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# AN INNOVATIVE SOLUTION BASED ON HUMAN-COMPUTER INTERACTION TO SUPPORT COGNITIVE REHABILITATION

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***Abstract***: This contribution focuses its objective in describing the design and implementation of an innovative system to provide cognitive rehabilitation. People who will take advantage of this platform suffer from a post-stroke disease called Apraxia and Action Disorganisation Syndrome (AADS). The platform has been integrated at Universidad Politécnica de Madrid and tries to reduce the stay in hospital or rehabilitation center by supporting self-rehabilitation at home. So, the system acts as an intelligent machine that guides patients while executing Activities of Daily Living (ADL), such as preparing a simple tea, by informing them about the errors committed and possible actions to correct them. A short introduction to other works related to stroke, patients to work with, how the system works and how it is implemented are provided in the document. Finally, some relevant information from experiment made with healthy people for technical validation is also shown.

***Keywords:*** Activities of Daily Living, CogWatch, stroke, cognitive rehabilitation, healthcare.

## Introduction

One third of the stroke sufferers experience long-term physical and/or cognitive disabilities, and stroke is considered to be the most common cause for severe disability and even death. Following a stroke incident, a significant proportion of patients can suffer from Apraxia and/or Action Disorganisation Syndrome (AADS) which, among other symptoms, is demonstrated by the impairment of cognitive abilities to carry out Activities of Daily Living (ADL) (Hermsdörfer, 2003; Goldenberg, 1998; Liepmann, 1908).

Most common rehabilitation systems are focused on treating physiological aspects of stroke, such as limb movement (Freeman, 2012), and are based on robot or virtual environment platforms which are expensive and not effective for a home base environment (Amirabdollahian, 2001; Kahn, 2001; Krebs, 2003; Shor, 2001). Furthermore, they are space dependent, requiring the patient to function within their working space rather than adapting to patient's natural environment.

To date, most common rehabilitation systems that are based on Information and Communication Technologies (ICT) focus on treating physiological symptoms of stroke (e.g. muscle weakness) (Galiana, 2012; Kesner, 2011; Mao, 2010; Ueda, 2010). These systems are inappropriate for rehabilitation of the cognitive basis of AADS. Moreover, these systems tend to be expensive and so impractical for home installations. As a consequence, this affects the continuity of therapy and weakens its impact.

This paper presents a different solution whose contribution is part of a European project called CogWatch (http://www.cogwatch.eu/). The aim is to provide a rehabilitation system based on highly instrumented common objects and tools, wearable and ambient devices that are part of patients' everyday environment and can be used to monitor behavior and progress as well as re-train them to carry out ADL through persistent multimodal feedback at home.

The document is divided into several sections. Section II presents a brief description of AADS patients and the effects of stroke. Once the main features of these patients are described, the physical description of the platform and how the system works are presented in section III and section IV in order to detail an experiment carried out to assess the solution adopted in section V. Finally, in section VI, a conclusion and brief summary of the general results are presented.

## Apraxia and action disorganisation syndrome

Apraxia is a cognitive impairment affecting the ability to make purposeful skilled actions with objects or to use communicative gestures which is not attributable to motor weakness or sensory impairment. It is commonly associated with lesions due to stroke in the left parietal region of the cerebral cortex. Action Disorganisation Syndrome is a cognitive impairment affecting the performance of sequential action. Lesions of frontal lobe of the cerebral cortex resulting from stroke can produce ADS.

Together, Apraxia and Action Disorganisation Syndrome (AADS) can lead to marked impairment in ADL task performance (Hanna-Pladdy, 2003).

Single case studies are informative for developing approaches to rehabilitation that are closely related to the needs of specific patients. However, group studies are important to test the generalizability of findings

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from single case studies and they have also been used to examine whether apraxia rehabilitation is effective.

Patients were randomly assigned to apraxia or control (aphasia) treatment. Apraxia training was based on progression from more to fewer cues. For instance, transitive gesture training involved progression through spoon, picture of spoon, verbal command. Intransitive gesture and meaningless gestures were also trained. Approximately 15 items in each condition were trained 3 times per week for up to 35 sessions. Before and after each treatment, patients underwent neuropsychological testing and caregiver evaluation of patient's ADL independence in personal hygiene, feeding and dressing. Apraxia treatment specifically reduced apraxia and improved ADL function. Control (aphasia) treatment improved patients' language and intelligence performance but had no effect on apraxia and ADL.

The group study, demonstrating the benefits of apraxia training, suggests the need for further rehabilitation research to determine which cues lead to what gains in which patients so that interventions can be targeted more effectively.

However, a barrier to such aim is the intensive nature of AADS therapy, requiring constant supervision by trained staff to monitor the patient's actions for errors and to provide the cueing. Given limited therapist resources, AADS patients generally receive relatively little practice in such tasks.

## System overview

As mentioned above, the goal of the system is to help the patient to perform ADL tasks independently. The first impression that this may cause to the reader is that the goal is extremely ambitious, the possible tasks that the patient can take and the ways for doing them are unlimited. For this reason, four different activities are selected to split the effort in general cases of some of the most representatives that the patient has to face daily.

These chosen activities are: (a) preparing a hot drink, (b) preparing a snack, (c) grooming and (d) dressing.

For each activity one task is chosen. This task is divided into component sub-tasks along the lines of Cooper (2000). The idea of segmenting the tasks is useful for several reasons. The first reason is that it allows performing one task in different ways, defined by the different order of execution of the sub-tasks. It makes the system suitable to adapt easily to other tasks of the same activity, i.e., when every sub-task for preparing a tea is defined, most of them can be used for defining how to prepare a coffee. Finally, it can provide a diagnosis of what particular ones are difficult for each patient.

Following these guidelines, the platform developed is based on standard electronic gadgets that can be easily installed and avoid drastic changes in the house layout.

Figure 6 and Figure 7 show the concept idealization of the platform located in different scenarios.

*Figure 1. Kitchen scenario. Source: Javier Rojo.*

*Figure 2. Bathroom scenario. Source: Javier Rojo.*

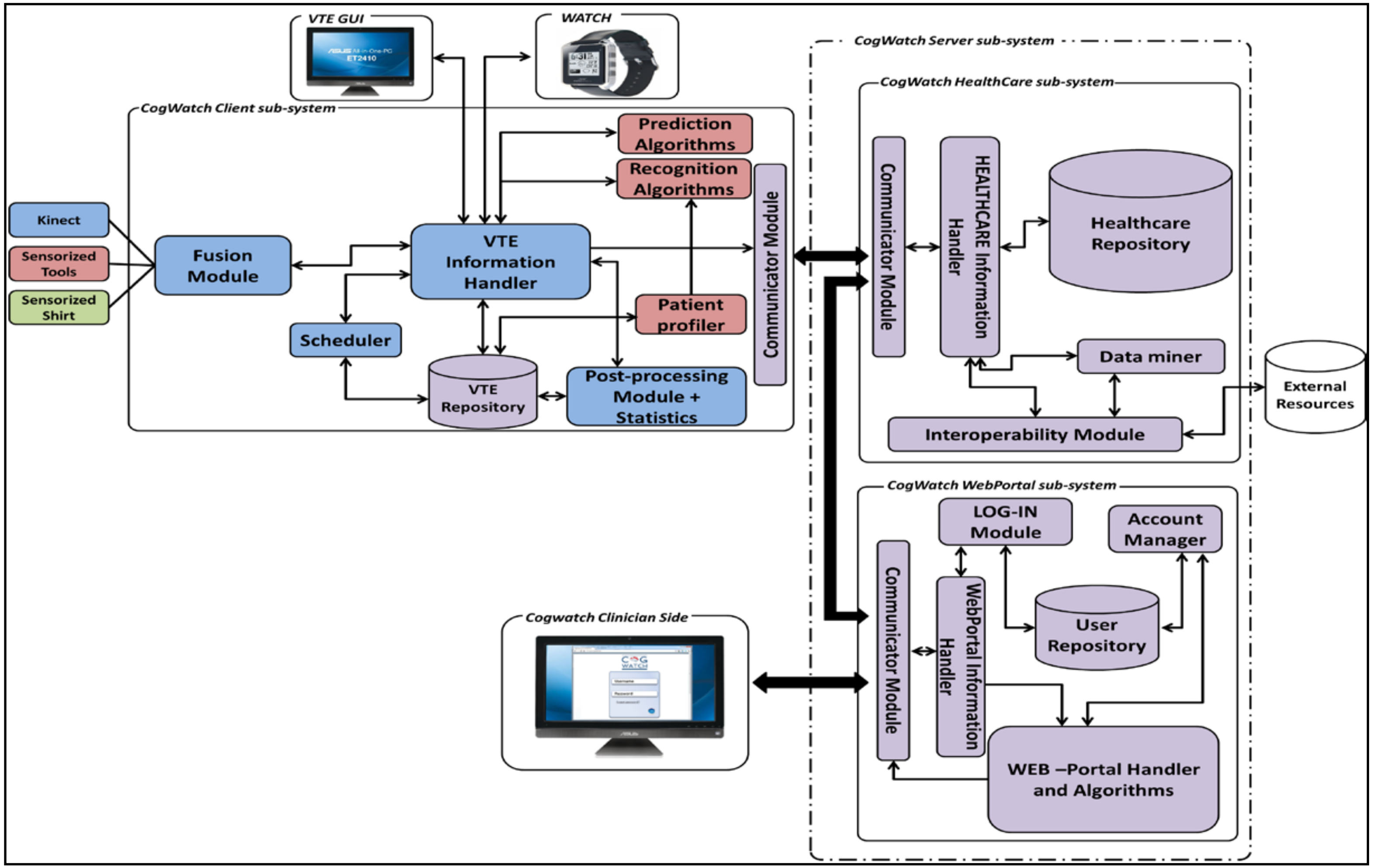
The patient will always have the possibility to get in contact with the clinician through the platform. Meanwhile, the clinician will dispose in his/her house or rehabilitation centre of dedicated software to supervise the rehabilitation sessions, send messages, personalize the interface to generate statistics, etc.

## Overall architecture

Once the bases for the utilization and installation are settle down, now it is time to focus on the technical description of the platform.

Figure 8 shows a general technical overview of the system architecture. The system is composed by two main subsystems, a Client sub-system (CCS) and a Server sub-system (SS).

*Figure 3. Main architecture of the system.Source: José M. Cogollor, Matteo Pastorino, Javier Rojo and Alessio Fioravanti.*



## Client sub-system (CCS)

The CCS, which will be located at the patients' house, is used for data acquisition and patient graphical user interface, during the rehabilitation sessions. It manages the patient data and presents the related rehabilitation sessions outcomes to the healthcare personnel.

Regarding the hardware components, a group of devices is used to capture and analyze the behavior and activity performance of the patients. These devices are divided into two categories: monitoring and feedback purposes.

First of all, the monitoring devices include vision-based systems and instrumented objects to be used during the tasks performance. Their main objectives are:

- Microsoft Kinect™: responsible for acquiring information from patient hands, movement and general video of the execution of the task.
- Sensorized objects: equipped with accelerometers and force sensitive resistors to capture their interaction with patient and collect the related data for future movement recognition (kettle, cup, etc.).

Meanwhile, feedback devices are composed by a smart wireless access wristwatch and a PC monitor which provide the following functionalities:

- Smart watch. This device vibrates in case of error, in order to make the patient aware of his/her mistake.
- PC monitor. It is known as VTE (Virtual Task Execution) monitor and it turns out to be an All-In-One computer whose main features are to provide to patients with the corresponding cues and possible risks for correction of the errors committed; it also collect the data coming from the patient rehabilitation session in a database.

On the other hand, taking into account the software modules, the main functions of the sub-modules of CCS are focused on: (a) handling the data, (b) storing relevant information in the database, (c) recognizing actions and errors committed by the patient by processing inputs from the sensorized objects and Kinect™ and (d) communicating with clinician application.

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## Server sub-system (SS)

The SS is composed by the HealthCare sub-system (HS) and the Web Portal sub-system (WS). The HS is the module installed in the rehabilitation center or hospital to be in charge of receiving and storing the data of the rehabilitation sessions. It is also designed to manage data coming from external resources different from rehabilitation session.

More in detail, the HS is responsible for: (a) communication with CCS side, (b) storage of personal information about the patient and (c) guaranteeing interoperability among existing and external devices in the healthcare center.

The WS is in charge of showing the rehabilitation sessions' data and statistics of patients to the healthcare personnel. The module installed in an external and unique server, based on a web-based portal, is accessible only by the healthcare and the administration personnel.

The WS main sub-modules are in charge of: (a) management of the user account, (b) security in the login access and (c) information management between all the sub-modules.

## Graphical interfaces

The system provides to both, patient and clinician, simple and attractive interfaces, in order to let the users interacting easily with it.

Considering the interface provided to the patient, this is showed in the VTE monitor and its purpose is to provide cues in sense of images, videos and messages (text and verbal) that make the patients aware of the error committed and try to tell them how to correct the action not executed or executed in a wrong way.

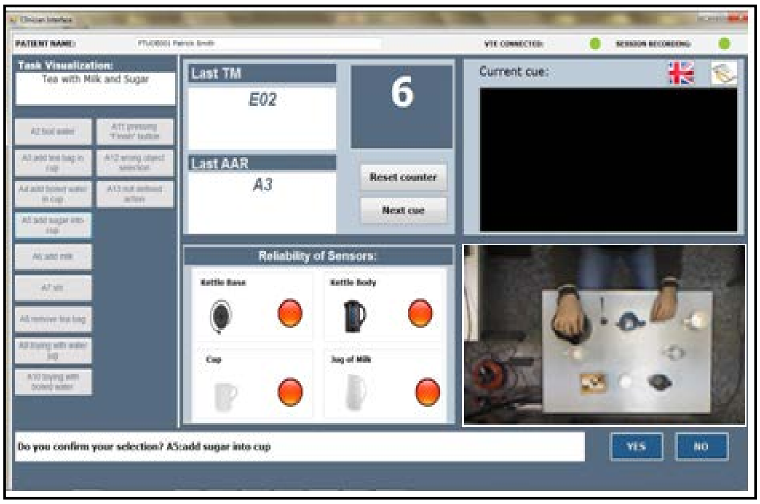
Figure 9 shows the appearance of the first window of patient interface, used to select the task to be performed.

*Figure 4. Patient interface on the VTE monitor. Source: Matteo Pastorino, Javier Rojo, Alessio Fioravanti and José M. Cogollor.*


Finally, the professional interface allows the clinician to check and control the performance of both, the system and patient, during the follow-up.

It is installed in a common computer and composed of several features, which make the clinician supervise the system and act when required. (Figure 10)

*Figure 5. Professional interface on the clinician laptop. Source: Matteo Pastorino, Alessio Fioravanti, Javier Rojo and José M. Cogollor.*



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## Experiment and validation

Once the architecture and components of the system have been shown, now it is time to test them and assess the suitability for being used at home during the execution of ADL.

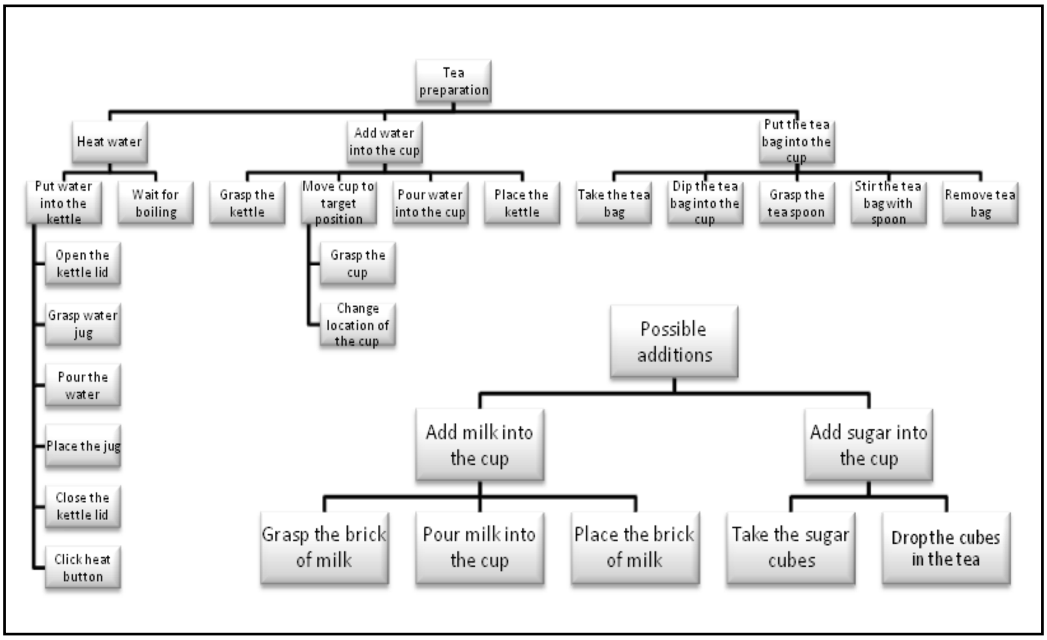
For this purpose, the platform has been installed in the kitchen of a specific Living Lab (Figure 11) to be used, initially, by healthy people for technical validation.

*Figure 6. Real kitchen used for validation. Source: Living Lab, ETSIT-UPM, Avda. Complutense 30, Madrid, Spain.*

A simple task was considered to be executed and simulate how a real patient would interact with the system. In this case, the task was focused on the preparation of a hot drink, in particular a tea, with four different versions: (a) simple tea, (b) tea with sugar, (c) tea with milk and (d) tea with sugar and milk.

For the preparation of the tea, a task tree (Figure 12) is considered, to collect all the necessary steps that the user must execute for the correct completion of the task.

*Figure 7. Task tree for tea preparation. Source: Alan Wing.*




The task tree helps to locale the steps patient has already performed in case an error occurs.

The errors are classified as: (a) addition, when adding an extra component not required; (b) omission, when forgetting to perform a step; (c) perseveration, when repeating a step or sub-task; (d) anticipation, when performing a step earlier; (e) perplexity, when presenting a delay in the performance of an action and (f) toying, when moving an object randomly.

Table 17 shows few examples of the errors committed by patients, intentionally for validation, with the corresponding cue provided.

*Table 1. Feedback provided for each error committed. Source: Alan Wing and Joachim Hermsdörfer.*

| **Error** | **Cue for feedback** |
|---|---|
| **Add sugar into the cup when not needed.** | Final message to abort the system. |
| **Forget to add water to the kettle.** | Image>>Video>>Final message to abort the |

| Error | Cue for feedback |
|---|---|
| | system. |
| **Add excessive water to the kettle.** | Vibration>>Text/verbal message>>Final message to abort the system. |
| **Drink tea without adding a tea bag.** | Image>>Video>>Final message to abort the system. |
| **A noticeable pause in placing the tea bag into the cup.** | Image>>Video>>Final message to abort the system. |
| **Touching the water jug repeatedly without using it.** | Final message to abort the system. |

As seen in the previous table, there are mainly three groups the errors were grouped into:

The first group is composed by those errors whose feedback provided was only a final text or verbal message in the monitor to indicate the error and abort the system because the error could be dangerous for the user and/or the task cannot be completed.

The second group is composed by those less dangerous errors which feedback is divided into three stages: (a) firstly, a simple image of the correct action was shown to the user; (b) in case the patient does not execute the subtask, a more explicit cue, represented by a real video, is played and (c) finally, if pause in movement continued, a final message is provided, informing about the error, and abort the system, letting the user to be relax and to try to perform again the task later.

The third and final group was composed by those errors which feedback was also divided into three stages, but different from the mentioned above: (a)

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firstly, a vibration from the watch is provided to the user; (b) if the user is not aware of the error, then a simple text or verbal message from the monitor is shown and (c) finally, if pause in movement continued, another final message is provided informing about the error and aborting the system letting the user relax and try it again later.

As said before, healthy people, not involved in the project, carried out the experiment testing the performance of the system.

Personally, they found the platform quite effective, attractive and useful. In addition, ergonomics and comfort are achieved for future patients due to the fact that the wearable device is a simple and commercial watch that can be purchased on Internet. The rest of the devices, such as VTE monitor or Kinect™, can be placed easily at home as a common TV or security camera, respectively.

Regarding technical aspects, only few relevant issues have been observed, mainly related to unexpected disconnection of the sensors placed in the sensorized objects and punctual repetition of the same cue, due to communication issues between both interfaces (clinician and patient). However, these aspects will be early improved, as the platform is just on a first prototype version of the whole system, continuously in development.

## Conclusion

This contribution has presented an innovative and totally different platform, which will provide a personalized, long-term and continuous cognitive rehabilitation for stroke patients with Apraxia and Action Disorganisation Syndrome (AADS).

The patients interact with mainly two groups of devices: for monitoring and for feedback which are in charge of monitoring the execution of the task and movements of the patient and providing feedback to make the patient aware of the errors committed, respectively.

In order to assess the implementation of the platform for its use at home, the system has been used during the execution of a simple task, such as preparing a tea. The results obtained from the performance show that it is quite easy to use, attractive and very useful for its objective.

It is relevant to mention that, up to date, the system is being used both by healthy people and real patients, following the work plan of the project.

As future work, the features of two of the main devices involved, watch and objects, will be extended for future versions of the platform. For instance, a new version of the watch will be analyzed to acquire relevant data from the internal accelerometer in order to have redundant information from the wrist movement of the patient. Meanwhile, objects will be redesigned to have an improved wireless communication and a better autonomy of the batteries.

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