m-Physio: Personalized Accelerometer-based Physical Rehabilitation Platform

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Abstract— **This paper proposes a rehabilitation system based on new technological tendencies in the mobility and ubiquitous computing areas. Specialists and patients related to rehabilitation area can use this proposed system to improve the fulfillment of exercises and the supervision of rehabilitation tasks. An important current problem is that sometimes these activities cannot be performed efficiently due to the lack of time or the large distances between patient homes and rehabilitation centers. We have developed our system using a mobile device and a bracelet to capture patient's rehabilitation relevant data. As a pre-process procedure, raw data output by mobile device accelerometer is filtered, and then we use the technique called Dynamic Time Warping to train and recognize movements. Based on this recognition, patients can perform rehabilitation without the continuous specialist's surveillance and can be sure of its accuracy. Experimental results show us that our system is able to adapt itself dynamically to the peculiarities of each user and enhance healthy rehabilitation in a proactive way.**

Keywords- ubiquitous computing; accelerometry; physical-rehabilitation; mobility;

I. INTRODUCTION

The ubiquity of mobile devices has led to the emergence of personalized and adaptive services that are able to respond particular needs of each specific user. These services allow us to develop a wide range of proactive applications such as ambient assisted living services (e.g., assistance to elderly people [15] and chronic diseases assistance [22]), entertainment (e.g., mobile quiz games [16]), and smart homes (e.g., personalized home control [17] and visualization services [23]).

A principal characteristic to take into account in our work is the capability of monitoring user movements. Motion recognition is a discipline that has been around us for years in the scientific community. Some of the related works address issues such as handwriting recognition, recognition of hand gestures, and monitoring of the user activities. Some of these researches have in common with our work the use of one particular technology: the accelerometry. Accelerometers are being used in many sectors and, due to the fast development in sensor technology, it is possible the integration of these sensors into every day devices [1], for example, into mobile devices.

Focusing on the rehabilitation area, patients usually have to move about their rehabilitation center several times, but sometimes, factors such as lack of time and large distances affect the number of visits to their specialists, and consequently affect in the quality of the rehabilitation. Moreover, some patients suffer a slight incapacitate and have to perform part of their rehabilitation at home and they also need medical examination to check their evolution. Also, the well-known health care systems overcharge can be lesser by means of this kind of m-Health systems.

The main goal of this paper is the development of a novel system that helps the kinds of patient mentioned above whenever realize their rehabilitation. Besides, physical rehabilitation specialists can improve the monitoring and supervision of tasks by using our web-based system in their rehabilitation center. Our whole system (web-based and mobile applications) lets specialists pay a better attention to patients and reduce the problem of performing rehabilitation without the attentive specialist's eye.

In this paper, we employ the iPhone, one of the first mobile devices equipped with an accelerometer. Later, several mobile devices such as RIM Blackberry Storm, Nokia N95, and Sony Ericsson W910 were equipped with this kind of sensor. They basically use accelerometers for user interaction with games [3]. Few relevant applications employ accelerometry with other purposes. For example, Sony Ericsson's shake control allows the changing of songs by shaking the mobile device. However, this paper presents a novel application that introduces m-Health area into a new challenge that has not been deeply explored, the mobile-based rehabilitation.

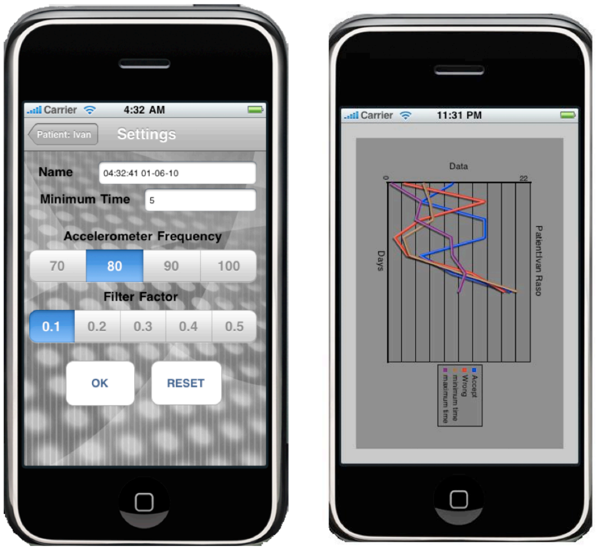
This paper is organized in five sections: Section 2 presents some related works that apply accelerometry to the rehabilitation area. Section 3 presents and explains the proposed applications. Section 4 presents evaluation results, and Section 5 discusses about the future works and the conclusions.

II. RELATED WORK

Accelerometry has become a powerful choice for evaluating variability of person's movement using these kinds of sensor that provide a non-invasive method of measurement and have a successful accuracy [4].

The entertainment sector is one of the most influenced by this technology as we can see in the Nintendo Wii game console that uses Wii Remote and Nunchuk to control avatars in games by means of natural gestures, and the PlayStation3 with its SixAxis and DualShock 3 controllers. Other sectors such as motor industry use these sensors to control ABS systems, airbags, and for checking the correct working of a machine. Transport industry also uses accelerometry to check wherever the merchandises suffer misshapes and their condition or their integrity has been damage by it [2].

Several works [5][6][7][8][10] have shown the accuracy of the accelerometer-based physical rehabilitation monitoring such as limb's motion, gait analysis before strokes, and other illness or accidents that cause malfunction in the physical condition of a patient.



(a) (b)

Figure 1. Application parameters (a) and stadistics gathered from the rehabilitation process (b).

Some related works to this paper are Wiihab [20], Telefonica's Rehabitic [9], and the Arteaga et al. proposal [19]. These projects use the accelerometers to help in the rehabilitation process. The Wiihab is used as an interaction object that encourages people to move their limbs. However, Rehabitic is made up of several accelerometers and a central device that saves the data received from the sensors, all complemented by a web page that the specialist uses to control the patients. This system gives important information relevant to help the patient in the rehabilitation exercises and contribute to the specialist's decisions about the evolution of the patient. Arteaga et al. propose a set of monitoring devices, each of which comprises of an accelerometer and a beeper, LED light and vibrator to provide redundant modes of inappropriate posture warnings that would hopefully trigger self-correction.

Other related contributions are the O'Donovan et al. [7] and Choquette et al. [18] proposals that allow scientific monitoring limb's motion and measures of heart rate using Body Area Network (BAN). Nowadays, the BAN devices use wireless technology and have become into Wireless Area Network (WAN) [5]. We have found many interesting similarities between these systems and our approach. However, the invasive characteristic of these systems prejudices their common use due to its numbers of devices and the tedious task of getting dressed with them. At this point, our application contributes to the rehabilitation area with a less invasive system than the above-described projects do. Moreover, a common problem with these proposals is the high effort needed to deploy the systems. Thus, our solutions achieve the objective of ubiquitous rehabilitation performance and monitoring that enhance the accuracy, less invasively and reducing infrastructural needs.

III. SYSTEM OVERVIEW

The mobile application (Figure 1) has been developed for iPhone 2G devices. This device includes an LIS302DL MEMS smart digital accelerometer [21]. It has 3-axis (X,Y,Z) and includes dynamically user selectable full scales from $\pm$ 2g to $\pm$ 8g.

According to some related studies [6][7][5], one of the best options to wear the accelerometers to the patient is a wearable system. The examples mentioned above were ruled out because their tedious wear system. We decided to use a bracelet that people use together with the iPhone for jogging or fitness.

Before presenting the principal system's components, we define what kind of rehabilitation exercises are related to this paper and their particular characteristics:

- Exercises end in the same point that they start.
- When a patient performs the exercise, it always starts at the same point approximately.
- The motion of the exercise will be slow due to the fact that the patient is doing rehabilitation.

Additionally, an exercise can be classified in four types:

- Correct exercise: The patient performs the exercise according to the pattern generated in the training process and imposed by the specialist.
- Wrong exercise: The patient performs the exercise according to the time limits but it was not the expected exercise according to the stored pattern.
- Exercise exceeds the maximum time: The patient performs an exercise but out of the maximum time allowed.
- Exercise does not exceed the minimum time: The patient completes an exercise but does not pass the minimum time imposed by the specialist.

A. Filtering

It is necessary to use a filter because the raw data of the accelerometer is noise and redundant. Consequently, we have chosen the following smoothing function for each axis (Equation 1):

$$S(A_t) = \begin{cases} A_t, & \text{if } t = 0 \\ A_t * \alpha + S(A_{(t-1)}) * (1.0 - \alpha)), & \text{if } 0 < t \leq T \end{cases} \tag{1}$$

$S(A_t)$ is the filtered acceleration vector output and At is the acceleration raw vector output, which is acquired by the interaction device at time t. Besides α is a smoothing factor in the range from 0 to 1. The α factor is critical for acquiring valid data to be analyzed in the pattern recognition process.

We have performed several experiments to select an α factor for rehabilitation exercises or other movements with similar characteristics; different kinds of movement may need additional studies to select a valid α factor. Figure 2 shows different graphs captured by the iPhones's accelerometer while a patient is performing a rehabilitation exercise. Each graph represents the same exercise with different α factors. The most representative capture of the rehabilitation exercise was the option (a), with α factor 0.1, because it filters peaks (remarked with circles) that not contribute to define the rehabilitation exercise. In the set of exercises performed for this paper we chose the option (a). On the other hand, fewer values of the α factor are not characteristic to the movement represented by the accelerometer axes.

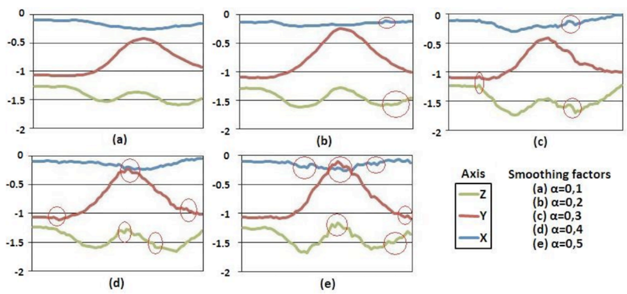


Figure 2. Test of different smoothing factors.

B. Pattern Recognition

The recognition of motion is a kind of pattern recognition. This recognition can be performed in several ways such as brute force, fuzzy logic, Gabor wavelet transform, hidden Markov model, support vector machine, and neural networks [3].

Instead of these examples, we have decided to base our development in the dynamic time warping (DTW) algorithm because it requires a simple training and its effective has been proved in many researches [11], [8]. Besides, it has been used for writing recognition [12] with great results, as well as for speech recognition [13].

DTW computes the distance between two exercises A and B by finding the minimum path that will be represented with a numerical value. In our application, the averaged Euclidean distance defines the cost between two different points Ai and Bj from the rehabilitation exercise.

C. Segmentation

The segmentation mechanism is used to determinate the beginning and end of an exercise. Some related works use the segmentation approach [3][1]. In our case, the segmentation is necessary because the patient has to know if he/she is beginning the exercises in the correct position as well as the device has to know when the exercise begins and ends. In order to achieve the segmentation mechanism, authors such as Schlömer [14] forces users to touch a button for detecting the beginning and end. Other authors [3] use mathematical equations such as the equation (2). According to the author when this equation is bigger than 0.3 the exercise starts and ends when drops to bellow 0.1.

$$D = \sqrt{((x_k - x_{(k-1)})^2 + (y_k - y_{(k-1)})^2 + (z_k - z_{(k-1)})^2} \quad (2)$$

The first method is not directly applicable in our system; patients cannot touch the mobile each time they realize a rehabilitation exercise because it may distort the pattern recognition process. On the other hand, the equation (3) is more interesting but neither applicable to our purposes; we manage several consecutive exercises and it requires that patients cannot stop for a while until the accelerometer drops to the value 0.1.

Our segmentation method is partially based on the push-button approach mentioned above and follows these steps:

- Patients have to touch the mobile's screen when they are ready to start the exercise.
- Once the patient touches the screen, the mobile device starts a countdown (five seconds) to allow the patients gets ready. For example, it could be possible that the patients have to make a rehabilitation exercise with their legs and then they need time for returning to the start position.
- After the mobile device countdown, it starts to calculate the exercise beginning and end, taking enough samples to represent these facts. The number of chosen samples was 30 after a wide testing process. In the rehabilitation and training process the segmentation is different from the capture steps because it is unnecessarily taken this number of samples again.
- As soon as patients finish the exercise, the mobile device uses the last sample to recognize the end of the rehabilitation exercise.

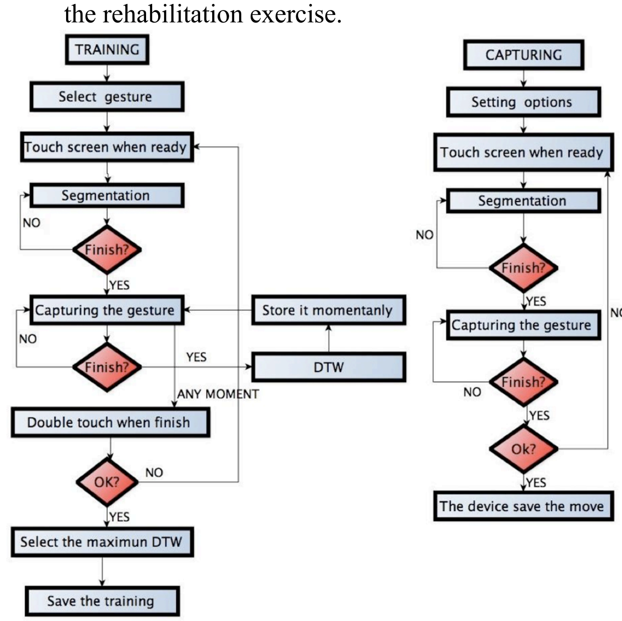


Figure 3. Flow charts representing the steps to capture and train an exercise.

This method has not only been designed to control the beginning and the end of exercises, but also to validate the device's position whenever patients are performing rehabilitation at home. If the position of the mobile device is detected as wrong, the mobile device does not start the countdown and notifies the warning to the patient. In this case, he/she has to wear the device again. Otherwise it could be fatal to the rehabilitation. This step is only performed in the rehabilitation and training process.

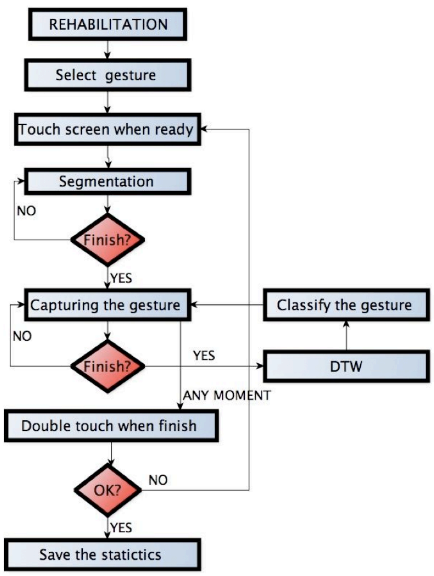


Figure 4. Flow chart that represents the steps to perform the rehabilitation process.

D. *Rehabilitation Steps*

Three important modules compound our application: exercise capture, exercise training and personal rehabilitation. Each module depends on the preceding results. The relevant modules' steps in response to the interaction of the patients are explained in the flow charts shown in Figure 3 and Figure 4.

- *Exercise capture*: Before using this module, the patient has to wear the mobile device and the specialist explains her/him the steps of the rehabilitation exercise. The specialist can set the movement's minimum time, the accelerometer's frequency, the movement's name and the smoothing factor α. The smoothing factor recommended after our set of test is 0.1 and the frequency is 80Hz. The capture of the exercise give to the mobile device the main configuration of the movement that is used in the following modules. Besides, once the exercise is captured, the mobile device completes the necessary information to enable the next steps of the system and stored the pattern that represents the particular rehabilitation exercise. This information includes the move's maximum time and the accelerometer's data corresponded to the exercise. This process is described in Figure 3 (left)
- *Exercise training*: Once the exercise is stored in the mobile database, it is necessary to train the exercise for being recognized when the patient begins to perform the rehabilitation. Whenever patients are performing the training, the mobile device acquires all the exercises performed by them and applies the DTW algorithm to analyze the movements. This part has to be performed under the supervision of the specialist. Depending on the specialist criteria, the training can be adapted to the patient needs. The specialist can suggest the patient not be accurate in the motion or, on the other hand, the specialist can force patients to perform more precise exercises. In more detail, if the training was hard because the injury was important, the rehabilitation will need an accurate exercise, otherwise if the injury was less relevant, the training will be leak. As we mentioned before, these decision belong to the specialist criteria. This process is detailed in Figure 3 (right)
- *Personal rehabilitation*: The personal rehabilitation is the most important step of our system. This module captures the exercises that patients perform in their rehabilitation process and classify them. This process is presented in Figure 4. There are four kinds of output to a patient's exercise and were defined previously. Once the rehabilitation ends, the mobile phone stores all the outputs and analyzes them to allow the specialist controls the patient's rehabilitation. Additionally, the mobile device synchronizes all the information with a centered database. This information can be accessed via the web application.
- Web application: The incorporation of the web application to the system complements the supervising cycle, giving to the specialists an efficient method to follow the patient's evolution.

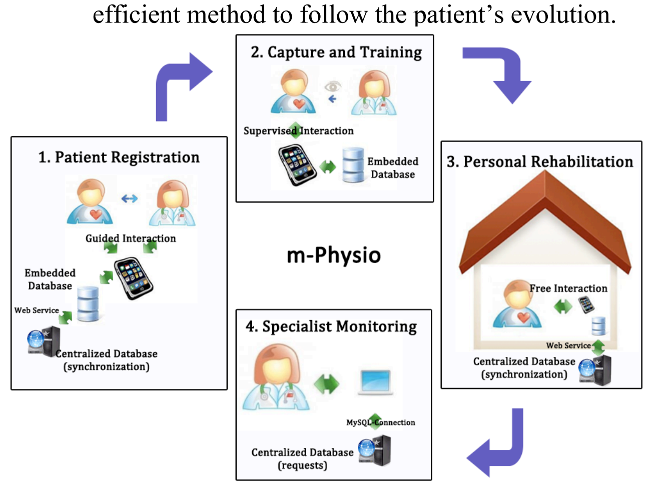


Figure 5. Principal steps on mPhysio rehabilitation process.

We now show the mainly steps for using our application to perform the rehabilitation process at home. First, a patient have to move about the rehabilitation center and the specialist studies the patient's case to decide the suitableness of our system in the specific patient's rehabilitation. Then,

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the specialist registers the patient's personal data into the mobile device. Once all the needed information is stored in the mobile device, the specialist gaits the patient with the capturing and training system's steps. When the specialist decides the training is enough, the patient can comeback to his/her home and performs the personal rehabilitation process. Whenever the patient ends his/her rehabilitation session at home, all the data is stored in the mobile device and is sent to the centered database through web services. Finally, the specialist can supervise the patient's rehabilitation evolution by means of the developed web application. If the specialist thinks the patient is performing significant errors, he/she could call or send a message to the patient advising him/her, and if required, set up an appointment in the rehabilitation center. All these steps are summarized in Figure 5.

IV. Results and Evaluation

In order to analyze the patient's experience with the application and its accuracy, we have tested it with five patients and two different rehabilitation exercises. The population includes one child, two teenagers, and two adults (with the ages of 43 and 64). The teenager users were familiar with the technology, while the other users were not familiar with this kind of system and device.

TABLE I. REHABILITATION AVERAGE BASED ON THE TWO EVALUATED EXERCISES AND FIVE PATIENTS

Day	Correct	Wrong	Min Time	Max Time
1	23.33 %	33.33 %	26.67 %	16.67 %
2	30.00 %	36.67 %	20.00 %	13.44 %
3	36.67 %	33.33 %	20.00 %	10.00 %
4	36.67 %	33.33 %	20.00 %	10.00 %
5	33.33 %	33.33 %	20.00 %	13.33 %
6	36.67 %	33.33 %	16.67 %	13.33 %
7	40.00 %	30.00 %	16.67 %	13.33 %
8	46.67 %	26.67 %	13.33 %	13.33 %
9	50.00 %	26.67 %	13.33 %	10.00 %
10	56.67 %	26.67 %	10.00 %	6.67 %
11	60.00 %	23.33 %	10.00 %	6.67 %
12	73.33 %	20.00 %	0.00 %	6.67 %
13	76.67 %	20.00 %	0.00 %	3.33 %
14	83.33 %	16.67 %	0.00 %	0.00 %
15	93.33 %	6.67 %	0.00 %	0.00 %

The tested exercise were a shoulder and leg movement shown in Figure 6. The exercises were repeated 30 times along 15 days, which provided 450 examples for each exercises and each patient. The training range was from 10 to 20 repetitions. The results in Table 1 and Figure 7 present the evolution of the patient's rehabilitation. The first days, only one out of every four rehabilitation exercises were performed correctly. Without using m-Physio or another monitoring system, patients are not aware of the incorrect development of the rehabilitation process neither the specialist. This fact brings as consequence an inadequate physical recovery and, in some cases, it may worsen the injury. Our system guides patients since the first day of rehabilitation and enables the enhancement of the performed exercises. Moreover, the specialist can supervise this process and take part whenever necessary.

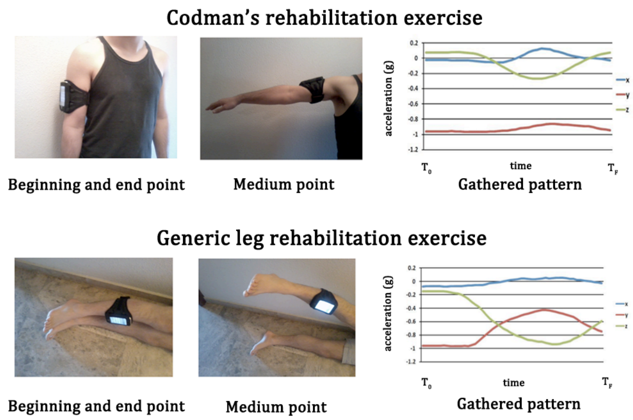

Figure 6. Shoulder and leg rehabilitation exercises.

Focusing again on tested exercises, these results show a high accuracy rate of 76.67% when users were using the application along 13 days and it improves during the next days rising up to 93% in the 15th day.

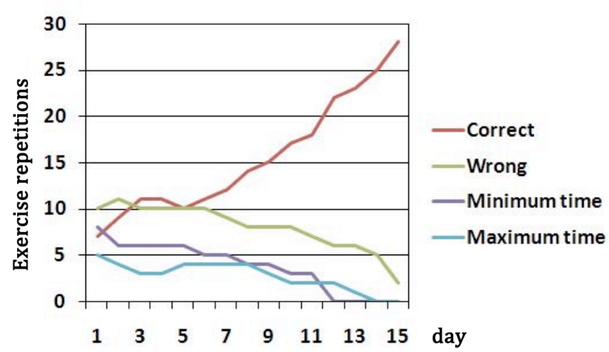

Figure 7. Daily evolution of the patients' rehabilitation during the tests.

V. Conclusion

In this paper, we have presented and evaluated a mobile-based rehabilitation system that can be used in rehabilitation centers for improving control and supervision. The proposed system is completely customizable, so the specialist can choose the position of the device, the frequency, minimum and maximum time of the rehabilitation exercises and the accuracy of the patient when they are performing the rehabilitation at home or without the continuous specialist's surveillance at rehabilitation center. Since the applied pattern recognition and segmentation techniques have been proposed and studied previously, we have analyzed their practical application to physical rehabilitation and we have optimized these techniques to this kind of movements.

One of the future works of our system includes the improvement of the segmentation process. A new technology implanted in the new mobile devices can be particularly helpful for the recognition and validation of the exercise's

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beginning and end. Moreover this new technology helps patients to wear the mobile device at home. This technology is the gyroscopes that being used together with the accelerometers can enhance the physical rehabilitation.

In summary, our proposal contributes to the ubiquitous health care. Our system improves the physician monitoring, guides patients on the rehabilitation process, and can reduce the problem of health care systems overcharge.

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REFERENCES

[1] Z. Prekopcsk, "Accelerometer based real-time gesture recognition," Proc. International Student Conference on Electrical Engineering, Prague, Czech Republic, May 2008, pp. 1-5.

[2] J. Doscher and C. Kitchin, "Monitoring machine vibration with micromachined accelerometers," Sensors, vol. 14(5), 1997, pp. 33-38.

[3] M. Joselli and E. Clua, "grmobile: A framework for touch and accelerometer gesture recognition for mobile games," Proc. Brazilian Symposium on Games and Digital Entertainment, Rio de Janeiro, Brazil, Oct. 2009, pp 141-150, doi:10.1109/SBGAMES.2009.24.

[4] K. M. Culhane, M. OConnor, D. Lyons, and G. M. Lyons, "Accelerometers in rehabilitation medicine for older adults," Age and Ageing, vol. 20, Oct. 2005, pp. 556–560, doi:10.1093/ageing/afi192

[5] E. Jovanov, A. Milenkovic, C. Otto, and P. C. de Groen, "A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation," Journal on Neuroengineering Rehabilitation, vol. 2(6), Mar. 2005, pp 1-10, doi:10.1186/1743-0003-2-6

[6] E. Mpofu and T. Oakland, Rehabilitation and Health Assessment: Applying ICF Guidelines. Springer Publishing Company, 2010, 760 pp.

[7] T. ODonovan, J. ODonoghue, C. Sreenan, D. Sammon, P. OReilly, and K. A. OConnor, "A context aware wireless body area network," Proc. Int. Conf. on Pervasive Computing Technologies for Healthcare, London, UK, Apr. 2009, pp. 1-8, doi: 10.4108/ICST.PERVASIVEHEALTH2009.5987

[8] G. Niezen and G. P. Hancke, "Gesture recognition as ubiquitous input for mobile phones," Proc. Int. workshop on Devices that Alter Perception, Sep. 2008, pp. 25-28.

[9] MovilForum, "Aplicaciones ehealth en la feria movilforum 2009," http://pressoffice.telefonica.com/documentos/Dossier (2010, Feb 20th)

[10] A. S. Alklind Taylor, P. Backlund, H. Engström, M. Johannesson, H. Krasniqi, and M. Lebram. "Acceptance of Entertaiment Systems in Stroke Rehabilitation," Porc. IADIS Game and Entertaiment Technologies, Algarve, Portugal, Jun. 2009, pp. 75-83.

[11] T. S. Leong, J. Lai, J. Panza, P. Pong, and J. Hong, "Wii want to write: An accelerometer based gesture recognition system," Porc. Int. Conf. on Recent and Emerging Advanced Techologies in Engineering, Pan Pacific, Malaysia, Nov. 2009.

[12] R. Niels and L. Vuurpijl, "Using dynamic time warping for intuitive handwriting recognition," Proc. Conference of the international graphonomics society (IGS2005), Salerno, Italy, Jun. 2005, pp. 217–221.

[13] L. A. R. Solano, Verificacion del hablante basado en Dynamic Time Warping. Universidad del Norte, 1998.

[14] T. Schölmer, B. Poppinga, N. Henze, and S. Boll, "Gesture recognition with a wii controller," Proc. 2nd international conference on Tangible and embedded interaction, Bonn, Germany, Feb. 2008, pp 11-14, doi: 10.1145/1347390.1347395

[15] D. Lopez-de-Ipiña, X. Laiseca, A. Barbier, U. Aguilera, A. Almeida, P. Orduña, and J.I. Vazquez. "Infrastructural support for ambient assisted living," Advances in Soft Computing 51, Springer, 2009, pp 66-75.

[16] J. Garduño, L. Pedersen, P. Brodal, T. Sund, G. K. Klungsøyr, T. Konstali, and H. Gundersen. "OMA-BCAST Quiz Gaming Prototype for Mobile". Proc. IADIS Game and Entertaiment Technologies, Algarve, Portugal, Jun. 2009,

[17] M. García-Herranz, P.A. Haya, A. Esquivel, G. Montoro, and X. Alamán. "Easing the smart home: Semi-automatic adaptation in perceptive environments," Journal of Univeral Computer Science vol. 14(9), 2008, pp. 1529-1544.

[18] S. Choquette, M. Hamel, and P Boissy. "Accelerometer-based wireless body area network to estimate intensity of therapy in post-acute rehabilitation," Journal of NeuroEngineering and Rehabilitation vol. 5(20), 2008, doi: 10.1186/1743-0003-5-20

[19] S. Arteaga, J. Chevalier, A. Coile, A. W. Hill, S. Sali, S. Sudhakhrisnan, and S. H. Kurniawan. "Low-cost accelerometry-based posture monitoring system for stroke survivors," Proc. 10th international ACM SIGACCESS conference on Computers and accessibility. Halifax, Canada, 2008, pp. 243-244, doi: 10.1145/1414471.1414519.

[20] M. W. Hinkel. "WiiHab rehabilitative therapy using the Wii." http://wiihabtherapy.blogspot.com . (2008, May 10th)

[21] ST Microelectronics. "LIS302DL Datasheets and characteristics," www.st.com/stonline/books/pdf/ docs/12726.pdf (2010, May 29th)

[22] J. Bravo, D. Lopez de Ipiña, C. Fuentes, R. Hervás, R. Peña, M. Vergara and G. Casero. "Enabling NFC technology for supporting chronic diseases: A proposal for alzheimer caregivers," LNCS 5355. Springer Publishing Company, 2008, pp. 109-125, doi: 10.1007/978-3-540-89617-3_8

[23] R. Hervás, S. W. Nava, G. Chavira, V. Villarreal and J. Bravo. "PIVITa: Taxonomy for displaying information in pervasive and collaborative environments," Advances in Soft Computing 51, Springer Publishing Company, 2009, pp. 293-301, doi: 10.1007/978-3-540-85867-6_34

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