CogWatch – Cognitive Rehabilitation of Apraxia and Action Disorganisation Syndrome

D2.1 Report on system specification

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Authors (per company, if more than one company provide it together)		**Manuel Ferre, José M. Cogollor, Sandra Campo and Javier Rojo (UPM-ROMIN), Laura Pastor and Matteo Pastorino (UPM-LST), Chris Baber, Manish Parekh and Martin Russell (UOB-EECE), Ricardo Ruiz (RGB)**	
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EXECUTIVE SUMMARY

This deliverable aims at defining CogWatch system specifications. They are derived from the analysis of system specifications and architecture.

Functional specifications are presented, considering that a major goal of CogWatch is to develop improved at home provision of rehabilitation for apraxia and action disorganisation syndrome, common impairments in stroke patients. General specifications are provided, as well as specific ones for each component and application. In addition, given the sensitivity of the information treated by the system (personal and medical information), security and privacy issues become a major concern in the establishment of communication networks.

The overall CogWatch architecture is defined, including a general schema, a description through block diagrams and an illustration of a possible deployment of the system components in one of the testing environments that will be piloting the system.

CogWatch system comprises two main subsystems, corresponding to the patient side that will use the system in order to perform rehabilitation sessions and the clinician/health professional side, in charge of monitoring patient performance and progress.

The patient side will comprise wearable components (watch, T-shirt), sensorized objects, and home devices (desktop computers and possible tablets). Specialised algorithms in order to assess the patient performance will be developed. The professional side will consist on a desktop or laptop computer used by the clinician. Appropriate user interfaces for both subsystems will be developed.

The system repositories deserve special attention. They are components that will be present both in the patient and in the professional side, in charge of storing all the relevant information available in the system, both as inputs and outputs.

The system will be deployed in three different sites, i.e. UPM (Spain), TUM (Germany) and UoB (UK), where the patients will be able to use it so it is extremely necessary a good communication and parallel progress to ensure an agreement with relevant points as data collection, interoperability, etc. In addition, the clinicians will be able to access to the professional side of the system through a web portal, available from any location.

The specifications presented and the proposed architecture are compliant with the project objectives and application field, ensuring its replicability and extensibility.

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REVISION HISTORY

Revision no.	Date of Issue	Author(s)	Brief Description of Change
V0	13/04/2012	UPM	Table of Contents.
V1	06/05/2012	UPM-LST	Contributions to: Executive summary, System requirements, Overall CogWatch architecture, Hospital subsystem, Networks and communications, System actors-healthcare professionals, Physical architecture – hospital computer, Hierarchical approach of the system components, Portable application specifications, Hospital/therapist applications.
V2	07/05/2012	RGB	Contributions to: Wearable devices, Insertion of comments and revision of some text.
V3	08/05/2012	UPM-ROMIN	Contributions to: Introduction, System requirements, Overall CogWatch architecture, Home subsystem, System actors, Wearable devices, Video image acquisition, VTE devices, Hierarchical approach of the system components, Watch application, Portable application, Insertion of comments and revision of some text.
V4	16/05/2012	UoB EECE	Contributions to: Recognition and prediction algorithms, Sensorised objects and tools. Sections renumbered, Text editing, formatting, Table/Figures numbering revisions.
V5	18/05/2012	UPM	Header (public to private), review revisions.
V6	25/05/2012	UPM	New comments about sensorized objects and a table about possible errors and feedback.
V7	28/05/2012	RGB	ECG Electronics
Final	28/05/2012	UPM	Revisions based on Quality Manager's feedback.

LIST OF ABBREVIATIONS AND DEFINITIONS

Abbreviation	Abbreviation
AADS	Apraxia or Action Disorganisation Syndrome
ADL	Activities of Daily Living
aVF	Augmented Vector Foot
aVL	Augmented Vector Left
aVR	Augmented Vector Right
BAN	Body Area Network
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
LAN	Local Area Network
OT	Occupational Therapist
PAN	Personal Area Network
PC	Personal Computer
PDA	Personal Digital Assistance
RCT	Randomized Control Trial
UI	User Interface
UML	Unified Modelling Language
URL	Uniform Resource Locator
VTE	Virtual Task Execution
WAN	Wide Area Network
Wi-fi	Wireless Fidelity

1. INTRODUCTION

This section introduces the system specifications document for the CogWatch project. It provides the main purpose and scope of the system.

1.1 Purpose

This system specifications document describes the functions and requirements specified for this CogWatch project by analyzing the aspects of the patients' behaviour that need to be monitored and the type of feedback that needs to be provided to initiate and guide actions and alert of potential risks and action errors.

CogWatch is needed to develop sophisticated tools and objects, portable and wearable devices as well as ambient systems to personalise the cognitive rehabilitation carried out at home for stroke patients with AADS symptoms, who were introduced in the previous deliverable D1.2 Literature Review. The assessment methods and technologies developed in the project will reduce hospitalisation time, improve rehabilitation rates and increase AADS patient's independence and quality of life. The personalisation of the rehabilitation is achieved by pointing out different scenarios and main tasks already defined in deliverable D1.1 Report on Scenarios.

1.2 Scope

The project will develop intelligent everyday objects such as cutlery, kettles, toothbrushes and special clothes which will sense the way these objects are being used and wirelessly transmit the information back to a central healthcare system. The objects contain sensors to monitor orientation, motion and grip strength that, when used in combination, will provide the system with a detailed description of how the objects are being used by the patient.

Moreover, since the aim of CogWatch is to be customisable and personalised, it will use brand-new devices that will interact effectively with the patient using visual, auditory and haptic feedback. Particular attention will be paid in signal quality and consistency over time, transmission speed, and reliability of sensors. These key aspects will play a crucial role in the effectiveness of the system.

The main objectives to be achieved in CogWatch can be summarized as follows:

1. Deliver of a simulation of the main tasks to be accomplished by the called *Virtual Task Execution* (VTE) displayed in a specific module in order to be followed by the patients.
2. Monitoring of the AADS actions during the execution of the corresponding tasks displayed by using the intelligent objects mentioned.
3. Correction of possible errors committed thanks to multimodal cues provided by the brand-new devices which make patients aware of their errors and how to take appropriate corrective actions.
4. Monitoring of AADS behaviour and physiological factors to assess progress and detect possible new episodes and/or deterioration of the syndrome.

2. SYSTEM REQUIREMENTS

This chapter lists all the different types of requirements the CogWatch system must fulfil. They have been derived taking into account CogWatch project objectives, users and main scenarios considered, taking the project Description of Work and CogWatch deliverable D.1.1 Report on scenarios as reference. The current state-of-the art in the technology fields addressed by CogWatch as well as commercial and market parameters have also been contemplated. These requirements have been organised into: functional requirements and interoperability requirements.

2.1 Functional Requirements

2.1.1 Generic

Requirement ID	Requirement description
CogWatch-SYS-REQ1	The CogWatch system is mainly composed of two main subsystems, the client side and the server side. They cooperate in order to provide the required support to the AADS patient and to the clinician.
CogWatch-SYS-REQ2	The system shall grant access to registered end-users only. “Guest” end-users shall not be supported.
CogWatch-SYS-REQ3	The user shall not be permitted access to the system from different devices at the same time. He/she shall first log out from the current active device.
CogWatch-SYS-REQ4	The system shall be user friendly and shall propose the right interaction mode according to user disability/impairment.
CogWatch-SYS-REQ5	The system shall propose to the user guidance through the rehabilitation session for the realisation of several tasks, and warning.
CogWatch-SYS-REQ6	CogWatch system should allow the remote monitoring of AADS once they are discharged home.
CogWatch-SYS-REQ7	The healthcare professional can obtain access to CogWatch services independently of his location and the access terminal s/he is using.
CogWatch-SYS-REQ8	The system performance while performing certain ADL (e.g. eating, dressing, grooming) should be monitored.

Table 1 - Generic functional requirements.

2.1.2 Components

Requirement ID	Requirement description
CogWatch-SYS-REQ9	The system should acquire information about the patient interaction with certain everyday objects.
CogWatch-SYS-REQ10	The everyday objects will be provided with sensors, able to track the patient interaction with the objects.
CogWatch-SYS-REQ11	The patient should receive appropriate warnings and reminders related to the use of CogWatch system.
CogWatch-SYS-REQ12	The patient will be provided with a wearable element, able to provide him/her with appropriate feedback in case of emergency or if their safety is at risk when handling tools and objects inappropriately or providing indications about the use of CogWatch system.
CogWatch-SYS-REQ13	The position of the patient and his/her hands should be tracked.
CogWatch-SYS-REQ14	The patient performance during the rehabilitation sessions should be video recorded.
CogWatch-SYS-REQ15	Monitor physiological parameters such as heart rate and blood pressure to help detecting the risk of potential stroke recurrence.
CogWatch-SYS-REQ16	Physiological parameters should be monitored by using wearable sensors.
CogWatch-SYS-REQ17	The patient should interact with a computer that will guide him/her during the rehabilitation tasks.
CogWatch-SYS-REQ18	The patients should be made aware of their errors, when they occur and the actions needed to correct them. Make patients aware of cognitive errors when they occur.
CogWatch-SYS-REQ19	The patient should be able to access to CogWatch client side from any room of the house.
CogWatch-SYS-REQ20	When the patient is in a room/scenario of his/her house, different to the main one, he/she should interact with CogWatch by using a smaller and portable device.
CogWatch-SYS-REQ21	The clinician should be able to monitor the task performance and evolution of the patient from a remote location.

Requirement ID	Requirement description
CogWatch-SYS-REQ22	The healthcare professional will be able to access CogWatch information from any place with a computer or Internet enabled device.
CogWatch-SYS-REQ23	It should be possible to check whether a patient has finalised certain tasks.
CogWatch-SYS-REQ24	Algorithms CogWatch system should know whether the patient has made mistakes during the performance of a task, when they happened and the type of errors.
CogWatch-SYS-REQ25	Information about each patient should be stored in the computer at home, together with the results of the rehabilitation sessions.
CogWatch-SYS-REQ26	Information about all the patients using CogWatch should be accessible from the clinician side.

Table 2 - Components functional requirements.

2.1.3 Applications

Requirement ID	Requirement description
CogWatch-SYS-REQ27	The patient will interact with a watch, that will provide visual and vibrotactile feedback, in case an emergency situation is produced or indicating that a new CogWatch training session should be initiated.
CogWatch-SYS-REQ28	Client side (VTE) The patient will interact with a tactile computer that will guide the patient through the rehabilitation session by providing multimodal feedback.
CogWatch-SYS-REQ29	The VTE will guide the patient through the realisation of certain tasks by displaying the appropriate hand positions.
CogWatch-SYS-REQ30	The system should initially provide a low level of detail regarding the tasks to be accomplished by the patient.
CogWatch-SYS-REQ31	Depending of the number and type of errors produced the level of detail will increase and the interaction modality will be adjusted.
CogWatch-SYS-REQ32	The patient interaction with the VTE should be as easy as possible, taking into consideration the characteristics of the AADS user.

Requirement ID	Requirement description
CogWatch-SYS-REQ33	The patient location and hands position of the patient will be tracked by using a Kinect device.
CogWatch-SYS-REQ34	The administration personnel in the hospital will be able to add new patients and new clinicians to the CogWatch system, as well as removing them.
CogWatch-SYS-REQ35	The administration personnel in the hospital will be able to assign patients to health professionals. In a typical case, one single clinician will be able to follow several AADS patients.
CogWatch-SYS-REQ36	The clinician will be able to access personal details of each patient.
CogWatch-SYS-REQ37	The clinician will be able to access contact information of the caregivers of each patient.
CogWatch-SYS-REQ38	The clinician will be able to access medical and treatment details of each patient.
CogWatch-SYS-REQ39	The clinician will be able to access the information about the rehabilitation sessions.
CogWatch-SYS-REQ40	The clinician will be able to see specific details of a particular rehabilitation session performed by the patient.
CogWatch-SYS-REQ41	The clinician will be able to access statistics about the rehabilitation sessions performed by a specific patient using CogWatch system.
CogWatch-SYS-REQ42	The clinician will be able to be informed about new events/notifications.
CogWatch-SYS-REQ43	The clinician will be able to schedule the next rehabilitation session of the patients.
CogWatch-SYS-REQ44	The clinician will be able to access additional information of the patient, such us images.
CogWatch-SYS-REQ45	The contents and interaction modality of the medical side of CogWatch should be appropriated and adapted to their needs.

Table 3 - Applications functional requirements.

2.1.4 Networks and communications

Requirement ID	Requirement description
CogWatch-SYS-REQ46	A Body Area Network (BAN) should be established including CogWatch wearable devices and sensors. They will communicate wirelessly, whenever it is possible.
CogWatch-SYS-REQ47	A Local Area Network (LAN) will be established including the BAN devices and sensors, with other components at the patient's house (home processor- VTE, sensorized objects, Kinect and portable devices). They will communicate wirelessly.
CogWatch-SYS-REQ48	A Wide Area Network (WAN) will be established between CogWatch client and the remote medical side.
CogWatch-SYS-REQ49	The clinician will be able to access the CogWatch medical side from any Internet enabled device.
CogWatch-SYS-REQ50	Energy efficiency should be taken into account when designing the network and communication strategy.

Table 4 - Networks and communications functional requirements.

2.1.5 Security and privacy

Requirement ID	Requirement description
CogWatch-SYS-REQ51	The system shall prevent access to unregistered users or to unauthorised users whose malicious intent may damage system integrity.
CogWatch-SYS-REQ52	The system shall support authentication in order to protect private user data.
CogWatch-SYS-REQ53	Sensitive data transmitted from the client side to the medical side and viceversa should be appropriately secured and privacy should be guaranteed.
CogWatch-SYS-REQ54	Each pilot site shall devise a proper backup plan that shall be scheduled in order to reduce damages in case of loss of data.

Table 5 - Security and privacy functional requirements.

2.2 Interoperability Requirements

Requirement ID	Requirement description
CogWatch-SYS-REQ55	CogWatch healthcare subsystem should be compatible with existing Hospital Information Systems (HIS).
CogWatch-SYS-REQ56	Clinicians should spend limited time inputting data into the system.
CogWatch-SYS-REQ56	Clinicians must review patient information at a glance.

Table 6 - Interoperability Requirements.

3. OVERALL COGWATCH ARCHITECTURE

This third chapter is focused on the description of the whole architecture of CogWatch to better understand the function of each component involved and the communication between all of them.

3.1 Architecture Scheme

The overall decomposition of the CogWatch system is illustrated in Figure 1. CogWatch system aims at developing improved at home provision of rehabilitation for apraxia and action disorganization syndrome of patients, consequences of stroke.

It is composed by two main subsystems, i.e. the CogWatch Client and the CogWatch Medical side. The first one of them will be located at the patient (s) home, and will be used by the patient to perform the rehabilitation sessions under the conditions and frequency prescribed by the health professional/therapist, often under the supervision of a relative or an informal caregiver. The second subsystem will be by the clinician, allowing him to keep track of the patient(s) performance in the development of tasks and evolution.

Each AADS patient using CogWatch system will have a client side installed at home. The client side will be composed by a smart watch, several wearable sensors, sensorized objects, a Virtual Task Execution (VTE) module, portable devices and a Kinect. The VTE is an “All In One computer”, that allows tactile interaction. Several algorithms will be developed and installed in the VTE in order to assess the patient performance when carrying out one or several tasks (e.g. preparing tea, grooming, dressing, etc.). It will have a repository/database where the information related to the patient will be stored (personal information, medical and treatment related data and signals acquired during the rehabilitation sessions). The raw signals acquired will be processed by the algorithms and also saved at the client side. The CogWatch client will have a communication module that will make possible the communication with the CogWatch medical side.

The medical side will be a web portal, accessible by the health professional/therapist or administration personnel from any location. They will be able to access information from several remote sources (i.e. various client sides) from any computer (laptop or desktop) connected to Internet. It is expected that often the health professional and person in charge of the administration will access the web portal from the hospital, but the flexibility of the portal does not impose limits to his/her location.

In order to communicate both subsystems, an additional subsystem, called CogWatch Server will be needed. It will need to be provided with appropriate communication module, ensuring the transmission of information between the client and the server side, and a security module, in order to guarantee that security and privacy requirements are fulfilled. It will also have a repository/data base with the information of all the patients of CogWatch system per pilot/location.

In a theoretical situation, there should be one server side per pilot, i.e. Germany (TUM), UK (UoB) and Spain (UPM), and additional severs should be deployed if new pilots/hospitals are included (See Figure 1).

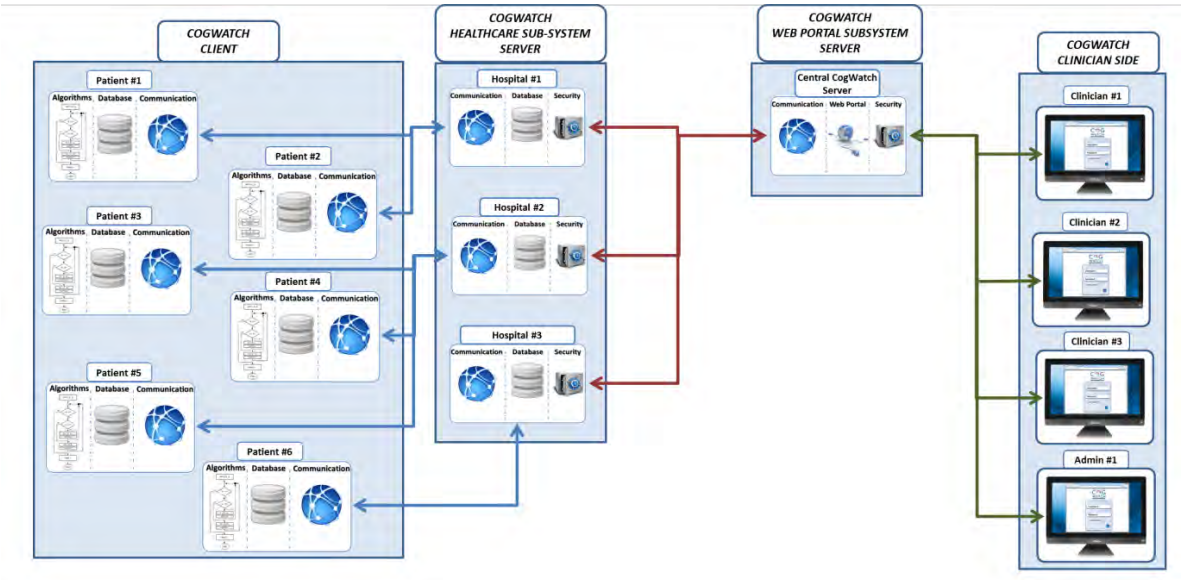

Figure 1 - CogWatch system architecture (theoretical case).

However, in practice, and in order to avoid the difficulties and restrictions that might be derived from the installation of new software in a hospital or rehabilitation centre, the strategy adopted in the framework of CogWatch project will be different. As illustrated in Figure 2, there will be one single server, installed at UPM premises in Spain. It will contain three different sub-servers, one per pilot site all of them with the same structure, and with the sever side of the portal.

Finally, Figure 3 shows a possible location of all the components in a fixed scenario. In this case, the pilot used by UPM (LivingLab) is chosen.

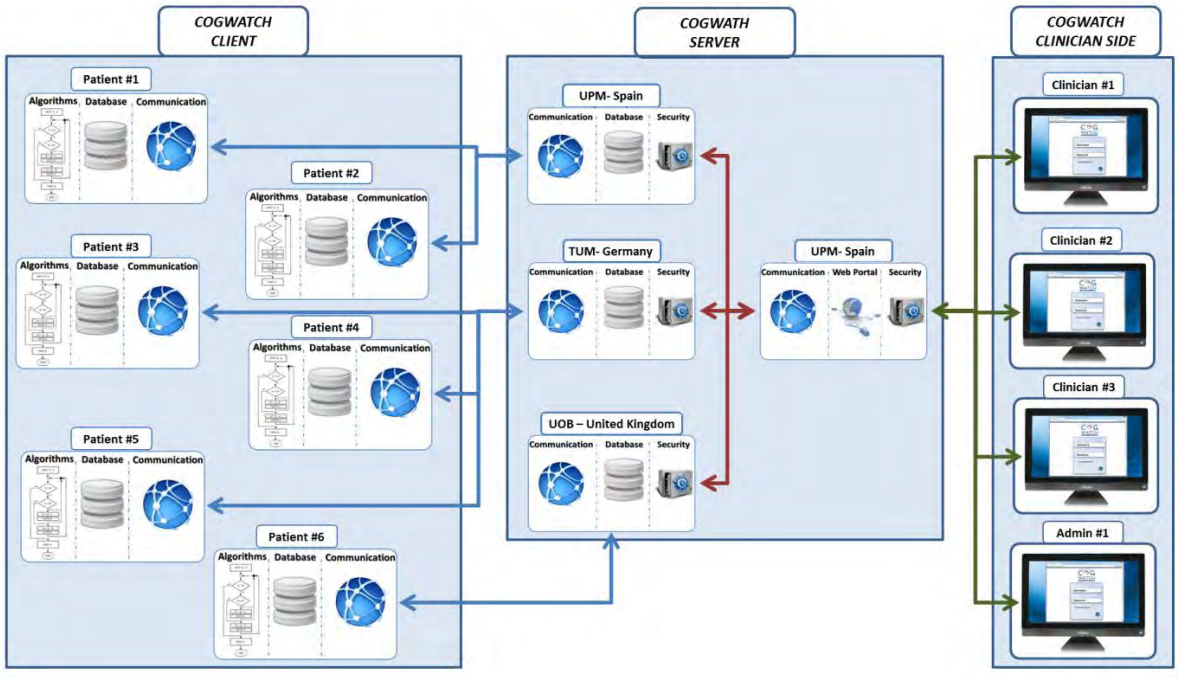

Figure 2 - CogWatch system architecture (practical case).

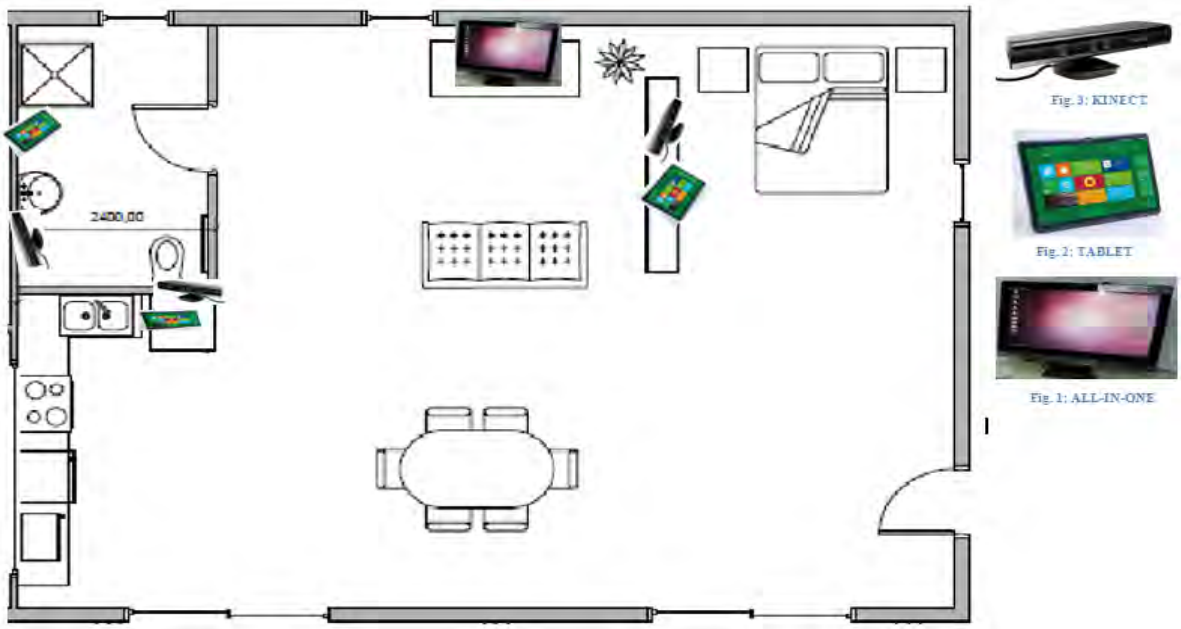

Figure 3 - Home devices situation.

3.2 Subsystems Schemes

Once the overall architecture of CogWatch system has been described, a more detailed explanation of each subsystem follows.

3.2.1 Home

The following Figure 4 shows all the components needed to be installed in the patient's house considering a specific area where the task is being executed:

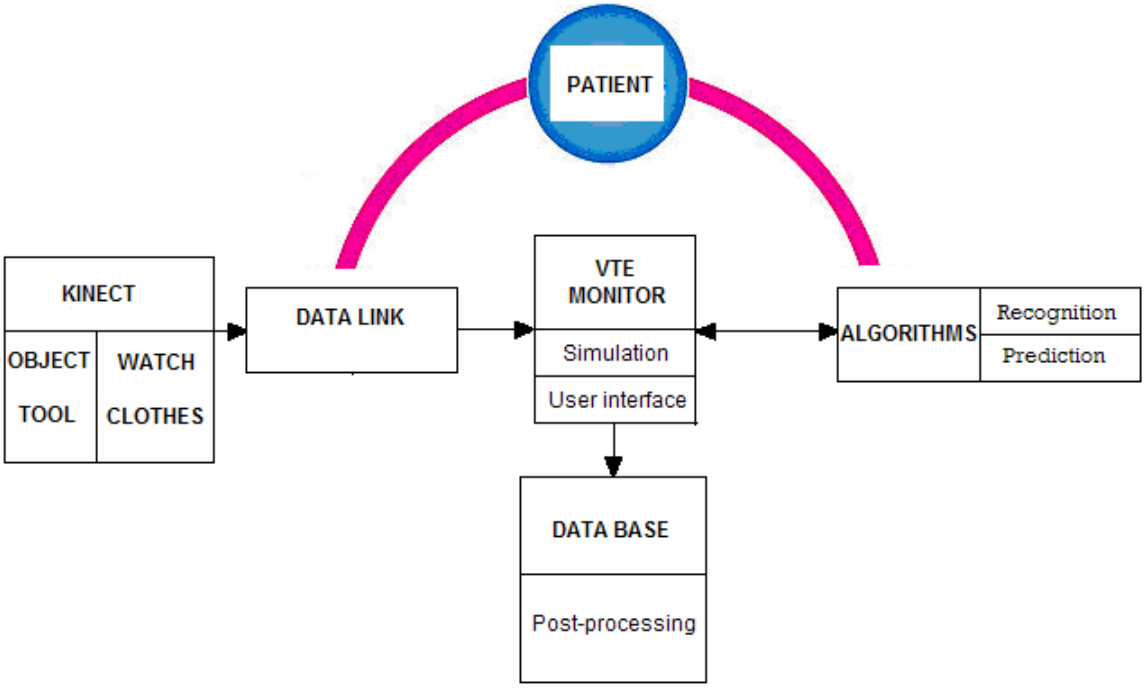

Figure 4 - Home scheme in CogWatch project.

As shown in the representation, the patient interacts with the following items: Virtual Task Execution (VTE) monitor (and additional tablets), instrumented objects and the wearable devices (watch and sensorized clothes).

VTE MONITOR

A possible solution lies in the use of an “All-in-one” computer which is composed by a LCD monitor and the central processor which would compute all the information. The main functions of this device would be:

- Touch screen. The patient could select the desired task to execute and start/stop the application. Once the task is selected, a list of the objects needed for execution could be shown before the simulation begins. So, the patient might memorize or look for these objects previously in case of memory loss.
- Virtual Task Execution (VTE). Once the task is selected, the patient could execute the task being aware that if an error occurred a simulation would run on the monitor in order to feedback and guide all the movements for correction. The errors will be known thanks to the algorithms of action recognition and prediction.

As an additional functionality, it is interesting that the visual guidance provided by the VTE would be complemented with:

- Voice messages.
- Alert sounds.

Finally, possible use of additional tablets would be considered in order to improve the flexibility of executing different tasks in different rooms. The objective of these tablets would be exactly the same as the provided by VTE monitor and they would be implemented in future prototypes.

INSTRUMENTED OBJECTS AND TOOLS

The objects would be handled by the patient in order to execute the corresponding task related to their functionality. These objects will be equipped with RFID transmitter for accomplish the main function which is:

- Identification to be sent to the processor via wireless connection in order to provide information to the prediction and action recognition algorithms.

Moreover, two additional and future functions for advanced prototypes of these instrumented objects would be:

- Vibration of the wrong object when it is grasped by the patient.
- Luminous information to indicate what is the correct object (green LED) and the incorrect one (red LED) for the next action.

WEARABLE DEVICES

The wearable devices are divided into a watch and sensorized clothes.

Considering the first one, the watch can be considered as a central device for CogWatch because it provides an innovative means of presenting information to the user. Different commercial solutions could be accepted with different and possible functionalities. However, the only and main function to be provided by the watch is:

- Vibration when the patient is grasping an incorrect object or executing an incorrect task or in a bad way.

Other functionalities the watch could provide in the future would be:

- Text messages during the tasks execution so the patient will be able to read some messages with tips and relevant explanations when errors occur.
- Images additionally used in combination with the text messages related to the objects handled and the objective and risks of the corresponding actions.
- Implementation of an accelerometer in order to obtain information about the movement of the hand.
- Simple user interface using the buttons or tactile display.

According with the sensorized clothes, the patient is supposed to wear some clothes which would have implemented the corresponding hardware in order to obtain information from:

- Non Invasive Measurement Blood Pressure.
- Electrocardiogram.
- Pulse Oximetry.

Both wearable devices would send the corresponding data to the processor using wireless connection.

Apart from the interaction between the patient and the previous devices explained above, there are other important devices as:

KINECT

This device would be connected by wire to the central processor (All-in-one computer) which will have to obtain:

- Information about patient's hands images to control their position.
- Video recording about the whole scenario.

As an additional and redundant function, it is possible with the use of Kinect:

- The recognition and position of every object by an adequate and more complex programming.

It is important to mention that this information could be optionally complemented with other cameras strategically installed and all the information provided by them would be sent to the central processor via bus connection.

Finally, all the information computed in the VTE monitor would be storage in a data base in order to process that information to be sent to the server subsystem.

3.2.2 CogWatch server

The CogWatch server is dedicated to store all patient data processed and collected in the CogWatch Client, assist the treating clinician in making appropriate decisions and show the results of the recorded sessions. As described in 3.1, the CogWatch SERVER will be composed by the Healthcare server and the Web Portal Server.

The Healthcare Sub-system is dedicated to the storage of the medical and personal information of the patient's assigned to each Healthcare center. Moreover it will contain the results and the statistics of the rehabilitation sessions performed. In the theoretical deployment of the CogWatch system, every Healthcare center, belonging to the CogWatch network, will be provided with the Healthcare Server and it will be adapted to the every healthcare particular system. However in order to avoid the difficulties and restrictions that might be derived from the installation of new software in a healthcare center, a virtual machine will be created for each participant healthcare center of the CogWatch trials. Every Virtual machine will be work as an independent server simulating the feature and characteristics of an independent server.

The inputs and outputs of the CogWatch Healthcare subsystem are as follows:

- Inputs: they are coming from the CogWatch Client (s). They include personal data of the patients, medical data, processed/analysed signals, videos and statistics of the rehabilitation sessions.
- Outputs: they are provided to the CogWatch Web portal subsystem. They consist of HTTP and HTTPS requests and responses.

Every Healthcare Sub-system (Figure 5) will contain a Data miner, an Interoperability Module, a Communicator module, an Healthcare Information Handler module and a dedicated Healthcare Repository and in particular:

- The Data Miner is not a mandatory a module, it is proposed in the CogWatch as a module to reveal previously unknown knowledge and information correlation for AADS disease, exploiting the CogWatch stored data. As the functionality of the Data Miner is very specific and not directly evident to the final system users, it required in-depth discussions with clinicians to reveal the usefulness of this module during the functional specifications phase. The data miner functionality concentrates at exploiting the available information to produce a system that can make associations among various conditions.
- The Communicator Module will be developed in order to support the multi-directional communication between all CogWatch subsystems.
- The Healthcare Information Handler, will be the module in charge of the information management exchange between different sub-modules and to encapsulate the centralized system's logic and ensure all users initiated or system initiated actions are performed smoothly, and the Healthcare Repository, in which all data are recorded.
- The Healthcare Repository contains information of all patients (including information from all base units, all devices, system generated alerts and clinician inserted data), and other assistive material, such as relevant pharmaceutical products.
- The Interoperability Module will guarantee the interoperability with existing and already in use repositories, at the Healthcare center.

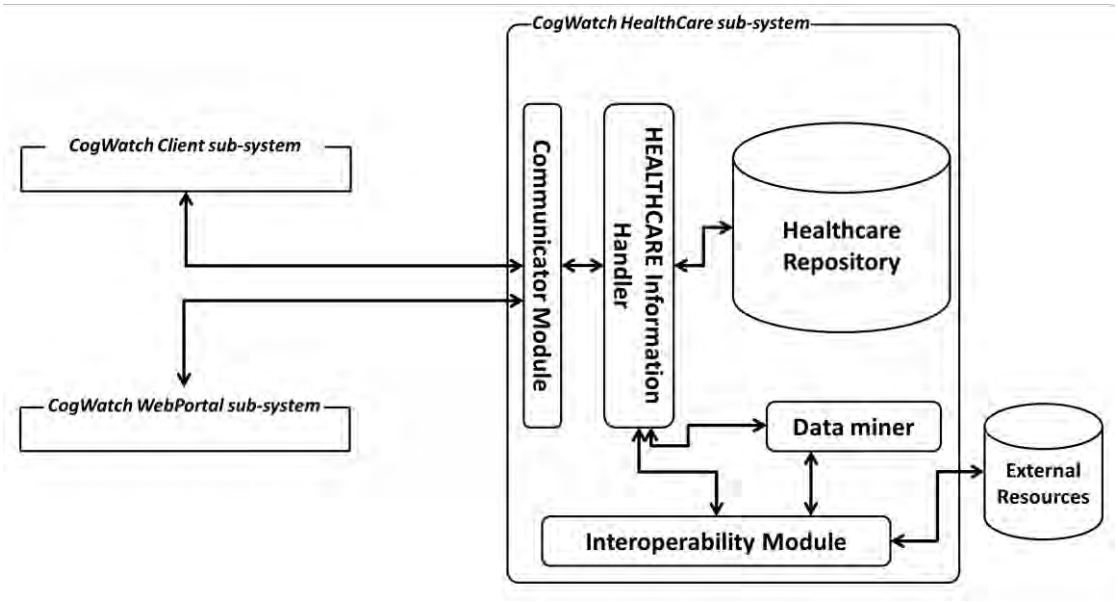

Figure 5 - CogWatch Healthcare sub-system overall architecture.

The Web Portal Sub-system is dedicated to the allocation of the medical web portal and the account information repository. This will be an independent and unique server. During the development of the CogWatch system the Web Portal Sub-system will be installed at UPM in Madrid, Spain. The Web Portal Sub-system will contain a Communicator Module, a Log-in Module, an Account Manage, the WEB-Portal handler and Algorithms and the User's repository.

Both the inputs (from the Healthcare sub-system) and outputs (to the CogWatch medical side) of the Web-portal Sub-system will be HTTP and HTTPS request-responses.

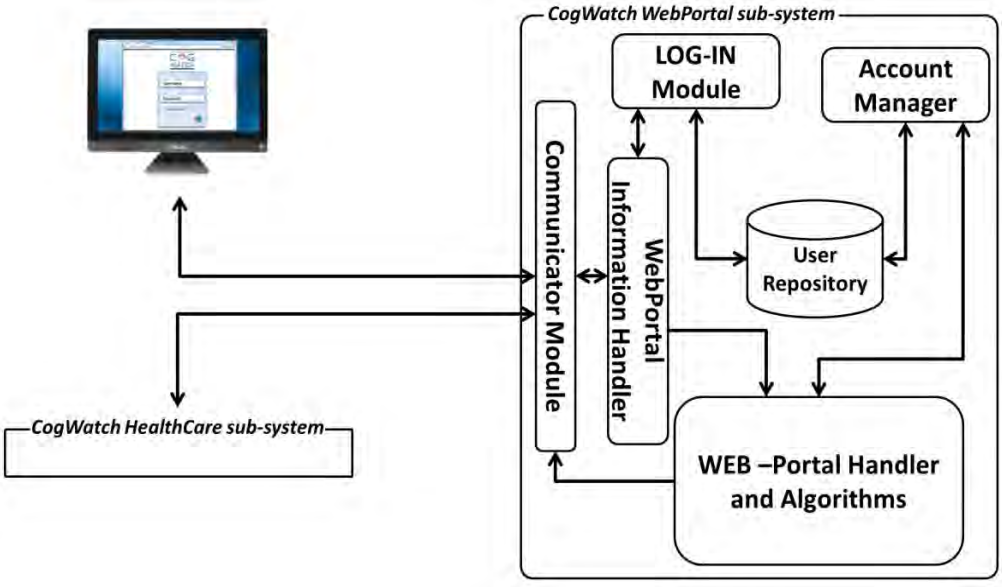

Figure 6 - CogWatch WebPortal sub-system overall architecture.

- The Account Manager is used to administer user accounts for doctors and administrators.
- The LOG-IN Module is used to allow for secured, role-based, multi-device access to the system data and for the definition/modification of the access authorization to the patient data, as described by relevant legislation on patient data ownership.
- The User Repository contains the user access information, authorization information and user action logs.
- The Communicator Module will be developed in order to support the multi-directional communication between all CogWatch subsystems.
- The WebPortal Information Handler, will be the module in charge of the information management exchange between different sub-modules and to encapsulate the centralized system's logic and ensure all users initiated or system initiated actions are performed smoothly, and the User Repository, in which all data are recorded.
- The WEB-Portal Handler and Algorithms will be the module that contains all algorithms of the web portal and it will manage the data in order to return the correct information to the user.

3.2.3 Repositories

The data collected during the sessions will be stored in the CogWatch Repositories. Three different repositories are been identified, depending on the location and characteristics:

- Home Repository: This repository will be allocated in the VTE and it will be used to store patient information together with the raw data acquired by the sensors, the results of the processed data and the session's statistics of each user.

  Inputs: patient information (personal data, medical data, caregiver data, signals acquired, signals processed sessions' statistics).

  Outputs: according to inputs and specific request (query).

- Healthcare Repository: This repository will be allocated in the Healthcare Sub-system (in practice deployed as part of the CogWatch Server) and it will be used to store the results of the processed data and the session's statistics of the users that belongs to the health care center.

  Inputs: session's statistics per user and clinician (or healthcare center).

  Outputs: according to inputs and specific request (query).

- User Repository: This repository will be allocated in the Web Portal Server and it will be used to store the authentication information of all users of the CogWatch Web application.

  Inputs: login, pass and user type (clinician or administrator).

  Outputs: according to inputs and specific request (query).

For all Repositories security procedure will be taking in account in order to preserve the confidentiality of the stored data (e.g.: using secure protocols for internal and external communication). Moreover a periodic back up will be scheduled in order to restore the data in case of a possible data loss event.

3.3 Network and communication

One of the most crucial issues concerning the success of CogWatch system is the design and implementation of the optimum communication and network architecture. Therefore, it is important to paid attention to it already in the design and early development stages of the project.

Figure 7 illustrates the proposed monitoring architecture divided in three network sub-architectures: (1) Body Area Network – radius of 2-5 m (2) Local Area Network – radius of 100m (3) Wide Area Network.

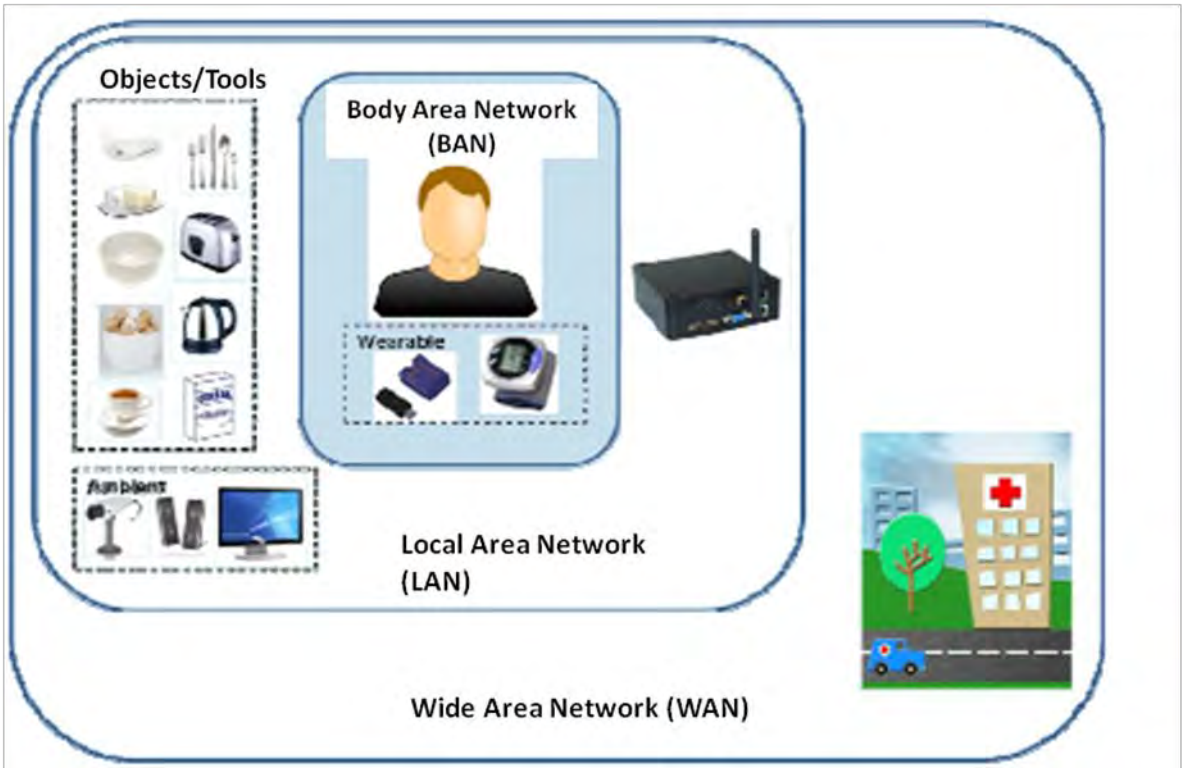

Figure 7 - CogWatch Communications and networks.

The patient with AADS is the main actor of the system and will be in the centre of the communications and network architecture. He/she will be wearing different wireless sensors and a watch operating within a confined area referred to as Body Area Network (BAN). These wireless sensors relay the collected information to a more powerful device, such as a computer or a portable device, part of a Local Area Network (LAN) at the patient home. The Patient/Client side is responsible for first stage information processing, acting as gateway to a WAN such as Internet, to relay information to the Hospital Processor for further processing, control or feedback by the medical doctors.

There are distinctly two types of communication at this stage: (1) Communication between Sensors (wearable sensors, ambient sensors and haptic sensors) and the home-based processor (2) Communication between home-based processor and the medical side.

1. Local Area Network (LAN) and Body Area network (BAN): This sub-infrastructure will be in charge of establishing a safe and efficient connection between the instrumented tools and objects, the wearable devices, the ambient systems, the home-based processor and the patient/users. The deployment of such a network will be implemented with a specific topology of sensors network, which will use a wireless communication protocol, most probably Bluetooth, given that the sensorized objects use Bluetooth communication protocol. It has a maximum range of approximately 10 meters and allows only 8 simultaneous connections.

   This design is required to be dynamic and scalable in order to assure an easy modification of the configuration of the devices and sensors and adapt it to the specific user's requirements.

2. Wide Area Network (WAN): This sub-structure will guarantee the connection between the patient and the clinicians who are in charge of monitoring the rehabilitation progress. This network will be able to assure a secure connection in order to guarantee the privacy of personal information sent on the network infrastructure. The communication between the user and the clinician will be implemented with a broadband connection, which will be able to get a direct access to the Internet network. In the specific, this sub-structure will be implemented by using an broadband fixed (or mobile) connection. On the medical side, the network will be interfaced with a Web Portal that will be in charge of monitoring and visualize the information gathered by the system installed in the house of the patients.

   The LAN and BAN will be operate at client site while WAN will allow the remote management of the CogWatch system, the medical side. The format for the data will be in an agreed format, e.g., Comma Separated Value (CSV), or eXtensible Mark-up Language (XML), depending on the nature of the data collected.

3.4 System Actors

3.4.1 AADS Users

For the execution of a simple task the system must be able to deal with a lot of possible cases. One of the aims of the project is to adapt as much as possible the quality of the system to the patient requirements.

In that order the system must pre-evaluate the capacities of the patient to be adapted to those necessities. According with that previously described in D1.2 Literature Review, there are some different problems that can be associated with Apraxia and AADS patients.

The system requisites needed to cover up the possible problems that the patient could find are:

USE OF SINGLE CONVENTIONAL TOOLS

All the gadgets that will be provided to the patient have to be as common as possible, i.e., as "common" is defined that the patient has to be able to identify every object in order to avoid external confusions to the main goal.

APHASIA

It was reported that this problem was intimately associated with apraxia patients. The communication between the patient and the clinician or the system will be reduced in this case so; some important considerations must be taken into account:

- Time. The system must provide the time patient needs to answer a question.
- Sensitivity to noise. All the voice messages must be clear so that the patient can perfectly hear what he/she is required to do.
- Communication channel. Parallel channels as visual have to be provided in case that the patient is not able to reproduce and audible answer.
- Reduce language level. The question asked to the patient are traduced to yes or no simple question, the system has to be able to provide that kind of response.

SOCIO-ECONOMIC IMPACT

The system has to be achievable to a medium class model person.

HEMIPARESIS

In some cases after a stroke the hemiparesis symptom appears. For those cases, the system has to be warned to not ask or reproduce tasks that the patient can´t do due to mobility issues.

3.4.2 Clinicians

There is a pressing need for a concerted approach to rehabilitation of apraxia after stroke because appreciable improvements in sensorimotor and cognitive function may occur, weeks or months later. AADS treatment is a recognised part of stroke rehabilitation (Tempest and Roden 2008), typically including practice in carrying out gestures of action sequences with redundant cueing of object/hand relations.

Patients need monitoring and feedback in order to regain, improve and maintain skills in using tools and sequencing actions in everyday tasks, ranging from self-care including washing and cleaning teeth, dressing, kitchen tasks such as preparing a drink or cooking and eating a simple meal, through clearing and tidying, etc.

Clinicians recognise the ability to carry out everyday actions as the most tangible aspect of patients' independence (Radomski 1994) considering that the only current approach for clinicians is to undertake one-on-one practice with patients slowly and laboriously practicing actions under close supervision in the hospital.

After stroke, occupational therapists work to facilitate and improve motor control and hand function in the stroke-affected upper limb; to maximize the person's ability to undertake his or her own personal self-care tasks and domestic tasks; to help the patient learn strategies to manage the cognitive, perceptual, and behavioural changes associated with stroke; and to prepare the home and work environment for the patient's return.

A number of studies have shown that rehabilitation of ADL tasks in a clinical setting is successful (Bowen et al 2009; Donkervoort et al 2001; Goldenberg and Hagmann 1998; Smania et al 2000).

After discharge, it is difficult to progress skill acquisition with further practice except, perhaps with a very close trained carer. Anyway, although carers may start motivated to support practice, it is probable that they could get nervous or loose temper and try to execute the tasks themselves in order to better explain to patients. This will cause a loss of skill for patients because they would focus on paying attention to carers instead of executing the tasks by themselves.

One of the goals of CogWatch is therefore to enable and to encourage the AADS patients to continue with and to build on the ADL competence they are first exposed to in therapy sessions in the hospital. Because of this, CogWatch system is intended to allow occupational clinicians to remotely monitor the performance and progress of AADS patients, once they have overcome the rehabilitation phase at the hospital.

4. PHYSICAL ARCHITECTURE

This new chapter describes the main physical features of each component considered.

4.1 Physical Components specifications

4.1.1 Sensorised objects and tools

4.1.1.1 RFID tags and reader

Radio frequency identification (RFID) technology can be used to wirelessly detect and identify objects fitted with RFID tags. The tags are small and require no power supply of their own so that they can be inconspicuously attached to objects (Figure 8). RFID reader can be attached to the user's wrist so that tagged objects that are handled by the user fall within the detection range of the reader. For the CogWatch project this method will be used to supply the computer with a history of all objects that have been interacted with. This data will be used to support the recognition algorithms that will be used to detect and identify errors in the tasks performed by patients.

This RFID based method has been used in past research to automatically recognise ADLs by looking at the sequence of objects interacted with. Similar methods could be used to detect sequence and omission errors in tasks, which the CogWatch project is required to detect. However a system that only uses RFID cannot detect what actions are performed with a single object – only the fact that it was handled. Many objects will require other sensors to enable the detection of usage errors. For very small objects, which are too small to support wireless electronics and a battery, RFID is the only suitable method of detecting interaction. Camera based methods can be used but the camera's sight of small objects is easily obscured.

There are many options for the tags that can be used. Due to high availability and low price, Mifare Ultralight tags are suitable for this project. The 45mm RFID sticker labels are well suited for tagging large items such as mugs, and 20mm sticker discs and 13mm laundry tags are available for tagging smaller objects.

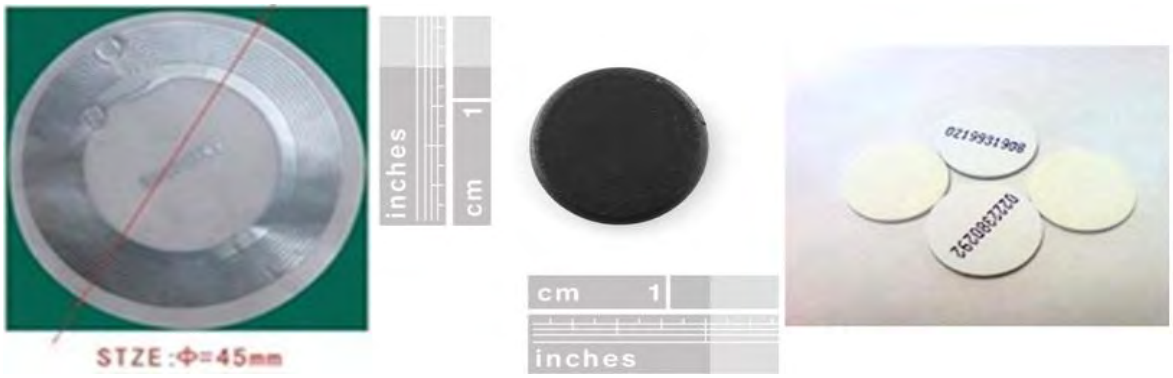

Figure 8 - Mifare RFID tags (45mm label, 13mm laundry tag, 20mm disc).

4.1.1.2 Object sensor unit

In order to facilitate the detection of patient errors a small selection of sensors needs to be embedded into many different objects used in ADLs. For this purpose a wireless embedded sensor unit has been developed. Two sensors were selected to this task, namely a 3 axis accelerometer and force sensitive resistors. The unit uses a Bluetooth wireless connection to send sensor data to the computer. The data is then used to support the recognition of activities and errors.

There are many other sensors that could potentially be added to the sensor unit but doing so would reduce the battery life of the unit and increase its size. It is important that the size of the embedded unit is as small as possible in order to minimise its impact on the familiarity and function of the object.

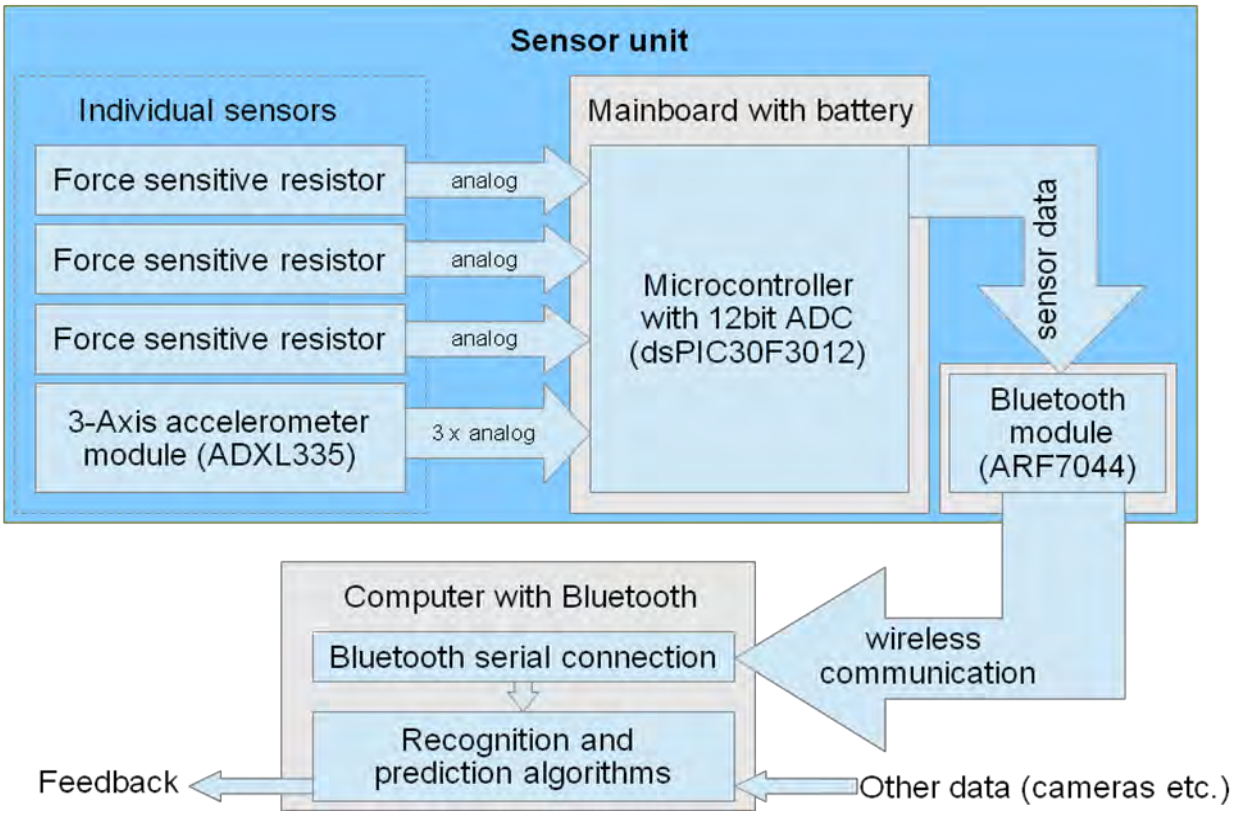

Figure 9 - System block diagram of sensor unit.

The sensor unit is composed of three separate parts:

- The main board, containing a microcontroller that is used to digitise the sensor data and prepare it for wireless transmission. This board also contains the power regulation for all of the parts of the unit.
- A Bluetooth module that manages the wireless connection. The module can easily be replaced by a wired connection to a computer for use with immobile objects that do not require wireless and battery powered communication.

- Individual sensors, which are wired to the main board so that they can be individually positioned to maximise their effectiveness.

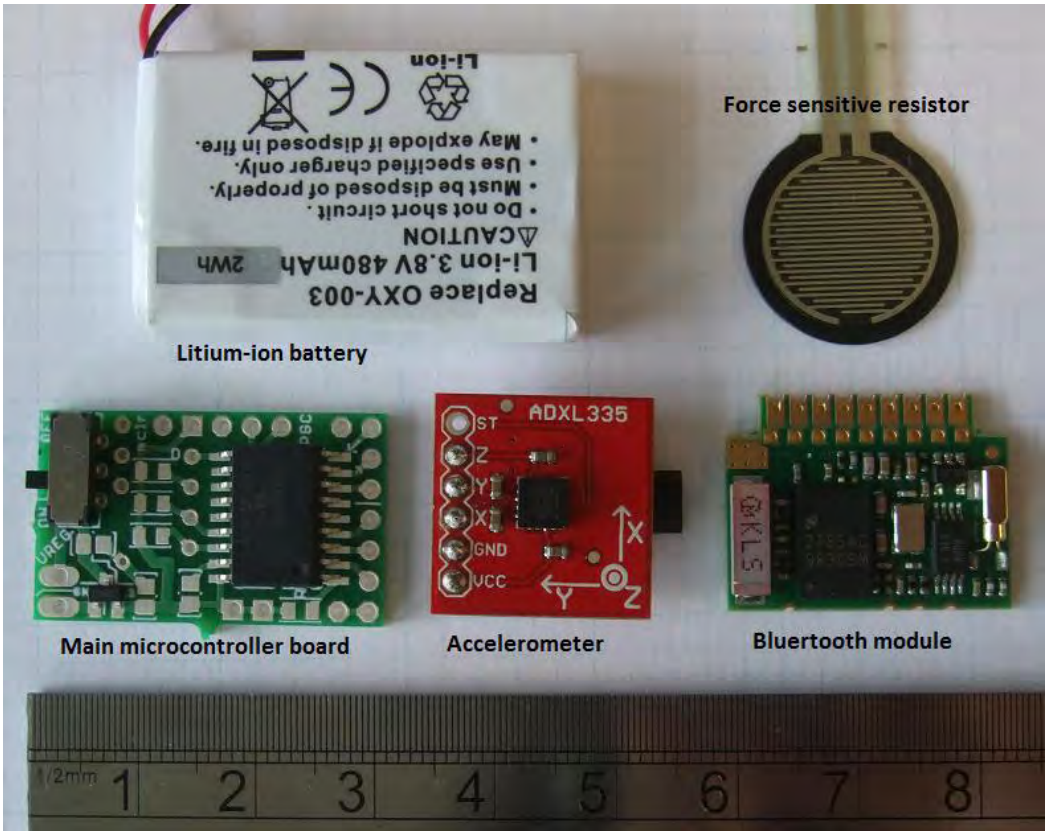

Figure 10 - Parts of the sensor unit.

ACCELEROMETER

Usage errors, such as holding an object in the wrong orientation or shaking a kettle instead of pouring from it, cannot be detected from simple RFID sensors. The use of vision based techniques using the Kinect camera system may make it possible to detect these kind of errors, however this can be very difficult and may fail completely if vision is obscured. For this scenario accelerometers attached to the objects can be extremely helpful in providing the data required. Accelerometers provide data about movement as well as orientation. They are commonly used in many activity recognition applications due to the quality of data they provide. They are also very small and have low power consumption, making them ideal for embedded electronics. For these reasons it can be argued that accelerometers should be embedded on all mobile ADL objects that can accept the electronics without hindering their use.

FORCE SENSITIVE RESISTOR

Force sensitive resistors (FSRs) can be used to measure a physical force applied to their surface. Applying these sensors to the bottom of objects such as a mug or a kettle results in data that can be used in two ways:

- The force data could be used to detect that the object has been picked up off the work surface, as the object's own weight would no longer be detected.
- If the quantity of water within the object changes (relevant to mug/kettle in the tea-making task) then this would be detected by the force sensors through a change in the weight in the object.

BLUETOOTH

Bluetooth is used for the wireless connection between the sensor units and the computer. Bluetooth is a well supported, low power standard for wireless communication for small devices, with a communication suited to rooms in a standard house. Due to its wide support, using Bluetooth opens up the possibility of direct connection to many devices such as mobile phones and tablet computers, allowing for future expandability.

Zigbee wireless (and similar proprietary protocols such as MiWi) based technologies may provide better power management (and hence better battery life) than Bluetooth and more flexibility for the management of large networks of sensor units. However, the amount of sensor data that can be transmitted using such technologies is much smaller and the implementation would be much more complex. The viability of such technologies cannot be confirmed until the minimal useful sensor data is confirmed through trials.

4.1.1.3 Instrumented handle

The instrumented handle is a wireless sensor setup for handles of objects such as cutlery and tools. The instrumented handle is not just embedded electronics; it is a replacement for the entire handle of the object. An accelerometer is used in the handle in a similar way to the object sensor unit. The instrumented handle also has strain gauges fitted to its sides to measure changes in grip force.

Objects with handles, such as cutlery, are handled in a rather complex manner, and correct grip plays an important role in successfully completing any task. Grip force sensing can be used to detect errors in patients involving significant insufficient or excessive grip force. Furthermore, the changes in grip over time can be used to assist the automated recognition of the activity that is being carried out with the instrumented object. Research has been done with multiple prototypes to ascertain the potential of strain gauge grip sensing in the CogWatch project.

DEVELOPMENT

The sides of the instrumented handle are made out of strips of steel. The strain gauges are used to measure the small amounts of bending that occurs when any force is applied. This gives a generalised measure of grip force applied across the handle. Adding more than one strain gauge to each side of the handle could help to build a more accurate calibrated model of grip force, but the increase in circuit size, power consumption and cost would be

unacceptable for the CogWatch project. For the same reasons, a design with a minimal number of strain gauge fitted grip sensing sides was chosen.

An initial prototype with only 2 grip sensing sides was rejected because it was found that during use a lot of grip force is applied to the wrong sides of the steel strips, where it cannot be properly detected. With three sensing sides most grip patterns apply force in the correct sensing directions and so this has been chosen as the ideal design:

Figure 11 - Prototype handle dissection and prototype instrumented fork.

An updated prototype is being built with much smaller electronics neatly integrated into the handle. The design of the circuitry is very similar to the sensor unit design, except for the addition of an amplification circuit for the strain gauge signal.

A simulated eating trial was conducted to test the quality of data obtained from an instrumented knife and fork. The participants were instructed to carry out eating actions with a knife and fork in two distinct styles. The styles of eating involved different orientations of the fork and usage of the fork; depending on culture, usually at least one of the styles of fork usage would be unfamiliar to the participant. For health and safety (as well as practical) reasons, participants were instructed to not actually eat the food but to put it back on the plate after raising it to their mouth as if they intended to eat it.

The following observations were made about the data collected from the experiment:

- There are many large variations between how different participants perform similar short actions (short action ~ 1 second long). As a result it may be extremely difficult to build a normal cutlery usage model; this would be required to detect small anomalies in grip and motion that patients may exhibit. However obvious mistakes such as incorrect orientation and extremes of grip are possible to characterise.
- Participants who were familiar and experienced with a style of eating exhibited very similar repetitions of grip and movement patterns (Figure 13). The inexperienced

participants showed a much higher variability in their actions (Figure 12). In theory changes in the quality of action repetition could be measured over time and used as rehabilitation metric.

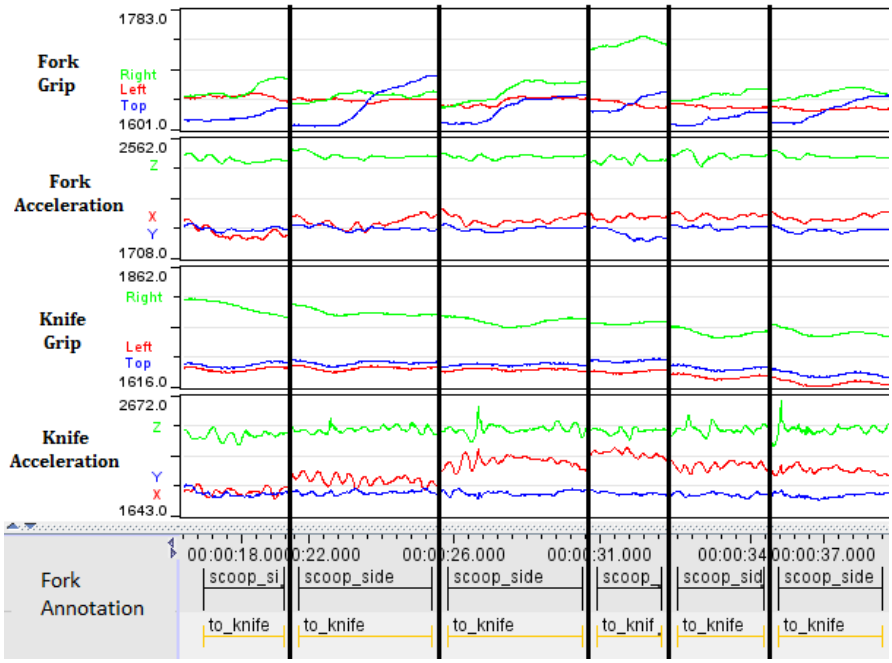

Figure 12 - Inconsistent cutlery used samples.

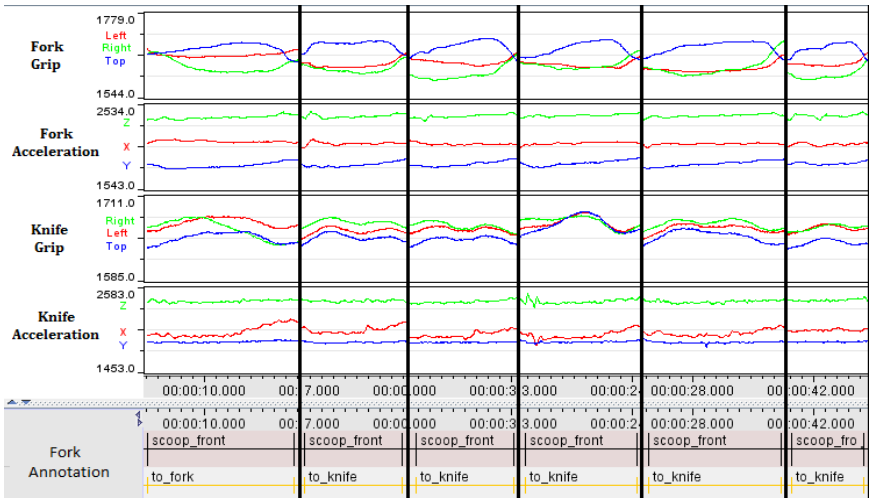

Figure 13 - Consistent cutlery use samples.

4.1.2 Wearable devices

4.1.2.1 Watch

There are different commercial devices to be used in the project with very interesting functionalities already mentioned before in the document. The following figure shows the possible designs of the wearable watches that could be used in CogWatch:

Figure 14 - Possible wearable watches.

The wearable watch selected must be composed by the following main components in order to achieve the corresponding functions provided in CogWatch:

DIGITAL DISPLAY

First of all, the digital display must have a buffer structure in memory. There are different types of digital displays supported by the platforms which can be used in the project today:

- 96x96 pixel TFT LCD,
- 16x80 pixel OLED,
- with or without colour,
- and possibility of tactile display.

In the first case, the LCD display is 96x96 pixel monochrome. Each LCD buffer is arranged as 96 lines of 12 bytes. According with OLED displays, they are both 16x80 monochrome. All buffers are arranged as two eight pixel high rows (lines), so the display can be used either as one line (16 x 80 pixels) or two lines (8 x 80 pixels each).

Finally, the display can be controlled from the local system or from a wireless connection.

ACCELEROMETER

An accelerometer could be embedded in the watch hardware. Motion events can be detected by setting it to wake up on orientation change, tap detection, or programming the accelerometer's motion thresholds.

The usage of the accelerometer is highly application dependent. The amount of power used by the accelerometer would exceed the rest of the watch if it were left on continuously. For that reason, control of the accelerometer must be left to the application.

The accelerometer will have its own dedicated port so the application task is not blocked for a long period of time waiting to access the corresponding bus.

BATTERY MONITOR

Battery state would be handled automatically. For the different devices to be used in the project acting as wearable watch the full state of the battery is achieved in, approximately, 4 hours and it lasts between 4 and 5 days. A micro USB socket with a kind of clip is usually implemented which allow to plug the watch into a USB hub or any 5V USB power source to recharge.

Common batteries of 3.7V 75mAH lithium ion coin cell can be used.

BUTTON/TACTILE DISPLAY INPUTS

Button or tactile display inputs would be interrupting driven so the button/display events would be sent to the application and/or VTE monitor immediately after the button/display debounce time.

VIBRATION MOTOR

The watch must contain a vibrator as its function is one of the main goals of the device. Its default use is to notify the user different kind of events, low battery, and to indicate that the Bluetooth link is lost. This will be used to achieve the goal of CogWatch focused on haptic feedback.

BLUETOOTH WIRELESS

Finally, a Bluetooth radio interface may consist of a serial port running at 115.2 kbits/s. A serial port speed can be used to limit the Bluetooth throughput to, for example, 80 kbits/s. With a common buffer configuration, the receive rate can be limited to 30 kbits/s. Clear to Send (CTS) can be used to wake the microcontroller when the radio is in sniff mode. This allows the microprocessor to remain in a low power mode while waiting for messages from the VTE monitor.

4.1.2.2 Sensorised clothes

Works have been carried out in two areas:

- Sensing Textiles: development of an intelligent shirt, with electrodes.
- Vital Signs Ubiquity Monitoring: development of domotic devices, data capture and communication.

ECG RECORD

RGB has been working on capturing ECG signals from textile electrodes. Several tasks have been performed:

- Design of textile electrodes based on conductive textile, and conductive ink to be printed on textile substrate.
- Set-up and characterization of textile solutions.
- Characterization and study of different topologies and placement by means of recordings with healthy volunteers.

STUDY OF CONDUCTIVE TISSUE

Several types of electrodes were developed from different conductive tissues, making a first evaluation starting with contact impedance, with a dry electrode surface. Gold- reference was a standard electrode with gel.

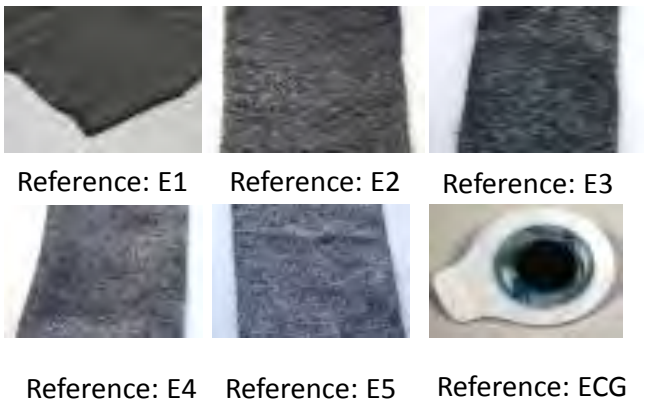

Figure 15 - Different kinds of electrode tissues.

In Figure 15, the different conductive tissues are represented, bellow a description of each referenced tissue is provided:

- Reference: E1. Fabric made of 92% nylon covered with silver, with 8 % of elastane.
- Reference: E2. Terry fabric made of polyamide-plated silver with a purity of 99%. Gauge: 10.
- Reference: E3. Terry fabric composed of 80% silver plated polyamide 99% purity + 20% cotton. Gauge: 10.
- Reference: E4. Single jersey fabric made of polyamide coated with silver by 100%. Gauge: 10.
- Reference: E5. Terry fabricm composed of silver coated polyamide with 99% purity. Gauge: 10.
- Reference: ECG. Conventional electrode ECG Ag/AgCl.

The impedance of each electrode was measured with respect to a common reference, based on a standard electrode. Measures were taken in different moments during an 8h interval in order to observe the evolution of both the textile electrodes as well as the standard ECG

electrode over long monitoring periods. A recording was made over a large bandwidth in the range between 20Hz and 200 kHz in order to get the maximum of information.

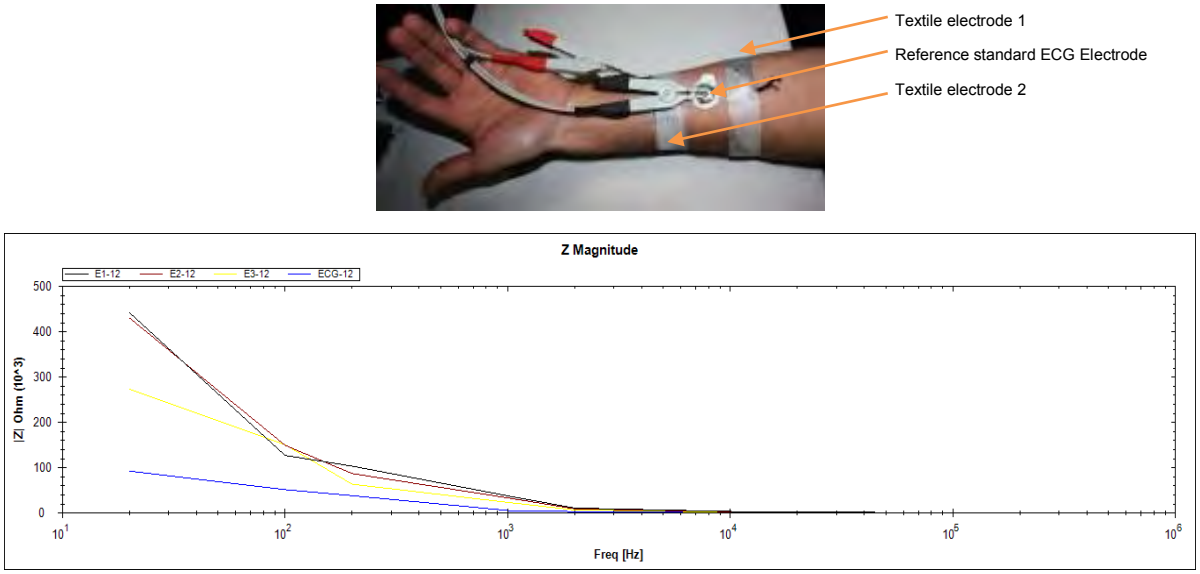

Figure 16 - Graphics E1, E2, E3 vs. ECG hour 2.

DESIGN SETUP CHARACTERIZATION OF ELECTRODES

In order to be able to objectively quantify the electrical performance of the electrodes, an artificial skin made of “Agar” as a base has been made.

Different Agar concentrations have been made with the NaCl 2,5 10 -4 M dissolution in order to study the Agar concentration. The best results are obtained with 14 % up to 16 % dissolutions of Agar. All measures will be taken with this system.

MEASUREMENTS OF IMPEDANCE VS APPLIED PRESSURE

In order to be able to obtain objective data regarding the quality of the electrodes contact with the skin, measurements of contact impedance of each type of electrode according to the pressure applied against the surface has been made.

For this purpose, some test samples has been designed of the amount of compression force of the Universal machine, which has 11 mm diameter and a connection to the impedance electronic monitor. The force of the clump on the electrodes was modified in a controlled way, recording it at 1 kHz frequency, 1 V. Figure 17 shows the impedance variation with force of silver tissues used to manufacture ECG electrodes.

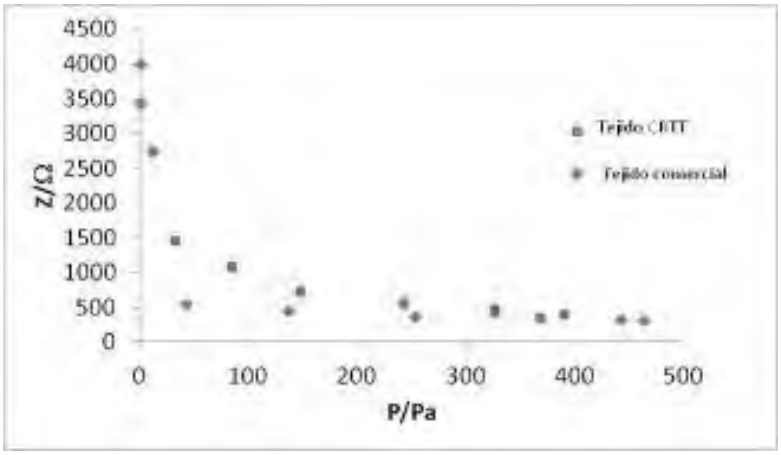

Figure 17 - Impedance variation with force of silver tissues used to manufacture ECG electrodes.

DESIGN AND CHARACTERIZATION OF TEXTILE ELECTRODES: TOPOLOGY, PLACEMENT AND RECORDINGS IN HEALTHY VOLUNTEERS

Once selected the most adequate tissues, several electrodes were made: Wrist, arms, Brest belt, and waistline.

The location of the electrodes has to be taken according to projections in vectors I, II, III, aVR, aVL and aVF of the Einthoven triangle shown in the next figure to represent the polarization and depolarization of the electrical activity of the myocardial cells. The green point represents the common ground to acquire a differential measurement.

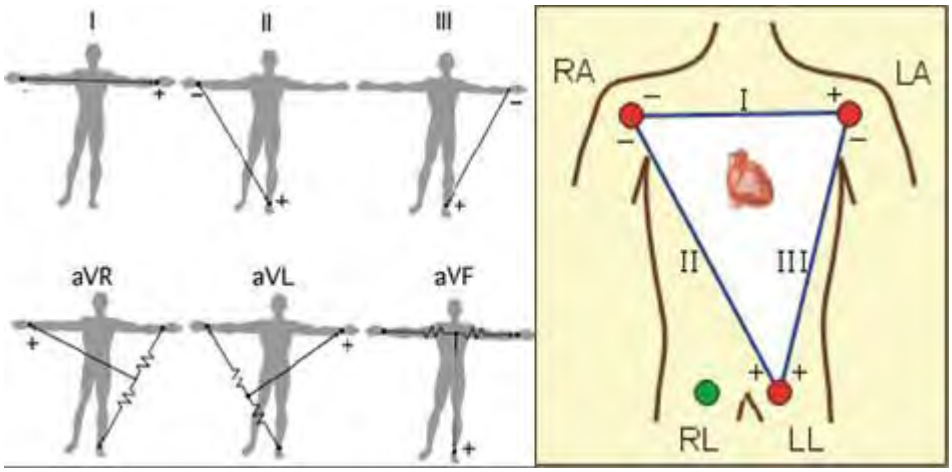

Figure 18 - Einthoven triangle.

The so designed electrodes have an elastic base with the tissue sewed on top of it. There is Velcro® at each end to facilitate adjustment in each patient. For the connection to the equipment, there are snaps.

Figure 19 - Arm Electrodes tissue E6.

Figure 20 - Brest belt electrodes tissue E6.

During the recording, the impedance between different points was measured. In the following figure, it can be observed how impedance values both for arm textile electrodes as well as ECG have similar performance.

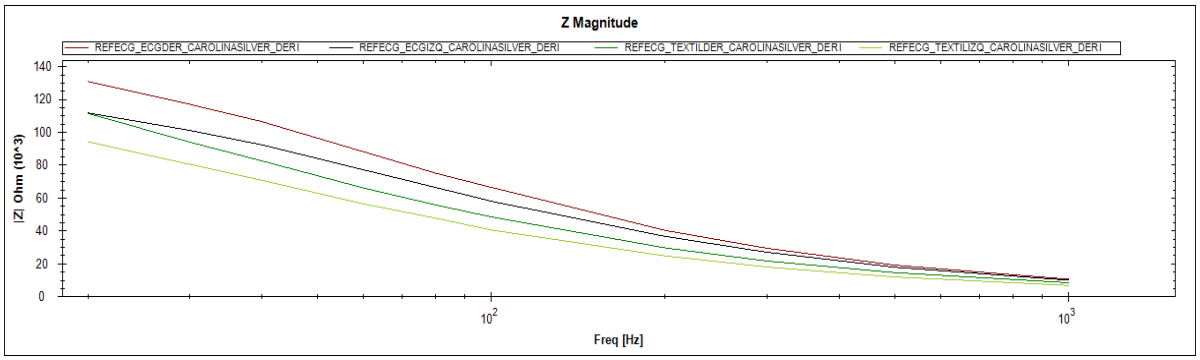

Figure 21 - Mean impedance between arm textile electrodes and ECG.

The combination of electrodes that provides the best results was decided to be arm, and waist so it was then developed a wearable shirt with electrodes incorporated as indicated in figure below.

Figure 22 - Inside view.

The integrated electrodes were made with conductive tissue using nylon tissue covered with silver “nylon knit fabric silver coated (reference E6)”, since it provided the best contact impedance value and being also more comfortable to wear.

In order to minimize artefacts to movement, the design of the shirt must guarantee a good and tight adjustment of the electrodes to the body. Therefore, in the arm electrodes, a Velcro® ribbon has been placed. The ribbon material absorbs the contour variations due to arm movement, which would otherwise affect the skin-electrode contact.

Figure 23 - Outside view of adjustments in arms and waist.

The Waist electrodes can be tightly fixed to the body by means of a belt that can also be used to allocated vital signs modules.

Figure 24 - Waist electrode.

Signal conduction from electrodes to the acquisition modules is made with ECG cable tunnelled though hidden tubes, using the same tissue as the shirt, and connected by means of snaps. The correct operation of the device was validated in healthy volunteers.

ECG MÓDULE WITH WIRELESS COMMUNICATIÓN

An ECG measuring board has been designed, as shown in Figure 25 below:

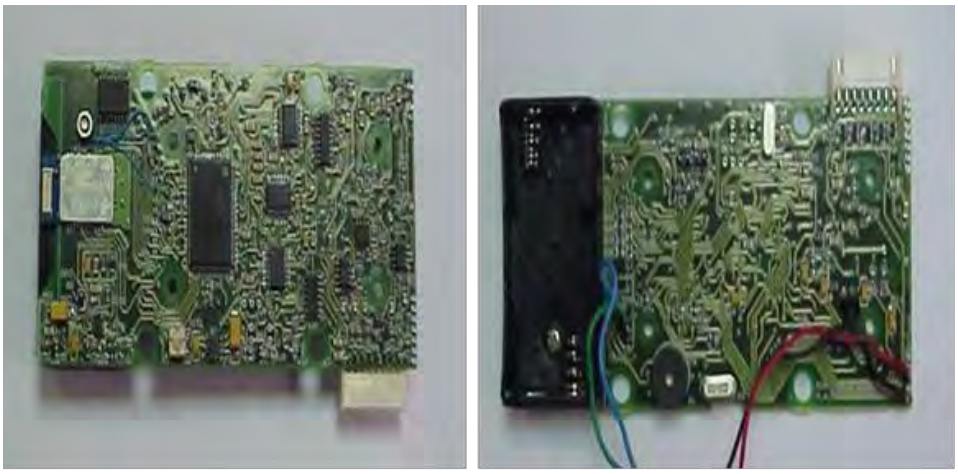

Figure 25 - ECG board, side A (left) and B (right).

In this design, a chip has been integrated to provide BT wireless communication, and a 128 Mbits flash memory that allows for capture and storage of vital signs.

ECG provides up to 5 electrodes. We will use the 4 electrodes configuration because it is easier to integrate in the shirt with textile electrodes, and we can record simultaneously the main waveforms I, II and III plus the amplified aVR, aVL y aVF. For the simultaneous recording of these waveforms, it has been necessary to integrate 3 analog/digital converters, operating in parallel. Normal leads are directly obtained from converters, but the amplified ones are computed from the previous. This has required a very precise signal conversion in order to guarantee that the samples obtained are well synchronized.

Two boards have been mounted which a first prototype has been developed with. In order to carry out the first experimental tests, it was programmed a real time communication protocol, that recorded lead I (between electrodes in the arms), such as it has been shown in figures above. This procedure has an electrical consumption of 110mA, that is, autonomy of 20 h at least. The duration can be augmented considerably, if we apply a packet based communication System to optimize the speed transmission of the BT module.

Figure 26 - ECG Module.

ECG ELECTRONICS

The biosignal is collected by means of electrodes with a voltage level in the order of milivolts, and is also contaminated by electric noise. The main two objectives of the adaptation electronics are:

- Amplify the signal in order to have enough resolution capable to identify the specific characteristics of the electrocardiographic signal.
- Filter noises coming from surrounding electromagnetic sources.

Before starting the ECG signal conditioning module, it must be provided an electric isolation at the input. In the following figure, we can see the schematics containing a high frequency pre-filtering, a high voltage protection and a signal follower. This electronics is applied to the input signal of each of the 5 electrodes.

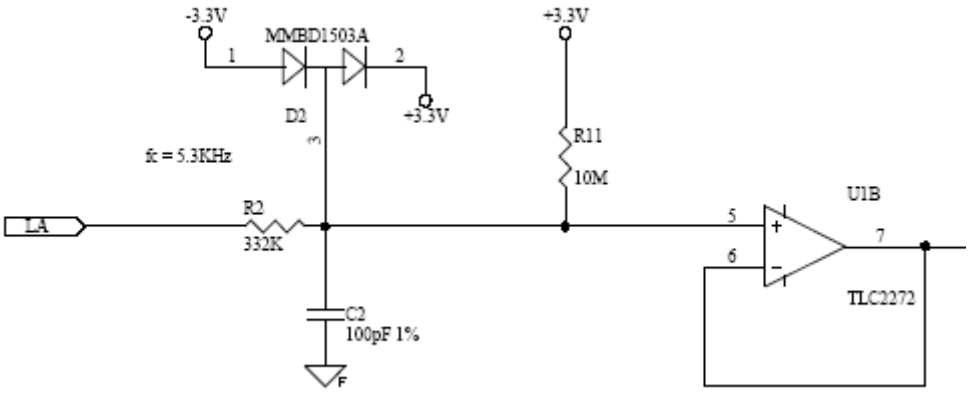

Figure 27 - Isolation stage.

In order to make the electronics work with the same voltage reference that the one coming from the electrodes, it is also necessary to include a feedback module. In the following figure we can see how this module captures the “Wilson point” for the RA, LA and LL electrodes, in order to amplify and invert it, and finally to inject the current in the RL electrode, which is used as reference.

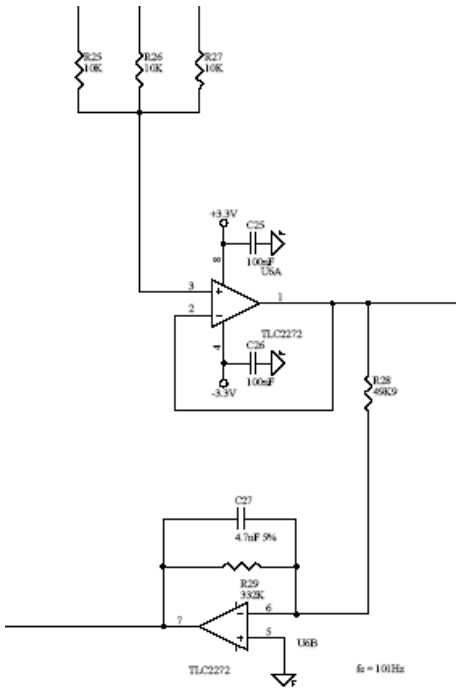

Figure 28 - Feedback image.

Once it has been achieved the conditioning, we can now initiate the capturing of the ECG signal. For this purpose it is used analog/digital delta-sigma converters that allow integrating in a single component the amplification stage plus the high resolution (24 bits) A/D conversion. Thanks to this high conversion resolution, it can be carried out a high performance digital filtering obtain a sufficiently clean signal that will make it possible to identify the essential features of the electrocardiogram (ECG).

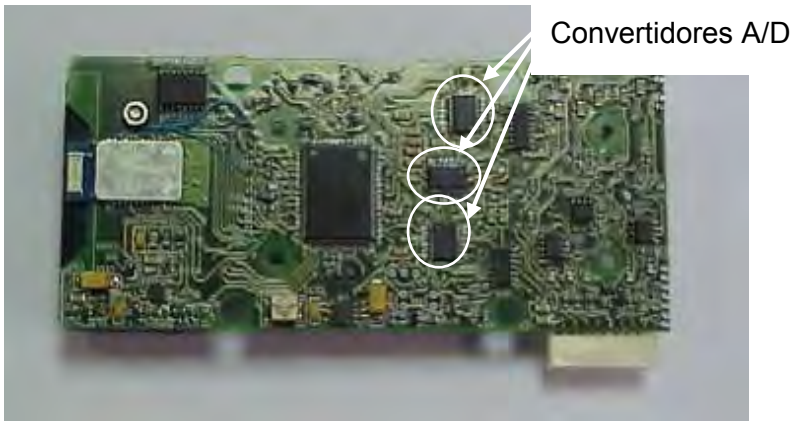

Figure 29 - Conditioning circuit for ECG measurement.

The electronic circuit has been designed in order to work with 4 or 5 electrodes. Therefore it has been incorporated 3 A/D converters with the objective to simultaneously obtain the I, II and II leads as well as aVR, aVL y aVF amplified leads when it is used the configuration with 4 electrodes. With the 5 electrodes configuration it is also obtained the precordial lead V.

4.1.3 Video image acquisition

Kinect is a very suitable device for achieving the task this section is focused on, because it provides two cameras and an infrared projector which allow knowing the different characteristics of the environment. The RGB camera is used to get a color image of the workplace and the infrared one to obtain information about the deepness of the different elements involved in the task.

The device is composed by the following main components showing in the Figure 30:

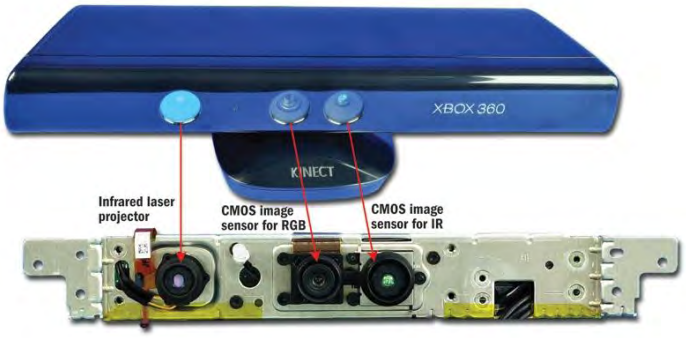

Figure 30 - Kinect components.

COLOR IMAGE DATA

This camera provides a color image of the environment. Color data is available in the two following formats:

- RGB color provides 32-bit, linear X8R8G8B8-formatted color bitmaps, in sRGB color space. To work with RGB data, an application should specify a color or color_YUV image type when it opens the stream.
- YUV color provides 16-bit, gamma-corrected linear UYVY-formatted color bitmaps, where the gamma correction in YUV space is equivalent to sRGB gamma in RGB space. Because the YUV stream uses 16 bits per pixel, this format uses less memory to hold bitmap data and allocates less buffer memory when the stream is opened. To work with YUV data, the application should specify the raw YUV image type when it opens the stream. YUV data is available only at the 640x480 resolution and only at 15 FPS.

Both color formats are computed from the same camera data, so that the YUV data and RGB data represent the same image.

The sensor array uses a USB connection to pass data to the VTE monitor, and that connection provides a given amount of bandwidth. The Bayer color image data that the sensor returns at 1280x1024 is compressed and converted to RGB before transmission to the runtime. The runtime then decompresses the data before it is passed to the application. The use of compression makes it possible to return color data at frame rates as high as 30 FPS, but the algorithm that is used leads to some loss of image fidelity.

DEPTH DATA

The depth data stream provides frames in which each pixel represents the Cartesian distance, in millimeters, from the camera plane to the nearest object at that particular x and y coordinate in the depth sensor's field of view. The following depth data streams are available:

- Frame size of 640×480 pixels.
- Frame size of 320×240 pixels.
- Frame size of 80×60 pixels.

Applications can process data from a depth stream to support various custom features, such as tracking users' motions or identifying background objects to ignore during application play.

A depth data value of 0 indicates that no depth data is available at that position, because all the objects were either too close to the camera or too far away from it.

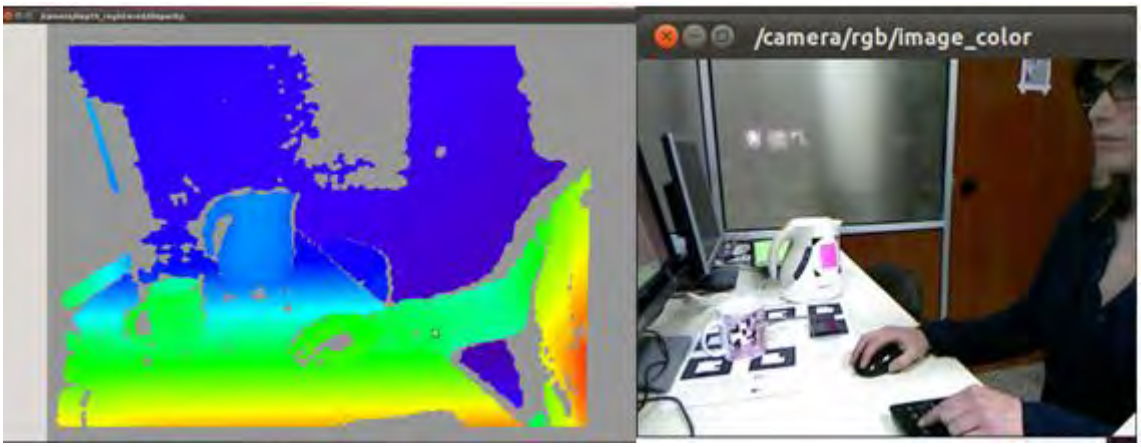

Figure 31 - Kinect data.

MICROPHONES

The device consists of four microphones faced down, one left and three on the right. These collect in the best way possible distance voices, and furthermore the board processing unit cancels the noise. In this way, it is possible to separate the voice of a person specifically detected and ignore the rest and the other sounds that may be there.

MOTOR

It allows a tilt movement that is necessary for taking a better vision of the environment.

Kinect sensor ranges and the sensor array specifications are shown in the following table:

Playable Ranges for the Kinect for Windows Sensor

Sensor item	Playable range
Color and depth stream	4 to 11.5 feet (1.2 to 3.5 meters)
Skeletal tracking	4 to 11.5 feet (1.2 to 3.5 meters)

Kinect Sensor Array Specifications

Sensor item	Specification range
Viewing angle	43° vertical by 57° horizontal field of view
Mechanized tilt range (vertical)	±28°
Frame rate (depth and color stream)	30 frames per second (FPS)
Resolution, depth stream	QVGA (320 × 240)
Resolution, color stream	VGA (640 × 480)
Audio format	16-kHz, 16-bit mono pulse code modulation (PCM)
Audio input characteristics	A four-microphone array with 24-bit analog-to-digital converter (ADC) and Kinect-resident signal processing such as acoustic echo cancellation and noise suppression

Table 7 - Kinect specifications.

A good advantage of this is that Kinect is a continuous development device. Lately, it is available Kinect for Windows. It expands the possibilities for innovation with features like Near Mode, which enables the depth camera to see objects as close as 40 centimetres in front of the sensor. In addition, up to 4 Kinect sensors can now be plugged into the same computer.

In order to ensure the correct implementation, firstly, it is necessary to calibrate Kinect so that the compilation of the information will be better, more accurate and more reliable. When this point is done successfully, and all the parameters are saved, Kinect is ready to be used. Secondly, it is possible to know the position of each joint of a person. This is the first goal of Kinect because it is necessary to tracking the patient hands for guidance during the execution of a daily task. With visualization interface, as shown in the figure, it is possible to see all of this.

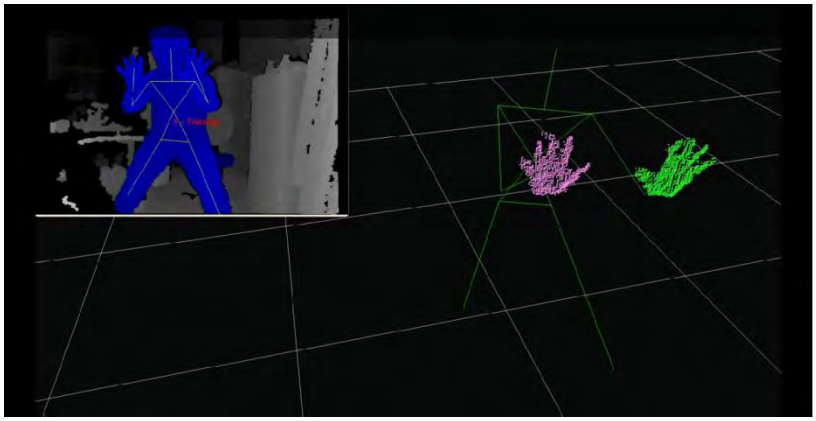

Figure 32 - Patient detection.

With Kinect it is possible to record video of the whole scenario where the patient execute the corresponding task in order to provide useful information to clinicians to assess the progress of the patients.

Finally, as mentioned before in the deliverable, besides the hands position detection and positioning, and video recording, Kinect also provides additional information of object recognition. In this case, it is necessary to use both cameras again but now the procedure consists of an image analysis. So, in Figure 33, the recognition of the kettle when it is moved around the work place is presented. Objects detected appear red coloured. Finally, once the model is saved, the object can be recognized when the task is running.

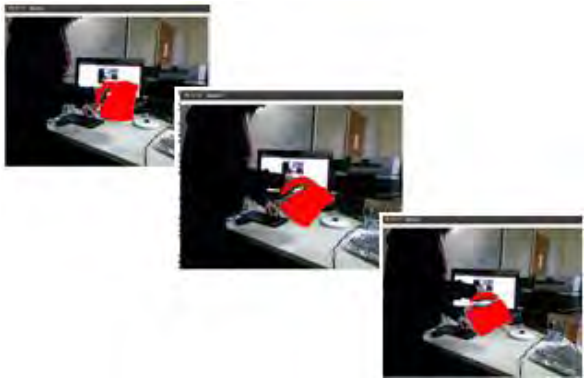

Figure 33 - Object recognition.

4.1.4 VTE monitor (All-In-One + tablets)

At patient's house, it is necessary to have a home processor and different displays for feedback during the executing of the daily tasks.

The best solution is to use an All-in-one computer, because it is composed by a screen and a CPU. It can be an advantage because it doesn't need too many cables, so it is easier to be installed at home.

This computer will be installed in the Kitchen/living room. In the other scenarios, the option of installing tablets could be considered.

VTE monitors are good devices and easy to be installed. They have tactile screen which is quite good and useful because the patient may have an interface and he/she might choose the task that he/she wants to do in order to start and stop the application.

Initially, Kinect would be plugged to the All-in-one, but the possibility of plugging it to the tablets could be considered.

4.1.5 Hospital computer

According to CogWatch expected impact 1, “The project will aim to develop a home-based personalised cognitive rehabilitation system that will allow AADS patients to be discharged from hospital as soon as appropriate assessments and training using the system have been completed successfully. Moreover, patients visits to hospital and/or visits of healthcare professionals to patients’ home will be reduced since: first, the action guidance, error correction and risk avoidance cues will provide continuous rehabilitation at home, when it is needed; and second, healthcare staff will be able to monitor and assess patients status and progress remotely by accessing behavioural and physiological data at the hospital site”.

Based on this, and the architecture previously described, the medical side will be composed by any computer or Internet enabled device that will be used by the administration and clinical personnel. Given that it will be developed as a web portal, it will be accessed from any location with an internet connection.

4.2 Hierarchical approach of the system components

This section presents a “hierarchical” view of the system. The system hierarchical layers are sorted according to the user’s experience: the first layers to appear that those that user “feels” first.

1. First layer: Human-Machine Interaction. The users (patients and therapist) access the CogWatch system. This level comprises all the end user devices: VTE, smart watch, portable devices, wearable sensors, sensorized objects, Kinect, etc.).

   Different interfaces and interaction modalities will be possible, depending on the patient type and capabilities (e.gl visual, tactile, speech and/or sounds, haptic, etc.). In addition, the medical professional and the administrative professionals at the hospital or rehabilitation centre will access a different interface.

2. Second layer: Components. This layer explains the system behaviour as modules and interaction between modules. Databases, modules, services, engines, communication protocols all appear at this layer. This is the layer where the core system architecture design will take place. Some examples are CogWatch client, the CogWatch healthcare sub-system, the CogWatch Web-portal sub-system, the CogWatch medical side, etc.

3. Third layer: Physical. This layer describes the system as devices, hosts, servers, networks, connections, software pieces, etc. that is the “physical” components of the system and how these components match to the architectural modules.

This layer is designed by Test Sites (UPM, UoB and TUM) by “instancing” the software architecture for the particular Site.

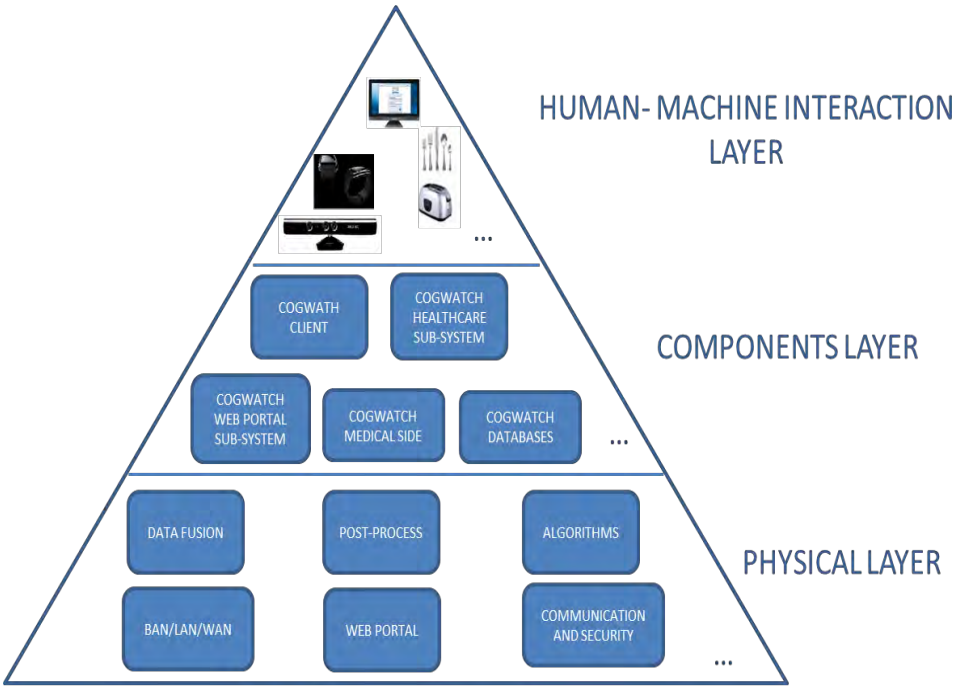

Figure 34 - CogWatch system hierarchical description.

5. APPLICATION SPECIFICATION

Once the specifications of the components and the general architecture have been introduced, now it is time to define the applications and functionalities provided by the main devices patients will interact with.

5.1 Home applications

5.1.1 Virtual Task Execution application (VTE)

5.1.1.1 Recognition and prediction algorithms

The recognition algorithms that will be used in the first CogWatch prototype system are described in deliverable D3.1 “Report on action recognition techniques”.

The optimal inputs to the recognition system will be determined empirically during development, but will be taken from the outputs of RFID tags, accelerometers and pressure sensitive resistors that are attached to the objects used in the task, plus hand coordinates obtained using a customized version of the Kinect system, as described in chapter 4.

A hierarchical tree based description of the tea-making task was presented in CogWatch deliverable D1.1. This breaks the tea-making task into a set of sub-tasks, which in turn are described in terms of a set of actions. In the prototype system we propose to model these actions using hidden Markov models (HMMs). The rationale for this choice is presented in detail D3.1. A simple text configuration file will express each sub-task as one or more sequences of these basic actions. The output of the HMM-based action recognizer will be a sequence of sub-tasks.

A Task Model (TM) will interpret these outputs. The function of the TM is to monitor the status of the participant with respect to the complete task. This may be deterministic, with a single TM-state capturing the current status, or a probability distribution over all of the TM-states (sometimes referred to as a belief state). The TM will update its state each time the participant completes a sub-task. If the sub-task is a valid extension of the current state then the TM moves to a new state, otherwise the TM remains in its current state and a cost is incurred. If the cost exceeds a threshold then the TM will indicate that errors are occurring and that the task may not be completed successfully, triggering appropriate cueing and feedback.

In the initial CogWatch prototype it is envisaged that the TM will be based on a Markov Decision Process (MDP), and that the states of the MDP will be defined through Hierarchical Task Analysis applied to the tree-based description of the tea making task. This is not ideal, and it would be much better if the TM were learnt automatically from real example data. However, in the short term (which includes the time-frame for developing the first prototype) this is not feasible and a more knowledge-driven approach is necessary. However it is envisaged that future versions of the system will employ a TM learnt from data supplied through WP1.

5.1.1.2 Graphical Users Interfaces

The graphical user interfaces describes the way in which the information will be presented and the software requirements involved in the task.

In the first hierarchical level, the patient will select the task desired by starting the application thanks to the multitouch screen.

The input data required for the simulation is the performance task and the position of the tools that involves the task. With this information a state machine will be launched.

For the task petition, once the patient has executed the corresponding action the clinician ask him/her to do, if there is an error or the time to execute the task is bigger than a fixed threshold, the state machine will perform what it is called micro tasks. The connection implemented between those micro tasks defines global tasks. This means that the system is able to execute the tasks as much detailed as the user wants. In case of additional voice guidance, the genre of the voice will be preferable female as many studies suggested that emphasizes with the patient and reduce the impact (Massimiliano, 2005; Carpenter, 2009; Cesta, 2007).

As the reproduction of a task order or the visualization of a picture does not require special features the system requirements will be focused on the graphical simulation.

The minimum technical graphic requirements for a good performance of the simulation are:

Graphics Card	Driver	Platform / OS
Nvidia GeForce 210	NVIDIA-Linux-x86-190.*-pkg1.run and 195.17 beta	64Bit Ubuntu Karmic
Nvidia GeForce GT 240	Default selected by Ubuntu 10.04 hardware manager	32Bit Ubuntu 10.04
Nvidia GTS 360M	Default selected by Ubuntu 10.04 hardware manager	64Bit Ubuntu 10.04
Nvidia GTX 275	Default selected by 10.04 hardware manager	64Bit Ubuntu 10.04
Nvidia GTX 285M	Nvidia 260 and 270	64Bit Ubuntu 10.04
Nvidia GeForce 9500 GT	Default selected by Ubuntu 10.10 hardware manager, or even better, the newest nvidia driver using ppa:ubuntu-x-swat/x-updates	64Bit Ubuntu 10.10
Nvidia GeForce 6200	Nvidia-Linux-x86-190.*-pkg1.run	32Bit/64Bit Ubuntu Hardy and Karmic

Graphics Card	Driver	Platform / OS
Nvidia GeForce 5200	Nvidia-Linux-x86-173.*-pkg1.run through 190.53	32Bit/64Bit Ubuntu Hardy and Karmic
Nvidia GeForce 8400GT	Nvidia-Linux-x86-173.*-pkg1.run through 190.53	32Bit/64Bit Ubuntu Hardy and Karmic
ATI Radeon HD 3450	Proprietary driver for ATI/AMD proprietary FGLRX graphics There are restricted drivers manager	Ubuntu Karmic
ATI Radeon HD 3850	Proprietary driver for ATI/AMD proprietary FGLRX graphics, also had to disable Gnome's fancy visual effects	Ubuntu Karmic
ATI Mobility Radeon HD 3470	Proprietary driver for ATI/AMD proprietary FGLRX graphics (Ubuntu restricted driver) - Need to turn off visual effects	64Bit Ubuntu 10.04
ATI Mobility Radeon HD 4670	Proprietary driver for ATI/AMD proprietary FGLRX graphics (Ubuntu restricted driver)	64bit Ubuntu Karmic
ATI Mobility Radeon HD 5730	Default selected by Ubuntu 10.04	64Bit Ubuntu 10.04
ATI integrated Radeon HD4200	Proprietary driver for ATI/AMD proprietary FGLRX graphics (Ubuntu restricted driver)	64Bit Ubuntu 10.04
ATI Radeon HD5770	Proprietary driver for ATI/AMD proprietary FGLRX graphics (Ubuntu restricted driver)	64Bit Ubuntu 10.04
ATI Mobility Radeon X1600	Open source ATI driver shipped with 64Bit Ubuntu Karmic. Occasional faults when system load is heavy.	64Bit Ubuntu Karmic

Table 8 - Minimum graphics requirements.

5.1.2 Watch application

Although, it is possible functionalities have already been introduced, the only goal of this device in the project is the vibration when the patient is grasping an incorrect object or executing an incorrect task or in a bad way.

5.1.2.1 Algorithms

In order to achieve the goal to be programmed in the watch, the following software structure composed by different tasks may be considered:

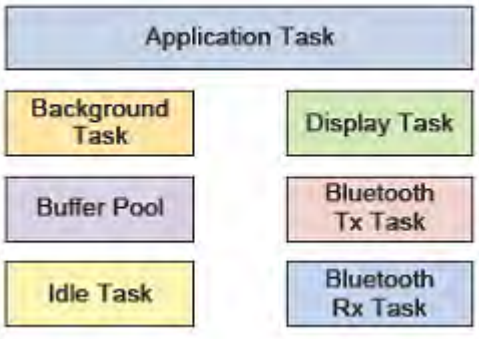

Figure 35 - Software architecture of the wearable watch.

APPLICATION TASK

The Application Task provides a way to customize functionality of the watch while executing a task during the rehabilitation but it also provides functionality when disconnected from the VTE monitor. It will be possible for the watch functions to be controlled completely through messages from the VTE monitor.

DISPLAY TASK

The Display Task is responsible for managing updates to the LCD (or OLED) display. Updates may be in response to a message from the Application Task or an internal event such as time update.

BACKGROUND TASK

The Background Task handles the system control and status functions, such as ambient light measurement, battery charging, button/tactile display status and monitoring/control of the vibration motor.

BUFFER POOL

Events and inter-task communication are performed using messages. A buffer pool is supplied to assist in managing message flow. Tasks are responsible for allocating a buffer when sending a message and freeing (or forwarding) a message placed on their queue.

IDLE TASK

The Idle Task is responsible for power management of the microprocessor. When no other tasks need to run, the processor is placed in a low power sleep mode.

BLUETOOTH TX/RX TASKS

Bluetooth communication is managed with a pair of tasks. Most of the communication does not require the involvement of the other tasks. Messages are sent to the VTE monitor by placing them on the Bluetooth transmit queue. Messages received from the VTE monitor are placed on the queue of the task(s) that has registered for them.

The Application Task is responsible for handling some Bluetooth events, such as pairing and (re)connection. Bluetooth API calls are provided to assist in managing the link.

5.1.2.2 Graphical Users Interfaces

Due to the limitations of the patients to interact with sophisticated devices, it is not very recommendable to design high complex user interfaces between the patients and the watch. However, it is attractive that patients could choose from different options related to the virtual task execution.

So, apart from the main objective of the wearable watch (vibration), in case of implementation of possible, simple and interesting proposal about graphical user interface, it could be interesting that the patient or therapist could (re)start the simulation from the wearable device by pushing a button or the tactile display.

The following figure shows the different interfaces the watch could display to the user:

Figure 36 - User interfaces of the wearable watch.

As shown in the figure, the first interface would let the patient start the simulation manually by selecting in the watch. Imagine that during the virtual task execution, the patient grasped an incorrect object; the watch would vibrate and show a message as indicated in the second interface. The third one shows a possible representation image of the cup the patient would have to choose, considering that he/she should have taken that one. Finally, the last interface would ask the patient if he /she want to start the simulation again or finish the application.

Finally, it is essential to mention that at the same time the messages shown in the figure appears, the watch vibrates in order to better catch the attention of the user.

5.1.3 Portable application

5.1.3.1 Algorithms

The algorithms used in the portable devices like tablets are the same as those used in the VTE monitor.

5.1.3.2 Graphical Users Interfaces

An important aspect of a user interface is the extent to which the logic of information display and control actions is consistent with the users' abilities, expectations, and likely behaviours.

The CogWatch system supports intelligent user interfaces which comprise advanced interaction methods both with the patients and the therapist, such as speech and visual output.

The patient interfaces (VTE, watch and portable devices) must be interactive and adapted to the capabilities of a patient with AADS, and not necessarily computer literate.

The therapist interfaces will be adapted to their content and presentation needs in order to facilitate the follow up of the patient's performance.

5.1.4 Summary of cueing methods during task execution

The following Table 9 shows a brief summary of the possible cueing methods (both basic and more advanced) that could be provided to the patients under a scenario, executing a specific task:

	WATCH	OBJECT/TOOL	VTE MONITOR
VISUAL CUEING	Static or dynamic text for warning/alerting error actions and for correct execution**	LED on correct/next object and for warning/alert sign**	Static or dynamic text/images for warning/alerting error actions and for correct execution*
AUDITORY CUEING			Warning/alert sounds by loudspeakers* Verbal statement of next action steps**
HAPTIC CUEING	Vibration*	Vibration**	

Table 9 - Cueing methods to patients.

* Basic functionality. (First prototype)

** More advance functionality.

Considering the visual cueing in VTE monitor, the following points should be taking into account:

- First/third-person perspective.
- Display virtual hands.
- Possible superimposed image of clinician.

Also, as a very advanced cue for future prototypes, the introduction of a kink of overhead video projection display on the table surface where the patient is executing the task could be interesting.

It is essential to point out the importance of intermittent reinforcement so the system would respond when a correct action has been made (e.g. green LED for correct object, red for wrong, etc.) and not just for errors. The cue for next action would be triggered with a slight delay after the error warning, so if the patient is fluent with the action, the cue does not display. Processing the cue demands attention and may compete with demands for action execution.

Finally, it would be useful to clarify that the cue which users respond the best to might not necessarily be the cue the user is most comfortable with.

5.2 Hospital/clinician applications

5.2.1 Graphical Users Interfaces

As previously mentioned, the medical side mainly consists of a Web portal. It can be accessed from any location provided with a laptop or desktop computer and an internet connection.

Two types of users are envisaged: the administrative personnel and the clinicians. The first ones will be usually employees at the hospital or rehabilitation centre, they will be able to register new patients, new clinicians and assign patients to therapists. The second ones will be able to follow up the performance and evolution of their patients.

The first page which opens when the appropriate URL is typed and is available to any potential user is the Login Page. This page consists of two text fields, one for the username and one for the password, and one button to submit potential user's credentials to the server. When a user types a valid username and password, he/she logs in the system according to his/her role (Figure 37).

Figure 37 - CogWatch login screen.

Following, some mock-ups of the healthcare professional user interface (UI) are provided. All of them have been designed following a common aesthetic, in coherence with CogWatch project image.

The screen will be divided into three different areas, as illustrated in Figure 38. The upper part indicates the name of the user, and has an icon identifying the type of user. In addition, it indicates the number of new notifications for the user.

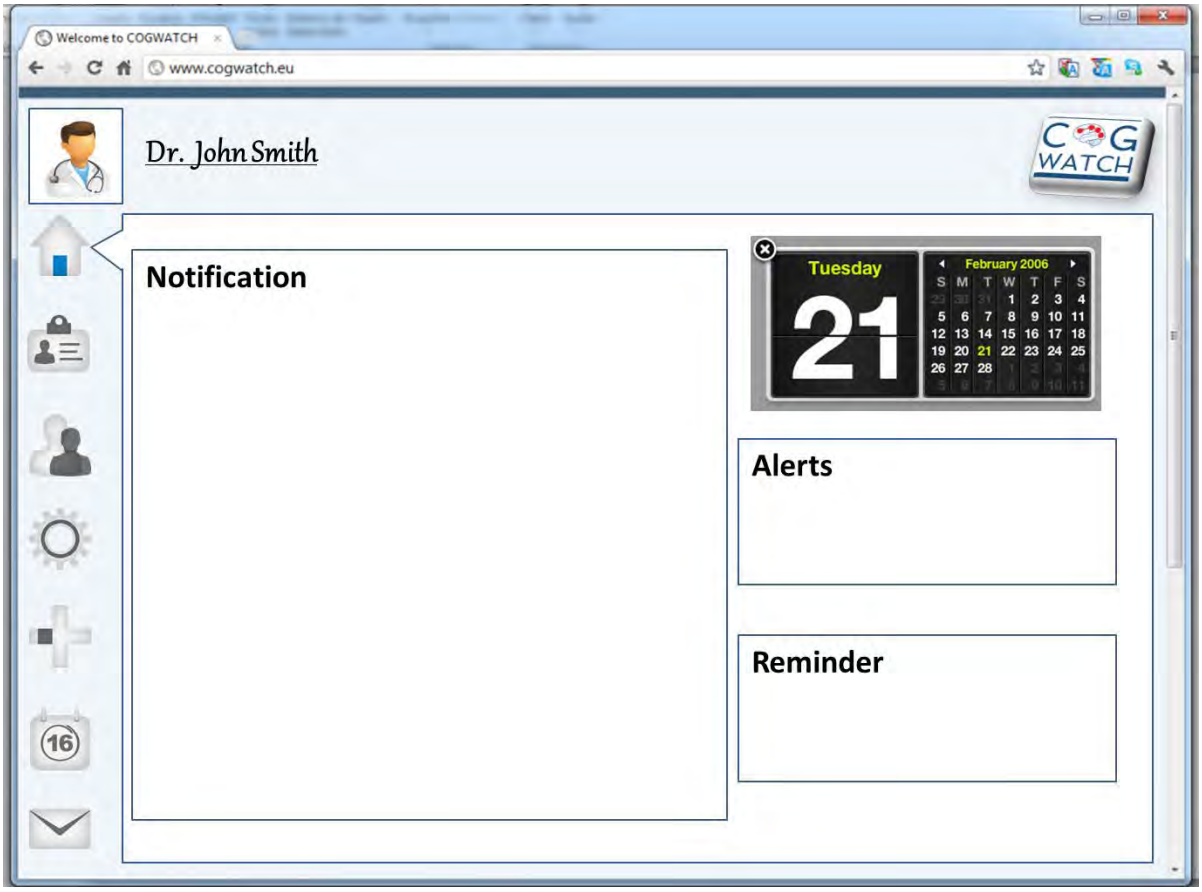

Figure 38 - CogWatch home screen.

The area to the left has several icons. Each one of them allows the access to different information. The active icon/information will be displayed in colour, in order to be differentiated from the rest. They are described below:

- Home: this is the main screen. The user will be able to see general information and notifications.
- Profile: it displays the information of the logged user.
- Patients: it presents an icon for each one the patients assigned to the specific clinician, as illustrated in Figure 39.

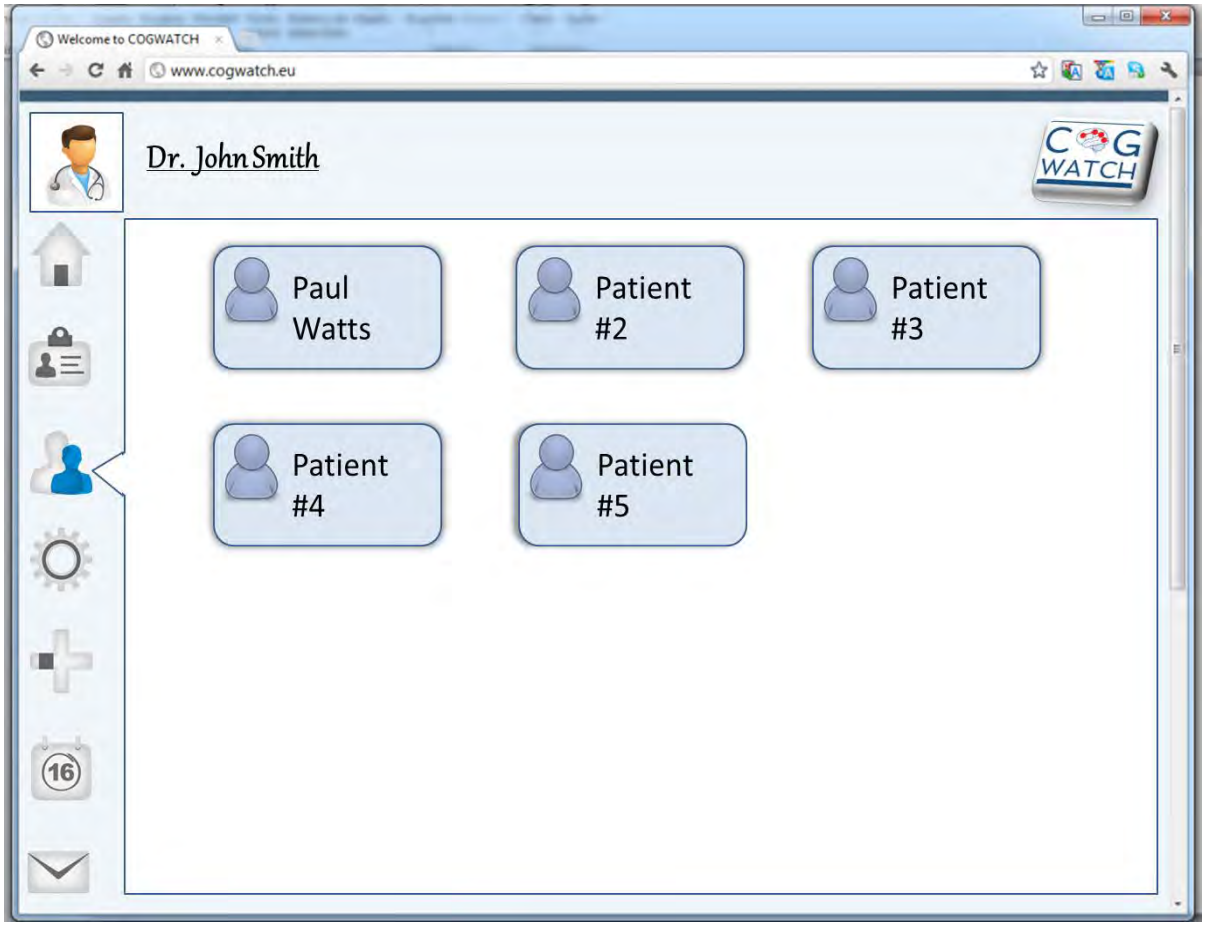

Figure 39 - CogWatch patients screen.

Once a specific patient is selected, the clinician will be able to access his/her information:

- Personal information: such as name, surname, address, telephone and e-mail.
- Caregiver information: information of the relative of informal caregiver of the patient such as the name, surname, address, telephone and email.

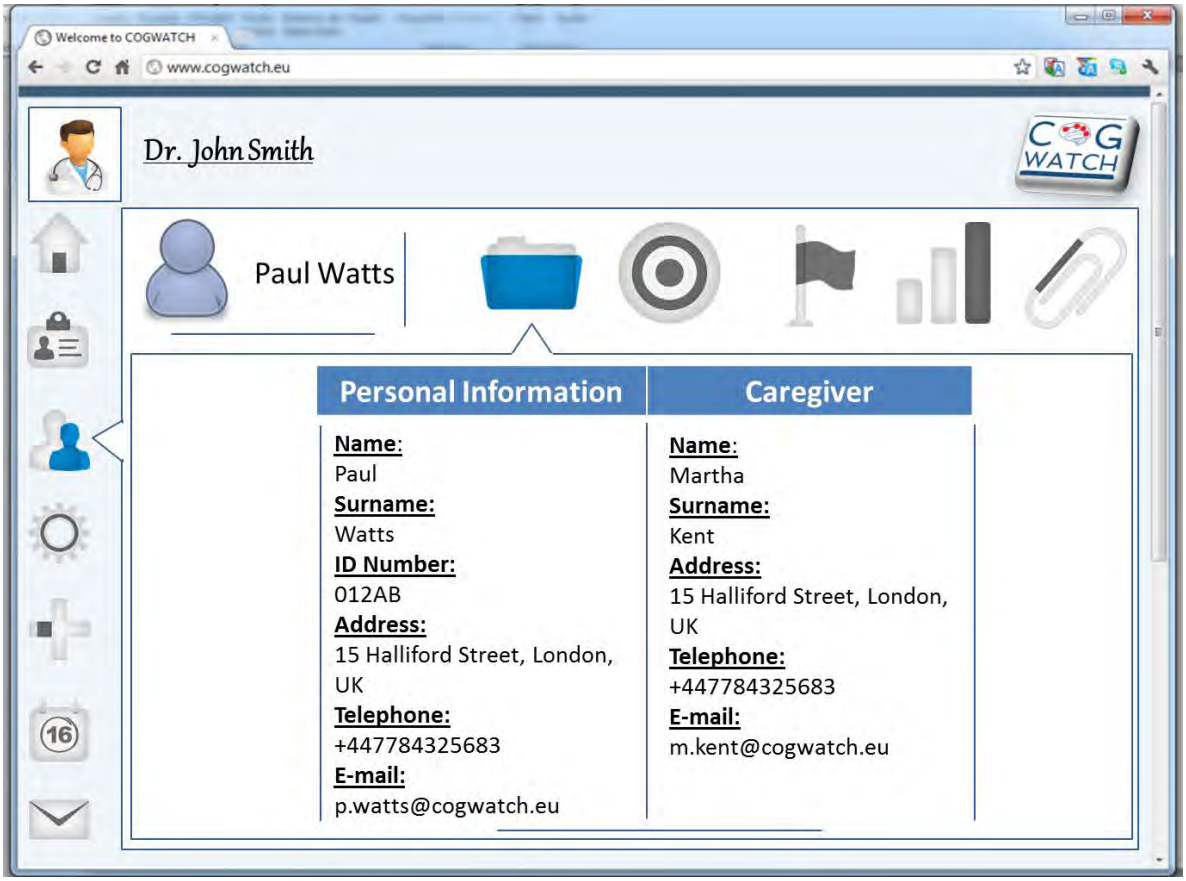

Figure 40 - CogWatch patient personal information and clinician data.

- Medical information: it will display information about the medical status of the patient. It includes relevant data such as the date of the last stroke event and the total number of suffered strokes, neurological diseases and other diseases of the patient.
- Treatment information: it includes information about the patient drug intake. i.e. drug type, dosage and intake schedule.

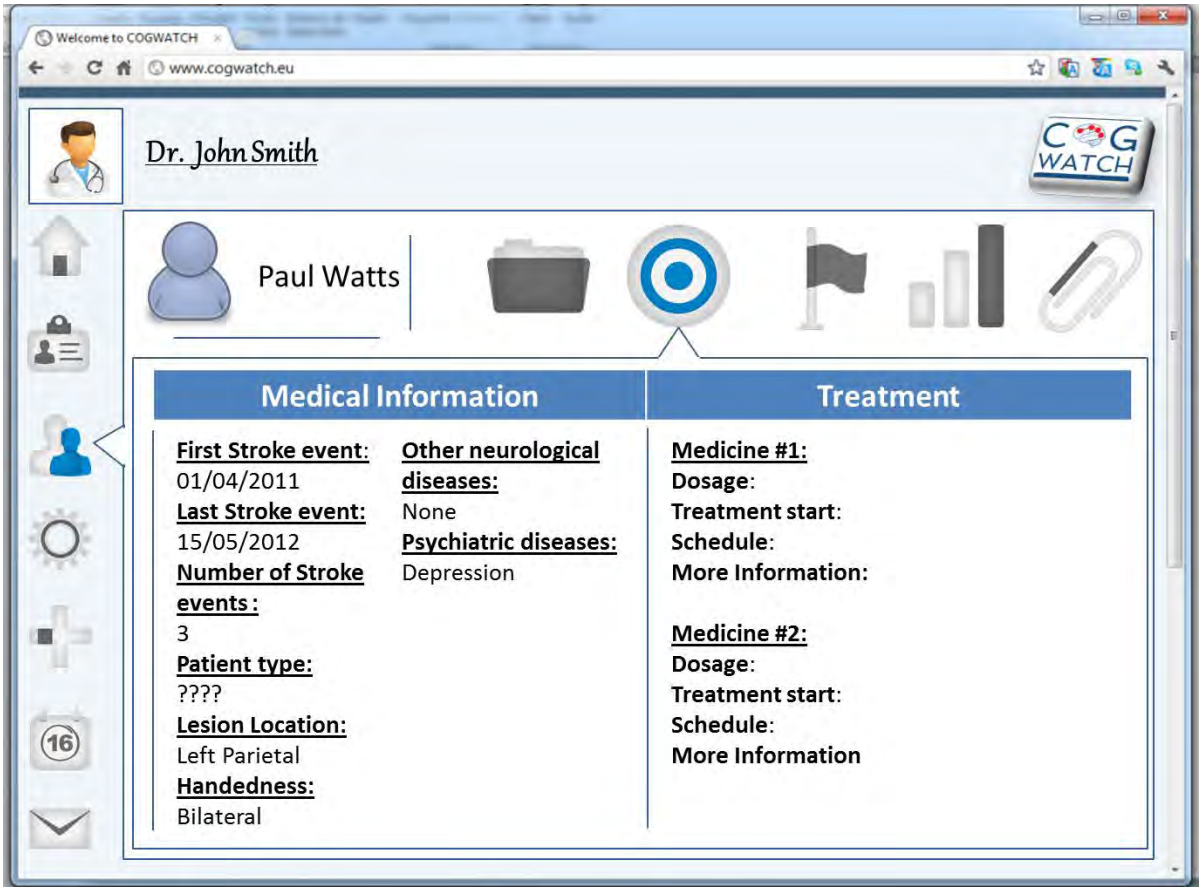

Figure 41 - CogWatch medical and treatment related information.

- Rehabilitation sessions: this screen displays one row per rehabilitation session, indicating the date and time of the session. The “new” sessions (i.e. not revised by the clinician yet) appear in a different color, as in Figure 42.

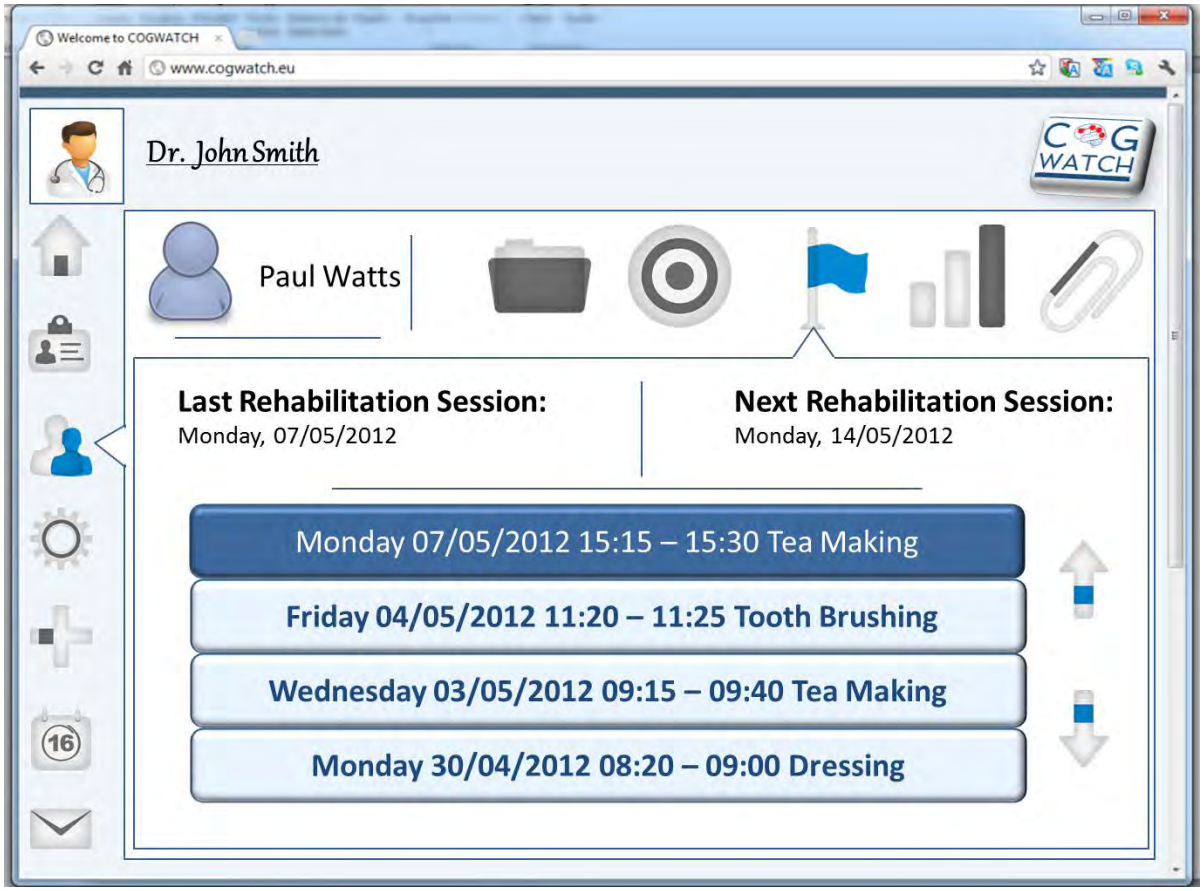

Figure 42 - CogWatch rehabilitation sessions.

Once the clinician clicks on a specific session, he/she will be able to see the detail of the session (Figure 43): whether it was successfully completed or not, the number and type of errors and whether support from the caregiver was needed.

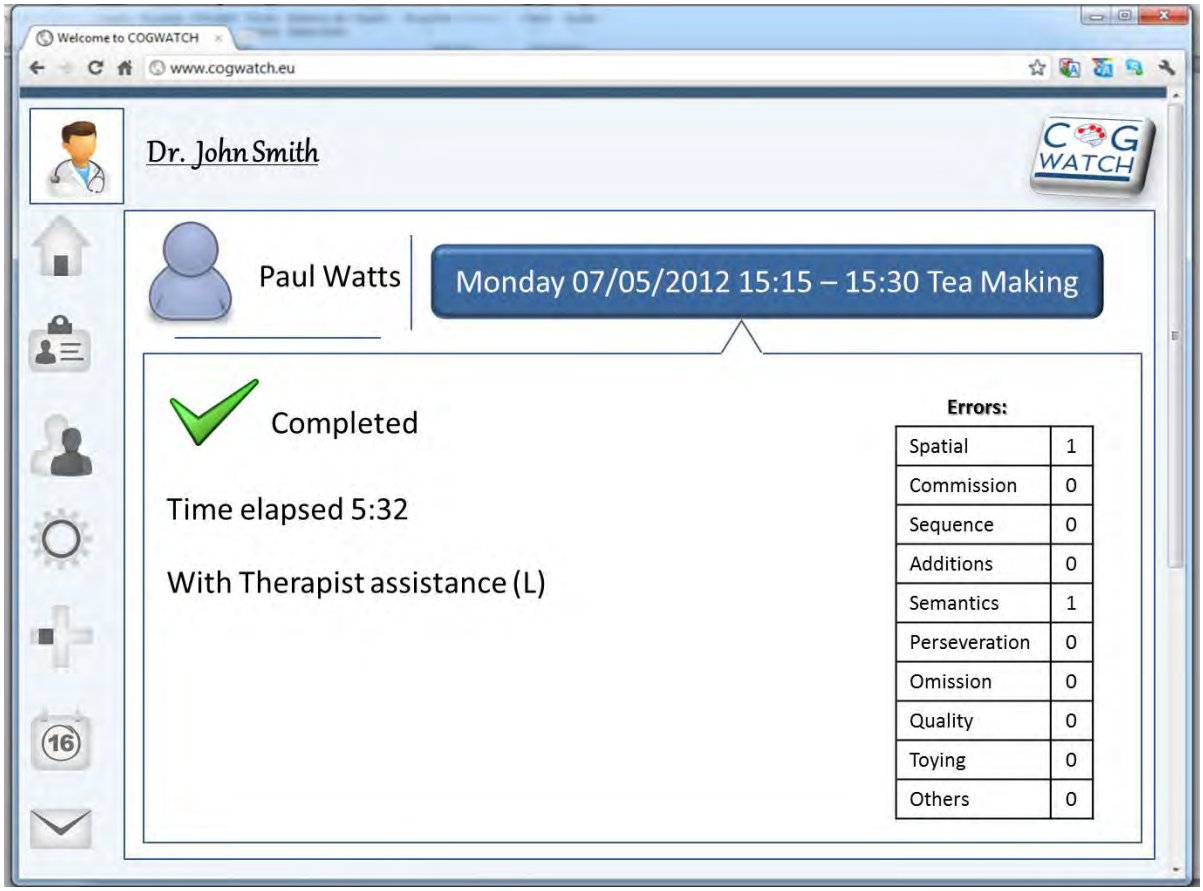

Figure 43 - CogWatch rehabilitation session detail.

- Rehabilitation statistics: this screen will display information about the patient use of CogWatch system and performance during the rehabilitation sessions. Statistics about the number and type of errors per specific task and/or date(s) can be visualized (See Figure 44).
- Other documents/attachments: in addition, the healthcare professional will have access to other data and documents, such as functional brain images of the patient.

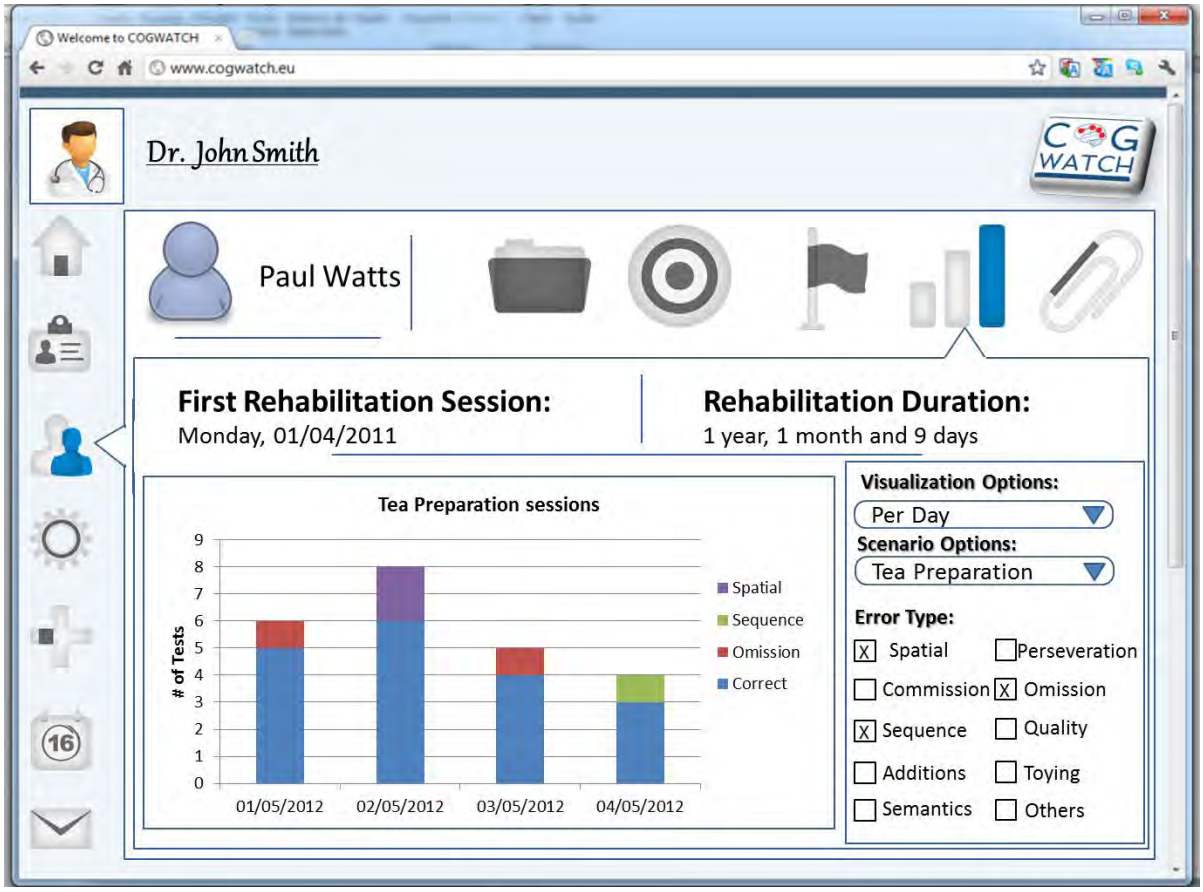

Figure 44 - CogWatch rehabilitation statistics.

- Settings: the healthcare professional will be able to adjust and select language, colour, font size, and change his/her personal data.
- Add: the healthcare professional will be able to schedule new rehabilitation sessions.
- Calendar/Schedule: this option will display a calendar showing the planned rehabilitation sections, visits and events related and not related to CogWatch. In addition, synchronisation with other calendars, e.g. Google calendar will be possible.
- Mail: this provides access to an internal messenger service among CogWatch system actors.

6. CONCLUSIONS

CogWatch system is focused on providing personalized, long-term and continuous cognitive rehabilitation for stroke patients with Apraxia and Action Disorganisation Syndrome (AADS).

This deliverable has defined and settled down the basis for the design and implementation of CogWatch system. General specifications have been provided, as well as specific ones for each component and application. Moreover, special mention to the communications and privacy in the data transfer has been done.

The next step has been to describe the general architecture of the whole system and each sub-system, in order to better understand the way users will interact with them and to show the solution proposed. The devices patients will use for rehabilitation basically will consist of: a watch for vibration feedback mainly; a sensorized T-Shirt for behavior data capturing from vital constants and sensorized objects and tools patients will manipulate for tasks execution. These objects will provide relevant data during the manipulation in order to detect errors. The detection is governed by special algorithms of action recognition and prediction. Finally, Kinect and possible additional cameras will be used to obtain data from the patients in order to complement the errors detection and create videos for future analysis.

CogWatch system will be used by two different user types: AADS patients and clinicians. The first ones aim at using the system for rehabilitation purposes, improving their daily living and retraining cognitive functions. The second ones will use CogWatch in order to remotely follow the rehabilitation process of the patients.

CogWatch system will comprise two main subsystems: the CogWatch client, corresponding to the patient side and installed at his/her house which will consist of wearable components (watch, T-shirt), sensorized objects, home devices (tablets and desktop computers) and specialized algorithms; the CogWatch clinician side will be implemented as a web portal, accessible from any place with an Internet connection. In addition, there will be a CogWatch Server in charge of storing all patient data processed and collected in the patient side, assisting the treating clinician in making appropriate decisions and showing the results of the recorded sessions.

In addition the network and communication strategy has been defined, by the definition of the network architecture: an BAN that will include all the wearable devices, a LAN that will be composed by all the devices and components at the patient's house and a WAN, including the communication with the therapist, who will be placed in a healthcare center or other remote location. The communication inside the house will be wireless, whenever it its possible, in order to facilitate mobility. The communication with the clinician will be done through Internet.

The system will be tested in three different sites, i.e. UPM (Spain), TUM (Germany) and UoB (UK), where the patients will be able to use it. Therefore, CogWatch system will be replicated in three different places. As an example, a suggestion for the arrangement of CogWatch components in the Spanish pilot has been provided. However, this configuration will need to be adapted to the specific characteristics of each pilot.

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