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HOSMARTAI
AI for the smart hospital of the future

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DELIVERABLE

D1.1 – Domain Landscape

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Executive Summary

The main objective of HosmartAI is to promote an effective and efficient health care system transformation using AI technological developments and robotics. HosmartAI will introduce an AI platform that will allow for core facilities to be shared and linked composing smart services for healthcare professionals, patients, information system managers, and health organisation administrations.

A total of 24 partners are collaborating on health services and technological developments of robotics and AI for the HosmartAI project. The approach will guarantee the integration of Digital and Robot technologies in the new Healthcare environments and the possibility to analyse their benefits.

The ambitions pursued in the project by the partners focus on the following targets:

- Diagnosis revolution
- Logistic efficiency
- Treatment improvement
- Surgical support
- Assistive care

This document addresses a state of play analysis on existing Healthcare procedures, Innovative AI-based and robotics systems, methods, components and tools that can be integrated into the HosmartAI services and platform backbone infrastructure.

Being an applied AI project, most of the methods and tools will be based upon the pre-existing know-how and background knowledge that the consortium partners bring into the project, including open-source tools actively supported by the corresponding communities, as well as on in-house components and tools developed by the consortium partners.

Deliverable D1.1 represents the Domain Landscape and comes from the direct outcome of Task T1.1, documenting the needs and challenges on existing Healthcare procedures. Additionally, innovative AI-based and robotics systems, methods, components and tools, pre-existing know-how and background knowledge that cope with the mentioned needs and challenges will be made explicit.

This document is structured as follows. Firstly, the needs and challenges from each Pilot are identified and described. These needs are grouped, and a set of taxonomy terms are proposed for each group when possible (see Table 15). Secondly, the updated descriptions of the background brought to the project from each of the partners are included, specifying the needs and challenges covered or solved by the corresponding background. This second part is structured according to the tasks defined for Working Package 3.

The main contribution of this document is not only the state of the play but also the discovery of some needs and challenges that are uncovered by HosmartAI. These needs are marked in **green bold letters** in the tables within Chapter 2, mainly in Table 15.

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Document History

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1.0	2021-04-27	INTRA	Final version for submission

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Definitions, Acronyms and Abbreviations

Acronym/ Abbreviation	Title
AF	Atrial Fibrillation
AGA	American Gastroenterological Association
AI	Artificial Intelligence
AU	Action Unit
CACS	Coronary Artery Calcium Score
CAD	Computer Aided Diagnosis/Detection
CCTA	Coronary Computed Tomography Angiography
CCTG	Computerized Cardiotocography
CDSS	Clinical Decision-Support Systems
CE	Capsule Endoscopy
CNN	Convolutional Neural Networks
CT	Computed Tomography
CTC	Connectionist Temporal Classification
CTG	Cardiotocography
CyL	Castilla y León
DL	Deep Learning
ECHO	ECHOcardiography
ED	Emergency Departments
EEG	Electroencephalogram
EF	Ejection Fraction
EGD	EsophagoGastroDuodenoscopy
EHR	Electronic Health Record
EMG	Electromyogram
ESC	European Society of Cardiology
FACS	Facial Action Coding System
FACS	Facial Action Coding System
FER	Facial Emotional Recognition
FHIR	Fast Healthcare Interoperability Resources
FHR	Fetal Heart Rate
FLs	Facial Landmarks
GA	Grant Agreement
GDPR	General Data Protection
GI	GastroIntestinal
HRI	Human-Robot Interaction
HRPU	High-Risk Pregnancy Unit
ICP	Iterative Closest Point

Acronym/ Abbreviation	Title
ICT	Information and Communication Technologies
iMAT	iPrognosis Motor Assessment Tests
IMU	Inertial Measurement Unit
KPI	Key Performance Indicator
LBP	Local Binary Pattern
LSTM	Long-Short Term Memory
LV	Left Ventrilular
LV-EF	Left Ventricular Ejection Fraction
ML	Machine Learning
PCI	Percutaneous Coronary Intervention
PD	Parkinson’s disease
PGHD	Patient Gathered Health Data
PP	Pulse Pressure
PREMs	Patient Reported Experience Measures
PROMs	Patient Reported Outcomes Measures
PROs	Patient-Reported Outcomes
PTP	Pre-Test Probability
PWTT	Pulse Wave Transit Time
RMN	Nuclear Magnetic Resonance
SARs	Socially Assistive Robots
SEIF	Sparse Extended Information Filter
SLAM	Simultaneous Localization and Mapping
SPBTU	Signal Processing and Biomedical Technology Unit
SRS	Social Robotic Systems
SUS	System Usability Scale
SWOT	Strengths, Weaknesses, Opportunities, and Threats
UWB	Ultra-Wide Band
WHO	World Health Organization

1 Introduction

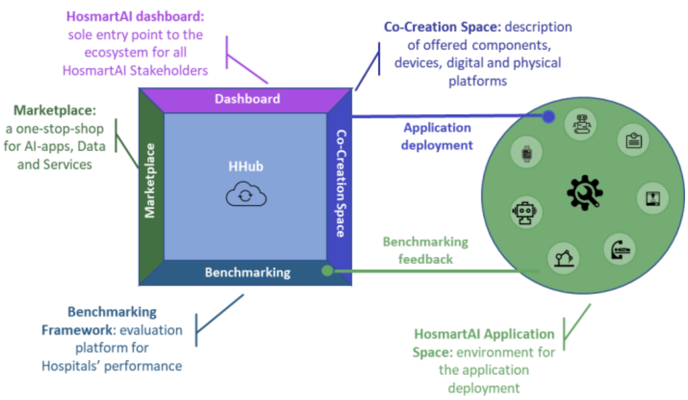
1.1 Project Information

VISION

The HosmartAI vision is a strong, efficient, sustainable and resilient European **Healthcare system** benefiting from the capacities to generate impact of the technology European Stakeholders (SMEs, Research centres, Digital Hubs and Universities).

MISSION

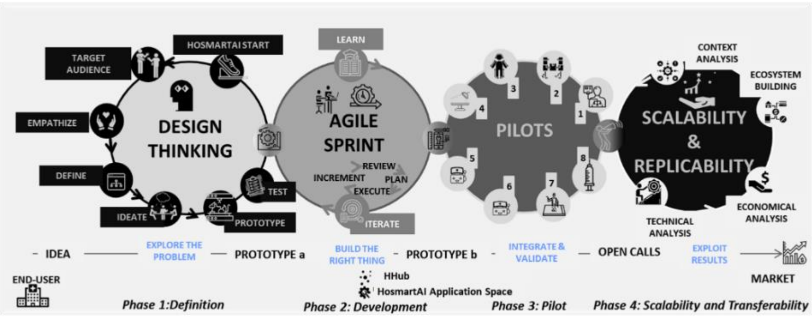
The HosmartAI mission is to guarantee the **integration** of Digital and Robot technologies in new Healthcare environments and the possibility to analyse their benefits by providing an **environment** where digital health care tool providers will be able to design and develop AI solutions as well as a space for the instantiation and deployment of a AI solutions.



HosmartAI will create a common open Integration **Platform** with the necessary tools to facilitate and measure the benefits of integrating digital technologies (robotics and AI) in the healthcare system.

A central **hub** will offer multifaceted lasting functionalities (Marketplace, Co-creation space, Benchmarking) to healthcare stakeholders, combined with a collection of methods, tools and solutions to integrate and deploy AI-enabled solutions. The **Benchmarking** tool will promote the adoption in new settings, while enabling a meeting place for technology providers and end-users.

Eight Large-Scale Pilots will implement and evaluate improvements in medical diagnosis, surgical interventions, prevention and treatment of diseases, and support for rehabilitation and long-term care in several Hospital and care settings. The project will target different **medical** aspects or manifestations such as Cancer (Pilot #1, #2 and #8); Gastrointestinal (GI) disorders (Pilot #1); Cardiovascular diseases (Pilot #1, #4, #5 and #7); Thoracic Disorders (Pilot #5); Neurological diseases (Pilot #3); Elderly Care and Neuropsychological Rehabilitation (Pilot #6); Fetal Growth Restriction (FGR) and Prematurity (Pilot #1).



To ensure a user-centred approach, harmonization in the process (e.g., regarding ethical aspects, standardization, and robustness both from a technical and social and healthcare perspective), the **living lab** methodology will be employed. HosmartAI will identify the appropriate instruments (**KPI**) that measure efficiency without undermining access or quality of care. Liaison and co-operation activities with relevant stakeholders and **open calls** will enable ecosystem building and industrial clustering.

HosmartAI brings together a **consortium** of leading organizations (3 large enterprises, 8 SMEs, 5 hospitals, 4 universities, 2 research centres and 2 associations – see Table 1) along with several more committed organizations (Letters of Support provided).

Table 1: The HosmartAI consortium.

Number[1]	Name	Short name
1 (CO)	INTRASOFT INTERNATIONAL SA	**INTRA**
1.1 (TP)	INTRASOFT INTERNATIONAL SA	**INTRA-LU**
2	PHILIPS MEDICAL SYSTEMS NEDERLAND BV	**PHILIPS**
3	VIMAR SPA	**VIMAR**
4	GREEN COMMUNICATIONS SAS	**GC**
5	TELEMATIC MEDICAL APPLICATIONS EMPORIA KAI ANAPTIXI PROIONTON TILIATRIKIS MONOPROSOPIKI ETAIRIA PERIORISMENIS EYTHINIS	**TMA**
6	ECLEXYS SAGL	**EXYS**
7	F6S NETWORK IRELAND LIMITED	**F6S**
7.1 (TP)	F6S NETWORK LIMITED	**F6S-UK**
8	PHARMECONS EASY ACCESS LTD	**PhE**
9	TERAGLOBUS LATVIA SIA	**TGLV**
10	NINETY ONE GMBH	**91**
11	EIT HEALTH GERMANY GMBH	**EIT**
12	UNIVERZITETNI KLINICNI CENTER MARIBOR	**UKCM**
13	SAN CAMILLO IRCCS SRL	**IRCCS**
14	SERVICIO MADRILENO DE SALUD	**SERMAS**
14.1 (TP)	FUNDACION PARA LA INVESTIGACION BIOMEDICA DEL HOSPITAL UNIVERSITARIO LA PAZ	**FIBHULP**
15	CENTRE HOSPITALIER UNIVERSITAIRE DE LIEGE	**CHUL**
16	PANEPISTIMIAKO GENIKO NOSOKOMEIO THESSALONIKIS AXEPA	**AHEPA**
17	VRIJE UNIVERSITEIT BRUSSEL	**VUB**
18	ARISTOTELIO PANEPISTIMIO THESSALONIKIS	**AUTH**
19	EIDGENOESSISCHE TECHNISCHE HOCHSCHULE ZUERICH	**ETHZ**
20	UNIVERZA V MARIBORU	**UM**
21	INSTITUTO TECNOLÓGICO DE CASTILLA Y LEON	**ITCL**
22	FUNDACION INTRAS	**INTRAS**
23	ASSOCIATION EUROPEAN FEDERATION FORMEDICAL INFORMATICS	**EFMI**
24	FEDERATION EUROPEENNE DES HOPITAUX ET DES SOINS DE SANTE	**HOPE**

[1] CO: Coordinator. TP: linked third party.

1.2 Document Scope

Task 1.1 (from Working Package 1) includes a state of play analysis on existing Healthcare procedures, Innovative AI-based and robotics systems, methods, components and tools that can be integrated into the HosmartAI services and platform backbone infrastructure.

Being an AI project, most of the methods and tools will be based upon the pre-existing know-how and background knowledge that the consortium partners bring into the project, including open-source tools actively supported by the corresponding communities, as well as on in-house components and tools developed by the consortium partners.

For each of the reported as candidate components, a respective testbed environment will be setup in order to analyse and report their benefits, capabilities, shortcomings and limitations. This analysis will serve as a landscape handbook and will conclude with the proposition of the methods and tools that the project will consider during the implementation phases.

Deliverable D1.1 represents the Domain Landscape and comes from the direct outcome of Task T1.1, documenting the needs and challenges on existing Healthcare procedures. Additionally, innovative AI-based and robotics systems, methods, components and tools, pre-existing know-how and background knowledge that cope with the mentioned needs and challenges will be made explicit.

1.3 Document Structure

This document is comprised of the following chapters:

Chapter 1 presents an introduction to the project and the document.

The rest of the document is split into two main parts: i) the identification of the needs and challenges from the different domains that HosmartAI faces and ii) the state of the art on how either the consortium knowledge or external projects, initiatives and solutions tackle these issues. **Chapter 2** is dedicated to identifying the needs and challenges while **Chapter 3** focuses on available solutions.

Three main domains are clearly identified from the HosmartAI DoA: i) Screening and preventive measure recommendation, ii) Diagnosis, treatment and surgical support and iii) Optimization of hospital resource utilization.

Additionally, the Diagnosis, treatment and surgical support subsection is split into several subsections, one for each of the different health tasks faced in HosmartAI: i) Computer-aided diagnosis systems, ii) Personalized rehabilitation and precise treatment, iii) Surgical support based on computer modelling and digital twins, and iv) Provision of assistive care. Each domain or subdomain includes one or more pilots, each of them with its own needs and challenges.

To elaborate the HosmartAI's complete list of the needs and challenges, these latter must be extracted from each Pilot. This is the reason why Chapter 2 is split into a subsection per pilot. For each of them, a description of the state of the play and the corresponding description of the needs/challenges is delivered. It is worth noticing that the subsections start with a relationship table between needs and challenges and the technological aspects, which offers a glance at how the different needs are met.

Finally, to unify the outcomes from each of the pilots, a final subsection aiming to unify and group the needs and challenges using a standard Taxonomy (SNOMED CT [REF-01]) is included, cross-referencing the terms with the needs from the different pilots.

Chapter 3 focuses on the available solutions to tackle the needs and challenges of the project. It is divided into subsections according to the main technological aspects covered in HosmartAI, that is tools for i) Diagnosis Revolution, ii) Logistic Improvement, iii) Treatment Improvement, iv) Surgical Support, v) Assistive Care, and vi) Screening & prevention. Each subsection details the needs that are already covered by the consortium and the technological state of the play of the partners to tackle them.

The main contribution of this document is not only the state of the play but also the discovery of some needs and challenges that are uncovered by HosmartAI. These needs are marked in **green bold letters** in the tables within Chapter 2, mainly in Table 15.

2 Health Procedures, Methodologies and Technologies

This section aims to find all the needs and challenges that HosmartAI would face. HosmartAI tackles three different domains: i) Screening and preventive measure recommendation, ii) Diagnosis, treatment and surgical support and iii) Optimization of hospital resource utilization. Furthermore, the Diagnosis, treatment and surgical support subsection is split into several subsections, one for each of the different health tasks faced in HosmartAI: i) Computer-aided diagnosis systems, ii) Personalized rehabilitation and precise treatment, iii) Surgical support based on computer modelling and digital twins, and iv) Provision of assistive care. Each domain or subdomain includes one or more Pilots, each of them with its own needs and challenges.

Applying the principle of divide and conquer, the section is split in its elemental units (the Pilots) in order to elaborate for each of them the corresponding list of needs/challenges. Afterwards, these needs are unified and taxonomy terms from standard taxonomies (SNOMED and LOINC) have been used; in this way, a grouped and unified list of needs and challenges is finally obtained.

The structure of this section is, thus, as mentioned: first, one section devoted to describing the state of the play for each Pilot as well as its needs/challenges; then, a section aimed to unify and group the list.

2.1 Pilot #1: Development of a clinician-friendly, interpretable computer-aided diagnosis system (ICADx) to support and optimise clinical decision making in multi-specialty healthcare environment

Leader: AHEPA

Misdiagnosis or delayed diagnosis are two of the most common types of medical malpractice, resulting in not receiving proper and timely care for patients and subsequently to serious deterioration of their health or even death. To showcase the above-mentioned issues, four representative clinical application scenarios have been identified by the clinical teams involved in this use case.

2.1.1 First medical application scenario

In patients under consideration for Capsule Endoscopy (CE), initial assessment typically includes symptom evaluation, laboratory assessment, and endoscopic procedures, as well as cross-sectional imaging (e.g., magnetic resonance enterography) in selected patients. For patients who have documented overt gastrointestinal (GI) bleeding (excluding hematemesis) and negative findings on high-quality EsophagoGastroDuodenoscopy (EGD) and colonoscopy, CE is performed as the next diagnostic step. CE can show additional findings in patients with prior negative endoscopic and imaging studies. In retrospective and prospective case series, the diagnostic yield of CE was 50%–72% in patients with obscure overt bleeding. In a retrospective cost-effectiveness study, the use of CE in patients with obscure bleeding had a higher diagnostic yield than other imaging procedures, and was associated with a lower cost per positive diagnosis. Based on the evidence of a relatively high diagnostic yield with CE, the American Gastroenterological Association (AGA) consensus recommended CE to be performed, rather than radiographic studies or angiography, in hemodynamically stable patients with overt bleeding. In those patients who are hemodynamically unstable, more urgent radiologic studies (e.g., angiography) may be more appropriate than CE. In patients with an overt, obscure bleeding episode, it is recommended CE to be performed as soon as possible. Because diagnostic yield appears to decrease with each day of delay, but optimal timing has not been defined definitively, CE is recommended to be performed as soon as possible within the first 24 hours in patients with ongoing overt bleeding after prior emergency negative studies. Finally, although CE is an effective non-invasive method to examine small intestine disorders, it suffers long review times [REF-10] for the busy GI department, it might lead to missed suspicious lesions and there is a need for experienced physicians to interpret its findings [REF-11].

Table 2: Pilot #1. Needs and Challenges for the first medical application scenario.

Needs and challenges	Reference
Need for accelerating examination time	**P1-N01**
A doctor typically needs several minutes to review a CE video. Given that the majority of the CE frames do not contain suspicious lesions, CE examination adds a redundant burden to GI department.	
Need for experienced physicians	**P1-N02**
Doctors must have the necessary training and experience.	
Need for increasing diagnostic yield	**P1-N03**
Small and/or unusual lesion cases may be missed.	

2.1.2 Second medical application scenario

A conventional routine in clinical practice over the years has been to employ validated diagnostic models of the pre-test probability (PTP) of stable, albeit obstructive, Coronary Artery Disease in order to direct downstream testing. After the first screening, adult patients with low to intermediate PTP undergoing coronary computed tomography angiography (CCTA), including calcium scoring, because of suspected Coronary Artery Disease. Most existent models have modest performance (with remarkable overestimation of risk in certain subgroups such as women) while very few studies have data regarding the effect of PTP-based models on clinical decision-making regarding further testing or patient outcomes. Practice guidelines for the management of stable chest pain from the European Society of Cardiology (ESC) are congruent in their recommendations for the use of CCTA as a first-line diagnostic option in symptomatic individuals deemed to be at a low to intermediate pre-test likelihood of having obstructive Coronary Artery Disease. However, in day-to-day clinical practice, a significant number of individuals undergoing CCTA have minimal or no Coronary Artery Disease. As a direct consequence of the expanding use of CCTA, there is a growing interest within the medical community regarding ways to optimize patient selection with the goal of improving diagnostic yield and cost-effectiveness of CCTA utilization within the context of clinical practice. Hence, there is a need for clinically based models that can predict the PTP of stable Coronary Artery Disease and as a result function as gatekeepers to identify low-risk individuals who are unlikely to have obstructive Coronary Artery Disease and unlikely to need further diagnostic testing.

Table 3: Pilot #1. Needs and Challenges for the second medical application scenario.

Needs and challenges	Reference
Need for increasing the cost-effectiveness of CCTA utilization in cardiovascular clinical practice	**P1-N04**
Better discrimination is needed among individuals who present with chest pain symptoms in cardiac units with regard to the need of having further and more specific examinations.	
Need for better individual risk stratification as regards to obstructive CAD	**P1-N05**
Identify risk level of symptomatic individuals leading to better downstream testing/treatment procedures in the clinical setting.	

2.1.3 Third medical application scenario

The number of patients receiving their initial care and diagnostic management in emergency departments (ED) is increasing. The standard diagnostic process for patients with suspected cardiovascular diseases in the ED includes patient’s current history, focusing on their most acute symptoms that led them to the emergency room, and previous history, focusing on disease states that may be related to their current condition, clinical examination, electrocardiography, chest X-ray and laboratory exams (including high-sensitive troponin assays). Based on the initial findings the physician decides if the patients should be hospitalized, as well as if an acute management should be decided, i.e., in acute coronary syndromes. All patients undergo a full echocardiographic study. Echocardiography, i.e., an ultrasound of the heart, is a widespread imaging technique that is routinely used to assess cardiac morphology and function. In particular, the assessment of Left Ventricular (LV) systolic function is important for diagnosis, management, follow-up, and prognostic evaluation of patients with heart problems. LV assessment involves the measurement of the Left Ventricular Ejection Fraction (LV-EF), which is the ratio of change in the left ventricular end-systolic and end-diastolic volumes. End-diastole and end-systole refer to the beginning and ending of the cardiac contraction, respectively. Accurate measurement of the LV-EF, also termed as EF, is critical, as it has been shown to be highly correlated with morbidity and mortality [REF-12]. Conventionally, LV-EF measurement requires manual tracing (classic "biplane" Simpson's approach) of the left ventricle in echocardiogram frames at the end-systole and end-diastole phases. Despite being performed by experienced cardiologists, the interpretation of echocardiogram images is a highly time-consuming process and suffers from high variance [REF-13], attributable to human subjectivity and irregularity of the heart cycles. Finally, echocardiography, clinical and laboratory results are analysed and used in order to design the therapeutic management.

Table 4: Pilot #1. Needs and Challenges for the third medical application scenario.

Needs and challenges	Reference
Need for special equipment	**P1-N06**
Typical ultrasound devices are cumbersome, so they are hard to use in a demanding situation i.e., the emerging room. The advent of portable/handheld ultrasound promises great advancements in managing cardiovascular diseases in the emergency department.	
Need for accelerating the examination time	**P1-N07**
The application of the classic "biplane" Simpson's approach for calculating the EF cannot be fast enough as it depends on a manual annotation from the physician.	
Need for eliminating the examination variability	**P1-N08**
The application of the classic "biplane" Simpson's approach for calculating the EF depends on a manual annotation from the physician so it shows significant variability (interobserver variability).	

2.1.4 Fourth medical application scenario

The most common indications for referrals and admissions of pregnant women in a tertiary obstetric clinic with a High-Risk Pregnancy Unit (HRPU) are threatened preterm labour, ischemic placental disease (mostly hypertensive disorders and fetal growth restriction) and finally, poorly controlled hyperglycaemia in pregnancy. These conditions are increasing in incidence in high-resource countries as advanced maternal age and obesity become more common. The patients will either attend the primary or secondary settings on a regular appointment where the health professionals will assess their exams or come to the emergency unit with a symptom. In the first scenario, health professionals need to decide on examinations already performed, most commonly ultrasound of the fetal or a recording of blood pressure or blood sugar levels that categorize the pregnancy as high-risk. They are faced with a dilemma of urgently referring the patient to a tertiary center or on a scheduled appointment basis. Often, they resort to the first choice and this is usually unnecessary. In the second scenario, a pregnant woman will present with symptoms of threatened preterm labour, vaginal bleeding, or reduced fetal movements, again creating uncertainty on a possible adverse outcome. Health professionals often assess correctly the patient but still refer to a tertiary center due to their own anxiety. This situation is associated with increased rates of anxiety of the pregnant women and their environment, which leads to unnecessary examinations and admissions and therefore consumes valuable resources. A cost-effective management of these conditions in pregnancy may be achieved by targeted training of health professionals, appropriate available equipment in primary and secondary settings and most importantly a clear pathway of communication with a multidisciplinary maternal-fetal medicine team in the tertiary center, allowing the triage of patients at the primary site. The current COVID-19 epidemic has clearly shown that this approach may prove even more crucial in times of crisis. This approach is targeted to improve efficacy and reduce the anxiety of health professionals, along with reducing the stress of pregnant women and unnecessary use of resources. More importantly, it is also expected that it will improve pregnancy outcomes.

Table 5: Pilot #1. Needs and Challenges for the fourth medical application scenario.

Needs and challenges	Reference
Need to reduce unnecessary use of resources	**P1-N09**
Lack of experience in primary and secondary healthcare settings often leads to the overdiagnosis of pregnancy risks and threats. Therefore, there is the need for a more cost-effective management of suspicious pregnancy cases.	
Need for accurate triage of pregnant women in primary and secondary healthcare settings	**P1-N10**
Pregnant women who visit a clinical site at the primary or secondary level may be found with suspicious symptoms after a routine examination or after they visit the emergency care for a serious side effect. There, inexperienced staff needs to classify the pregnancy risk. This fact may lead to misdiagnosis and therefore a need for more accurate interpretation of clinical exams and data is required to ensure more informed decisions.	
Need for improved access to resources (experienced staff and affordable technology)	**P1-N11**
Multidisciplinary team on call, available for guidance of the referring primary and secondary centers who will be alerted in case of suspicious cases identified and further consultation is needed before a referral to a tertiary center takes place. In addition, affordable diagnostic tools are need especially in settings which lack resources and reside in remote areas.	

2.2 Pilot #2: Optimizing the use of radiotherapy

Leader: CHUL

State-of-the-art: the Radiotherapy Unit at CHU de Liège face organisational challenges in dealing with a considerable number of patients. Type, aggressivity, size and location of the tumour are among the relevant parameters for an appropriate radiotherapy. Although the specific characteristics of the tumour and the patient's physical conditions are the roots of all radiotherapy, caregivers cannot ignore oncological treatments and psychosocial context. Thus, before starting the radiotherapy, an accurate patient-centred planning considering all these parameters is needed, while following guidelines to ensure the right treatment at the right time on the right treatment machine throughout the entire course of the treatment. The availability of the machines and of human resources, not to mention patient preferences and travel possibilities are among the obstacles to optimize scheduling. To remedy this problem, it is necessary to accurately weigh each one of dozens of variables according to the oncological, psychosocial and organisational context of the patients, in order to offer them the best possible treatment schedule with a solution reaching Pareto optimality [REF-06]. Nevertheless, unforeseen events are frequent (machine maintenance, patient absence, room availability, caregiver or transport service unavailable), forcing rescheduling for several patients.

At present, four coordinators at CHU de Liège are dedicated to manually schedule and reschedule treatment plans, following guidelines, adjusting to Pareto optimality and considering the constraints and wishes of the patient. It is not surprising that this staff has reached the limit of human processing capacity, given the many variables that must be quickly taken into account in the decision-making process.

Goals/Objectives: to establish an AI algorithm for optimizing patient scheduling [REF-07][REF-08] in a context of patient-centred planning where variable weighting and resource availability may change. It is expected that the AI system will take into account i) all variables as electronically present in the patient record; ii) electronic forms completed by the consulting radiation oncologists; iii) treatment machine characteristics, iv) scheduling for other patients as present in the patient management system used by the radiotherapy department (Mosaiq) [REF-09], v) patient preferences thanks to a chatbot. The algorithms will not only act as a black box but will provide a digital twin that can give insights to the radiotherapy team about the entire scheduling and can be used by the radiotherapy department as a simulation tool to anticipate the impact of unscheduled events or changes of processes over the scheduling.

The specific objectives are: i) Optimizing the use of radiotherapy rooms; ii) Improve the patient experience/pathway by reducing the hospital waiting time and planning changes; iii) Improve identity-vigilance (right patient in the right machine). Pilot Testbed description: i) Conversational robot (chatbot) delivering conversational intelligence.

Table 6: Pilot #2. Needs and Challenges.

Needs and challenges	**Reference**

Optimizing patient scheduling where variable weighting and resource availability may change	**P2-N01**
To accurately weigh each one of dozens of variables according to the oncological, psychosocial and organisational context of the patients, in order to offer each of them the best possible treatment schedule with a solution reaching Pareto optimality. Create an AI patient flow solution that is at least as efficient as the flow established by the CHU de Liège staff. At present 3 staff at CHU Liège optimize the flow of patients based on a methodology established in the Radiotherapy department. To do this, a considerable number of parameters related to patients, caregivers and irradiation machines' availability must be taken into consideration.	
Improve AI flow solution by grouping patients by treated organ, adapting to patient performance status and anxiety of the first session	**P2-N02**
Particular accessories/devices are needed for the irradiation of a specific organ. Avoiding moving these accessories/devices from one room to another throughout the day, should prevent staff fatigue and save time in the daily treatment flow. Establish an AI solution allowing successive schedules of patients who all have a tumor in a specific organ. On the top of the above, the solution should take into account the performance status of the patient for increasing session length according to his/her health condition. The first irradiation session generates significant anxiety in most patients. Therefore, it is important to spend considerable time reassuring them for the success of their treatment. The AI flow solution should adjust the patient flow when a new patient is scheduled.	
An AI system that proposes very quick a rescheduling	**P2-N03**
Being able to quickly adjust appointments when urgent and unexpected patient treatments enter the flow. The new schedule must respect the original treatment plan of each patient. The same is true when other types of unforeseen situations arise, such as the absence of a doctor or machine breakdowns.	
An AI solution adapting to the number, irradiation mode and complex treatment	**P2-N04**
Depending on the tumors, the guidelines recommend an odd or even number of irradiation sessions, which, moreover, may or may not be successive. The AI system must adapt to each type of irradiation situation in order to optimize human resources and make full use of the irradiation machines. Furthermore, the scheduling must include time slots longer than the standards for more complex treatments.	
Take into account the patient input through a chatbot	**P2-N05**
Patients have needs and preferences related to timing and irradiation locations. Indeed, a patient may have preferences for time of the day; day of the week; actual, ideal, and	

reasonable travel times for their radiotherapy; and actual, ideal, and reasonable delays between irradiation and oncologic consultation. Providing them with alternatives would allow the recognition of the elements related to what is relevant for patients, which can be considered as important for a successful treatment.

2.3 Pilot #3: Treatment Improvement with the use of innovative technologies and robotics in rehabilitation process

Leader: IRCCS

At IRCCS San Camillo rehabilitation therapies are delivered both as conventional care by a dedicated Clinical Service for Neuromotor Rehabilitation and as experimental modalities by a dedicated research laboratory (Laboratory of Rehabilitation Technologies). Innovative modalities include a variety of technology-based approaches (e.g., virtual reality, inertial measurement units, robotics).

So far, almost 90% of the rehabilitation care is provided in one-to-one (patient/therapist) settings and scheduled on a weekly basis, by collecting information from each single Operative Units of the Neurorehabilitation Department and manual allocation of treatments according to resources available. Moreover, eventual adverse events and the delivery of services can be registered only manually, being dependent on the presence of the therapist.

As a state-of-art, each technology operates like an independent environment where all data is collected and stored, with possibility to have access to raw data and/or to synchronise them with the clinical history of each patient. Currently, the best standard commercially available just allows back-up data from different devices of the same company, in a common repository (physical or cloud) to avoid information lost, in case of hard storage corruption.

Table 7: Pilot #3. Needs and Challenges.

Needs and challenges	Reference
Active control of the hospital environment.	**P3-N01**
There is need for accessing information on who, when, how long and where patients are before, during and after the treatment, with the aim to avoid risky behaviours and optimising resources allocation.	
Monitoring the largest number of activities, the patient can perform both autonomously and under therapists' supervision	**P3-N02**
The needs exist of detecting automatic information on time of presence/absence in the therapy room, right session pattern (use first device A and then device B), with the aim to include such parameters on the estimation of therapy effect.	

Clinical profiling of patients by automatic detection of behaviours based on continuous data acquisition from wearable devices.	**P3-N03**
Data collected via wearable devices (e.g., smartwatch, GPS) on spontaneous impaired behaviours (e.g., gross and fine motor impairment estimation, voice degradation, sleep assessment) will be combined with those collected via therapeutic devices and sensors to provide a comprehensive clinical profile of the targeted patients	
Modelling home based treatment settings before hospital discharge.	**P3-N04**
New generation of environmental sensors will extend the monitoring capacity of wide physical settings, allowing to transfer information collected in hospitals treatment areas, to home-based treatment settings.	

2.4 Pilot #4: Robotic Systems for minimally Invasive Operation

Leader: SERMAS

Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia in adults and one of the 3 cardiovascular pandemics of the XXI century according to the World Health Organization (WHO). The currently estimated prevalence of AF in adults is between 2% and 4%, and a 2.3-fold rise is expected, owing to extended longevity in the general population and intensifying search for undiagnosed AF. This disease is associated with substantial morbidity, (5-fold increased risk of stroke and 3-fold increase risk of heart failure) and mortality (2-fold risk of death). In addition, it is also associated with significant health care cost burden mostly associated with hospitalizations. Most treatments are aimed to reduce the complications of this disease, like anticoagulation to prevent stroke. However, pharmacological therapies to prevent AF episode or the progression of the disease have shown disappointing results with minor or neutral effects in major outcomes. Catheter ablation has shown more effective than drugs to keep patients without this arrhythmia, to prevent its progression and to reduce follow-up events. However, ablation is an invasive treatment which is associated with a small but still significant risk of complications and with suboptimal results because the precise AF mechanism and best mapping approach are still poorly defined. In addition, it is mostly performed by manual operation of catheters which require a significant amount of dexterity and experience. This results in substantial heterogeneity of clinical practice and important barrier to offer this therapy to many patients. As an example, 5164 AF ablation procedures were performed in Spain in the year 2019 which means that only 0.1% of Spanish patients with AF had the opportunity to receive this treatment that year. Robotic systems aimed to reduce the learning curve required to perform AF ablation procedures, to reduce complications and to make the procedure less operator dependent and more automatized have been developed in the past. However, most of these systems were based on mechanical navigation of the catheter with little impact on safety and operator dependency or were based on permanent magnets which resulted in slow operation, long procedures and difficulties to give the catheter enough contact force with the tissue.

Table 8: Pilot #4. Needs and Challenges.

Needs and challenges	Reference
Need for special equipment	**P4-N01**
A new robotic system for cardiac catheter navigation based on electromagnetic fields which could be rapidly changed in order to allow fast and automatic catheter steering with powerful tissue contact force for catheter ablation of AF.	
Need for special equipment	**P4-N02**
A new mapping approach developed with the help of artificial intelligence and big data techniques to better select the most appropriated targets for AF ablation	
Need for special equipment	**P4-N03**
An interface to integrate the new mapping approach and the robotic system with commercially available mapping systems	

2.5 Pilot #5: Assistive Care in Hospital: Robotic Nurse

Leader: UM

Pilot #5 deals with exploiting AI and other technologies to increase patient satisfaction and optimization of hospital resource utilization by delivering a more personalized care. Introducing robotics in healthcare can compensate for the shortage in the human workforce. Robots and ICT can implement passive sensing (e.g., telemonitoring, recognition of moods and (psychological) symptoms), and virtual support (e.g., companion mode and empathy) and offer i) more time for professionals to provide care rather than miscellaneous and repetitive tasks or administration, ii) new types of data and new means of representation to be included in the decision making during the regular clinical workflow. The overall objective of the pilot is to develop a social robotic system (SRS) that **supports nursing and care** through automated data collection, **improves decision making during clinical workflow** by aggregation and efficient representation of relevant patient data during regular grand rounds (doctor visits) and **improves the quality of care and patient experience** via companion functionality.

In this, the Application of the Robotic Nurse is divided into the following two studies: Clinician-Centred use and Patient-Centred use.

2.5.1 Clinician-Centred use

During grand rounds, the clinicians have limited access to retrospective health data of the specific patients and in paper format. The decision-making process is based on clinical guidelines and can be partially adjusted based on the feedback of patients given during ground rounds. The provision of support to medical staff includes:

- displaying patient vital signs,
- lab reports,

- plans, to-do lists,
- Taking, storing and displaying photographs of chronic wounds to track healing progress,
- patient diet,
- sleep tracking,
- providing basic tools for supporting clinical decision making (calculators, drug/medication information)
- Alerting personnel to potentially life-threating conditions (early warning system)

The robotic unit serves as a tool to collect and display telemonitoring data (vital signs, blood pressure) in a user-friendly envelope, alerting staff when parameters deviate outside of a normal range. The robotic unit collects and tracks mental and physical well-being using validated scoring systems and AI supported classification algorithms (i.e., facial-, voice- and text- features). In addition to prospective data, it can represent data from the patient's electronic health record during ground rounds. The data is represented in an efficient and user-friendly format on measured variables (blood pressure, pain, etc.) as opposed to conventional access to patient charts and lab data. It provides access and search functionality to ease the access to retrospective data stored in the digital clinical records of the patient.

In this study, the application of newly collected patient-gathered-health-data, patient-reported outcomes (PROs) and access to retrospective clinical data are assessed in a randomized cohort study with two cohorts, Cohort 1 (grand round supported by Robotic Nurse), Cohort 2 (grand round not supported by AI - control). The two groups are compared in terms of how well are blood pressure, pain, etc. managed. The hypothesis is that HosmartAI supported group is different and the measured clinical parameters are more adequately controlled as in the control group.

Table 9: Pilot #5. Needs and Challenges for Clinicians-Centre used.

Needs and challenges	Reference
Secure and efficient integration into clinical routine	**P5-N01**
Willingness of staff to include the robot into daily workflow (potential technophobia, fear of redundancy). The robot should first and foremost serve as an additional and synergetic component in medical care to enhance it without medical personnel becoming over-reliant. Safety of patients and data. Fear of rogue AI taking over the ward and ruling with an iron fist.	
Usability of 'patient gathered health data' during hospitalization	**P5-N02**
How to collect and integrate data measured with digital devices (e.g., blood pressure, heart rate) into EHRs efficiently and how to represent efficiently during clinical routine. The following aspects must be further considered: i) **Practicality of use:** can patients managed the devices themselves, do measurement depended on movement of the patients, do patients wear wearables over the whole day, can multiple patients use the same sensor; ii) **Accuracy:** many existing telemonitoring systems do not meet clinical requirements	

especially regarding blood pressure measurements and iii) efficient integration of new resources (e.g., FHIR).	
Usability of PROMs and PREMs during hospitalization	**P5-N03**
Facilitate the collection and incorporate patient experience into the clinical workflow to improve the decision making and implement risk assessment as an early detection mechanism. How to collect and integrate data measured via standardized questionnaires or AI-supported feature extraction and classification (i.e., pain, mood/emotion) into EHRs efficiently and how to represent efficiently during clinical routine. The following aspects must be further considered: i) **Modes of interaction** (speech + touch); ii) Which kind of **standardized PROs** and summary representing key assumptions; iii) **Explainability of AI** and storage of captured interaction for post-hoc analysis and evaluation; iv) Efficient integration of new resources with existing patient data.	
Facilitate the risk assessment and detection of frailty or signals of psychological distress	**P5-N04**
Using PGHD and PROs the system should perform a risk assessment. It should have access to action protocols defined based on professional knowledge and standards given the specific setting, and, when possible, connect with aspects of personalization (such as user preferences).	
Patient consent and compliance	**P5-N05**
Patient must be a willing, active and motivated participant. The main challenge will be to optimize the interaction, especially the targeted data collection (PROs) so that patient remains motivated and detect and mitigate possible deviations. Moreover, in case of problems or unexpected behaviour, the patient must not be left alone and proper support must be offered.	
Interoperability and compatibility of telemonitoring devices, the robot's proprietary software and hospital's system.	**P5-N06**
Integration of the units into the overall IT system without risks to the core hospital system, ensure data portability and compatibility between the care support system and core hospital's system	
Support decision-making with retrospective data, user-friendly access and visualization	**P5-N07**
The PGHD and PRO should be efficiently integrated into clinical workflow and interconnectable with existing retrospective data, care plans, activities and results, to improve professional decision-making. How to efficiently pre-define the most common search patterns and how to design the interface to get access to required pieces of data with minimal interaction effort. The following aspects must be further considered: i) Exploitation of barcode recognition by the unit to pre-pare key data, ii) Exploitation of FHIR to predefine patient specific patterns	
Optimize resources supporting existing care	**P5-N08**
Complementing the current services extending the interventions while monetizing time spent by professionals and with potential to reduce the cost of common materials used.	

Expand the interventions using the Empathic Agent (physical robot) to support patients and service processes and decrease the load on the nursing and care staff.

2.5.2 Patient-Centred use

One of the major issues during hospitalization is patient boredom. In many cases, patients do not know what to do with the available time thus try to engage in discourse with staff. Although the delivery of care and interaction with patients should still remain firmly in the purview of humans, robots could assist and take the initiatives in human-machine conversation. Moreover, routine, repetitive and schematic tasks, such as taking measurements of vital signs or collection of PROs, represent a significant burden to the staff. By 'outsourcing' these tasks to a machine we can increase the frequency and data collection and extend the types of data collected

The Robotic Unit offers an alternative social outlet for patients (chatbot, video-calls with relatives, access to the internet and to the world outside the hospital, providing insight and information on treatment goals, patient motivation and entertainment etc.); a simple to invoke, simple to use communication option to engage with the patients in discourse and to ease their access to internet and information about the events outside the hospital, to ease the temporal and local disorientation and acts as an enabler of more efficient communication with their family.

In addition to collection of experiences, mental and physical well-being, and PROs the robotic unit would: provide cognitive stimulation during hospitalisation, particularly for older patients by engaging into domain and scenario restricted (goal oriented) discourse (i.e., giving them clinically approved suggestions and advice regarding post-operation and recovery, regarding the procedure, relevant links to information and life outside the hospital and connections to relevant patient associations or workshops organized by the hospital, etc.).

In this study, the companion functionally and assistive value of the SRS is assessed in a randomized study with two groups, Group 1 – the usual way for getting access to data, internet, and communication with the relatives and Group 2- Robot-assisted group. The outcome measures would be patient satisfaction (subjective). The objective measure would be System Usability Scale (SUS), and the Efficacy of interactions and duration of successful communication attempts during a hospital stay.

Table 10: Pilot #5. Needs and Challenges for Patient-Centre used.

Needs and challenges	Reference
Efficient placement and integration of the robotic unit into the clinical setting	**P5-N09**
The solution should be accessible, useful and filling the different requirements of the two complementary settings (i.e., the two departments). Principals of unobtrusiveness aimed at improved patient experience and quality of care must be considered while ensuring safety, a sense of control generating trust and accomplishing with confidentiality and	

security requirements. How to prevent damage and injuries to patients? How to optimize and efficiently integrate 'on-request' mode with the predefined 'data-collection' mode? Can we exploit 'free' conversation to collect subjective parameters? For the introduction of socially assistive robots in care settings, the robot must be responsive to the needs and requirements of multiple personas, from patients (adults and elderly) to staff.	
Restricted and managed useful assistive and socially interactive functions functionalities domain and scenarios of discourse	**P5-N10**
Constructed under assistive and social value co-creation potential, including services such as health monitoring and safety, encouragement to engage in rehabilitation or general health-promoting exercises, social mediation, interactions, and companionship. However, day-time operation only and with operator present who manages usability. Monitored and managed access to information and managed operational capacity. Limit the access to managed (medical) information. Limit the available discourse domains. Prevent cases where the unit could share misinformation or create doubt in patients with incorrect or to-informed answers. Restrict and completely manage what kind of health literacy support may be given by the robotic unit.	
Interaction capabilities and empathy	**P5-N11**
Low digital skills required with a good level of usability and accessibility expected, avoiding cognitively demanding interfaces. Support for spoken language interaction v.s. text-touch based interaction v.s. hybrid. How to efficiently design interaction scenarios and integrate the full spectrum of robots' capacities including voice and gesture. Special consideration must be given to the acoustics of voice (e.g., loudness, tone) and applicability of gesture given the interaction space and context to prevent injuries, damage or to offend the patient or invoke distress in patients. Integrate politeness and empathy into responses.	
Reduce Temporal and Spatial Disorientation, Boredom and Unwanted loneliness	**P5-N12**
One of the main issues of hospitalization are Boredom, Unwanted Loneliness and Temporal and Spatial Disorientation, relevant especially for elderly patients. With important social, health and financial impacts, loneliness and isolation are a heterogeneous phenomenon due to their different forms and impacts with multiple causal determinants The intervention through the SRS, the robotic unit with social skills and informative, entertainment capacities, represents a unique opportunity to offer activities oriented to detect and reduce the feeling of boredom, isolation and unwanted loneliness. It may also represent a healthy link between the patient and the world outside the hospital.	

2.6 Pilot #6: Assistive Care in Care Centre: Virtual Assistant

Leader: INTRAS

2.6.1 Context of intervention and usual services provision

INTRAS Memory clinics and neuro-psychological rehabilitation centres work both in outpatient setting and at home, with a catalogue of services involving Neuropsychological assessment, Cognitive stimulation and rehabilitation, Active aging programs, Psychomotricity program, Speech therapy, Multisensory Stimulation Therapy, Training in instrumental activities of daily living, and Psychotherapeutic and psychoeducational programs for caregiver. These care services aim for cognitive, physical, social and emotional health and wellbeing, making already use of digital tools (e.g., remote sessions, Suite Gradior, VR) as an important resource supporting the therapeutic plans.

2.6.2 Care and rehabilitation workflows, communication gaps and decision-making

Despite the innovative culture in prevention, rehabilitation and assistive care for older adults, there is still a gap in systematizing information collection processes from the patient journey to allow a greater degree of personalization. Each technology usually operates as an independent environment and is not significantly endowed with aspects of personalization and decision support. In addition, the low communication among public-private sectors and between social-health services sometimes do not facilitate integrated case management and care coordination, making difficult early detection, adequate holistic monitoring progress or high personalization of health and social prescriptions.

Alternative solutions are required to also address the concerns of citizens for ageing-in-place, with a growing demand for innovative services aimed to provide care that is both affordable and meets the emotional, social, cognitive and physical needs of older adults, while they can also be an answer to the increasing ratio of older adults living alone or suffering unwanted loneliness, one of the epidemics of the century, implying risk of premature death, worsening of health, physical, cognitive deterioration and loss of quality of life of the elderly. At the same time, it is important to attend to the difficulty of balancing sustainability and resources with high demand and the need for adequate intensity and quality of services.

2.6.3 The research, development and implementation gaps

In this sense, integration of information technology holds promise for reducing loneliness and social isolation, while supporting the caregiving processes [REF-02], especially assistive technologies as Socially Assistive Robots (SAR's) oriented to support the caregiving process or keep the elderly at home for longer [REF-03][REF-03], addressing areas of need that influence admission to a nursing home (physical, cognitive, medical and psychosocial issues), with its social presence evidencing an important advantage to care plans adherence.

Most common archetypical service categories according to a systematic review were handling adverse conditions, assessing state of health, consultation and education, motivation and feedback, service ordering and social inclusion [REF-04]. As a result, many solutions are already available but with limited scope. Moreover, the combination of both intervention dimensions (social or assistive robots for the elderly) is under a new paradigm with scarce examples of it. Some of the current demanded functions are the capability to facilitate preventive interventions delivery, monitor relevant general health and wellbeing state parameters, facilitate care logistics, stimulate positive behaviour change (health education & empowerment) and promote meaningful social interactions.

As a result, a framework to support the continuum of care, for deployment in different but complementary life settings, introducing virtual assistants into the intended practice in both care centres and in homes of older people, is highly demanded. Although integration of technology into care is one of the core determinants of successful support, little is known that arises from the deployment of technology in care settings.

There are also many recognized critical challenges, as on usability (e.g., speech interaction, ensure older adults take a proper role in human-robot interaction, and a lack of affordances), and related with the introduction of robots in the context of care and autonomous use by older adults [REF-05].

Table 11: Pilot #6. Needs and Challenges.

Needs and challenges	**Reference**
Overcome fragmentation bridging the gap among social and health care services and plans	**P6-N01**
Ability to support health and wellness care plans (recording, facilitating and monitoring) acting as a bridge among health and social services to fill the gap in the communication among professionals, especially between public and private services. Enable the establishment of improved coordination mechanisms and protocols among the actors involved, with users maintaining control over their data.	
Facilitate a unique comprehensive intervention approach (eCoaching) integrating different health and wellbeing dimensions	**P6-N02**
Interface with prevention and intervention programs/contents (e.g., personalized recommendations, psychoeducation contents, awareness-generation strategies, stimulation or rehabilitation exercises, risk monitoring and adherence follow-up methods), tackling wellbeing dimensions – psychological, emotional, social, cognitive, physical, empower for self-care. Facilitate implementation of a model where patients feel increasingly empowered to decide upon and manage their health and wellness (through information, training and facilitating tools).	
Modular solution adaptable to the different life settings, following a goals-specific strategy	**P6-N03**
The solution should be accessible, useful and filling the different requirements of the two complementary settings (home setting, and daycare centres or rehabilitation centres), as connected spaces for continuing care plans. Adjustable to a wide range of centers (public and private) with similar processes and/or services offered.	
Low digital skills required and high accessibility level	**P6-N04**
Low digital skills required with a good level of usability and accessibility expected, avoiding cognitively demanding interfaces.	

Responsive to the needs and requirements of various network actors	**P6-N05**
For the introduction of socially assistive robots in elderly care settings, the robot also must be responsive to the needs and requirements of various players (network-conscious approach), a challenge largely neglected in the existing research. It should also specifically caters to older people regarding objectives, content and digital accessibility.	
Combine useful assistive and socially interactive functions to support independent living	**P6-N06**
Constructed under assistive and social value co-creation potential, including services such as health monitoring and safety, encouragement to engage in rehabilitation or general health-promoting exercises, social mediation, interactions, and companionship. The solution should offer increased support of independent living for elder people and their careers to improve and maintain their independence, functional capacity, health status as well as preserving their physical, cognitive, psychological and social well-being.	
Facilitate the detection of the risk of frailty or signals of decline	**P6-N07**
Provide a follow-up approach allowing the early detection of risk. Enable to fill the gap in the monitoring the adherence to care plans and relevant progress indicators connected, helping to compensate the limited time and resources available for this action.	
Enable a link to primary, secondary and tertiary prevention	**P6-N08**
After risk detection the system should have access to action protocols defined based on professional knowledge and standards, and, when possible, connecting with aspects of personalization (such as user preferences). It must be flexible to adapt to the pathways of detection of frailty or symptoms and to the different levels of prevention.	
eCoach to stimulate active lifestyle	**P6-N09**
Empowering the patient through a cross-linked ICT based solution that stimulates self-care behaviour (AHA lifestyles, adherence to care plans), connect with personalized features and facilitate access to care interventions and recovery services at home.	
Follow-up adherence to care plans according to the use settings	**P6-N10**
Increase follow-up opportunities based on data gathered in both use settings: memory clinic and neuro-psychological rehabilitation Center and older adults' homes.	
Support professional decision-making with “live information” and automatic reporting	**P6-N11**

Systematize automatic data collection on care plans, activities and results, to improve professional decision-making.	
Oriented to reduce isolation and unwanted loneliness	**P6-N12**
With important social, health and financial impacts, loneliness and social isolation are a heterogeneous phenomenon due to their different forms and impacts with multiple causal determinants (e.g., sociodemographic variables; health and functional autonomy; psychological; social and participation). The intervention through the virtual agent (with both interfaces – tablet and social robot) should include opportunities and activities oriented to detect and reduce feelings of isolation and unwanted loneliness.	
Support care logistics	**P6-N13**
Act as an assistant supporting the care professional team & able to detect/locate/identify a user and initiate planned interactions - individual or with a group.	
Facilitate care plans customization	**P6-N14**
The intervention model and behavior change model using a motivational approach (for self-care and motivating adherence to the care plans) must collect and relate with information on older adult's requirements, life project, care plans and preferences.	
Unobtrusiveness, safety, confidentiality, sense of control and trust	**P6-N15**
The solution and devices to be deployed in older adult's homes and in care centres should accomplish with principals of unobtrusiveness interactive technologies aimed at assisting older adults in their own independent life while ensuring safety, a sense of control generating trust and accomplishing with confidentiality and security requirements.	
Developed under a robust participatory requirements elicitation process with real users, and enabled to progressive modular growth	**P6-N16**
Consider the following aspects: i. needs of care/rehabilitation facilities, the patients and the extent to which currently available technology is able to provide support to develop accessible and acceptable systems; ii. barriers and enablers to the adoption of technology (by care services, professionals and older adults); iii. extend the knowledge by defining virtual assistant roles (including the social robot) according to the value they can co-create with a service beneficiary, as well as the existing value that potentially could be co-destroyed.	
Enable research study on successful interaction with HosmartAI, new modules and services integrated	**P6-N17**

The system should support the continuous study of successful interaction with technological devices and systems, involving the perceptions and expectations towards the future solution to reach the market. In addition, the study on further enablers and barriers to older adult's adoption towards HosmartAI and the integrated solution envisioned for pilot 6: usability, affordability, accessibility, emotion, confidence, independence, compatibility, reliability, social, technical support, and cost, perception of real advantage and system trusts.	
Optimize resources supporting existing care, rehab. or assistive programs	**P6-N18**
Complementing the current services extending the interventions while monetizing time spent by professionals and with potential to reduce materials cost. Expand the interventions out of the formal therapy sessions using the Empathic Agent (physical robot) to support patients and service processes in specialized care centres (such as Memory Clinics) and non-specialized (daycare centres). A concrete example can be to develop or integrate dedicated modules to support reminiscence-personalized activities, pills of mindfulness exercises used at the beginning of the sessions with personalized music, etc.	
Integrate PREMS and PROMS to inform continuity of care	**P6-N19**
There are current limitations also in wrap-up, digest and facilitate decision-making for new investments on new facilitating technologies. PREMS and PROMS are rarely used to inform continuity of care or across transitions of care but in HosmartAI these will be an important source of data. HosmartAI should facilitate the collection and incorporate the so-called "patient experience" into the health and social care processes, to improve it, adapting as much as possible to the life circumstances of the people under treatment or receiving support. It should also support the study of PROMs and PREMs at micro (patients, family caregivers, and healthcare providers), meso (organizational managers/executives/programs), and macro (decision-/policy-makers) levels.	
Support older adults to reduce digital divide	**P6-N20**
Empower older people to be active technology users, not just passive recipients of technology. HosmartAI should promote concerted and thoughtful efforts to help older people with digital technology making their lives easier, particularly during and after the COVID-19 pandemic. A multi-functional Socially Assistive Robot ensuring empathic/familiar, unobtrusive interaction, age-friendly highly usable interfaces, safe and adjustable to the varied and changing needs of older adults may help to surround/overcome the issues and concerns of the digital divide.	

2.7 Pilot #7: Smart Cathlab Assistant

Leader: Phillips/UZ Brussels

Pilot #7 addresses the minimally invasive treatment of patients with cardiovascular diseases. Such a procedure is called catheterisation and is typically performed in a Cathlab. As an example, Percutaneous Coronary Intervention (PCI) is an image-guided procedure used to treat a narrowing of the coronary arteries of the heart by placing a stent to widen the blood vessel diameter. Currently X-ray imaging is typically used during such procedures for navigation, but other data sources like ultrasound imaging and blood flow measurements are often included, in particular to treat complex cases.

2.7.1 Complex clinical workflow and decision making

The integration of multiple imaging and data sources leads to data clutter and makes it difficult for a clinician to interpret the data and extract meaningful insights to diagnose and treat the patient. Image interpretation is usually done manually, requiring highly skilled experts and may lead to fatigue and errors. To assist the clinician in the understanding and assessment of clinical data there is a need for smart clinical applications that are able to automatically interpret medical images and do a quantitative assessment where possible. Computer-assisted interpretation of images could go a long way in further improving accuracy, offering a helping hand to the clinician.

2.7.2 Administrative burden

In addition to the primary clinical tasks, proper reporting is another important part of a clinician’s work. However, administrative work is widely recognized as a major source of professional burnout in healthcare, and particularly for invasive cardiologists. Excessive administrative tasks that are not central to direct patient care can lead to delayed or missed patient care, clinician dissatisfaction and workplace burnout. Clearly there is a need to assist or automate as much a possible the reporting for PCI interventions by automatically tracking each step of the procedure, logging relevant events and actions, and auto-populate reports with images and measurements acquired during the procedure. The clinician would only have to supervise, complete, and sign off the pre-populated report at the end of the procedure.

Table 12: Pilot #7. Needs and Challenges.

Needs and challenges	Reference
Real-time clinical decision support	**P7-N01**
Challenge is to develop AI-enabled tools to provide real-time clinical decision support in the interventional suite: intuitive guidance, automated clinical & quantitative analysis. This includes automatic image analysis and extraction of relevant patient data.	
Automatic reporting	**P7-N02**
Challenge is to develop AI-enabled tools to alleviate the administrative burden in the interventional suite, allowing clinicians to focus more on the procedure and the patient. This includes automatic event logging, consistency checks and automatic generation of procedure-related documentation.	

2.8 Pilot #8: Prognosis of cancer patients and their response to treatment combining multi-omics data

Leader: VUB

Pilot #8 focuses on accurate glioma diagnosis, which contains two major elements: (1) segmentation and (2) characterisation of the tumour, including both the determination of the subtype and grade. In this pilot, we address the ability to connect researchers with clinicians in a ‘rapid learning healthcare’ approach. To do so requires a digital health research platform, where multimodal data and advanced analytics are integrated for the analysis of brain tumours, and a decision support system based on integrated molecular and image-level research on the tumour that directly connects to, and informs, clinicians.

2.8.1 Digital health research platform

The unique expertise and data present at the VUB and the UZ Brussel are here leveraged to create a general framework to store and analyse raw medical data, both at the image and molecular level, in relation to brain tumours, their clinical behaviour and response to therapies. The platform offers an integrated view on the patient data for research, while conforming to GDPR and patient legislation, thus enabling AI-driven extraction of new information on such tumours. An important feature of the platform is the tight integration with the hospital information system. Extraction of data from the latter is performed (semi-) automatically, allowing to iteratively update the data collection, retrain models and deploy them in the clinical setting.

Table 13: Pilot #8. Needs and Challenges for the digital health research platform.

Needs and challenges	Reference
Connect image with molecular data	**P8-N01**
These data are typically stored in different locations in the hospital, and need to be i) related to each other and integrated while being connected to ii) the central PRIMUZ patient database	
Making data adhere to GDPR	**P8-N02**
This step involves pseudonymisation of the patient information, as well as the ability to select only the data relevant for a particular research question.	
Making data accessible for research	**P8-N03**
Access to the data has to be provided in a convenient way, whilst ensuring privacy and security of the data. Systems such as Jupyter-based access exist and will have to be employed for this.	
Patient data availability	**P8-N04**

Funding and systems are set up and ready to collect data on glioma patients; these data are essential to the project and have to be efficiently stored and organised within the digital health research platform.

2.8.2 Decision support system

Researcher access to the digital health research platform, combined with expert insights from clinicians, will enable progress in assisting and improving the diagnosis and decision-making process (i.e., help in segmentation and characterisation of tumours). Current decision support tools in oncology are typically knowledge-based (i.e., based on guidelines and best practices) or evidence-based, relying on reports of (meta-analysis of) high quality clinical trials. These need to be manually updated as guidelines evolve and are not based on local technical possibilities or past performance. This pilot aims to demonstrate the use of a rapid learning healthcare, by developing a platform that enables to compute and continuously update data-driven decision-support based on data from clinical routine, collected in-house. The underlying analysis effectively constitutes a critical review of the hospital's own practice past performance based on real-world data and can be seen as a complement to existing external guidelines and best practices on disease management based on clinical trials.

Table 14: Pilot #8. Needs and Challenges for the decision support system.

Needs and challenges	Reference
Efficient framework to connect researchers with clinicians	**P8-N05**
Efficient communication between researchers and clinicians is essential to i) ensure researchers understand clinicians' needs as well as accessing their insights, ii) ensure clinicians can understand the limitations of the AI-based research results provided by the tools developed by the researchers. This ideally requires a user-friendly framework to do so.	
Ability for critical review on current practice	**P8-N06**
The researcher/clinician insights that reveal possible shortcomings or suggest improvements to the hospital's current practice, at any level (e.g., clinical or data organisation) have to be efficiently communicated to the persons responsible at the hospital level.	
Analysis of image and molecular data in relation to glioma	**P8-N07**
The separate ongoing research at the tumour image and molecular analysis levels has to be integrated in order to provide the most useful information to the clinicians.	

2.9 A taxonomy of needs

In this subsection, the needs from the different previous section are unified and grouped according to their relationship with each of the different tasks from WP3. If possible, a taxonomy term from LOINC or SNOMED is also assigned to each unified need.

Table 15: Taxonomy of the needs and challenges.

Taxonomy	Needs and Challenges	References	Diagnosis Revolution	Logistic Improvement	Treatment Improvement	Surgical Support	Assistive Care	Personalized Treatment
Clinical equipment and/or device (physical object) SCTID: 272181003	Need for special equipment. Specialized Sensors	P1-N06	X					
Aids to daily living (physical object) SCTID: 360301002	Need for special equipment. Environmental Sensors	P3-N04			X			
Aids to daily living (physical object) SCTID: 360301002	Need for special equipment. Telemonitoring	P5-N06, **P6-N08**, P1-N11	X				X	
Assistive equipment (physical object) SCTID: 360296002 Surgical equipment (physical object) SCTID: 397980000	Need for special equipment. Robots	P5-N09, P4-N01			X	X	X	
Community special services management	Need for time and resources management	P1-N01, P1-N04, P1-N07, P1-N09, P1-N11	X					

Taxonomy	Needs and Challenges	References	Diagnosis Revolution	Logistic Improvement	Treatment Improvement	Surgical Support	Assistive Care	Personalized Treatment
(procedure) SCTID: 385761006								
	Need for experienced specialist	P1-N02, P1-N08, P1-N11	X					
Motivating patient (procedure) SCTID: 225223002	Patient enrolment, consent and compliance	P1-N05, P5-N05, P2-N05	X				X	
Functional training (procedure) SCTID: 118629009	Special training of specialists or patients	P2-N05	X					
Scheduling (procedure) SCTID: 410538000	Applied AI. Tracking	P2-N01, P2-N03, P3-N01, **P6-N13**, **P6-N14**		X	X		X	
	Applied AI. Clustering	P1-N04, P2-N02, P2-N04, P3-N02, P5-N04	X	X	X		X	
	Applied AI. Classification	P1-N03, P1-N05, P1-N10, P3-N03, P5-N03, P5-N04, P6-N07, P8-N07	X		X		X	X

Taxonomy	Needs and Challenges	References	Diagnosis Revolution	Logistic Improvement	Treatment Improvement	Surgical Support	Assistive Care	Personalized Treatment
	Applied AI. Intelligent Man-Machine Interfaces	P2-N05, P5-N07, P5-N11, P5-N12, P6-N03, P6-N04, **P6-N06**, P6-N09, **P6-N20**, P4-N03		X		X	X	
	Applied AI. Social Robotics	P5-N10, P5-N11, P6-N02, **P6-N05**, **P6-N06**, P6-N09, **P6-N12**, **P6-N15**, **P6-N16**, P6-N18					X	
	Applied AI. Intelligent Data Gathering	P2-N03, P2-N04, P4-N02, P5-N03, P6-N10, **P6-N19**, P8-N04			X		X	X
	Applied AI. Decision Support	P1-N03, P1-N05, P1-N08, P1-N09, P6-N11, P7-N01	X			X	X	
	Applied AI. Intelligent Reporting	P5-N02, P5-N08, P7-N02				X		

Taxonomy	Needs and Challenges	References	Diagnosis Revolution	Logistic Improvement	Treatment Improvement	Surgical Support	Assistive Care	Personalized Treatment
Community special services management (procedure) SCTID: 385761006	Coordination of Services	**P6-N01**, P8-N06					X	X
	Services Integration	**P6-N17**, P8-N01, P8-N05					X	X
Privacy policy acknowledgment of electronic data usage (record artifact) SCTID: 721913004	Data Privacy and Accessibility	P5-N01, P8-N02, P8-N03						X

3 Background knowledge

This section aims to detect the needs that are covered either by the consortium background knowledge or by external projects and platforms. The structure of this section follows the WP3 package, where all the Pilots must be implemented; there is a subsection that corresponds with each WP3's task. Each section will detail the background of the consortium and how the needs are covered.

3.1 Tools for Diagnosis Revolution

Leader: AUTH

The AUTH team, specifically the Lab of Medical Physics and the Signal Processing and Biomedical Technology Unit (SPBTU) will collaborate to address the following needs, as outlined in Section 2 hereof:

- Need for accelerating examination time **(P1-N01)**
- Need for experienced physicians **(P1-N02)**
- Need for increasing diagnostic yield **(P1-N03)**
- Need for increasing the cost-effectiveness of CCTA utilization in cardiovascular clinical practice **(P1-N04)**
- Need for better individual risk stratification as regards to obstructive CAD **(P1-N05)**
- Need for special equipment **(P1-N06)**; the needed equipment will be provided during the development phase of HosmartAI.
- Need for accelerating the examination time **(P1-N07)**
- Need for eliminating the examination variability **(P1-N08)**
- Need to reduce unnecessary use of resources **(P1-N09)**
- Need for accurate triage of pregnant women in primary and secondary healthcare settings **(P1-N10)**
- Need for improved access to resources (experienced staff and affordable technology) **(P1-N11)**

3.1.1 AI tools for medical diagnostic applications

Artificial Intelligence (AI) technologies are rapidly attracting attention in the field of Computer Aided Diagnosis/Detection (CAD). CAD systems aim to support diagnostic procedures by providing complementary insights to clinicians, by employing signal/image processing techniques for the detection of pathologic patterns. The integration of AI technologies in CAD systems has been underpinned by the advancements in computing hardware, the massively increased availability of data and the development of sophisticated Machine Learning (ML) algorithms. The effectiveness of such algorithms is found in their ability to learn generalizable, semantic patterns and representations by experiencing available data and leveraging statistical methods.

In the field of AI-based image processing, also referred to as computer vision, a momentous advancement of the past decade is the advent of Deep Learning techniques, in the form of Convolutional Neural Networks (CNN) [REF-79]. The latter enables the automatic extraction of meaningful, information-dense features from images, overcoming the need for the laborious and time-consuming feature development practices adopted in the past. CNNs have been applied with outstanding success in a wide variety of applications, demonstrating human-level performance [REF-98] in vision-related tasks. This performance can be attributed to the inner architectural design of CNNs, that encourages the decomposition of image content into hierarchically organized features that express semantic information in varying degrees of complexity. Regarding the HosmartAI CAD systems to be developed, CNNs are expected to be employed for image analysis in two clinical scenarios of Pilot 1 “Development of a clinician-friendly, interpretable computer-aided diagnosis system (ICADx) to support and optimize clinical decision making in multi-specialty healthcare environment”, namely Capsule Endoscopy (CE) and Echocardiography. CNNs are also suitable and will be utilized for signal analysis in the obstetrics clinical scenario. Since interpretability and transparency are key in ensuring smooth clinical translation of AI technologies, visualization methods such as GradCAM [REF-81] and/or AblationCAM [REF-82] will be used to highlight image regions that are important for the CNN model decisions.

3.1.2 Scenario-specific descriptions

In the CE scenario, large public CE databases will be used to train modern, highly competent CNN architectures (e.g., VGG, MobileNet, ResNet variants, DenseNet) [REF-83], to recognize and localize abnormalities such as bleeding and lesions. Automatic recognition will enable comprehensive summarization of long CE videos into suspicious video frames that require attention, shortening review times and enhancing diagnostic yield, therefore assisting expert and less experienced physicians in the diagnostic process. **P1-N01, P1-N02** and **P1-N03** are thus addressed.

In the CCTA (Coronary CT Angiography) scenario, the platform to be developed aims to support cardiologists to choose individual-tailored therapy/prevention methods, combining CCTA, clinical and laboratory data by predicting patients likely to have obstructive CHD. To this end, an AI-based model will be developed, adopting a network medicine approach and utilizing clinical risk factors, coronary artery geometric features and the coronary artery calcium score (CACS), to predict the presence and the complexity of CAD on CCTA. Regarding the needs, **P1-N04** and **P1-N05** are covered.

In the echocardiography scenario, a state-of-the-art CNN architecture, EchoNet [REF-84], will be used to accurately quantify the ejection fraction (EF) for assessing the heart’s left ventricular (LV) function. Specifically, EchoNet consists of two subnetworks. The first subnetwork predicts the ejection fraction for each cardiac cycle using 3D spatiotemporal convolutions with residual connections, while the second one generates frame-level semantic segmentations of the LV using a CNN model with atrous convolutions [REF-85]. The outputs of both networks are combined to automatically predict beat-to-beat, i.e., the overall EF. Automatic EF quantification will facilitate an efficient and accurate diagnostic procedure, countering interobserver variability, eliminating the need for laborious manual annotation of images and providing a robust baseline for preliminary interpretation in areas with insufficiently qualified cardiologists. Regarding the needs, **P1-N07** and **P1-N08** are covered.

In the obstetrics scenario, the tool to be developed aims to support obstetricians to choose whether a suspicious pregnancy incidence should be referred or not for an expert sonography to a secondary hospital, thus covering needs **P1-N09**, **P1-N10** and **P1-N11**. The tool will comprise a computerized Fetal Heart Rate (FHR) analysis combined with deep CNNs. In order to increase the acceptance of the final decision of the platform, the aim is to provide auxiliary tools for visualization and interpretation of the results. Computerized CTG (cCTG) and Doppler sonography findings will be compared in order to investigate: 1) whether cCTG allows early identification of signs of fetal compromise, so that secondary hospitals need not refer small for gestational age fetuses for expert sonography, and 2) whether cCTG and clinical evaluation of the cervix allow identification of the true cases with threatened PTL compared to traditional CTG.

3.1.3 Background of involved teams

The Lab of Medical Physics is a major research and development center in assistive technologies; applied neuroscience; medical education; affective computing; semantic web; medical robotics and brain computer interfaces; radiodiagnosis and non-ionizing radiation. The Lab of Med Physics is ISO-9001 certified on Software Design, Development & Production and Design & Implementation of Education/Training programmes. The multi-disciplinary synergy of engineering and computer science enables end-to-end solutions from raw data to insightful clinical results derived from the employment of artificial intelligence (AI) techniques, while also providing data protection and EU GDPR consultancy and technical support. The Lab has experience in developing solutions and tools based on artificial intelligence through its participation in a number of EU and nationally funded research projects such as the H2020 LifeChamps, the H2020 CAPTAIN, the FP7 USEFIL and the IntelTriage (nationally funded).

The SPBTU serves educational and research needs of the School of Electrical and Computer Engineering and its main scientific areas of interest are in the field of Active and Healthy Ageing and include the acquisition, processing, and pattern analysis of biomedical data. Over the years, the unit has conducted and published extensive research on the development of advanced signal and image processing techniques with applications in several fields of biomedical engineering such as electromyogram (EMG), electroencephalogram (EEG) processing, respiratory/cardiac/bowel sounds processing, endoscopic/ultrasound/magnetic resonance image analysis, brain computer interfaces, music perception, biomusic, affective computing, mobile biomedical applications, virtual and augmented reality biomedical applications. The SPBTU has participated in several projects such as the H2020 i-PROGNOSIS and H2020 Protein, as well as the RadBrainMRI (nationally funded).

3.2 Tools for Logistic Improvement

Leader: ITCL

ITCL in collaboration with TMA and CHUL will be in charge of the following needs:

- Optimizing patient scheduling where variable weighting and resource availability may change **(P2-N01)**

- Improve AI flow solution by grouping patients by treated organ, adapting to patient performance status and anxiety of the first session **(P2-N02)**
- An AI system that proposes very quick a rescheduling **(P2-N03)**
- An AI solution adapting to the number, irradiation mode and complex treatment **(P2-N04).**

These needs as far as possible have to include the analysis and assessment of data acquisition, storage and processing tools like Apache Spark, Tensorflow, Numpy, Pandas and Cassandra with the development of **"radiotherapy treatment planning computer".** The use of CNN (Convolutional Neural Networks) and LSTM (Long-Short Term Memory) algorithms for the improvement of radiotherapy scheduling treatment with the development of **"radiotherapy treatment planning application software"**. The software has a configuration file to change the variable weighting and adjust to new graphics parameters change by the actors.

ITCL's experience is based on optimizing planning in a heuristic way according to constraints for truck weighing management in an industrial environment and planning of recharging electric vehicles taking into account multiple electrical restrictions, the number of parking spaces and recharging sockets, as well as entry times and approximate date for the departure of the vehicle [REF-14], [REF-15], [REF-16], [REF-17], [REF-18]. ITCL also has a patent (P201230485) about a method and energy distribution system in multiple charging stations network, e.g., for electric vehicles, that plans and optimises the charging times of every device regarding certain charge parameters that are estimated by pattern recognition methods.

TMA's proprietary Online Scheduling addresses the **P2-N01** need to optimize the patient scheduling under varying weighting parameters and resources availability. As far as functional and technical characteristics go, the system allows the patient to view his/her scheduled appointments, uses intake forms to request any kind of medical information from the patient upon booking, syncs with Google calendar of all stakeholders and it can optionally send come back reminders for patients for followup visits. Most importantly, as far as HosmartAI is concerned, it features a REST API which allows for the integration with external systems that will allow for dynamic and rescheduling or just as an extension system.

UM's proprietary conversational intelligence framework and speech synthesis system define the solution for the need **(P2-N05)** in sections **3.5.1.1.6** and **3.5.1.1.7**. With the technology we will deliver a more personalized and easy to use interface for patients to express their requirements and needs related to timing and irradiation locations.

- **(P2-N01, P2-N02, P2-N03, P2-N04)** Given its many departments treating a large number of patients, the CHUL has acquired knowledge on complex patient flows. Within the hospital, specialized staff have been trained for identifying key parameters and their relative weight to establish the best possible patient flows. In addition, several staff members master the Mosaiq software at the base of the planning of treatments, appointments and of the underlying database model. The Mosaiq's software ELEKTA is committed to work constructively with CHUL in new projects that advance both institutions.

CHUL has extensive experience in data extraction and modeling in FHIR and DICOM format. Patient data sharing follows a strict protocol controlled by the Data Protection Officer who has been appointed to ensure GDPR.

Clinical studies and clinical trials approved by the Ethics Committee are conducted by experienced teams ensuring excellence and rigor.

3.3 Tools for Treatment Improvement

Leader: VIMAR

In the context of Pilot 3 VIMAR in collaboration with AUTH will work to solve the following needs:

- Active control of the hospital environment (**P3-N01**)
- Monitoring the largest amount of activities, the patient can perform both autonomously and under therapists' supervision (**P3-N02**)
- Clinical profiling of patients by automatic detection of behaviours based on continuous data acquisition from wearable devices (**P3-N03**)
- Modelling home-based treatment settings before hospital discharge (**P3-N04**)

VIMAR has a several-decade-long experience that went from simple electrical installation to modern home automation systems, creating a multifunctional interface that dialogues with the user. The group will provide devices from View Wireless line, which presents a range of solutions that enhance the building, with the aim of controlling the hospital environment (**P3-N01, P3-N04**). Devices and commands easy to use, reliable and safe, enable the improvement of living spaces even with simple home automation solutions.

The potentials offered by Vimar are:

- Smart devices for a connected environment
- Easy and straightforward installation, flexibility and scalability
- Communication between devices and with the cloud
- Control through smartphone.

The iPrognosis technologies by AUTH enable complimentary, remote, longitudinal monitoring of people with Parkinson's disease (PD) receiving pharmacological treatment and/or undergoing rehabilitation for motor symptoms. Information collected by the iPrognosis smartphone application and motor assessment tests can be used for evaluating the performance and optimising treatment **(P3-N02, P3-N03)**.

3.3.1 Smart home solutions

The Vimar View Wireless system is designed to manage lighting in environments, roller shutters or motorised curtains, and monitor energy consumption. The users can control and interact with many devices in their home with an app on the smartphone, through which it is also possible to create personalized scenarios. The installation is simple and does not require masonry, thus it is ideal for renovations or to boost the functions of an existing system. The possibility of interacting with different devices using exclusively a smartphone makes this solution a useful means of support for the elderly and people with restricted mobility.

3.3.2 Installation

The installation of the connected framework is easy and does not require invasive intervention. It is possible to create a connected system with recessed devices, suitable for any architectural context, thanks to the completely matching styling of the digital products and their easy functional expandability. The wiring of connected devices requires a power supply (L, N) and connection to the related loads and/or electro-mechanical control devices (2-way switches, 1-way switches, push buttons) to replicate control points or activate scenarios. The battery-free and wireless controls based on energy harvesting technology by EnOcean make it possible to add control points in complete freedom at any time. It is sufficient to substitute the traditional modules with the new connected version.

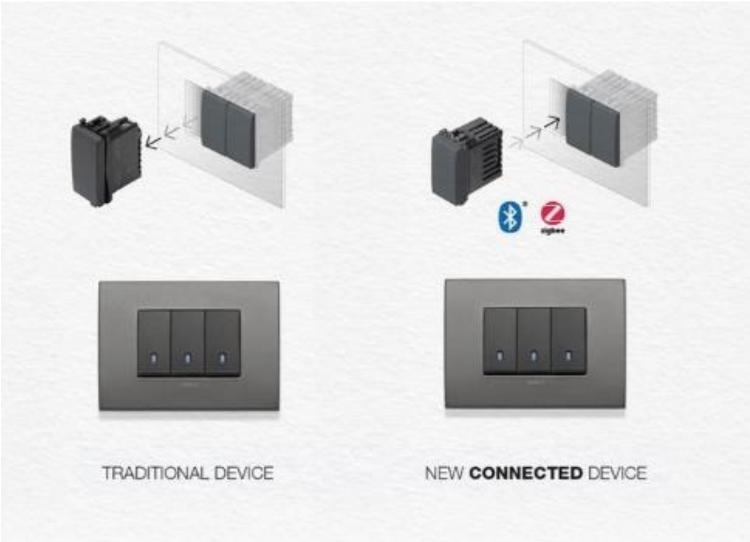


Figure 1: Example of connected devices compared with traditional ones.

A gateway module needs to be installed, it allows the connection and communication with the cloud.

Each device must be installed and configured through View Wireless App.

3.3.3 Network and Communication

The devices are pre-configured by default with the Bluetooth® technology 5.0 standard and this is the communication protocol that will be used for the Hosmartai installation. The devices can also operate with the Zigbee technology standard.

The Bluetooth technology standard is designed to use devices in a mesh network, in which the gateway (Bluetooth® and WiFi technology) is designed to control the system from the user View App both locally and remotely, and to control the system with voice assistants. The system is compatible with IFTTT, also integrating IFTTT compatible third-party devices.

The system is configured in Bluetooth Mesh technology mode and all the parameters are set via the configuration APP.

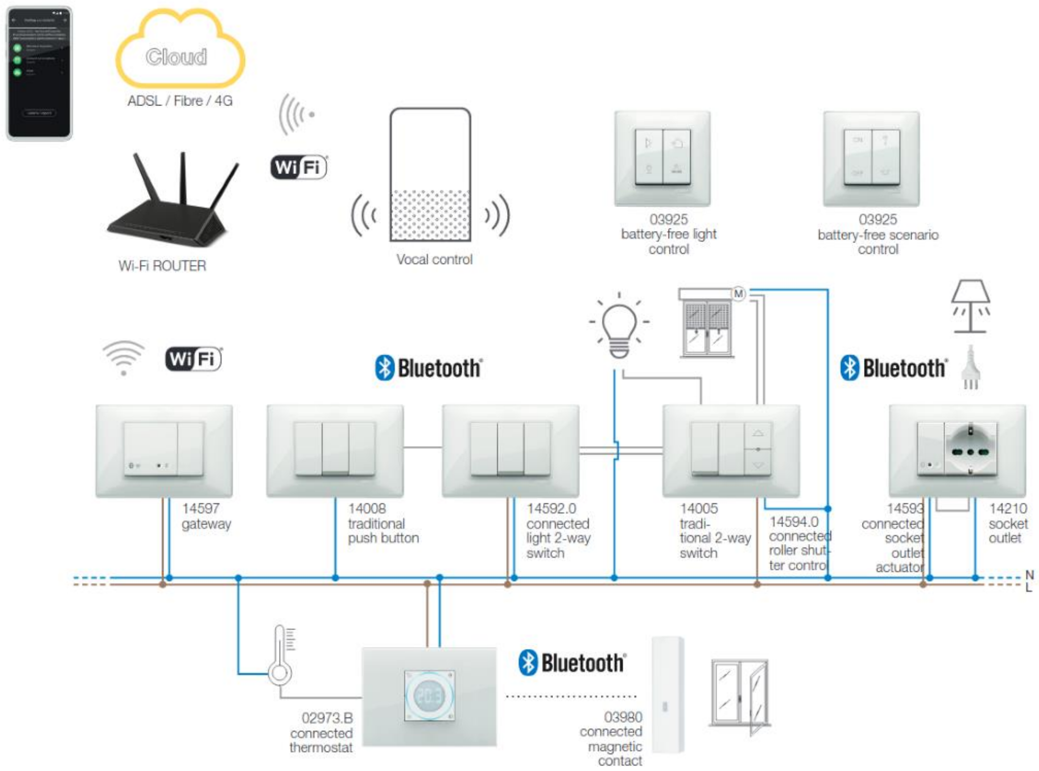


Figure 2: Architecture of the system.

3.3.4 App View and View Wireless

The connected environment can be managed and controlled through App View Wireless and App View, both available in main stores. The first is used by the installer to set up and configure the system. It allows the creation of environments and the association of all the devices with the respective environments. For every device (up to 64 devices can be connected), the installer can set the function, the parameters and any accessory devices. The gateway should be associated last since it will be storing all the information relating to the configuration of devices.

The installer, via the View Wireless App, delivers the configured system to the Administrator. The Administrator user, via the View App, can now manage the system functions and associate other users assigning rights and permissions. App View allows the user to:

- Customise up to 16 scenarios;
- Check the status of lights, roller shutters, or curtains and of the loads connected to the socket outlets;
- View the consumption throughout the home;
- Receive notifications if the contractual power level is exceeded;
- Integrate the app with the IFTTT platform to integrate with third-party connected devices;
- Check the presence and access of users.

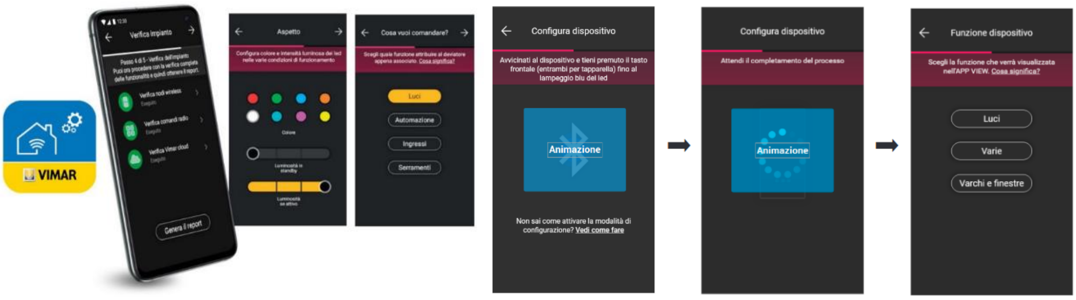


Figure 3: Examples of the VIMAR App.

3.3.5 Available Devices

Table 16: Catalog of available devices.

Type of device	Code	Description	Functions
Connected gateway 	20597 19597 16497 14597	Bluetooth technology Wi-Fi device designed to allow dialogue with wireless devices to permit the configuration, supervision, system diagnostics and its integration with voice assistants. Main device that manages the Bluetooth technology Mesh network. Via the View Wireless App it receives the system configuration through Bluetooth technology. The presence of Wi-Fi connectivity is required to allow the connection to the cloud for supervision and for integrations with the Alexa, Google Assistant and Siri voice assistants.	
Connected 2-way switch  	20592.0 19592 19592.0 16492 14592.0 14592 03981	The electronic switch mechanism connected is designed to operate a load via on-board push button, through a wireless connection and from a traditional remote push button. The device is equipped with 2 interlocked relay outputs to accomplish the switch function and a front key to control the connected load. It performs the automatic opening of the relay for thermal protection. Switching on zero crossing. The electronic switch can be connected to existing wired multi-way/two-way switches to make the load function “connected”.	• Toggle on/off • One-position stable activation time
Connected rolling shutter mechanism	20540 19594	The device makes it possible to control the roller shutter/slat using the on-board keys and via a wireless connection. It is equipped with mutually exclusive activation of the relays with a minimum	• Slat orientation • Roller shutter activation • Preferred position • Movement check • Scenario activation

Type of device	Code	Description	Functions
	19594.0 16494 14594 14594.0 03982	interlocking time. The front keys of the device control the on-board roller shutter actuator, starting or stopping the slat movement or the rotation. It allows also the recall of a favourite position.	• Status check
Connected actuator 	20593 19593 16493 14593	The actuator is equipped with a relay output with a current meter and a front push button with which to reset the load and perform configuration/reset. Its function is to protect against overcurrent by cutting off the load when the thresh-old value set via the View Wireless App is exceeded. Load reactivation, aside from the front push button, can also be done via the View App. The View App also makes it possible to View the instant power consumed.	• Load cut-off threshold function • Consumption threshold for load cut-off • Load status when the power supply is restored • Relay operation: two-position stable or one-position stable • One-position stable activation time
Monophase IoT energy meter 	02963	The device is designed to measure the consumption/production of instantaneous electricity and consumption logs with an hourly, daily, monthly and annual resolution. It should be connected to the single-phase line using the current probe provided. Only one meter for total consumption can be installed in a system.	• Energy consumption/production • Monitoring of instant power consumption/ production • Monitoring of instant energy consumption/ production
NFC/RFID smart card landing reader 	19462 20462 14462	Access control is achieved with the combined usage of NFC/RFID smart card landing reader and NFC/RFID smart card reader pocket, both controlled and configured by using View Wireless App. The smart card landing reader device is designed to be installed outdoors and near an entrance and it grants access only if the smart card associated with it is read and recognised.	• Recognition of the smart card (that triggers the door opening) • Anomaly detection on the reader • Do Not Disturb signalling • “Crossover relay” option for combined operation with card reader pocket
NFC/RFID smart card reader pocket 	19467 20467 14467	NFC/RFID smart card reader pocket allows the activation of utilities only if the wireless smart card associated with it is read and recognised. The two devices are designed to communicate (if associated during configuration) to manage accesses to the same room and ensure greater safety via the “Crossover relay” option.	• Recognition of the smart card (with toggle off if card removed) • “Crossover relay” option for combined operation with card landing reader

Type of device	Code	Description	Functions
Ultra Wide Band (UWB) 	Not yet commercialized	This sensor can detect human movement/presence without using Fresnel lens. It employs a military-based radar UWB technology capable of detecting centimetres wide human movements. It has been conceived a recessed version and one to be installed in the ceiling.	• People Presence/absence • Micro movements detection/Breath detection • Load activation • Area/volume of detection parametrization

The devices will be used to transfer the hospital monitoring capabilities to patients' homes (**P3-N04**). A first installation will be used to set a replication of a real domestic environment that patients will face after dismissions from the hospital. The medical staff will be able to detect potentials issues that the patients could be facing at home. Furthermore, these new sensors can be installed in patients' homes, enhancing the monitoring capability and the consequent increase in adherence to the therapies.

3.3.6 Available Data

Table 17: Data generated per device.

Device	Dynamic Data on Cloud
Connected 2-way switch	• Actual load status
Connected rolling shutter mechanism	• Generic level status
Connected actuator	• Actual load status • Continuous Active power • Continuous Active energy
Monophase IoT energy meter	• Continuous Active power • Continuous Active consumption energy • Continuous Active production energy
NFC/RFID smart card landing reader	• Smart card recognition
NFC/RFID smart card reader pocket	• Smart card recognition
Ultra Wide Band (UWB)	• Status of Presence/Absence

All the available data will be stored on IRCCS Cloud. The information will be merged and pre-processed, then AI algorithms will be applied by VIMAR to detect possible unsafe behaviours of patients and to optimize hospital resources allocation (**P3-N01**). We will manage and analyse the data with Pandas and Matplotlib Python libraries. Then we will test through cross-validation several Machine Learning and Deep Learning algorithms from Scikit-learn, TensorFlow, Keras and PyTorch libraries. These well-known libraries are widespread, and they can be easily integrated into the framework.

3.3.7 iPrognosis Technologies

The candidate technologies are the iPrognosis application and the iPrognosis Motor Assessment Tests (iMAT), developed by AUTH. Both technologies constitute results of the Horizon 2020 project i-PROGNOSIS (i-prognosis.eu) and are intended for detecting and/or assessing the severity of Parkinson's disease (PD) symptoms. Although none of the technologies has been certified yet, scientific evidence providing a proof of concept have been published. A short description of both technologies follows.

3.3.7.1 iPrognosis application

iPrognosis is a digital phenotyping mobile application intended for detecting and/or assessing PD symptoms. The application collects data passively from smartphone sensors during the natural interaction of users with their device and converts them to digital biomarkers, via Cloud-based machine learning (ML) models. iPrognosis produces the following biomarkers:

- A bradykinesia and a rigidity severity score (in the range of 1 to 4) based on keystroke dynamics data collected during natural typing with the iPrognosis custom virtual keyboard [REF-70], [REF-71], [REF-72]. Keystroke dynamics refer to the timing information associated with key taps; characters typed are never recorded.
- Whether or not tremor is detected in motion data captured while users hold their device during a phone call (postural tremor) [REF-73]. Motion data refer to inertial measurement unit (IMU) data (accelerometer and gyroscope).
- Whether the user has PD or not based on voice spectral and time-domain features extracted from natural speech during phone calls [REF-74]. Speech impairment is a common PD motor symptom. Voice recordings correspond to the first 75 s of the phone call and are processed locally on the device.

The iPrognosis application is available for Android and iOS devices. In the case of iOS, only the typing-based bradykinesia and rigidity score estimation is available due to restrictions imposed by the operating system. The aforementioned ML models were trained and tested on data provided by people with early-stage PD (Hoehn and Yahr stage 1-2).

3.3.7.2 iPrognosis Motor Assessment Tests (iMAT)

iMAT is a series of tests exploiting human pose estimation technology to assess the motor capacity of people with Parkinson's disease (PwP) [REF-75]. Standing in front of a 3D camera (Orbbec Persee), users perform a series of movements displayed on video by an expert. Movements displayed are similar to those performed during clinical assessment of the patient based on standardized scales such as the Unified Parkinson's Disease Rating Scale Part. At the end of each test, a score is produced reflecting the similarity of the movement performed by the user with the one performed by the expert.

3.4 Tools for Surgical Support

Leader: ETHZ

ETHZ has developed multiple robotic systems to steer catheters and endoscopes with an external magnetic field [REF-67]. Those robotic systems can be installed in an electrophysiologist lab and would be able to steer ablation catheter to a target location [REF-68]. Furthermore, algorithm have been developed to navigate catheter to a target location [REF-69]. This covers the need (**P4-N01**).

91 provide the following background to cover the need (**P4-N02**) a **Data Management Solution** for the aggregation, categorization, restructuring, and pivoting Big Data with multiple variables and dimensions in real-time variables and characteristics, **AI models** (NOVA) that captures large data sets with multiple factors and orthogonalizes and cluster into unique sets with key, defining properties and features, and **a SaaS platform** that uses AI to automate the collection, digitization, structuring, and normalization of data from multiple sources, and present them in a unified, user-friendly UI, integratable via API to other systems.

The need **P4-N03** is not covered by the background and is one of the key developments in the scope of HosmartAI for ETHZ and 91.

PHILPS in collaboration with VUB will address, as explained later in this section, the following needs:

- Real-time clinical decision support (**P7-N01**)
- Automatic reporting (**P7-N02**)

PHILIPS is working on AI-enabled software applications that will benefit Percutaneous Coronary Interventions (PCI) procedures performed in the CathLab in two areas: 1) Clinical support, 2) Operational efficiency and workflow. Prototypes of these applications are available to start first evaluations, but further development of the algorithms and associated clinical data will be required to mature the applications and will be performed in the context of the HosmartAI project.

3.4.1 Clinical support

With respect to clinical support, we focus on an AI approach to stenosis segmentation in coronary vessels. The accurate segmentation of the vessel outlines is needed in quantitatively characterizing the degree of stenosis, selecting the appropriate diameter and length of coronary stents to treat such stenosis and examine the final result after coronary stent implantation. This is important as recurrent symptoms and complications after Percutaneous Coronary Intervention (PCI) are often related to inadequate sizing and deployment of stents, leading to under-expansion and/or mal-apposition. [REF-67],[REF-68], [REF-69], [REF-70], [REF-71].

Novel segmentation and reconstruction models are based on state-of-the-art machine learning approaches; they consider multiple views, acquired with a shift either in time, space, or both. Despite these models commonly outperform traditional approaches in segmentation and reconstruction tasks, they are totally or partially based on learning from data, making them prone to poor generalization and susceptibility to domain shifts. This black-box nature makes model development inefficient and mainly based on a trial-and-error approach. For a guided development effective technique to fully understand the internal workings of the model are missing. In turn, this makes the interpretation of the results difficult and potentially misleading. Visual analytics techniques that support the understanding, interpretation and presentation of the models and results will be an essential component to provide the effective development and deployment of machine learning models in the segmentation and reconstruction domain. New visual analytics strategies can provide the necessary insight into the models and may, therefore, become a key enabler for the development and acceptance of accurate coronary segmentation.

Figure 4: Example impression of stenosis segmentation in coronary vessels.

3.4.2 Operational efficiency and workflow

For operational efficiency, we target automation of the case reporting through AI. The tool developed in this activity aims to automate the patient case report form and automatically generate information to support the clinical and administrative workflow. The administrative burden on clinical staff is a known issue, and tasks clinical staff with workload that does not necessarily form their primary objective. The aim of this pilot is to reduce the administrative load by automating through the application of artificial intelligence and big data techniques. Specifically, in this work we will jointly identify the elements in the reporting that can be automated, and deduce as much of this information from the data-rich CathLab environment. Examples are stenosis characterization, vessel branch labelling including stenosis and stent localization, automatic selection of images for the report, etc.

Figure 5: Example impression of automated case reporting.

3.5 Tools for Assistive Care

Leader: UM

Currently the use of Socially Assistive Robots (SAR) and virtual coach systems, despite being considered as enablers of continuum of care, the paradigm to support the process of caregiving or keeping elderly at home longer, is limited. The field of human-robot interaction (HRI), while developing quickly, has yet to reach the maturity where a robot is capable of observing and interpreting human intentions expressed through facial expressions, body language and speech. One of the main challenges is represented by the integration of robots in hospital/institutional/home settings and the balance between safety, actual benefits and ethical, legal considerations. The scope and the specificity of the real-life operational environments is highlighted in Section 2, Pilot #5 addressing the placement of a *''robotic nurse''* placed in the clinical care workflow in a hospital ward, and Section 2, Pilot #6 addressing the placement of a ''virtual assistant'' placed in the care workflow of elderly, and Section #2 addressing the placement of a chatbot as a tool to contribute with more efficient patient flow and patient-data collection in relation to radiotherapy.

In the following subsections technologies and artificial intelligence to answer specific requirements of Pilots #2, Pilots #5 and Pilot #6 will be highlighted.

3.5.1 Digital tools to support requirements of the in-hospital care setting (Pilot #5, Pilot #2)

In this setting a robotic unit is placed in the hospital ward to serve as: i) an assistant to clinicians (collect patient-gathered-health-data (PGHD) and reported outcomes (PROs), integrate it with electronic health records (EHR) and efficiently represent them during ground rounds) and ii) a socially aware systems capable to engage with patients in domain restricted discourse.

3.5.1.1 Socially aware Robotic system – Pepper

Pepper [REF-32] is an autonomous humanoid robot designed by Aldebaran Robotics, and released in 2015 by SoftBank Robotics (SoftBank acquired Aldebaran Robotics in 2015). Since 2016, the robots are available in Europe [REF-33]. Main target market as well as the most natural use case for Pepper is interaction with human. Its height and physical proportions and dimensions make it appear similar to a human being. Although the Pepper robot is a relatively new construction, it already proved to be successful in various areas of application. Its main role is engaging people ([REF-34], [REF-35]) even in clinical settings ([REF-36], [REF-37], [REF-38]).

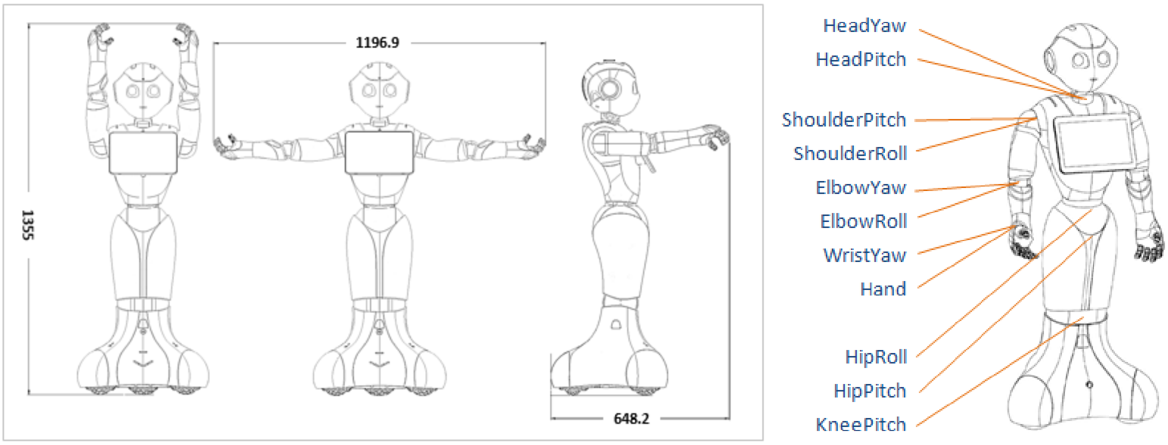


Figure 6: Pepper's size and Motors located on Pepper's body allow delivery of a wide variety of conversational behaviour.

To respond to specific Pilot #5 requirements (**i.e., P5-N02, P5-N03, P5-N05, , P5-N08, P5-N09, P5-N11 and P5-N12**) UM will integrate Pepper with its proprietary Conversational intelligence and Dialog Framework [REF-39]; the built-in user interaction mechanism will be extended by partially redirecting them to a proprietary network. The relevant technologies will be outlined in the following subsections.

3.5.1.1.1 SLAM algorithms to support safe autonomous movement

Paepper's ALNavigation API [REF-40] allows the user to perform safe displacements when using the robot domain and scenarios of discourse. The baseline includes obstacle avoidance, safe trajectory execution and finding free space (to perform a show for example). While moving, the robot tries to detect obstacles in its move direction, using all its sensors.

However, the baseline navigation implementation has several limitations when applied to real-life purposes. For instance, the built-in function learn-home requires the environment to be less than 2m^2 [REF-41]. Moreover, in contrast to custom robots which generally rely on expensive LIDARs for metric localization and navigation, which work in both indoor and outdoor environments, Pepper has short-range LIDARs and an RGB-D camera that provide reliable localization only in small indoor rooms, being unable to provide useful information to localize the robot in large environments [REF-42]. This represents a big restriction for integrating Pepper into highly diverse and dynamical public spaces such as hospitals.

To address this issue and the requirements **P5-N01, P5-N08 and P5-N09,** UM will extend the baseline navigation system with a Simultaneous Localization and Mapping (SLAM) to create a hybrid visual SLAM. SLAM is the field of intensive research for more than two decades. In a service robot scenario, we are particularly interested in the task of building maps of the environment that include automatically recognized objects. Most systems for simultaneous localization and mapping (SLAM) build maps that are only used for localizing the robot. In Pilot #5 the robot Pepper is equipped with a 2 RGB cameras and a Stereo Camera at the forehead and a reconstructed 3D Depth sensor. Therefore, Visual SLAM algorithms are of great interest [REF-43][REF-44][REF-45][REF-46]. Since Pepper also supports interface with ROS diagnostics stack [REF-47] we will consider to integrate model-based diagnosis and repair approach [REF-48].

3.5.1.1.2 Algorithms for Proactive planning, collaboration and optimization of the robots' workload

GC will provide proactive planning, collaboration and optimization of the robots' workload. GC's AI solution will consist in algorithms enabling mobile IoT devices (robotic, sensors, terminal) to interact together and with users and facility for smooth integration of the robots in its environment, resilient and secure data collection and transfer, and collaboration. The task will consider the use of mobile mesh networking for the connectivity of robotics and sensors, the use of the robot SDK for intelligent navigation inside the hospital according to given metrics, edge computing for fast and secure data processing and distributed algorithms for fleet management.

GC will build on its expertise in wireless networking and distributed systems. The company will use its technology Green PI, an open communication platform [REF-77] with edge cloud and services, to provide the communication infrastructure among robots with distributed edge cloud environment. The company commercializes Green PI since 2010 for the Internet of Moving things, massive IoT and IoT in constrained environments. Green PI is the result of 20 years of research and development and a technology transfers from top French universities and the CNRS. Green PI products have gained the trust of leading organizations across Public Safety, Defense, Energy, Transports, and Public Internet sectors. The technology is protected by patents on routing and energy savings. Interested readers can refer to the following publications: [REF-93], [REF-94], [REF-95], [REF-96] and [REF-97]. The following is the list of patents registered by GC:

- Khaldoun Al Agha, Nicolas Cavallari, Thomas Claveirole and Ignacy Gawedzki, _Distributed system and method for sharing capacity in an ad hoc network. FR-INPI 1359228, US20150085702 A1, EP2854467A1, 2013.
- Khaldoun Al Agha, _Method for extending routers in a communications network and router implementing this method. FR-INPI 09 58890 - EP2727403A1, US20140293805, WO2013000996 A1, 2011.
- Ignacy Gawedzki and Khaldoun Al Agha, _Method for the qualitative routing in a multi-hop communication network, and network node management facility. FR-INPI 09 58 890, EP2510656A1, US20120257545, WO2011070304 A1, 2009.
- Ignacy Gawedzki, Khaldoun Al Agha and Laurent Reynaud, _Protocole de routage ad hoc résistant aux nœuds égoïstes. FR-INPI 06 52963, WO2008078016 A1, PCT/FR2007/051650, 2006.

GC will use its background knowledge on SLAM and AI for drone swarming to create a solution adapted to ground robots evolving in the healthcare facility environment. GC already connects drones to work together in groups for public safety applications. We provide embedded software in order that drones could collaborate and provide autonomous positioning in the air for optimizing their mission. GC's solution enables real-time video streaming relayed from drone to drone to reach the command center.

Finally, this is the list of awards:

- Laureate of the "Game of Drones" challenge and showcased at Viva Technology 2016 show: https://www.green-communications.fr/wp-content/uploads/2016/11/VivatechDronesLesEchos.png
- Second innovation price at SOFIN 2017 (Special Operations Forces Innovation Network Seminar): https://cercledelarbalete.org/startups-sofins-2017/
- Admitted to the National Competition of Outdoor Robotics 2017 organized by the ONERA and the French Ministry of Economy.
- Laureate of the "Assistance to emergency helicopter landing" challenge organized by Cisco at Viva Technology 2017.

3.5.1.1.3 Multimodal sensing and monitoring network

The conceptual network is designed as an enabler for collection and integration of PGHD (**P5-N04, P5-N06**) and PROs (**P5-N03**) as an enrichment of existing clinical data (**P5-N01, P5-N02**). It is built around conversational intelligence enriched with an embodied conversational agent as the tool for data collection and connecting the patient and the patient's care team. In HosmartAI we collect two types of digital biomarkers, objective and subjective. Under the umbrella of objective biomarkers, we consider: i) physical biomarkers collected medical grade telemonitoring platforms measuring and blood pressure, heart rate, ii) speech related and acoustic biomarkers, face related and language related features expressed during interaction and classification of symptoms of psychological distress (depression). Under the umbrella of subjective biomarkers, the chatbot will deliver PROs in order to gather self-reported patient data by adopting strategies of gathering information patients' health in a digital manner, e.g., electronic questionnaires (e.g., Brandtzaeg & Følstad 2018 [REF-49]; Te Pas et al. 2020 [REF-50]). By combining objective and subjective biomarkers we will deliver software sensors directly exploiting the gathered data to track patient's mood and even identify symptoms of distress (e.g., symptoms of depression).

In Pilot #5 we will focus particularly on Speech features will include: Prosodic Features (e.g., intonation, rhythm), spectral features (e.g., Mel Frequency Cepstral Coefficients) and Voice Quality Features (e.g., jitter and shimmer) to classify emotions from speech. These acoustic features represent the more revenant markers of psychological distress [REF-52]. These sensors will be delivered by considering the following libraries and frameworks (preliminary tested as part of UM's Research Activities [REF-53]): openSMILE, auDeep, LibRosa and Speech Emotion Analyzer.

To extract facial features, FACS (Facial Action Coding System) will be considered, where all facial emotions are considered and described by the contraction of facial muscles being considered as AUs (Action Units) [REF-54] [REF-55]. **Facial Action Coding System** (FACS) describes the correspondence between facial muscle movements and expressions through observations and biofeedback. To deliver these sensors the following libraries and frameworks (preliminary tested as part of UM's Research Activities [REF-53]): OpenFace, OpenPose.

The text features that will be considered to be exploited will be those to enable emotion classification and detection of symptoms of psychological distress from text [REF-74][REF-75]. Among the more relevant are **Sytle features** (e.g. direct speech, punctuation, morphology, etc.), **Syntactic features** (e.g. distribution of n-Grams, POS frequencies, lemmas, etc.) and **Emotion lexicon features** (e.g. ration positive/negative words, minimum and sum of emotion scores, emotion intensity, etc.) To deliver these sensors the following libraries and frameworks (preliminary tested as part of UM's Research Activities [REF-53]): Stanza, ReLDIanno, CLASSLA and Spacy.

3.5.1.1.4 Visual sensing and action recognition

Robots in the field of action recognition by images are really extended due to the wide application in different fields. Different methods have been used for years, but nowadays the best results are obtained by using deep learning, particularly LSTM' (Long Short-Term Memory) and CNN (Convolutional Neural Network) networks are very commonly used, for example, in healthcare applications and also transport like in [REF-30], where they use a simulation data for human action recognition.

The action recognition can be separated into different stages. Firstly, it is necessary to determine where the user is inside the image and extracting the corresponding crop of the image. These areas of the images are known as ROIs (Region of Interest). Secondly, one key feature in order to determine the action that is been done by the user is obtain information of their posture, i.e estimate where are located different parts of the body (mainly joints), such as: Head, shoulders, elbows, hands, etc. [REF-31].

A temporal integration of the posture information allows to perform an action recognition by means of recurrent neural networking.

This system can recognize different actions such as: calling for help moving the arms, taking medications or people falling to the ground and can be an interacting method for the users with the robot. The action recognition system reduces the problem of low digital skills (**P5-N11**) and can mitigate the boredom and loneliness of the users promoting supervised healthy activities (**P5-N10**, **P5-N12**).

Figure 7: Posture estimation in two different environments: Office left, Factory right.

3.5.1.1.5 Speech recognition to support spoken language interaction

In order to mitigate expected low digitals skills of the participants (**P5-N11, P2-N05**) and to extend the practically of use and enable the patients to easily engage with the robotic units (**P5-N02, P5-N03**) a hybrid speech-touch interfaces will be designed. Speech also represents the most efficient modality to deploy services (**P5-N09**) and positively impacts patient adherence/compliance [REF-58] (**P5-N05**).

To support Slovenian (Pilot #5) and French (Pilot #2) language, we will deploy the UM's proprietary automatic speech recognition (ASR) System SPREAD [REF-59]. In piltos #5 and #2 we focus on end-to-end connectionist temporal classification- (CTC-) based models (like original DeepSpeech model). CTC allows finding an alignment between audio and text. The CTC model can be used in both conventional and E2E ASR systems [REF-60].

3.5.1.1.6 Speech Synthesis to support spoken language interaction

Speech Synthesis or Text-to-Speech is the task of artificially producing human speech from a raw transcript. To enable efficient and coherent spoken language interface, offer speech as both input and output modality (e.g., requirements **P5-N11, P2-N05**) UM's proprietary speech synthesis system [REF-61] will be delivered to support Slovenian (Pilot #5) and French (Pilot #2) language. The figure below outlines the general pipeline. This TTS architecture is developed for real-time or close to real-time system. This text-to-speech (TTS) system is a combination of two neural network models:

- a modified Tacotron 2 model,
- a flow-based neural network model – WaveGlow.

For inference of TTS engine, we will consider NVIDIA Triton Inference server. NVIDIA® Triton Inference Server (formerly NVIDIA TensorRT Inference Server).

3.5.1.1.7 Conversational intelligence and chatbots to engage with patients and support data collection

In order to engage with patients (**P5-N12, P2-N05**) collect patient gathered health data and experiences (PROs) (**P5-N03**) and to provide the baseline for the risk assessment and detection of frailty or signals of psychological distress (**P5-N04**) and to improve patient experience and compliance [REF-62] (**P5-N05**). In order to deliver the functionally, UM will deploy RASA NLU [REF-63] as an open-source conversational intelligence; machine learning framework to automate text-and voice-based conversations. Rasa enables the delivery of contextual assistants capable of having layered conversations with lots of back-and-forth. With Stories and Policies in Rasa NLU enables to define the specific dialogue management modes and restrict interaction and responses (**P5-N10, P5-N12, P2-N05**). The responses generated by the RASA NLU are text. To use the non-verbal (i.e., gestures) modality and speech in Pilot #5, the textual sequences must be transformed into natural responses. In Pilot #5 UM's EVA framework [REF-64] will be exploited. In Pilot #5 we will deliver a novel kinematic model capable to execute gestures intended for conversational agents on the robotic units. Following UM's proprietary algorithm [REF-65] we will assume the dynamics are addressed mostly by the relation between the temporal distribution of the co-verbal expression (movement-phases) and the spatial configuration of the shapes. Virtual movement can be specified as almost instantaneous, whereas the movement controllers of the robotic unit require longer temporal periods. The responsiveness of the servomotors (the robot's physical movement controllers) is defined by the motors' maximum angular velocities and by their maximum angular acceleration. An example is outlined in the following figure:

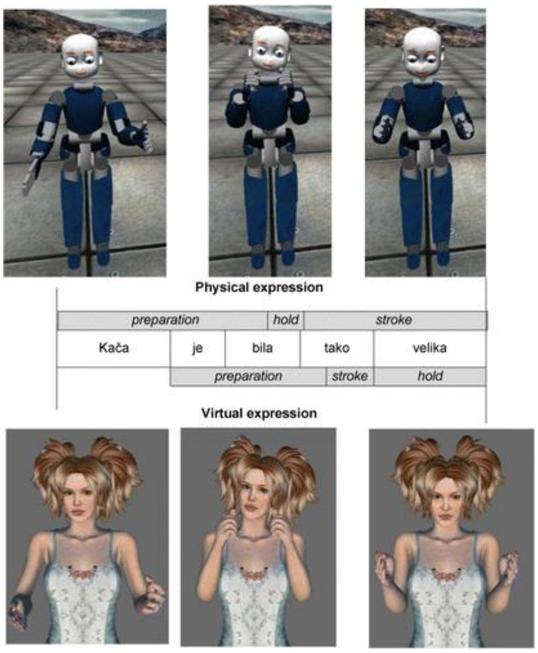


Figure 8: Recreating communicative acts by a Robot (iCub simulator) and embodied Conversational Agent.

3.5.1.1.8 Telemonitoring system to collect patient gathered health data

There are several telemonitoring systems available. In order to address **P5-NO1, P5-NO2 and P5-NO7** UKCM reserved a budget to purchase a commercial grade solution with certification, reliable measurements and with non-invasive calibration. In Past UKCM already evaluated the esCCO measurement system (Nihon Kohden®, Tokyo, Japan)[REF-66].

3.5.2 Digital tools to support requirements of the nursing setting (Pilot #6)

In alignment with the needs and challenges found so far in the previous chapter of this document, the following issues must be covered, assuming all the dialogs and messages are in the mother tongue of the Pilot 6's country:

- Empathic framework (robot – emotional detection)
- Movement detection (robot)
- Chatbot
- Real life-monitoring solutions.
- Activity plan editor.
- e-Pokratis system.
- AI and Big Data diagnosis support system.
- Networking and cloud technologies.
- Gradior cognitive.

3.5.2.1 Real life-monitoring solutions

A real-life monitoring solution by AUTH, namely i-PROGNOSIS, for remote extraction of behavioural characteristics and early symptoms detection and assessment. More specifically, a smartphone and a smartwatch application along with cloud-based machine-learning models passively collect sensorial data and detect/assess symptoms related to

- fine motor impairment (via touchscreen typing patterns),
- voice degradation (via voice analysis during phone calls),
- hand tremor (via smartphone and
- smartwatch IMU data analysis),
- sleep quality (via smartwatch data analysis) and
- in-meal eating behaviour (via IMU smartwatch data analysis).

Additionally, location data are used to extract patterns of daily walking capacity and mobility-related indices towards the detection of behavioural change of lifestyle-related parameters. The real life-monitoring solutions would be provided by iPrognosis Technologies (**see section 3.3.7**).

3.5.2.2 Activity plan editor

Activity plan editor is a coach-feature addressed to care professionals, for creating reminders, recommendations and other training resources in an efficient and user-friendly fashion. This task will be developed in cooperation by AUTH and INTRAS.

3.5.2.3 E-Polratis system

TMA's E-pokratis acts as Patient Health Record system. It consists of a server system where the doctors and the patients have access to all medical data and patient health records, while it also allows for real time video consulting. The patient using the e-pokratis mobile application and a set of medical Bluetooth-enabled devices can send vital measurements such as ECG, blood pressure, oxygen saturation, temperature as medical reports straight to e-pokratis server. The patient can request from the mobile app using VoIP a remote consulting with a doctor.

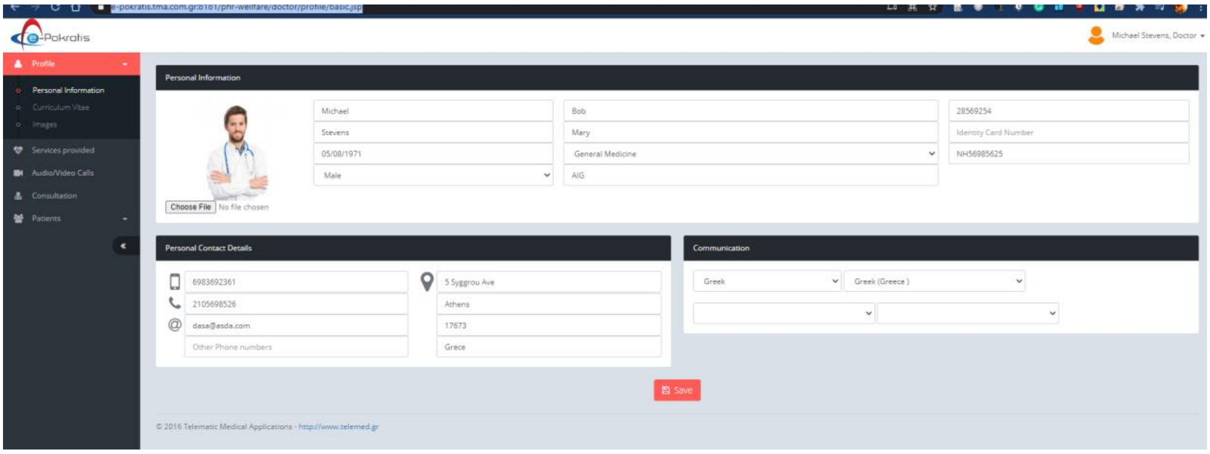


Figure 9: E-pokratis screenshot from the doctor's account.

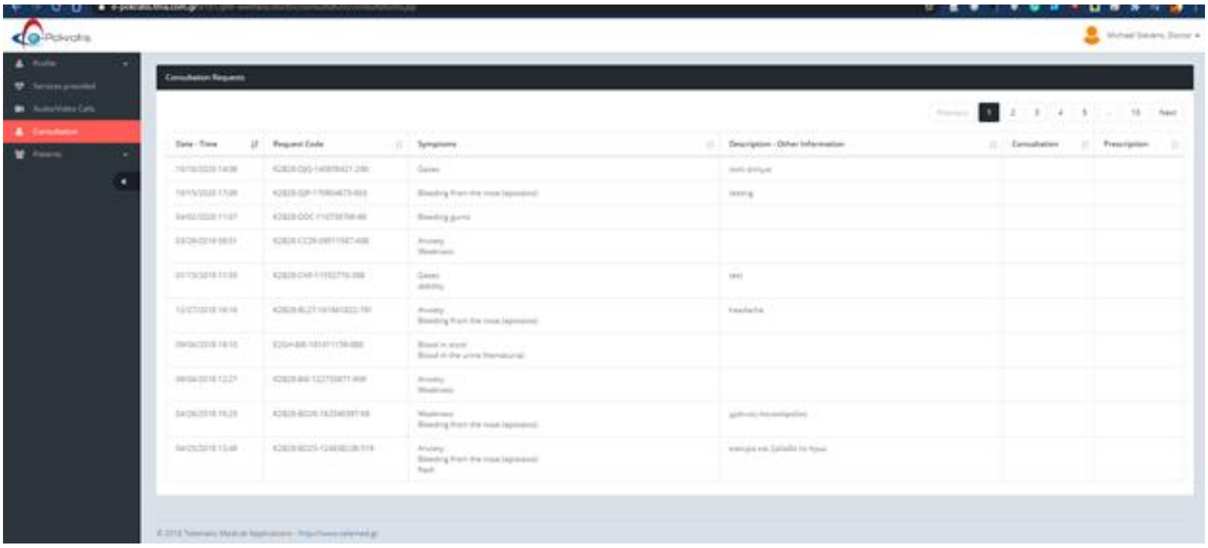


Figure 10: Screenshot of E-pokratis showing the past cases for a doctor.

As far as the mobile app is concerned, the indicative screenshots are the following:

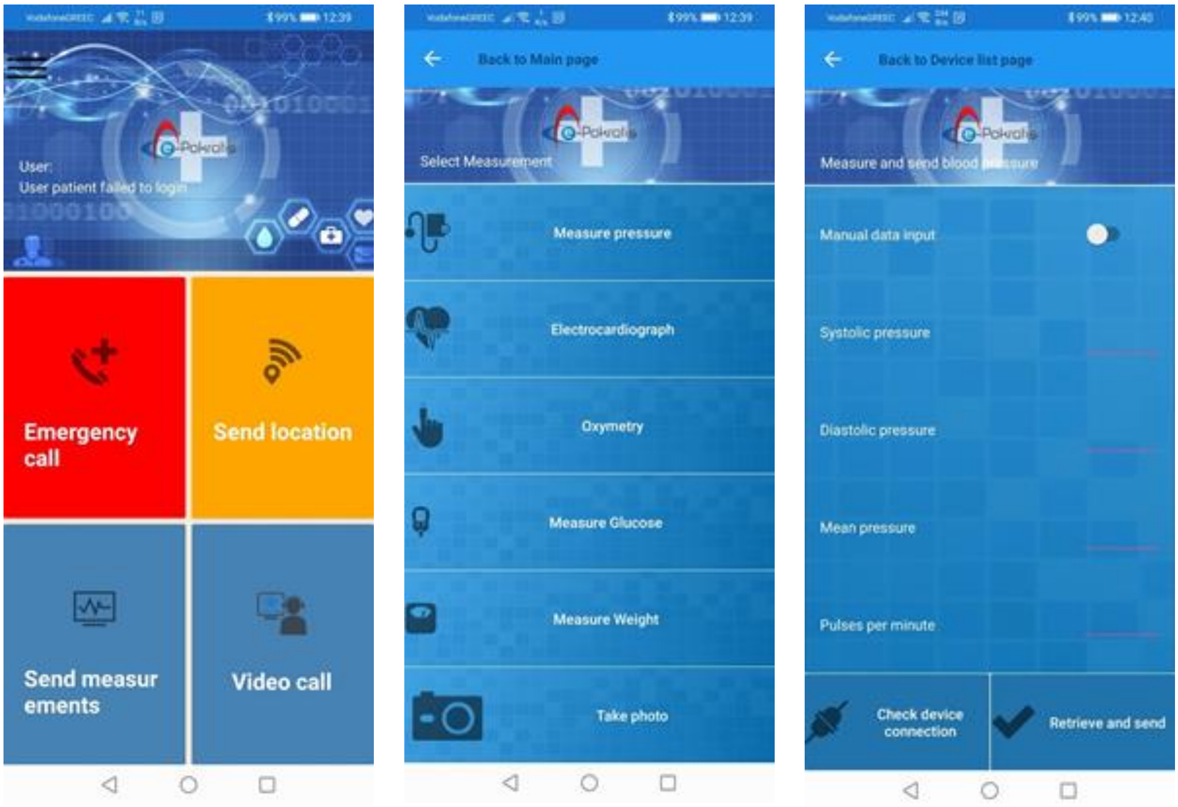


Figure 11: Main screenshots from the smartphone App.

The mobile app can also send the current location of the user using both SMS and e-mail while it can make an emergency call to predefined numbers. Depending on whether the mobile device is connected to the Internet, the phone call will be automatically placed either via VoIP or GSM.

3.5.2.4 AI and Big Data diagnosis support system

AI and Big Data processing system for efficient medical assistance, diagnosis and treatment prescription, both for dependant and non-dependant individuals. This system analyses and processes data provided by third party medical sensors and eHealth systems and databases to provide the physicians with reliable data on the patient's evolution and condition trends. The Big Data backend allows the data to be stored, pre-processed, analysed, and classified to render the AI outputs reliable. The system provides medical practitioners with guidance and decision-making tools that can be integrated with third party eHealth systems and make use of the implemented AI algorithms to provide support in diagnosis and early condition diagnosis (by using pattern trend anomaly detection algorithms), lifestyle and prescription adaptation, medication control, etc.

ITCL has experience in the analysis of time series in order to detect abnormal behaviour patterns and to predict possible episodes of apnea, stroke and epilepsy [REF-19], [REF-20], [REF-21], [REF-22], [REF-23], [REF-24], [REF-25], [REF-26]. On the other hand, they have also been used in time series microarrays for gene behaviour clusters [REF-27], [REF-28], [REF-29]. With this experience we could support the following needs: **“Support professional decision-making with “live information” and automatic reporting”** and “**Facilitate the detection of**

risk of frailty or signals of decline" (P6-N07, P6-N11). For these needs, it is necessary to make use of well-proven architectures, such as NARX models or ConvLSTM networks. For the need **P6-N07**, ITCL will develop the algorithms with the data obtained by TMA.

3.5.2.5 Networking and cloud technologies enabling data interchange interfaces

GC will provide Networking and cloud technologies that enable data interchange interfaces, data processing and systems communications and interoperability in care facility and at home.

GC's solution will consist in developing an edge-based Internet and Cloud solution to connect users and sensors and provide digital services in both care centres and in homes of older people. The objective is to create a modular infrastructure adaptable to the different life settings (**P6-N03**), easy to administrate with low digital skills (**P6-N04**), interoperable with robotic nurses developed under Pilot #5 and that give access to digital services (edge-based or cloud-based) that may be developed by other partners to fulfill the needs of **P6-N06** to **P6-N19**.

GC will build on its expertise on wireless networking and edge computing. The SME will use its technology Green PI, a plug&play Internet and edge cloud platform [REF-77], to provide the communication infrastructure with access digital services in care facilities and at home. The company commercializes Green PI products since 2010 for IoT and public Internet applications. Green PI is the result of 20 years of research and development and a technology transfers from top French universities and the CNRS. The technology is protected by patents on routing and energy savings.

The company will use its background in decentralized Internet infrastructures to extend the above described solution to multiple sites (edges) including homes. For a white paper, please refer to [REF-78]. The following is the list of related patents obtained by GC:

- Khaldoun Al Agha, Nicolas Cavallari, Thomas Claveirole and Ignacy Gawedzki, Distributed system and method for sharing capacity in an ad hoc network. FR-INPI 1359228, US20150085702 A1, EP2854467A1, 2013.
- Khaldoun Al Agha, Method for extending routers in a communications network and router implementing this method. FR-INPI 09 58890 - EP2727403A1, US20140293805, WO2013000996 A1, 2011.
- Ignacy Gawedzki and Khaldoun Al Agha, Method for the qualitative routing in a multi-hop communication network, and network node management facility. FR-INPI 09 58 890, EP2510656A1, US20120257545, WO2011070304 A1, 2009.
- Ignacy Gawedzki, Khaldoun Al Agha and Laurent Reynaud, Protocole de routage ad hoc résistant aux nœuds égoïstes. FR-INPI 06 52963, WO2008078016 A1, PCT/FR2007/051650, 2006.

3.5.2.6 Gradior Cognitive app

Integration of Gradior Cognitive app for cognitive stimulation by INTRAS, neuropsychological assessment and rehabilitation for professionals supporting patients suffering from mental illness, neuro-degenerative diseases or elderly people with memory complaints. GRADIOR facilitates professional monitoring of results and the adaptation of patient sessions. GRADIOR can remotely assess neuropsychology problems and allow the professional to tailor interventions to the specific cognitive difficulties (attention, perception, language, reasoning and memory) of the person with MCI and early-dementia along with other conditions such as brain damage.

INTRAS Foundation has more than 25 years of experience in the mental health and wellbeing field, with an extensive R&D activity in neuropsychological rehabilitation, and considering comprehensive approaches (cognitive, functional, social, and emotional). INTRAS will integrate Gradior Cognitive app in pilot 6. It is a neuropsychological evaluation, stimulation and rehabilitation system for a comprehensive approach to cognitive function (**P6-N02**), offering training and recovery programs of higher cognitive functions in people with cognitive deficits and/or impairment [REF-86]. It allows working in adults Attention, Perception, Memory, Orientation, Calculation, Executive Function, Language and Reasoning, making it easier the detection of risk of frailty or signals of decline (**P6-N07**).

Conceived as a support system for the therapist (**P6-N18**), it is aimed at people with brain damage, head injuries, dementias, mild cognitive impairment, and neuropsychiatric disorders (brain, mental illness or other pathology where cognitive function is affected)[REF-87], and used as a preventive approach in non-pathological aging and subjective memory complaints (**P6-N09**).

GRADIOR is based on a solid scientific foundation built over more than 20 years, during which advances in technology, neuropsychology and daily clinical practice have been integrated, attending to the needs and end-use preferences. More than 35 national and international publications endorse the effectiveness and clinical viability of GRADIOR's treatments and contents [REF-88] and the value of the system as a whole in terms of RDi, which has been recognized by the different ministries of science, technology and industry of the last two decades.

GRADIOR constitutes a system of high benefit, developed and recognized in the more than 40 RDi projects carried out within the framework of the main scientific-technical excellence programs at the national and European level. Gradior Cognitive is currently used in INTRAS rehabilitation centers, and in more than 500 external pilot care centers (https://www.gradior.es/sobre-nosotros/).

3.5.2.6.1 Simple and individualized planning

The exercises, designed following the GRADIOR methodology, allow to work according to the principles of cognitive effort and neural footprint, which are crucial for an effective cognitive intervention. The novelty and variety in the activities and stimuli presented avoids the "learning effect" and the different levels allow it to be adapted to each user.

It offers different possibilities to the therapist for planning interventions individually, from manual planning of the intervention with a very intuitive interface to the possibility of starting from a standard treatment personalizing it according to the user evolution throughout the sessions or the use of the so-called “performance level. Based on standard evaluations, it determines the cognitive and functional capacity of the user, proposing an individualized rehabilitation treatment automatically.

GRADIOR has been conceived as a multi-device solution that can be run on a PC, a Tablet or a Smartphone, working both online and offline to accompany the users wherever they are.

3.5.2.6.2 Usable, intuitive and enabling more efficient monitoring and follow-up

In the case of GRADIOR Cognitive, data are available that confirm a sufficient degree of usability for patients with cognitive impairment [REF-89]. The Foundation has extensive experience in analyzing solutions in terms of accessibility and possibilities of real use by end users. As an example, which supports this experience, we can refer to the international project LLM-Long Lasting Memories (ICT PSP Program) that involved the validation of an integrated technology platform that combined cognitive exercises (GRADIOR) with physical activity[REF-90].

The practitioner module offers a highly intuitively designed dashboard and views with key indicators and summary information that makes it easy for therapists to follow up and perform possible adjustments to the intervention (**P6-N11**).

For the clinical evaluation of the user's evolution in the medium/long term, GRADIOR also offers different types of reports, according to cognitive modality and sub modality, with the data recorded from the user's session history as a reliable and consistent basis for studying their progress (**P6-N10**).

3.5.2.6.3 GRADIOR: Integration capacity

GRADIOR Cognitive was conceived as a horizontal system integrating other possible modules for multi-therapy approach, which is what has given rise to the GRADIOR Suite.

The first integration of GRADIOR Cognitive was in the LLM-Long Lasting Memories project (ICT-PSP, GA: 238904) [REF-91]. It was lately adapted and integrated into e2REBOT (robotic platform for rehabilitation of upper limbs in people with disabilities, co-funded by the Spanish Center for Industrial Technological Development [REF-92]), as a program supporting the motor neuro-rehabilitation therapy, and more recently in ehcobutler project (H2020, GA: 643566).

For the integration between devices for the HosmartAI Pilot #6, Gradior synchronization with Pepper should be automatic regardless of the devices for its execution. While a session is running on a PC or a Tablet, Pepper listens on a certain port; a service developed in ASP.Net maintains communication without interruptions. When necessary to interact, either it can be sent through a specific control command or the interaction content is sent directly to be transmitted through the network and reproduced by Pepper. For communication security, the adoption of an upper layer of encryption using AES protocol with its private cables hidden so that no other device connected to the network can recognize the transmitted information.

3.6 Tools for Personalised Treatment

Leader: VUB

Rapid technological advances are providing ever growing amounts of patient-specific data, while the health sector itself is facing crucial challenges, such as an ageing population and increasingly limited budgets. More efficient and improved diagnosis and treatment of diseases such as cancer are therefore both possible and urgently necessary. After all, the more we can quantify different aspects of a disease, the more we can also understand the underlying processes, thereby enabling a personalized approach to medicine, with patients benefitting by receiving targeted treatments.

Several challenges restrict the development of this personalized approach to medicine in practice. Firstly, a data deluge has forced hospitals into the 'digital universe', where, despite societal pressures to lower the cost of medical care, they need to build robust mechanisms for handling increasing data volumes, to be harnessed for a maximum of information. Second, these data are often dispersed, with personal and clinical information in the patient's electronic health record, raw medical data often stored separately for interpretation by a specialist, and the minutes of consultations to determine the best treatment stored in yet another location. Finally, for data privacy and protection reasons, these data are rarely accessible for research, or subject to stringent restrictions.

Novel technologies such as artificial intelligence (AI) therefore cannot be easily applied, even though these approaches have enormous potential in assisting clinicians in personalized patient diagnosis, treatment and outcome. The first crucial step to unlock this potential is the development of a digital health research platform that integrates clinical data and enables their analysis. This platform forms the basis to provide better access to raw data and derived information for complex diseases, with the aim of supporting and improving the clinical decision-making process.

Pilot #8 focuses on such a digital health research platform in relation to solid tumors at the VUB and UZ Brussel. The main components of this platform focus on clinical data and images, gene and protein level (molecular data), in the context of glioma:

1. Existing clinical data, including treatments, are covered by PRIMUZ, the integrated patient record system at UZ Brussel, while image analysis of tumor data in combination with patient information is the focus of the research by Jef Vandemeulebroucke (ETRO, Engineering faculty, VUB).

2. Gene level data are generated and analysed by the BRIGHTcore platform at the individual patient level (coordinator Sonia Van Dooren, researcher Catharina Olsen, medical genetics, Faculty of Medicine and Pharmacy, VUB). The protein level is addressed by research at the Interuniversity Institute of Bioinformatics in Brussels (Wim Vranken, Faculties of Sciences and Bioengineering sciences and Medicine and Pharmacy, VUB).

Other aspects important for such a platform are legal aspects (see WP8) and security, as well as clinical decision support (see Figure 12).

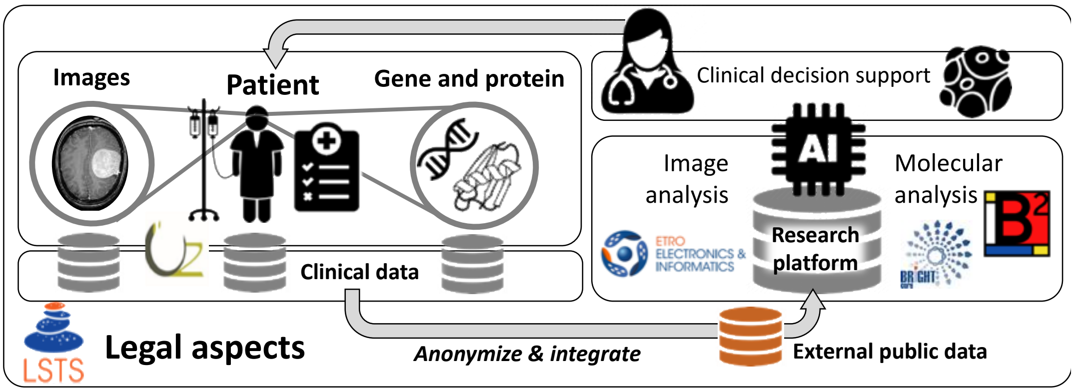


Figure 12: Overview of tools for personalised treatment covered by Pilot #8.

3.6.1 Computer-aided diagnosis of medical images

Medical images for diagnosis or disease monitoring are an important source of information on patient state and prognosis. However, these images have to be organized and analyzed to extract quantitative tumor image features such as shape, texture and activity. Glioma are brain tumours that offer opportunities in terms of expertise and large amounts of data available at VUB-UZ Brussel, so constituting an excellent test-case to evaluate future possibilities and practical difficulties. Deep learning approaches currently achieve state of art results for tumor segmentation, while (multi-modal) radiomics has shown great promise for detailed characterization of the tumoral tissues. We will provide accurate staging of the disease, through quantification of the tumour volume and grade; monitor disease progression, through comparison with follow-up imaging; and make predictions about treatment response, by correlating the tumor features with treatment outcome for historical data [REF-75] (**P8-N07**). Previous experience is present within the consortium and our developments will further benefit from public image databases for which the outcome is known.

3.6.2 Molecular level analysis

DNA sequencing can identify mutations that drive cancer development, which can result in target-specific personalized treatment strategies, such as a mutation-specific drug independent of cancer type. Knowledge of the mutations occurring in tumors is, therefore, an essential starting point to understand cancer at the molecular level, as well as an increasing aid in determining treatment, especially in conjunction with other tumor information. We will provide pipelines for a comprehensive cancer gene panel of 165 genes, for which data collection on patient cohorts has started at BRIGHTcore, based on current expertise in pathology. Public databases for molecular data such as TCGA and of known mutations such as COSMIC, are supplementing the local data for the purpose of i) initial testing and priming the analysis part of the pipeline, ii) assessing the similarity of unknown mutations to known ones from the public domain. We also translate the genome (DNA) to the proteome (protein) level, with currently very few proteome data available in a 'digestible' form. **Protein data** can help situate mutations, for example by revealing the subcellular location of cancer-related proteins in human cells via the Human Protein Atlas. We delineate the proteins' change in 'molecular phenotype' due to mutations, such as their structure, stability and solubility, as shown by the MutaFrame work (http://mutaframe.com/) on rare diseases [REF-76], and will connect to protein-specific molecular data available from pathology. The final output of the pipeline will be a list of relevant mutations in the tumor and a list of features that summarize the information on a gene and protein level for use by clinicians (**P8-N07**).

3.6.3 Digital health research platform

The joint digital health research platform (**P8-N01**, **P8-N05**, **P8-N06**) will enable (i) access to **integrated patient data**, also available off-site by pseudonymization of data in a secure environment (**P8-N02**, **P8-N03**); (ii) the automated **extraction of clinically relevant findings** from imaging and molecular data; (iii) **predictive machine learning** based models using multifactorial patient information, and the associated uncertainties of such models. By defining different data 'building blocks', we create a flexible system that can use a 'mix-and-match' approach depending on the requirements of a disease (**P8-N04**). In cancer, such data integration has shown great potential; mammography images in combination with genetic information; radiomic signatures can predict somatic mutations. However, to the best of our knowledge, these studies use only a couple of data types at the same time, neglecting other data that are used for diagnosis and treatment, as well as publicly available data.

Besides research, it is essential that we employ the platform as the basis for supporting clinical decisions: the increasing amount and complexity of available medical data necessitates the development of computer-aided clinical decision-support systems (CDSS). Developing a full system to do so is beyond the current scope of the project. We will, however, pursue: (i) the intuitive **visualisation** of image and molecular patient data, continuing from the MutaFrame work; (ii) personalizing **therapeutic recommendations** through predictive models of response to treatment and outcome. This is being done in close dialogue with expert clinicians, in order to provide the most relevant information in the most efficient way. By combining biological and clinical data, we want to achieve the highest accuracy in predicting tumor response and follow-up.

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