Smart Objects Ecosystem for Post-Stroke Upper Limbs' Motor Functions Monitoring

How to collect objective and quantifiable data on the upper limbs' motor functions currently assessed by visual and subjectives estimations ?

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This paper presents a new ecosystem of smart objects inspired by the Action Arm Research Test used to assess the stroke patient's motor functions. This ecosystem aims to collect objective and quantifiable information on upper limbs motor functions of stroke patients by using physical objects manipulated by the patients without overloading cognitive functions with virtual environments or without asking the patients to wear sensors. The ecosystem is composed of a jack and a cube embedding sensors designed to monitor the hand prehension (fingers movements, fingers precision, global hand movements) and a wrist band devoted to monitor the arm movements during rehabilitation exercises. The therapists can easily collect, visualize and analyze the patient's data through a mobile application developed to present a summary of the patient's state at the end of the session and allowing to compare records of different sessions to assess the patient's evolution.

CCS Concepts: • **Applied computing → Health care information systems**; **Health informatics**;

Additional Key Words and Phrases: Internet of Things, Stroke, Monitoring, Smart objects, Rehabilitation

ACM Reference Format:
Maxence Bobin, Margarita Anastassova, Mehdi Boukallel, Franck Bimbard, and Mehdi Ammi. 2018. Smart Objects Ecosystem for Post-Stroke Upper Limbs' Motor Functions Monitoring: How to collect objective and quantifiable data on the upper limbs' motor functions currently assessed by visual and subjectives estimations ?. *ACM Comput. Entertain.* 9, 4, Article 39 (March 2018), 6 pages.
https://doi.org/10.1145/3240117.3240133

1 INTRODUCTION

Many stroke survivors encounter motor disorders such has muscle weakness [Ada et al. 2003], spasticity [Sommerfeld et al. 2004] or visual problems [Rowe et al. 2008] and rehabilitation is often required to retrieve independence in

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Fig. 1. The monitoring ecosystem: a) the objects collecting data and b) the visualization application.

the everyday life. Rehabilitation is a long process and reducing recovery time after a stroke is a real challenge for occupational therapists. At the early stages of recovery, patients go to the hospital to perform rehabilitation exercises under the supervision of an occupational therapist. The therapist thus assess visually if the exercise is correctly executed based on subjective estimations (correct position of the hand on the grasped object, succeed in moving the object, etc.). Assessing the patient's recovery with objective and quantifiable information is only done during checkup sessions with standard validated protocols. The Brunnstrom Approach (BRS) is based on longitudinal observations and allow to assess the motor recovery of stroke patient's by evaluating basic and complex arm and hand controls [Brunnstrom 1966]. Other protocols are more stroke-specific and focus on lower and upper extremities assessment such as Fugle-Meyer Assessment (FMA) or Wolf Motor Function Test (WMFT) [Fugl-Meyer et al. 1974; Woodbury et al. 2010]. The most interesting assessment protocol is the Action Arm Research Test (ARAT) [van der Lee et al. 2001]. Indeed, ARAT evaluates 4 categories (grasp, grip, pinch and gross movements) with 19 different items. Moreover, ARAT is performed in standard conditions and is thus easily reproducible. It also requires less time to administer than the BRS or FMA [De Weerdt and Harrison 1985]. However, no qualitative monitoring is performed between these checkup sessions.

Different approaches have been developed for stroke monitoring and rehabilitation during sessions at the hospitals. As rehabilitation consists in repetitive tasks, the patient's motivation can decrease over time. Serious games provide playful environment using virtual reality or neurofeedback allowing to maintain the patient's commitment over the rehabilitation sessions [Hou and Sourina 2013; Vogiatzaki and Krukowski 2014]. Wearables for their part consists in small devices worn on the human body to monitor stroke patient activities. Many works are based on accelerometers [Bussmann et al. 1998; Patel et al. 2010] but wearables also includes smart textiles were the sensors are knitted directly onto the garment [Tognetti et al. 2005]. Although these approaches are complementary, they present several constraints. Serious games can prevent the patients to fully focus on the required task by overloading cognitive functions and wearables are often used for overall body monitoring.

This paper present a new approach to monitor stroke patient activity during rehabilitation sessions with objective and quantifiable information. Our approach is at the crossing between current visual monitoring during sessions without quantifiable data and qualitative assessment with specific devices during checkup session. We propose an ecosystem of smart objects composed of three devices, a jack, a cube and a wrist band, based on the ARAT protocol designed to monitor the hand and arm functions of the patient during rehabilitation sessions. The devices provide objective and quantifiable information that cannot be retrieved with visual evaluation and allow the therapists to access to a summary of the patient's physical state at the end of the session as well as to compare recorded data in order to assess the patient's recovery evolution.

2 DESIGN CONCEPT

Based on the objects used for the ARAT protocol and the literature, we identified the data to be monitored in order to assess the hand and arm functions of the patients. This section presents the monitored information and the resultant devices composing the ecosystem.

2.1 Monitored Information

The four categories assessed by the ARAT protocol can be used to assess the hand and the arm functions of stroke patients. Finger extension appears to be the motor function most likely to be impaired among stroke patients [Radomski and Latham 2008], this is why ARAT focuses on pinch assessment. In addition, ARAT aims to assess the grip and grasp functions as they are essentials for a functional hand. The fingers placement on an object during pinching and the pressure applied on the object while pinching and grasping are two essential quantifiable measures to assess the ability of the patient's hand.

Then, the items scored in the ARAT protocol (block grasping, ball bearing, displacement and moving hand around the head) showed that monitoring the movements of the hand and the arm of stroke patients brings useful information on the recovery of motor functions. Indeed, sudden, brief and non-repetitive arrhythmic involuntary movements can appear after a stroke i.e. chorea [Alarcon et al. 2004].

Finally, the evolution of tremor assessment has been widely studied. It appears that a relapse of the motor functions may be detected by monitoring the tremors frequency and magnitude [Deuschl et al. 2000]. Indeed, tremors often appears after a stroke with frequency under 5Hz and perpendicular to the direction of the movement [Smaga 2003].

2.2 The ecosystem

We propose an ecosystem composed of three devices inspired by the ARAT protocol to monitor the patient's hand and arm activities. First, a jack is devoted to monitor the placement of the fingers on its sides as well as the pressure applied by the patient during grasping. Indeed, grasping a jack with the fingers is similar to pinch little metal balls of the ARAT pinch section. In addition, the jack is able to monitor its movements and the tremors of the patient during manipulation.

Second, a cube allows to monitor the hand prehension by collecting information about the pressure applied by the patient during the grasping, its movements and the tremors of the patient during manipulation. Functionalities of the cube are similar to the jack but its usage remains interesting as the different grasping configuration of the hand may bring complementary information on the motor functions of the hand.

Third, a smart wrist band is dedicated to monitor the arm activity of stroke patients during the different exercises. The wrist band is able to monitor the movements of the patient's arm as well as the patient's tremors during the exercise.

Finally, we designed a mobile application allowing the therapists to visualize in an easy and fast understandable way the patient's motor data. The therapists are thus able to easily collect, record and visualize data in real-time on a tablet and visualize previous records. At the end of each session, a summary of the patient's state is accessible and the therapists can also compare the session data with previous sessions to assess the patient's evolution.

3 IMPLEMENTATION

3.1 The smart objects

3.1.1 The jack. The jack is a rounded parallelepipoid (6cm x 6cm x 3cm) with cylindric recess helping for grasping. The jack is based on Raspberry Pi Zero Wireless (RPi-Z) platform and the fingers position and the pressure applied on the jack during grasping are collected with "Force-Sensing Linear Potentiometers" (FSLPs[1]). The FSLPs are located on the middle of the jack's sides and follow its shape. An 9-axis "Inertial Measurement Unit" (IMU) from InvenSense (MPU-9250[2]) is dedicated to monitor the movements of the jack as well as tremors. The jack also embeds a 3700mAh battery, a micro-USB connector for charging and a power switch to turn on/off the device. The data is transmitted in real-time to an Android application via Wi-Fi as the transfer rate is sufficient to assure data reliability.

3.1.2 The cube. The ARAT protocol suggests a 5cm side cube. Moreover, it is easily graspable by the patients and perfectly fits the pressure sensors size. The cube is based on the RFDuino platform. "Force-Sensitive Resistors" (FSRs) have been used to monitor the physical pressure applied on the cube during grasping and the same MPU-9250 has been used to monitor the cube's movements and tremors. The cube embeds a 340mAh battery, a micro-USB connector for charging and a power switch to turn on/off the device. The data is transmitted in real-time to an Android application via the Bluetooth Low Energy chip available on the RFDuino. The BLE transfer rate is lower than Wi-Fi but assures data reliability and consumes less energy since the battery capacity is 10 times smaller.

3.1.3 The wrist band prototype. As sensors integration is excellent and the data collection is easy with an Android smart watch, we used the Motorola 360, which embeds an tri-axis accelerometer used to monitor the arm movements of the patient during rehabilitation exercises.

3.2 The visualization interfaces

The visualization interface includes a real-time monitoring on the left side of the screen and a post-record interface on the right side of the screen for each object.

The jack interface (See Figure 2.a) displays in real-time the distance of the fingers from the grasping recess on the left and the pressure applied on each sensor of the jack on the right. We used a bar graph because these values are instant values. Moreover, it is easier to compare the pressure applied by each finger with bars rather than lines. The therapists can thus extrapolate the fingers abilities of the patients.

The cube interface (See Figure 2.b) displays in real-time the mean pressure applied on two opposite sides of the cube. We used a line graph because it allows to better evaluate the evolution of the pressure than a bar graph which display instant values. We also decided to merge the pressures of two opposite sides in order to avoid overloading the interface with too much information.

The watch interface (See Figure 2.c) displays the accelerometer data which corresponds to the movements of the patient's arm. We used a line graph for the same reason as the cube: it is easier to evaluate the evolution of the arm's movements and detect irregular movements.

3.2.1 The post-record interface. The post-record interface (See Figure 3) is shared by the three objects and appears on the right of the screen at the end of the record. It displays the translational tremors' frequencies and magnitudes on the left and the rotational tremors' frequencies and magnitudes on the right. We used a bar graph to represent the tremors' magnitudes that are single values. Each bar represents the magnitude of the tremors according to the corresponding axis and a click on a bar displays the tremor's frequency.

[1]https://www.pololu.com/product/2730
[2]https://www.invensense.com/products/motion-tracking/9-axis/mpu-9250/

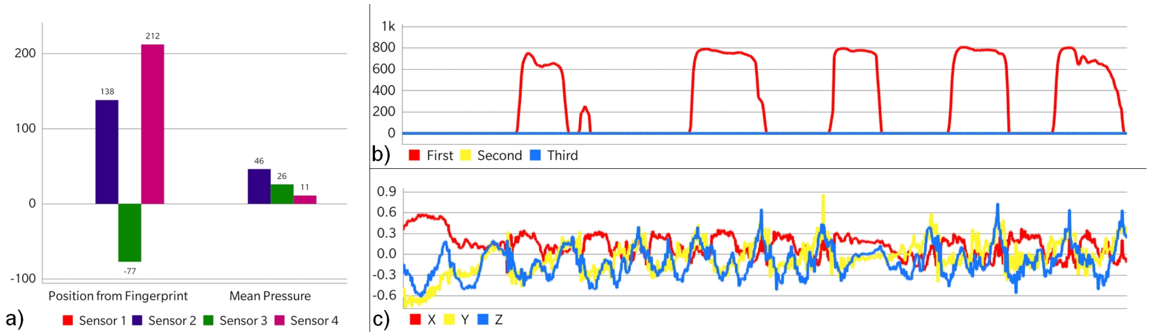

Fig. 2. The real-time interfaces: (a) the jack, (b) the cube and (c) the watch.

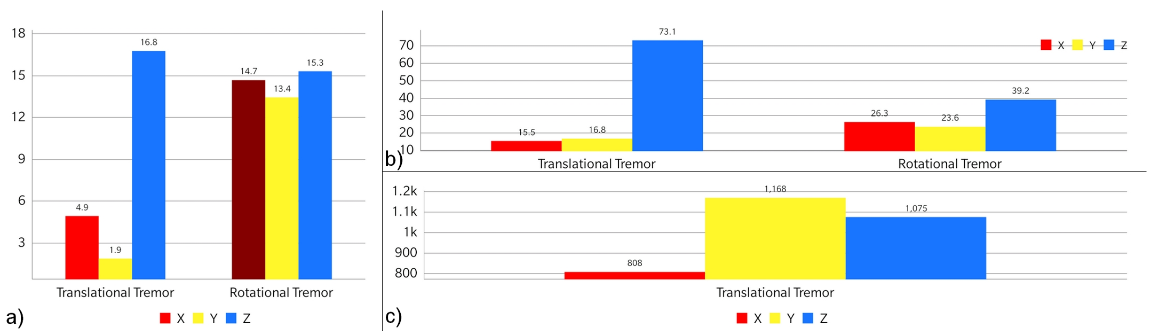

Fig. 3. The post-record interface representing the tremors.

4 CONCLUSION AND PERSPECTIVES

This paper presents an ecosystem of smart object designed to monitor the upper limbs motor activities of stroke patients during rehabilitation session without overloading cognitive functions using physical objects. The ecosystem has been designed based on the ARAT protocol and includes a jack and a cube for assessing the hand prehension, a wrist band for assessing the arm movements of the patients and a visualization application allowing the therapists to assess the patient's improvements over time.

Future works will focus on first evaluating the ecosystem with occupational therapists working at rehabilitation centers in order to assess the functionalities of each objects and collect possible improvements on the visualization interfaces. At the same time, we will perform pre-test with few stroke patients in order to detect possible malfunctioning of the objects or bad sensors integration. Second, we will focus on evaluating the acceptability and usability of these devices by stroke patients during rehabilitation sessions. Exercises will be performed during rehabilitation sessions with these objects. At the end of the session, questions will be asked to the patients about acceptability and usability. This experiment will also allow to collect data with a large panel of disabled stroke patients aiming to assess the reliability of the ecosystem with different motor disorders.

REFERENCES

Louise Ada, Colleen G Canning, and Sheau-Ling Low. 2003. Stroke patients have selective muscle weakness in shortened range. *Brain* 126, 3 (2003), 724–731.

F Alarcon, JCM Zijlmans, G Duenas, and N Cevallos. 2004. Post-stroke movement disorders: report of 56 patients. *Journal of Neurology, Neurosurgery & Psychiatry* 75, 11 (2004), 1568–1574.

Signe Brunnstrom. 1966. Motor testing procedures in hemiplegia: based on sequential recovery stages. *Physical therapy* 46, 4 (1966), 357–375.

Johannes BJ Bussmann, Joke HM Tulen, Eva CG van Herel, and Henk J Stam. 1998. Quantification of physical activities by means of ambulatory accelerometry: a validation study. *Psychophysiology* 35, 5 (1998), 488–496.

WJG De Weerdt and MA Harrison. 1985. Measuring recovery of arm-hand function in stroke patients: a comparison of the Brunnstrom-Fugl-Meyer test and the Action Research Arm test. *Physiotherapy Canada* 37, 2 (1985), 65–70.

G Deuschl, R Wenzelburger, K Löffler, J Raethjen, and H Stolze. 2000. Essential tremor and cerebellar dysfunction clinical and kinematic analysis of intention tremor. *Brain* 123, 8 (2000), 1568–1580.

Axel R Fugl-Meyer, L Jääskö, Ingegerd Leyman, Sigyn Olsson, and Solveig Steglind. 1974. The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. 7, 1 (1974), 13–31.

Xiyuan Hou and Olga Sourina. 2013. Emotion-enabled haptic-based serious game for post stroke rehabilitation. In *Proceedings of the 19th ACM Symposium on Virtual Reality Software and Technology*. ACM, 31–34.

Shyamal Patel, Richard Hughes, Todd Hester, Joel Stein, Metin Akay, Jennifer G Dy, and Paolo Bonato. 2010. A novel approach to monitor rehabilitation outcomes in stroke survivors using wearable technology. *Proc. IEEE* 98, 3 (2010), 450–461.

Mary Vining Radomski and Catherine A Trombly Latham. 2008. *Occupational therapy for physical dysfunction*. Lippincott Williams & Wilkins.

Fiona Rowe, Darren Brand, Carole A Jackson, Alison Price, Linda Walker, Shirley Harrison, Carla Eccleston, Claire Scott, Nicola Akerman, Caroline Dodridge, et al. 2008. Visual impairment following stroke: do stroke patients require vision assessment? *Age and Ageing* 38, 2 (2008), 188–193.

Sharon Smaga. 2003. Tremor-Problem-Oriented Diagnosis. 68 (2003), 1545–1552.

Disa K Sommerfeld, Elsy U-B Eek, Anna-Karin Svensson, Lotta Widén Holmqvist, and Magnus H von Arbin. 2004. Spasticity after stroke: its occurrence and association with motor impairments and activity limitations. *Stroke* 35, 1 (2004), 134–139.

Alessandro Tognetti, Federico Lorussi, Raphael Bartalesi, Silvana Quaglini, Mario Tesconi, Giuseppe Zupone, and Danilo De Rossi. 2005. Wearable kinesthetic system for capturing and classifying upper limb gesture in post-stroke rehabilitation. *Journal of NeuroEngineering and Rehabilitation* 2, 1 (2005), 8.

Johanna H van der Lee, Heleen Beckerman, Gustaaf J Lankhorst, Lex M Bouter, et al. 2001. The responsiveness of the Action Research Arm test and the Fugl-Meyer Assessment scale in chronic stroke patients. 33, 3 (2001), 110–113.

Emmanouela Vogiatzaki and Artur Krukowski. 2014. Serious games for stroke rehabilitation employing immersive user interfaces in 3D virtual environment. 6 (2014).

Michelle Woodbury, Craig A Velozo, Paul A Thompson, Kathye Light, Gitendra Uswatte, Edward Taub, Carolee J Winstein, David Morris, Sarah Blanton, Deborah S Nichols-Larsen, et al. 2010. Measurement structure of the Wolf Motor Function Test: implications for motor control theory. 24, 9 (2010), 791–801.