a present?

Love it! Like it. Ho hum… Don't like it!

5. How do you feel about spending free time reading?

Love it! Like it. Ho hum… Don't like it!

Figure 2.5: An example of questionnaire to be filled in by the monitored older adult after enrolling in vINCI (initial assessment of his clinical status).

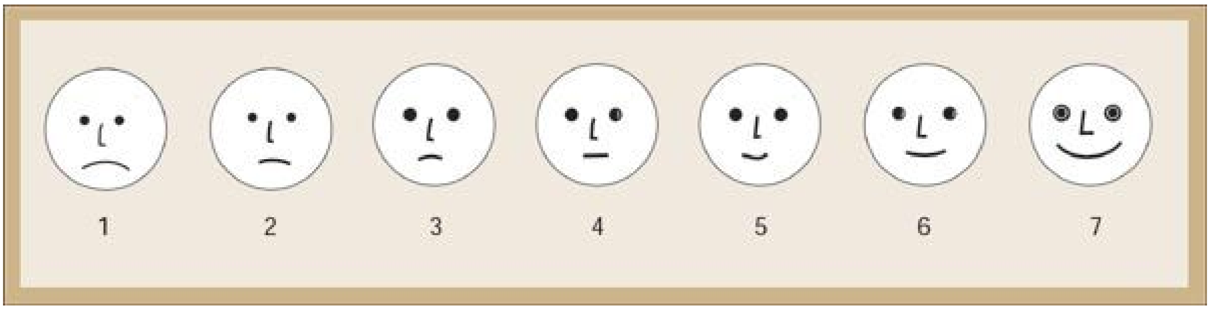


Figure 2.6: An example of using smileys for the questionnaires.

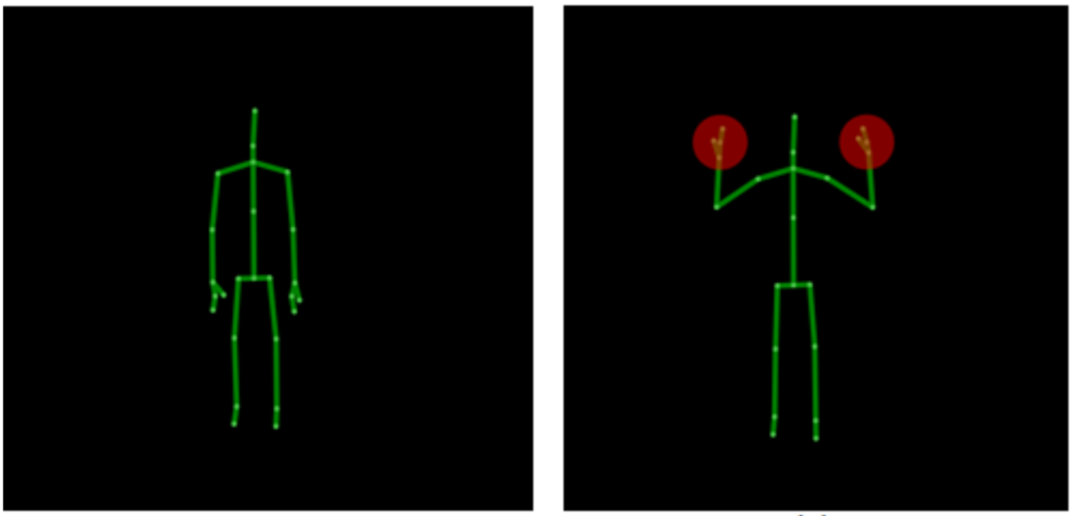
in front of depth camera. This is needed to evaluate his potentially degrading abilities, in time, of performing movement (to see fragility-associated degrading conditions).

Each clinical investigation has to have an associated ICT algorithm describing the process. The clinical partners need to define / explain the process, such that to be able to program it (the ICT partners).

Second, at some interval, as in number of days or months, the patient needs to re-enter data into

(a) Amphitheater (b) Laboratory

Figure 2.7: Illustration of the kind of technology the older adult will be wearing.



(a) In front of the sensor (b) Raised hands, closed fists

Figure 2.8: Tracking the skeleton of a person with Kinect.

the questionnaire (via the same tablet), and re-visit the clinical facility to be investigated (EKG again, psychometric investigations, etc.). The data needs to re-update the trained model of the patient profile.

Finally, as the patient is monitored, he is asked to re-visit the clinical facility via his watch (depending on how he is performing, he sees a happy or sad face - for example, if he doesn't walk a certain number of steps; but who / how establish how many steps are enough?; he sees a sad face, and as he walks the face becomes a happy one).

The smart shoes will be able to give a picture of the physical activity level of the patient, by recognizing different states, like standing, running, walking. At the server side, by a proper processing of the data transmitted by the shoes, it will be possible to recover a kind of "timeline" of the different states alternating during a given time interval (a day, a week, or longer). The different evolution in the amount of time spent by the patient in each recognized state can provide some insights about potential fragility conditions (e.g. if the amount of time spent in a static state increases over time, this can denote a decreasing physical condition, or a worsening psychological condition leading the patient to a more sedentary behavior). Could they also input data on potential fragility conditions associated with the patient?

As for the depth camera, we intend to put the patient perform specific physical activities in front of the camera and evaluate his ability to perform "correctly" those activities - could we associate again this with deterioration associated with fragility conditions (like he is unable to reach the hand perfectly

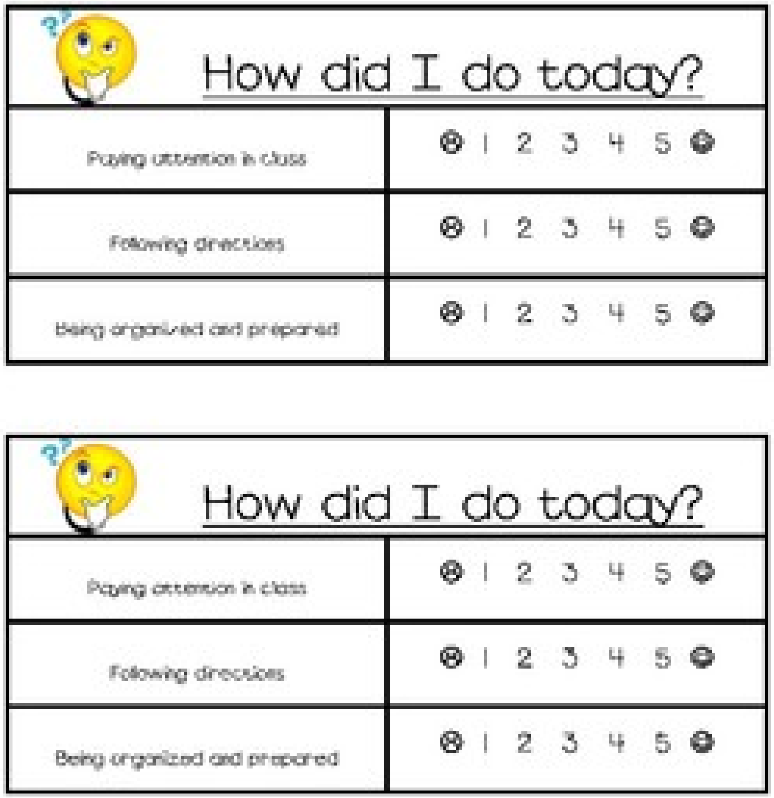


Figure 2.9: An example of filling in the IPAQ activity questionnaire.

horizontally - what does this tell us?; he is not able to completely perform squats - what does this tell us?). The depth camera may be used for different purposes, such as:

- Monitoring how much time the patient spends sitting on a sofa or chair;
- Evaluating the capability of the subject to perform some physical tasks.

In the former case, the typical configuration uses a depth camera installed on the ceiling: depth frames are collected by a computer that processes them to identify the subject and analyse how much time is spent in the same position. In the latter case, the depth camera has to provide joints extraction capability (like Kinect does) so that body joints coordinates are automatically extracted when the patient is standing in front of the camera. Once the spatial coordinates of different body joints are available, it is possible to describe the movement performed by the subject, and possibly compare it to a model representing the "ideal" or "correct" movement to perform. This aspect needs a research-oriented approach to evaluate the feasibility of the remote performance evaluation.

The patient profile is a combination of all these input parameters – see Figure 2.11 an illustration of the processes.

Figure 2.10: The parallel screening done in a controlled environment, for the assessment of the health status, in relation to vINCI services being provided.

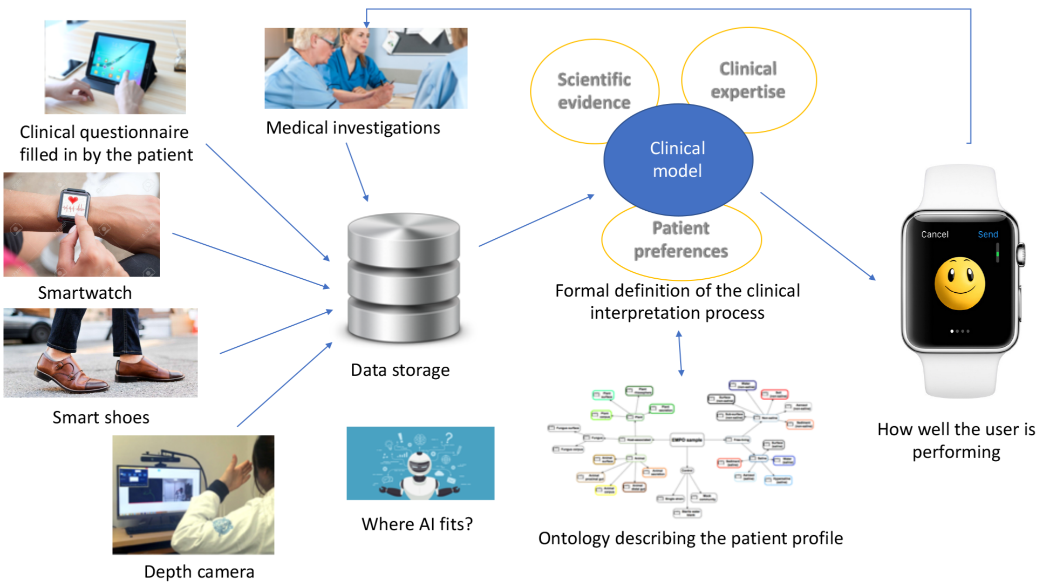


Figure 2.11: An aggregated view of the processes being supplied, in an integrated manner, throughout the vINCI clinical support framework.

Chapter 3

Technical and non-technical requirements

The Internet of Things (IoT) is not a single fold technology as it integrates technologies that are already surrounding us, with any type of devices ranging from wearables to smart vehicles and other devices which can passively play a role in our daily runtime [35]. These technologies in an AAL environment should work together by making use of new communication standards and applications [36].

In practice, these technologies should embrace new protocols in wireless communications, allowing the interaction between people and machines, and between machines-to-machines (M2M). New services and devices have already started to incorporate these technology elements and in-turn this incorporation will increase in the coming years. The development of standards is a fundamental part of this technology integration into a unified and fully operating architecture with support of the massive use of IPv6. In this context different devices enable different gateways which serve primarily as the data bridge between Network devices and enable IoT Nodes that don't have direct network connectivity or common communication language to communicate with the use of APIs. Each device is seen as a gateway that will enable the so-called smart edge, as nodes are usually neither able to execute complex computations nor to maintain long term and secure connection.

3.1 Technology for the smart shoes

The smart shoes (SS) to be used in the vINCI architecture exploit a wireless communication interface suitable for use in an indoor scenario. This includes Bluetooth Low Energy (BLE)) or WiFi Low Power. In both the cases, a proper transceiver is used in the embedded electronics, to convert the data generated from the sensors into packets to be transmitted to a BLE receiver, like a smartphone, or to a WiFi Access Point, for further relaying to a remote server. Both the communication interfaces work according to the corresponding standardized specifications, in the ISM bands. For each pair of SS, one of the shoes is equipped with an onboard sensing device that includes Force Sensor Resistors (FSR) located under the insole and connected to an embedded electronic board. Such a board is equipped with the wireless transceiver, featuring a low power consumption, so that the device can be battery-operated for a reasonable and effective amount of time. The sensing device exploits the radio interface to transmit the data generated by the onboard firmware to the remote server, through a "data aggregator" (the smartphone, in the BLE case, or a WiFi AP), as schematically shown in Figure 3.1. The gateway operates transparently, delivering data packets to the remote server, exploiting the available communication technology at the "backbone" (Ethernet or WiFi, GPRS, LTE etc), over a direct link or through the internet. Each message transmitted by the sensing device onboard the shoe contains a numerical value describing the activity state recognized by the device itself, i.e.: noncontact, run, walk, stand.

At the remote server, packets collected over a given range of time will allow to identify different physical state conditions experienced by the user (based on those identified by the sensing device in the shoe), and to estimate how much time the user spent in each state, by looking at the timestamp applied to each received packet by the remote server.

3.2 Technology for the depth sensor

The depth camera is typically equipped with a USB communication interface (see, for example, USB3.0 for Kinect v2, or USB 2.0 for Orbbec Astra Mini), and needs to be connected to a computer in order to provide a long range transmission of data (e.g. to a remote server), by exploiting an Ethernet or WiFi connection supported by the computer itself. It is possible to use a so-called mini computer

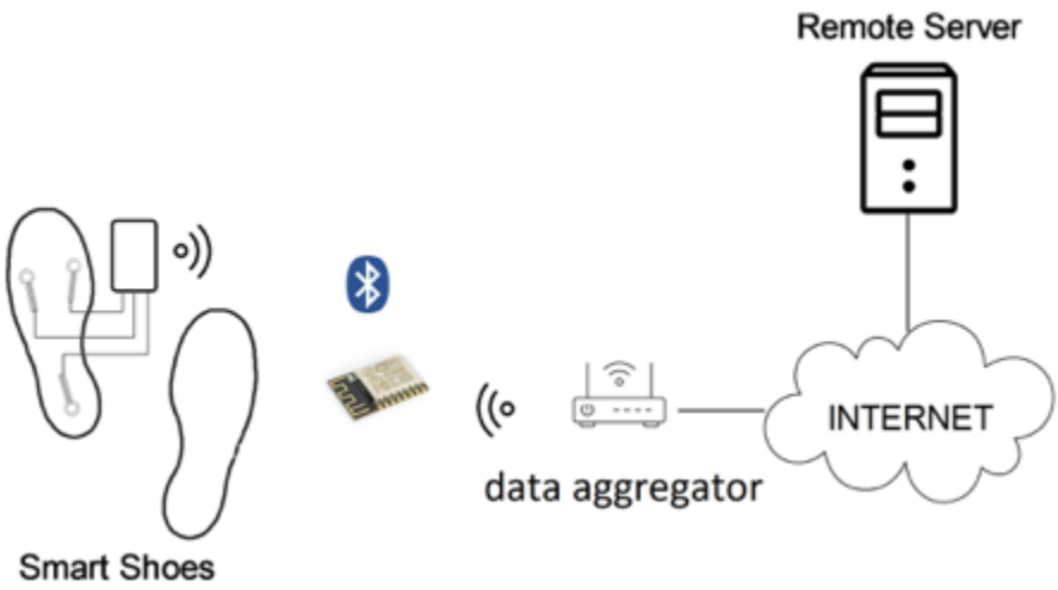


Figure 3.1: Data transmission architecture for the smart shoes.

(like the Intel NUC i3-7100U) to interface the sensor, acquire depth signals and process them locally, so that the data transferred to the remote server are not the "raw" ones (body joints coordinates or depth frames) but they have been already processed locally. For this reason, and due to the hardware requirements typically associated to depth sensors (irrespective of the specific device chosen) in terms of data throughput, it is not feasible to use embedded boards like RaspberryPi or Arduino, to interface them, despite being more cost effective. Figure 3.2 schematically shows how to connect the depth sensor to the remote server.

Figure 3.2: Connection of the depth sensor to the remote server.

If the depth camera is used in top-view configuration (i.e. it is installed on the ceiling), then raw depth frames need to be processed to identify the patient's "blob" and locate it in the observed environment (the amount of area covered depends on the sensor and on the height at which it is located). It is possible to measure how much time the patient spend in specific areas (e.g. on the sofa).

If the sensor is used in front view, typically it is possible to extract the patient's body joints, and their spatial coordinates. This way, objective measurements about specific movements executed by the patient may be obtained, by properly processing the coordinates through geometric relations.

In both cases, the sensor will transfer signals (depth frames or joints coordinates) to the local mini PC; the amount of data transferred to the remote server will depend on the specific application designed. Typically, in the top-view monitoring, the local mini PC will transfer the information about the position of the subject within its field of view once in a day (e.g. at 12.00 PM). The processing of this data is not real-time.

3.3 Technology in the smartwatch

The HumanLink smartwatch is using a GSM and WiFi networks in order to send the information from the device to the CMD platform.

The platform then interprets the data and sends it to the application that is installed on the phone of the caregiver.

The information that is transferred from the watch to the platform (see Figure 3.3) is:

- GSPS Location/point in time,
- Battery status,
- The watch is on the hand or not,
- Setup SMS.

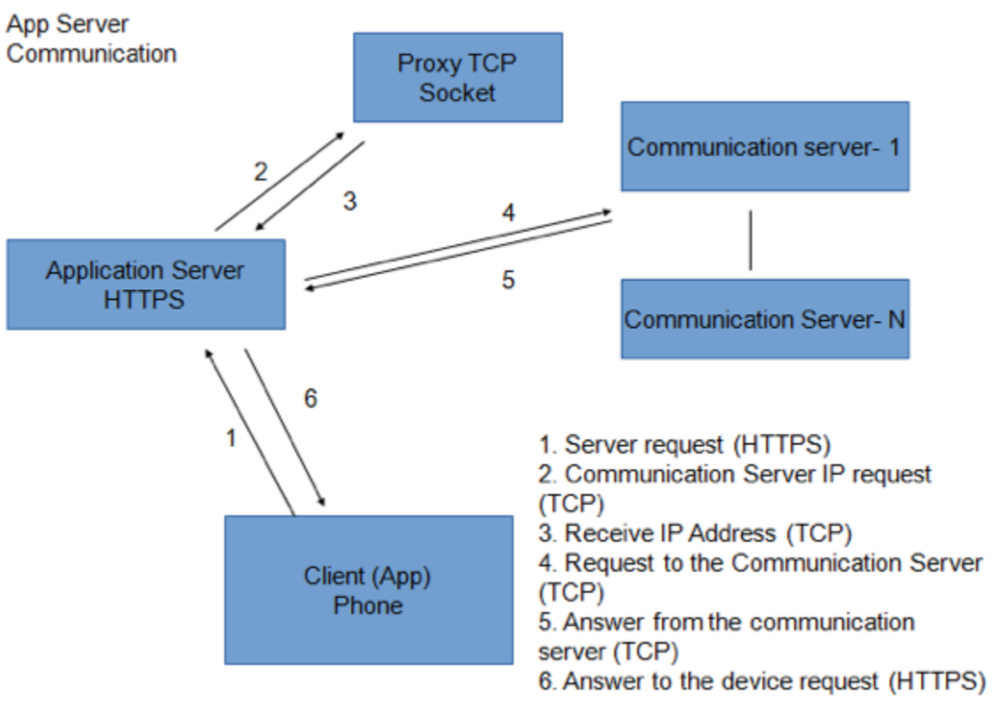


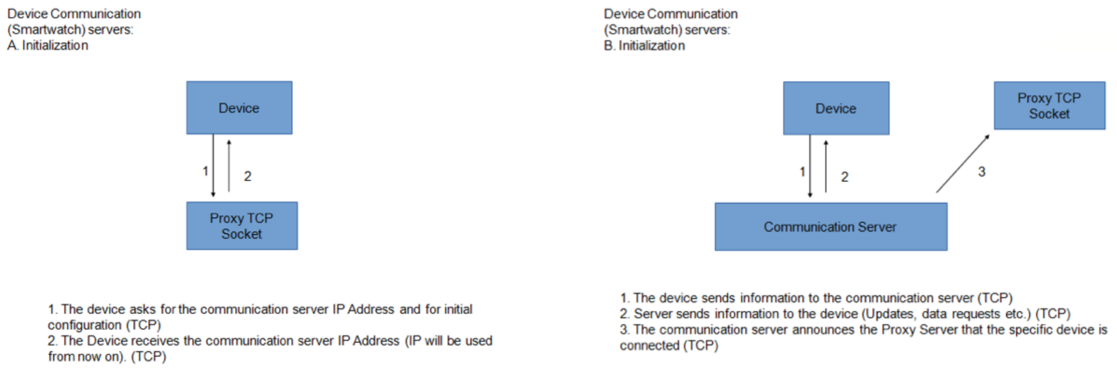
Figure 3.3: Connection between the CMD watch and the platform.

The platform stores and interprets :

- CUID of the watch,
- Phone number of the watch,
- Phone number of the device where the application is installed,
- GPS and point in time that results in a track,
- Safe zones/geo fences,

The application is used for the input of the information and the setup of the watch (see Figure 3.4):

- The user creates an account.
- After the account creation the user scans the watch. After this scan, the application sends to the platform the information and the platform decides , taking into account if the watch was already scanned or not, to allow connections between the specific watch and the specific account. The watch can be scanned by different accounts but the first account that scans it will have the Administrator rights. Following scans from different applications will trigger an announcement message sent to the administrator in order to approve or block the connection between the 2 devices.
- From the application the user can create the safety areas for the watch, can call the watch and can send audio messages.
- All the alerts are received in the App from the CMD Platform.



(a) In front of the sensor

(b) Raised hands, closed fists

Figure 3.4: Initial steps in communication between the watch and the platform.

3.4 Technology in the vINCI Digital Caregiver application

The vINCI Digital Caregiver application will run on mobile tablets or personal laptops or desktop computers. The connectivity between the application and other vINCI modules will be provided using conventional broadband network technologies: WiFi or LTE in case of tablets, Ethernet or WiFi in case of laptops and desktop computers. Moreover, the vINCI Digital Caregiver will have direct access to the vINCI platform, without the need to use any gateways or other type of edge nodes.

3.5 Platform requirements

The vINCI platform is dedicated to collect and analyse data related to monitored older adults. It includes two main components (see Figure 3.5):

- Collecting module, which gathers input data from different sources (smart shoes, depth sensors, smartwatches, as well as clinical questionnaires, interviews and observations available through the Digital Caregiver application) and stores the data in internal data storage.
- Analysis module, which processes gathered data to construct the patient profile. The results of analysis are available to caregivers via the Digital Caregiver interface. Data analysis can also trigger an alert that is sent to patient's smartwatch to indicate to her/him the necessity to carry out a specific action (for example, performing more steps).

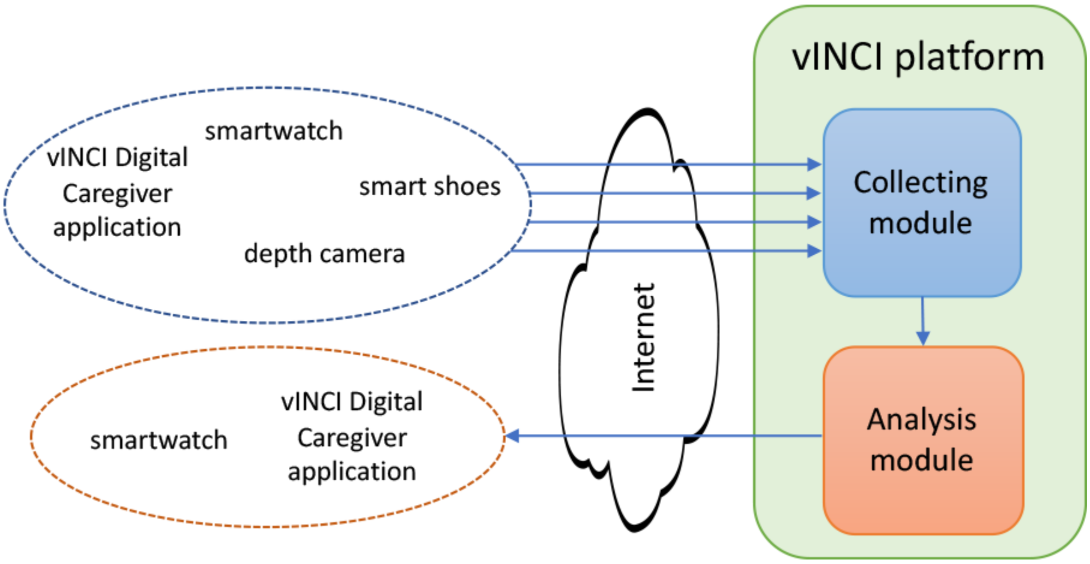


Figure 3.5: General concept of the vINCI platform.

The connectivity between the vINCI platform and the input data sources and receivers of the output data should be provided through the Internet. The platform will offer set of interfaces adapted to different data inputs. On the other hand, all the received data should be recorded and shared to the analysis module in unified format.

It is desirable that the vINCI platform offers all services on standard HTTP/HTTPS open ports (port number 80 and 443, respectively), to avoid any issues with firewalls and proxies. Nevertheless, if handling of messages received from different data sources will require distinct mechanisms, and diverse protocols will be used, the particular platform services will be available also on ports other than those commonly utilized by HTTP and HTTPS protocols.

Process of collecting input data assumes that the platform plays role of a server which listens for messages generated by the data sources. On the other hand, platform's output data will be provided to the Digital Caregiver application on a request generated by the application. The output data can also be pushed to the smartwatch via the CMD platform. This action will be triggered by the analysis module, if it discovers adverse changes in patient's behavior. In this case the vINCI platform will play role of a client, and the CMD platform will be a server that receives and handles alerts generated by the vINCI platform.

Because the vINCI platform handles confidential data related to patients' health status, appropriate mechanisms should be used to ensure health data security and privacy.

3.5.1 Patient Profile

There exists a necessity of deploying better assistive care for older people that is up to create age-friendly environments, personalized treatments and support, appropriate medical devices and access to upgrade knowledge and information [37].

In this context, the new digital technologies have a critical role and the potential to sustain the implementation of new elderly-centred solutions. A digital ecosystem should be based on a holistic approach able to link and interconnect multiple healthcare domains, patient-centred insights, and technologies [38]. Considering that there is an application developers' concern to new approaches of elderly-centred solutions, our application design is based on the patient profile model.

The elderly person must be seen from a new and comprehensive perspective that encompasses not only the improvement or preservation of his / her health, but also a continuous and personalized assistive care, active and preventative support from a broader range of healthcare specialists and informal caretakers, and last but not least, digital technologies able to sustain the empowerment of the elderly and the management of the personal care and healthcare system.

The patient's profile design is very important as a strategy for designing the products and health care information technology systems [39, 38]. Many health solutions require active participation of an informed patient for the treatment to be successful [40].

In the last years, there has been an increased use of assistive based technologies to aid older people with cognitive impairments [40]. These applications aim to enhance the patient's quality of life, but no many provide some form of personalized service [41, 42].

vINCI project proposes a novel approach for providing personalized assistance services for patients in an IoT-based ecosystem. For vINCI care, the user profile will be the input to provide personalized support for daily / medical activities. The profile will be used as evidence to evaluate the impact of vINCI on the perceived QoL level, allowing a proper adjustment (if needed) of the intervention support provided by caregivers.

In this study, we seek to investigate the utility of user profile as a methodological tool to develop an in-depth understanding of the limitations and possibilities of the aged patient population. The resultant conceptual model of the aged patients can be leveraged to inform design and development decisions of vINCI.

Models are widely used in system analysis and design. Studies have found that these models are useful to allow developers and system stakeholders to visualize data processing and the interaction between the system and external entities [43, 44].

The user profile is a conceptual model of target groups, the selected older people that can serve to promote the shared understanding that underlies the process of analysing, designing, developing and implementing system. A user profile is a dynamic repository used to classify the target user groups of a system and uses of the applications.

In the patient's profile design, the following steps have to be considered: (1) data gathering, (2) analysis and modelling of personal data using different methods, techniques.

There are several data sources to collect information needed to build patient profile: selected questionnaires, interviews, clinical examinations, and observations. These data, which define a static profile of the elderly patient, are supplemented with data collected through smart IoT devices (non-intrusive watch, shoes, and sensors) proposed in the project.

This personal data (Personal Data Records - PDRs) are to be used as a basis for tracking and profiling older adults. This data collection is the regular patient monitoring that will provide information in dynamics. The sum of these collected data defines the database with complete information about the studied person, information that can provide, following the interpretations using the tools, the analysis techniques and results.

Understanding the conceptual model of patients to a specific context helps to develop a system with appropriate requirements, utility, quality of information and interface quality. These features are important to the success of the application.

The schema for identifying patient profile attributes that are important to reach our conceptual vINCI user model is shown in Figure 3.6.

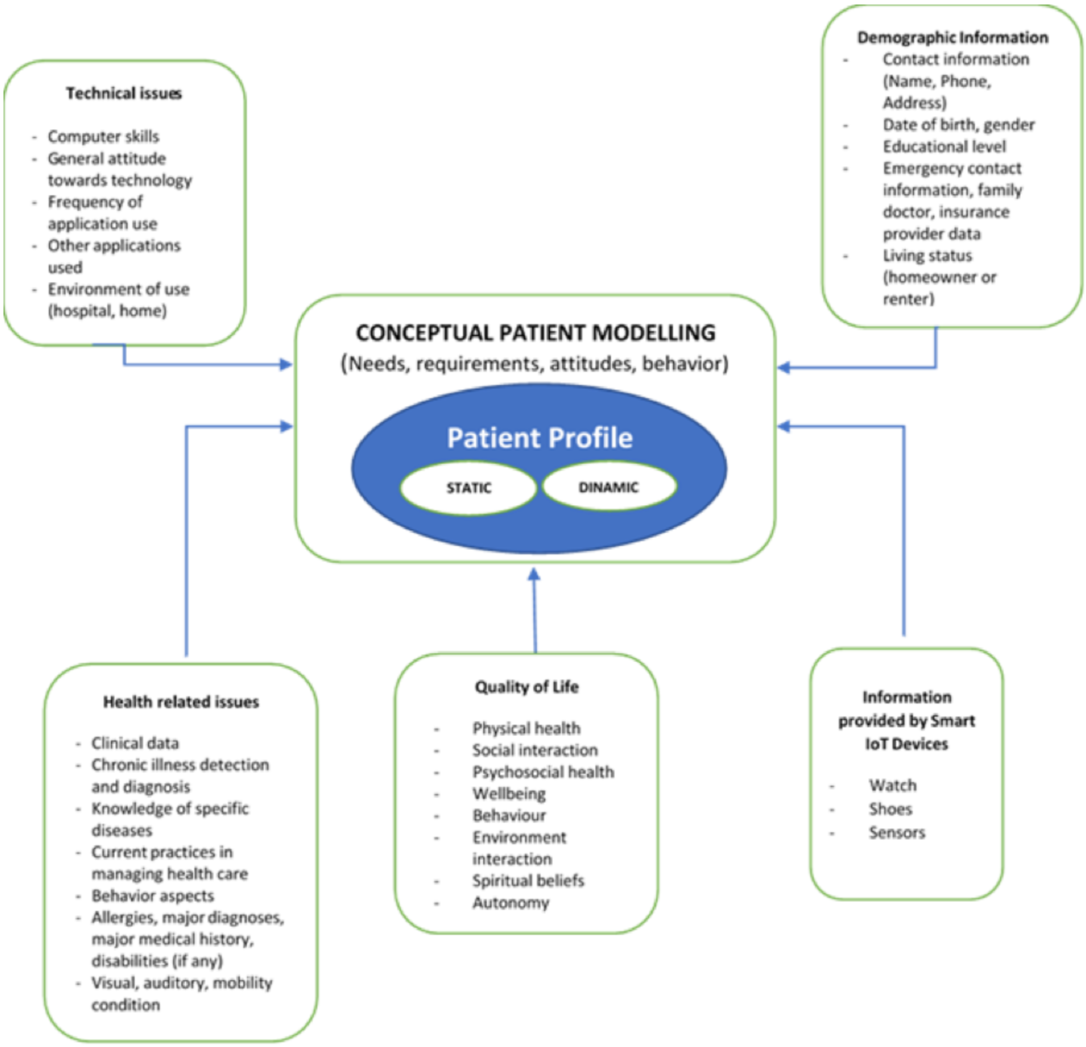


Figure 3.6: Conceptual model of the patient profile.

The attributes presented in this model are derived from the literature, description of our technology, health care literature, and data from this study.

Our model demonstrates that the technical, demographic, health issues and QoL domains must be considered to adequately capture the complete pattern of vINCI users.

The basic common demographic characteristics [45] captured by a group of users of interest include:

- Contact information (Name, Phone, Address);
- Date of birth, gender;
- Educational level;

- Emergency contact information, family doctor, insurance provider data;
- Living status (homeowner or renter).

Additional profile attributes that have been shown to be relevant to technology usability [46, 47, 48, 49] and that we use in this study include:

- Computer skills;
- Attitude towards technology;
- Frequency of application use;
- Other applications used;
- Environment of use (hospital, home).

"Traditional" user profile does not recognize psychological / psychosocial traits within people and their impact on health choices and outcomes. They fail to recognize research that indicates that cognitive and behavioural patterns of perception and action can affect both short-term and long-term success with interventions directed to managing a disease or adopting health [50]. Thus, the following features [51, 52], health issues have been added:

- Clinical data;
- Chronic illness detection and diagnosis;
- Knowledge of specific diseases;
- Current practices in managing health care;
- Behaviour aspects;
- Allergies, major diagnoses, major medical history, disabilities (if any)
- Visual, auditory, mobility condition.

According to the World Health Organization (WHO) definition [53], *Quality of Life* represents the individual's perception of their position in life in the context of their culture and values systems and their goals, expectations, standards and concerns. It comprises a broad range of parameters reflecting from the person's physical health, psychological state, personal beliefs, social relationships, to his relationships and to main features of surrounding environment.

In the Quality of Life research, health is one of the most important social factor nominated by the population in setting their living standards [54]. Thus, based on this empirical evidence, it was considered justified to include health among the QoL dimensions or among the factors that decisively influence QoL [55].

Health-related Quality of Life (HQRL) is a concept of Quality of Life related to health, pathology, illness or health model, including all aspects of QoL that influence functional, physical and emotional health status [56].

The objective of vINCI is to enhance older adults' active aging and, as a result, their QoL through technology.

With selected questionnaires, QoL will be measured for older adults without mild cognitive impairment over the project period repeatedly at set times.

The patient profile will be supplemented with QoL information on the following domains:

- Physical health
- Social interaction
- Psychosocial health
- Wellbeing
- Behaviour
- Environment interaction
- Spiritual beliefs
- Autonomy

Quality of Life provides a broad and flexible framework to identify common elements and factors that influence the quality of life of old age. From the studies so far, the following features of QoL can be distinguished: 1) QoL is multidimensional, there is no limit or convention in its specific fields; 2) It is a dynamic concept in which each dimension can be evaluated differently from one person to another, depending on the context, from where the measurement challenges. 3) The values attached to each dimension can change over time due to changes in life and life experience.

The patient data collection and monitoring devices (smartwatch, smart shoes, depth cameras) proposed in the project also provide specific information related to the patient.

The patient is monitored via the smart watch and the smart shoes at predefined time intervals. Also, the patient has to visit a specially-designed room, where he needs to perform some activities in front of depth camera. The data provided by each of these devices complements the patient's profile. This is the dynamic component of the model.

The patient' needs (see Figure 3.7), requirements and capabilities in the development of the patient's profile model are obtained from multiple techniques such as: professionals' observation, interviews, analyse context, etc.

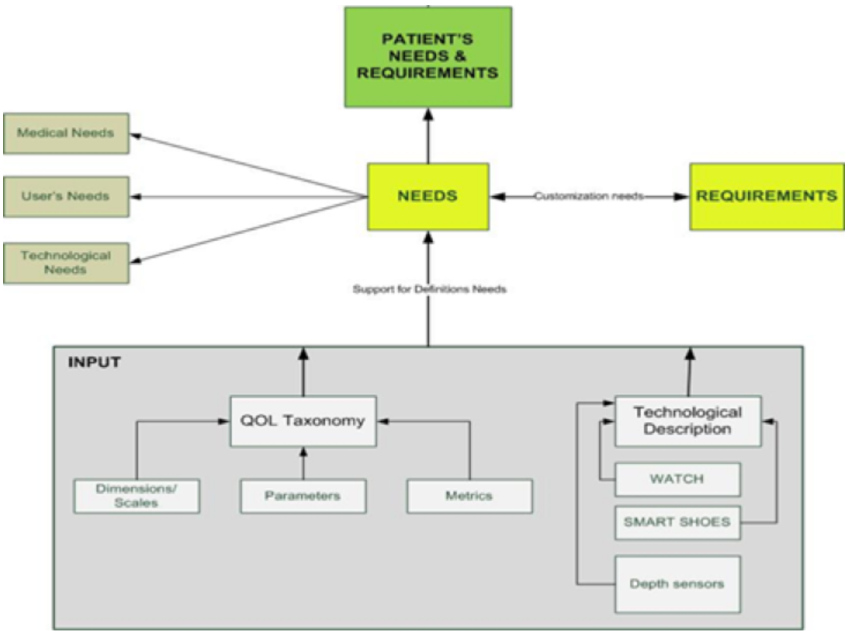


Figure 3.7: The patient's needs, requirements – a component of patient's profile.

The input for vINCI consists of (Figure 3.7):

- The static profile of the patient: Seniors without severe impairments;
- QoL Taxonomy (see Figure 3.6): Dimensions, Parameters, Metrics;
- Technological Description for: Smart Watch, Smart Shoes, Depth Sensors.

The steps for defining user's needs are then (Figure 3.7):

1. Definition of target group (identifying end - users)
2. Defining / establishing / understanding the context
3. Understanding and defining the needs of the target group

User needs can be structured in the following dimensions:

1. *Medical Needs*: Identifying and understanding the medical needs for the target group by medical staff:
   - *Methods*: Self-documentation, interviews, online survey;
   - Target: Medical staff.
2. *User's Needs*:
   - Identification of the end user's subjective medical needs:
     - *Methods*: Self-documentation, online survey, persona (profile of archetypical end-user), questionnaires, context analyse;
     - *Target*: end user.
   - Identifying how the user's medical needs can be met by the system:
     - *Methods*: Self-documentation, online survey, questionnaires, context analyse;
     - *Target*: end user.
3. *Technological Needs*: Identifying technological needs
   - *Methods*: Self-documentation, questionnaires, context analyse;
   - *Target*: Technical staff.

The analysis and modelling of the captured information, using different techniques can provide descriptions about lifestyle, changes in clinical and behavioural dynamics of the patient and other complex information about each person.

The data analysis will lead to lifestyle description, information about changes in clinical and behavioural dynamics of the patient.

This analysis allows the building of formal model of the patient's lifestyle and of the patient's behavioural, clinical and biological dynamics, which will be integrated in the computer-based systems.

This contributes to improve the diagnosis and management of geriatric syndrome in primary care, as well as to increased levels of wellbeing, QoL and perceived health.

For vINCI care, the patient profile will be the input to provide personalized support for daily / medical activities. Finally, the patient profile will be used as evidence to evaluate the impact of vINCI on the perceived QoL level, allowing a proper adjustment (if needed) of the intervention support being provided by caregivers.

Chapter 4

Towards the vINCI Architecture

4.1 Requirements analysis

Analysis of user interactions along with the communication entities of the participating communities improve our understanding of health-related behaviors and inform the design of technological solutions that support behavior change. In this section, we present the methodology and the analysis of datasets as well as the infrastructure that will be needed in order to allow network analytics. Merging different devices' technologies and integrating them into one unified architecture brings big challenges as well to the technology and equipment vendors. It assumes new service platforms with high capability to deal with the complexity of the network infrastructure, the difficulty of interoperability between different service platforms of the respective devices, and the diversity of Application Programming Interfaces (APIs). The scenario architecture is being presented and described along with the different interactions among the entities whereas the various links with EU initiatives are discussed.

4.1.1 Scenario Architecture

Today, the Internet of Things (IoT) has become for many of us a new image of how the future will look like in the upcoming years, since, during each of the past few years, the number of devices that can have Internet access has been consistently increasing. More and more devices and sensors are interconnected; they can be easily controlled remotely and the multitude of data types being generated lays the groundwork for outstanding opportunities in terms of innovative products and services.

IoT Platform-as-a-Service (PaaS) providers ensure that all data collected by sensors or other similar devices is received and sent to other services where it can be stored, viewed, analyzed and used to generate a response for other devices, in a highly available, scalable and secure way. The providers also offer software developments kits (SDKs) that help developers to quickly connect hardware devices to their platform.

Naturally, there are many suppliers on the market that provide powerful IoT PaaS services, such as Amazon AWS IoT[1], Microsoft Azure[2], Google Cloud Platform[3], or IBM Watson Internet of Things[4]. Adhering to similar architectural principles, they use the following components: message broker, rule engine module, security and identity module, a module that knows the state of sensors or connected devices. Each provider supports bidirectional communication between hardware devices and platform, but with different implementations. Amazon uses a message queue to send messages to a device that is subscribed to a certain topic. On the other hand, Azure provides two endpoints that are used to send and receive data. All mentioned platforms use the HTTP and MQTT protocols[5]. Another important aspect of IoT platforms is given by the SDK languages support. IBM Watson IoT and Azure offer SDKs for Java, C#, Python, NodeJS and C, while AWS only for C and NodeJS.

Nevertheless, despite their undeniable strengths, the aforementioned solutions suffer from a common condition. Clients who desire to use their services, besides having to program their hardware in the supplier's paradigm, must also possess knowledge on how to create their own piece of application to

[1]https://aws.amazon.com/iot
[2]https://azure.microsoft.com/en-us/product-categories/iot/
[3]https://cloud.google.com/gcp
[4]https://www.ibm.com/internet-of-things
[5]https://medium.com/mqtt-buddy/mqtt-vs-http-which-one-is-the-best-for-iot-c868169b3105

interpret the raw data received.

There are other several other projects which try to address these issues, such as Kaa IoT[6], a flexible, multi-purpose, open-source middleware that offers features similar to AWS or Azure IoT. The main advantage is given by the possibility to be hosted in private, hybrid or public clouds. Kaa provides the possibility to store data on Apache Cassandra and MongoDB, but comes up short in regard to filling the client-technology gap.

The problems described above were also indicated by Gartner in a 2016 report [57], which suggests that, because of the existent gaps, companies would rather prefer to develop an in-house container service. It is also predicted that this approach will fail to meet expectations through 2018, leading to a major shift towards high-productivity and high-control PaaS options – which is why we propose to build the collecting IoT platform around several IoT PaaS principles.

vINCI's architecture is depicted in Fig. 4.1. Hardware device (e.g., watches, smart shoes) is first registered in vINCI with a *unique ID*. All data sent by the sensors could first be received using the MQTT protocol by a device gateway which forwards all data to a cloud gateway. Because vINCI provides multiple services/kits, for every end-user we will define a list of sensors that the vINCI platform needs to manage, and will select which services/kits they want to use and which sensors will provide all data needed for each service. Also, every sensor can be used by multiple services.

Compared to other solutions, the main goal of vINCI is to ensure high availability, scalability and also further development. To meet these requirements, vINCI's model is implemented using a microservices-based architecture, which has the following advantages: every microservice can be independently developed from others; microservices are usually faster and less expensive to develop than regular monolithic services; each component has its own database, depending on service needs; microservices are quick to build and deploy; a microservices-based architecture ensures high availability and scalability.

Each microservice developed will be packaged in a Docker container [58]. This ensures a faster launch of microservices in production, a better use of hardware resources, and better isolation from the host machine's operating system. All containers are managed by Kubernetes [59], an open-source orchestrator for clusters of containers. By using a microservices-based architecture and Kubernetes for managing clusters, vINCI will provide two main features: the ability to add new services for new uses, and the possibility of offering customers the opportunity to create their own services that can better meet their own needs.

Another key factor in a scalable and high-availability system is communication, thus vINCI uses the HTTP and MQTT [60] protocols. All data transmitted from sensors to device gateways employs MQTT, whereas for communication from the device gateways to our service, HTTPS is employed. Furthermore, communication between microservices is asynchronous, event-based and uses the CQRS (Command Query Responsibility Segregation) pattern [61].

Because vINCI could need to store high volumes of data, its storage layer must have the ability to scale, perform, and offer continuous uptime. The best database in the market that can meet these requirements is Apache Cassandra, because it was designed to scale almost linearly, to replicate data automatically in one or more data centers, and to deal with failover situations.

After data is received and stored in a database, it must be processed and analyzed. vINCI can perform two types of processing: batch processing and real-time processing. Real-time processing can be used to detect the occurrence of important events, whereas batch processing can be used to analyze all received data within a given time frame from multiple sensors and predict a possible future evolution.

For both types of processing (batch and real-time), vINCI will use Apache Spark [62], a fast and general use engine for large-scale data processing. The main advantage of Spark is given by the ability to do

[6]http://www.kaaproject.org

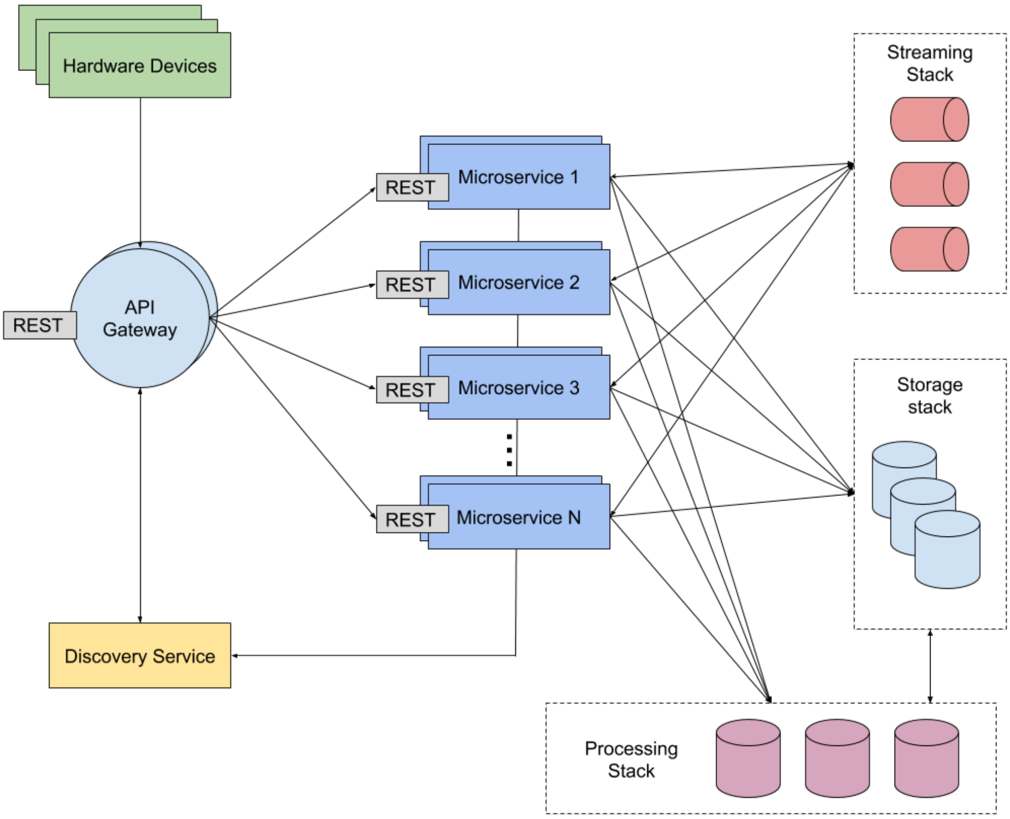


Figure 4.1: vINCI architecture.

all processing in-memory and the support for sophisticated analytics and real-time stream processing using multiple languages like Java, Scala, Python.

Hardware devices refer to the sensors used to collect data and send it to the vINCI platform. A network server receives data, and ensures that there are no duplicate data entries, and then sends the remaining data to the device gateway using REST. It should be mentioned that the network server does not perform other data analysis (such as verifying if the sensors that the data come from are registered in the system), all subsequent operations being performed at the API gateway and microservice level. An example of data sent to the API gateway and stored in the database is shown below. In this example, a JSON array is sent with information for multiple devices. *lat* and *lon* represent the geographical coordinates of the LoRa device gateway sending the data, *timestamp* is the time when the data were received at the LoRa network server or the mobile device, *devAddr* and *devEUI* are device addresses, while *payload* is the actual useful information sent by the device.


```
{
  "devices" : [
  {
    "lat" : "45.862",
    "lon" : "26.642",
    "timestamp" : "2018-02-13 T 10:30 UTC",
    "devAddr" : "DD15AF9E",
    "devEUI" : "0004A30B001C1C79",
    "payload" : "00FF00FF00FF"
  },
  {
    "lat" : "45.861",
    "lon" : "26.342",
    "timestamp" : "2018-02-13 T 10:31 UTC",
    "devAddr" : "DD15AF0E",
    "devEUI" : "0004A30B011C1C79",
```

```
    "payload" : "FF00FF00FF00FFFF"
  }]
}
```

The **device gateway** next is the access point in the system, and its role is to route messages to the API gateway. As seen in Fig. 4.1, all hardware devices connect directly to it. The **API gateway** is the connection point between the "outside world" (i.e., the data collectors) and the applications. It has the following roles:

- user registration;
- authentication using JSON Web Tokens: 1) the client sends a user and password; 2) the API gateway sends them to the AUTH microservice, which is a specialized authorization component; 3) the gateway receives a token containing the user's ID and role, which is then sent to the client; and 4) for each subsequent request, the client includes the token, which the API gateway checks using the AUTH microservice;
- sensor data storage by communicating with the storage stack;
- user data retrieval (account information, available applications, available sensors, etc.);
- application parameters retrieval (requests types of parameters and display mode from the application);
- application retrieval (requests types of output and display mode from the application);
- sensor data retrieval (the client performs periodic application requests to read sensor data, and the API gateway returns the data from the storage stack);
- user interface, consisting of: 1) editing account data; 2) adding standalone sensors (by defining names, UUID, type, description, etc.); 3) adding virtual sensors (for the mobile application); 4) selecting applications (defining associated sensors and parameters); 5) visualizing per-application data; and 6) visualizing data from any application defined in a customizable client dashboard;
- admin interface, consisting of: 1) adding, retrieving, deleting, modifying users; 2) adding applications; 3) user statistics; and 4) sensors and applications statistics.

Finally, a application / kit is a set of stateless microservices that use data from various sensors to perform computations on them, display them, etc. An application defines the following things:

- general application parameters (for example, the telephone number where an SMS alert is sent when certain conditions are met);
- per-sensor application parameters (for example, the temperature limit reached to trigger an alert);
- minimum and maximum limits for the number of sensors in the application and their types;
- other application ID dependencies;
- data visualization format.

Each component of an application is a separate microservice running as a Docker container. Since they are stateless, applications perform periodic requests to the storage stack for reading data from the sensors or from other applications. The storage stack verifies all the sensors associated with the application and returns the desired data, which is serialized using Protocol Buffers [63]. If the application generates data itself, it will send them to the storage stack along with the user ID and the application's virtual DevEUI (which is automatically generated whenever an administrator adds a new application to the system, and is unique per application). For complex data processing and computations, applications can employ the processing stack, while the streaming stack is useful when data streaming is required. Furthermore, the same microservice (i.e., application module) can be employed for multiple applications. In order for the API gateway to be aware of the available microservices and their state, a discovery service is employed.

So, in vINCI we see three stacks: *storage*, *processing*, and *streaming*. The storage stack contains several databases used for storing various types of information, from sensor data to application information. It has the role of serializing and deserializing the information, retrieving data for applications, etc. A Cassandra database is employed for sensor data, whereas a PostgreSQL database is used for other types of information (application data, user data, etc.). The processing stack contains components for ease of data processing, such as Apache Spark, while the streaming stack has helpful tools for continuous data.

Just to illustrate these principles, these are real data coming from the CMD THL One Smartwatches:


```
[
    {
        "_id": "5b19c84e807dd234ff805f4f",
        "ei": "352413080006397",
        "si": "9226103000013506",
        "dt": "2018-06-08T00:05:34.590Z",
        "s": "::ffff:109.166.135.51",
        "c": "#@H10@#;352413080006397;9226103000013506;862182;2018-06-08;03:05:33;heart;\u0005;\u0001",
        "y": 2018,
        "m": 6,
        "d": 8,
        "p": "H10"
    }, {
        "_id": "5b1b1496807dd234ff8064df",
        "ei": "352413080006397",
        "si": "9226103000013506",
        "dt": "2018-06-08T23:43:18.150Z",
        "s": "::ffff:109.166.135.133",
        "c": "#@H11@#;352413080006397;9226103000013506;862182;2018-06-09;02:43:17;Shutdown;3;?;\u0001",
        "y": 2018,
        "m": 6,
        "d": 8,
        "p": "H11"
    }
]
```


The data being sent to vINCI from the smartwatches comes from a query of type:

```
query: {
 "collection":"commlog",
 "query":{"ei":"352413080006397","y":2018,"m":6,"d":8}
}
```

In the returned results, we are interested especially in two record types: $H02$ – *GPS*, and $H14$ *WiFi*. The watch sends current possition in $H02$ format if it has an active GPS connection, or in $H14$ format when it doesn't.

The fields in the records above are:

- *_id*: record ID
- *ei*: IMEI
- *si*: device ID
- *dt*: data
- *s*: IP

- *c*: registered LOG
- *y*: year
- *m*: month
- *vd*: day
- *p*: logging code

4.1.2 Links to EU initiatives (FIWARE and IoT ARM)

Initially designed to build the federation of cloud infrastructures for the EU-funded FI-Core (FP7-ICT-622893), FIWARE offers Cloud services as composable building blocks named Generic Enablers (GEs) as well as standard Application Programmer Interfaces (APIs). Applications are then designed, implemented, and deployed by employing GEs from the FIWARE's resource catalogue publicly accessible from the FIWARE Portal[7] as well as exposing and consuming APIs.

Furthermore, FIWARE has been augmented with data models for handling IoT data streams in a standardised format. While the initial models have been employed in smart cities, different research groups in Europe have started to employ FIWARE in eHealth on cloud infrastructures. The FI-STAR project (FP7-ICT-604691) https://www.fi-star.eu aimed to nurture an innovative vertical community for eHealth developers. To create a sustainable ecosystem for all user groups in the global Health care, FI-STAR proposed early trials across Europe to validate the use of FIWARE GEs for eHealth applications.

More specifically, remote patient monitoring using a web frontend has been reported as part of the EU frontierCities project (FP7-ICT-632853) http://www.fi-frontiercities.eu/. The frontierCities OpenStack cloud infrastructure underpins medical and environmental sensors in order to securely interact with medics, practitioners and older adults [64].

From a commercial perspective, ARM has developed an IoT platform which has subsequently been used in remote patient care applications [65]. Applications keep patients notified on medicine intake and vitals via their personal devices (smartphones or tablets). By making devices IoT-A compliant, the IoT ARM platform can use all functions of the wider IoT-A ecosystem.

vINCI will build upon both FIWARE and ARM IoT-A ecosystems to deliver non-intrusive monitoring and care support for older adults. Personal sensed data will be securely monitored starting from sensors (e.g. detecting physical and social activity), coupled with data gathered from wearable devices (e.g. smart watch, smart clothing/shoes).

To form a true information ecosystem (the vINCI network), IoT endpoints will furnish standards-driven communication protocols combined with sophisticated data aggregation and analytics techniques. Adequate models will be developed to assess older adult QoL profile, identify impairments associated with old age, and help aging people get a sense of independence. vINCI data models will then conform to standardised data models by reusing as much as possible schema.org data types (Text, Number, DateTime, StructuredValue, etc.), as well as existing international data standards such as the ones derived from FIWARE, ITU-T H.810 [66] and IEEE 1073 [67] to ensure interoperability of devices used in vINCI applications.

Traditional medical services will be augmented with monitoring capabilities, such that the caregiver will have access and track exercises, activities, health status, being able to adapt the caregiving procedures against variables designed to lead to an increase in the level of wellbeing, QoL and perceived health.

[7] https://www.fiware.org/

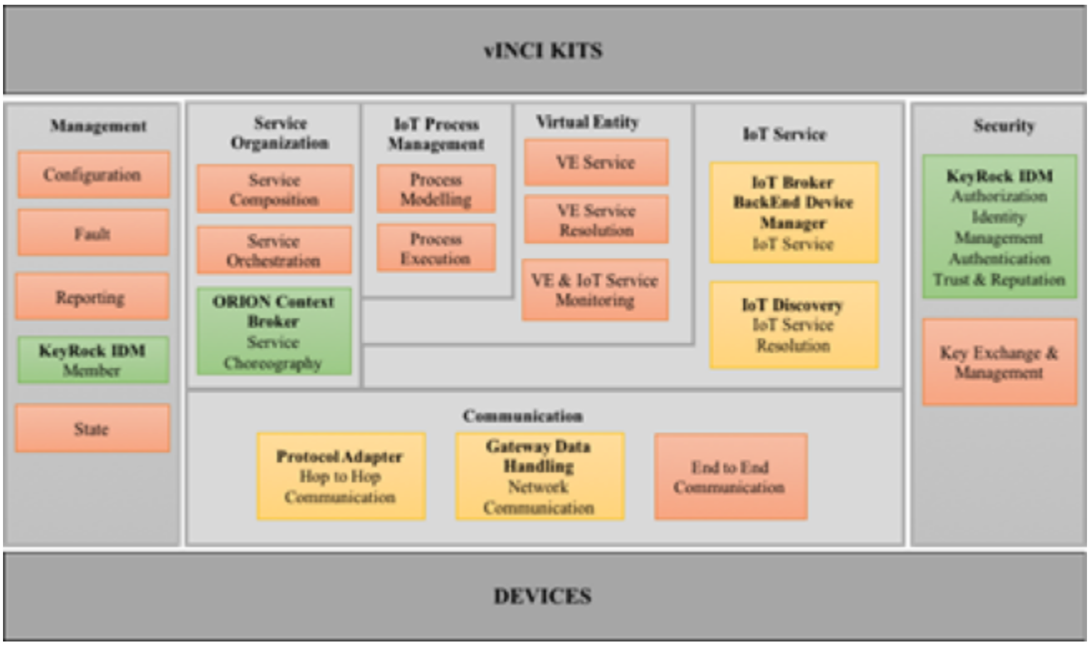


Figure 4.2: vINCI's architecture in relation to IoT-ARM and FIWARE.

4.2 Proposed architecture

The proposed integrated architecture for the Device Relationship Management Integration (DRMI), see Figure 4.3 comprises of an end-to-end user-centric Architecture that will host the monitoring applications. The platform will integrate (1) wearable monitoring systems, where of-the-shelf wearable devices, and context-related parameters for the individual, and (2) content-aware driven networking components for monitoring services. The conceptual architecture is shown in Figure (below) where the different components are promoted through the IoT interaction sub-Level (cross-layer) and provide Data Quality, Filtering, and Improvement based on the data requirements and provision. In Figure 4.3 the Middleware platform with the associated cross-level mechanisms are presented. As indicated, in order to provide all these features, the user is equipped with a wearable device able to measure the standing balance of the end-user, more specifically the heart rate, the blood pressure and other parameters that may affect their health in contrast with their Geo-monitoring. More in detail, the wearable device accomplishes two main tasks: it continuously tracks the user by leveraging a Bluetooth Low Energy (BLE) infrastructure, and recognizes the existing IoT surrounding devices indoor as well as M2M outdoor in order to provide through both infrastructures the processing and requested information (data). The results of this twofold activity are sent to the IoT interaction sub-Level (cross-layer) and then used by the requested services that are in charge to provide all the other features of the system.

To accomplish the mentioned processing and related services and tasks, the different levels of the Middleware exploit a multiprotocol sub-mechanism that allows a transparent access to heterogeneous IoT technologies, hiding the low-level communication details. This multiprotocol sub-mechanism hosted on the middleware will be designed to be easily extended to new technologies, in order to improve flexibility and scalability. Exploiting new IoT-enabling technologies to create smart environments able to predict users' desires is the current trend in both academies and industries. To this end, the propose middleware will exploit this capability by allowing a direct communication with IoT enabled devices as well as –in a BLE and MP2P manner- the D2D/M2M communication.

On the contrary with existing literature where the integration of different devices over a single platform is usually set as "black box", the proposed architecture achieves high level communication link

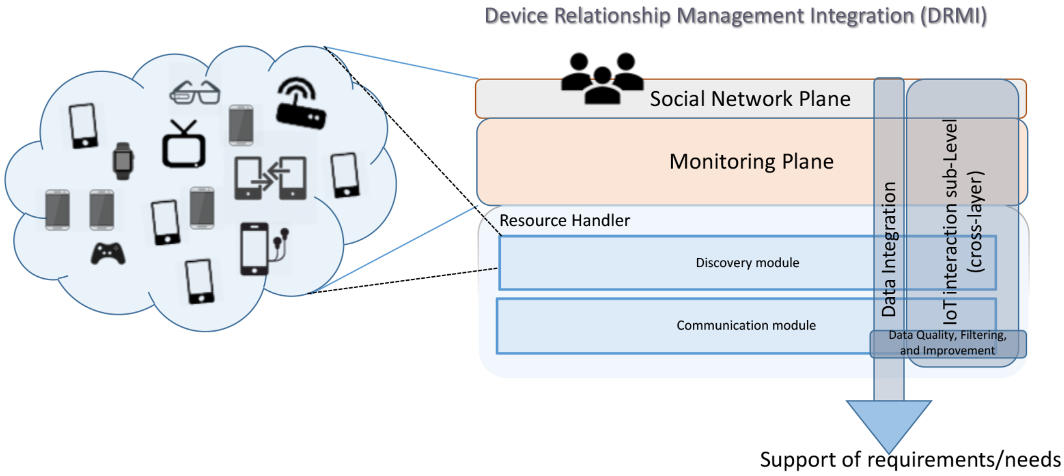


Figure 4.3: Device Relationship Management Integration (DRMI).

among entities providing the relation and interactions between the components, whereas it shown the actual “link" among the different devices. The design objectives motivating this framework are related to the development of an Ambient Care System with offering its integrated capabilities via all communication levels. Figure 4.3| demonstrates the interactions of the different elements in communication plane for manipulating the IoT resources effectively. The Resource discovery module monitors the available resources in terms of the wireless devices (to be monitored) Edge devices connected on the community/cluster whereas, the IoT devices are being monitored via the Resources Monitoring Plane using the interactive interfaces among Edge-devices. The communication module allows the data integration to be performed between the IoT devices (data fusion) where is as a result of the IoT cross-layer interaction among the Discovery module, Communication module and Monitoring Plane. At the Communication level the Data Quality, Filtering, and Improvement comes as a superposition of the support of the requirements based on the end-user's needs. All inter-communication of the different devices and components will be performed via the existing API of each supported device (as provided by the vendor). The DRMI will be responsible to inter-connect the operating end-users' components and to allow efficient communication among devices while preemptively reserves the required resources. To support such an AAL system the architecture should guarantee real-time performance parameters even in a highly dynamic environment (multiple disconnections, time-overhead for reconnect via alternatives such as other operator etc). Many functionalities, like the parameters in references will be experiencing severe variations. They are thus hard behaving in real-time, where the respective deadlines and other timing constraints must be met. In the proposed architecture, communication and synchronization between the devices add time overheads when taking a decision after a critical event, therefore real-time latency evaluation analysis is required in order to guarantee timely operation. The layers of the architecture in Figure 4.3, aims to orchestrate the various parameters over the existing APIs and cross communication components in order to allow fault tolerance and reliability of the offered services to the end-users.

The communication architecture of the vINCI system is presented in Figure 4.4. It assumes that vINCI platform is accessible on public IP address and connectivity with the input data providers and output data consumers is realized through Internet. In case of data sources related with the sensors, the platform interacts with the following edge nodes:

CMD platform, which provides the data produced by smartwatches:

- **SS server**, which processes raw data produced by smart shoes and next provides extracted information about user behaviour;

- **DC gateway**, which processes raw data produced by the depth camera and next provides extracted information to the vINCI platform.

The edge nodes implement functionality of the communication and discovery modules of DRMI (see Figure 4.3), as well as DRMI Monitoring Plane.

The last data source is vINCI Digital Caregiver application that interacts directly with the vINCI platform and provides data obtained by means of clinical questionnaires filled in by the patient and medical investigations performed by the clinical personnel. Both the Digital Caregiver and the edge nodes, communicate with the vINCI platform using conventional broadband network technologies (Ethernet, WiFi or LTE).

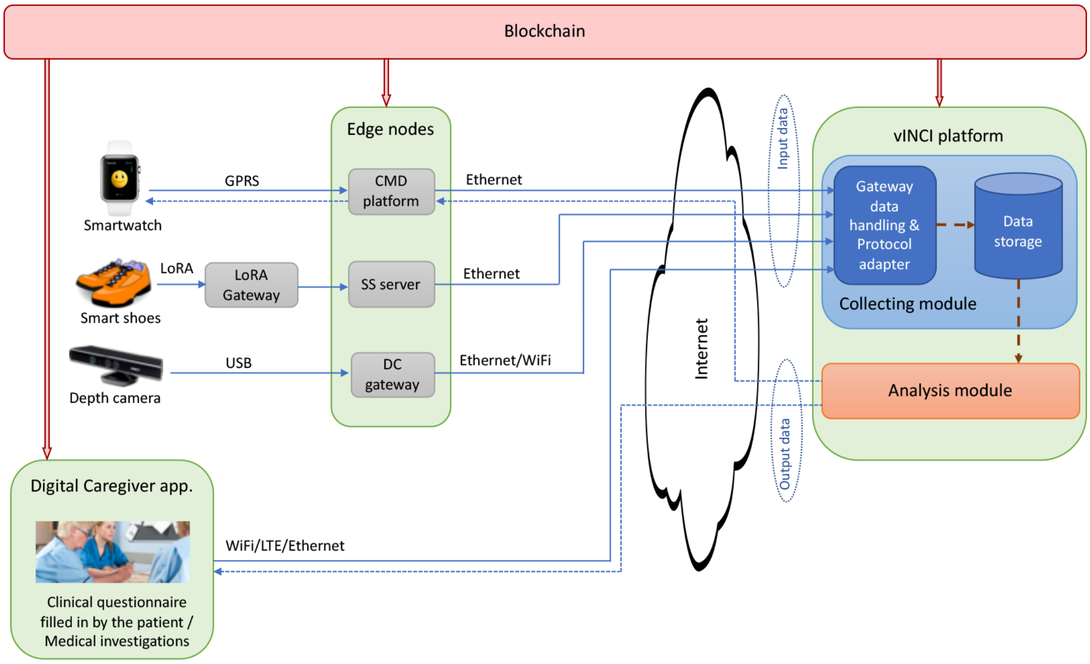


Figure 4.4: Communication architecture for vINCI platform.

The vINCI platform includes two modules: 1) collecting module that interacts with input data providers (i.e. the sensors and the Digital Caregiver application), and 2) analysis module that interacts with output data consumers (the Digital Caregiver and the smartwatch). The collecting module consists of data storage submodule and a submodule that provides gateway functionality to cope with diversity of interfaces used by engaged input data providers (i.e. CMD platform API, SS server API, DC gateway API and web services REST API in case of the Digital Caregiver). The latter submodule translates messages received from different sources into unique format used by the data storage and the analysis module.

The security and privacy requirements are met through the use of blockchain technology [68]. The blockchain manages access and permissions to collecting health information and using the personal data stored in the vINCI platform. For this purpose, the blockchain collaborates with the vINCI platform, the edge nodes and the Digital Caregiver application. The entities, with granted proper permissions, can deliver data to the platform or access health records only when their identities and cryptographic keys have been verified by blockchain.

List of Figures

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