SyMPATHy: Smart glass for Monitoring and guiding stroke PATients in a Home-based context

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SyMPATHy : Smart glass for Monitoring and guiding stroke PATients in a Home-based context

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Figure 1. SyMPATHy glass prototype : (a) half-filled glass held correctly, (b) half-filled glass tilted with white leds on the same side and (c) half-filled glass totally tilted with white leds on the same side.

ABSTRACT

This paper presents a solution to monitor and guide stroke patients during Activities of the Daily Living. It consists of a self-content smart glass that the patient can use to drink at different times of the day (water, coffee, etc.). The smart glass embeds a series of sensors that track in a transparent way the patients activity in everyday life (glass orientation, liquid level, target reaching and tremors). This solution allows therapists to monitor and analyze easily the Activities of the Daily Living of the patient in order to adapt the weekly rehabilitation sessions with suitable exercises. In addition, the smart glass embeds visual displays aimed at providing gestural guidance information when the patient do not use properly the glass. The paper presents the first prototype of the smart glass by highlighting the methodology adopted to design the software and hardware components of the platform.

ACM Classification Keywords

H.5 Information Interfaces and Presentation; H.5.2 User Interfaces

Author Keywords

Stroke; Rehabilitation; Activity monitoring; Internet of Things; Home

INTRODUCTION

Every year, stroke affects 15 million people across the world [17]. Five million die and five million are left permanently disabled. After stroke, motor deficits such as muscle weakness, spasticity and visual problems are often observed [5, 13]. In hospital, stroke monitoring and rehabilitation are very expansive because of the required human and material effort. Home rehabilitation can be an alternative solution at some phases of the recovery process [1]. Moreover, recovery evaluation still remains empirical through specifics tasks and scales [18].

Different research showed that New Information and Communications Technologies (NICTs) provide flexible solutions for rehabilitation and monitoring. However, existing platforms are limited to stroke-specific exercices or requires the presence of therapists [3]. Besides, the standard stroke evaluation methods are empirical and based on visual estimations that can only be retrieved during the evaluation session with the therapists [4, 7]. Smart objects are promising solutions to overcome these limitations and are very adapted to home context [8, 11]. Several research highlighted new evaluation methods involving objective measures such as kinematical features of movements [6, 10, 14, 15]. These measures are an efficient tool for the qualitative evaluation of stroke patients, especially with smart objects. Finally, some research highlighted the relevance of Activities of the Daily Living (drinking, cooking, cleaning etc.) for a continuous and transparent patients' assessment [9].

To overcome the limitations of existing platforms and approaches for monitoring rehabilitation, we propose SyMPATHy, a smart glass which embeds a series of sensors to monitor stroke patient activity. The glass is a common object that patients use at different times of the day when drinking (water, coffee, etc.). When the glass is manipulated, several information can be retrieved such as glass orientation, liquid level and the evolution of tremors. The smart glass includes also visual display to provide useful gestural guidance information to the patient when he does not use or manipulate properly the glass.

In the paper, we first introduce the concept and the design methodology. Then, we present the architecture of the proposed solution and we describe the data acquisition and processing. A study on the accuracy of the tracking is also presented. Finally, we present a conclusion and the prospects for the SyMPATHy platform.

DESIGN CONCEPT

In order to design Sympathy, we adopted a design methodology that includes three main steps: (1) Identification of the task, the related data to monitor and information feedback to the patient, (2) Hardware and software implementation of the platform, and finally (3) technical test of the platform.

Task identification

The identification of the task from ADL is a strategic point in the design process. The main objective was to provide to patients a useful, usable and commonly used device. In order to identify the task, we interviewed two qualified health professionals working at a stroke rehabilitation center. The interviews highlighted that ADLs are transparents tasks which means that activity of stroke patients in the everyday life will not be modified. Moreover, Timmermans and al. showed that positioning and manipulating is the preferred task from stroke patients [25]. According to the literature [2, 21] and the professionals feedback, we focus our work on the task of reaching, filling and transporting a glass. This task is based on different motor sub-tasks (arm movement, hand grasping, etc.) with the upper limb which are involved on other usual ADLs.

Monitored data

Based on this ADL (glass manipulation), we identified the data to track. The interview highlighted four main relevant data to assess the patient's recovery progress.

- Liquid level during glass filling
- Orientation of the glass during manipulation
- Glass position when it is placed on the table
- Apparition and evolution of tremors

Tracking the liquid level allows the analysis of the filling speed as well as the quantity of liquid poured into the glass. This information will be used by the therapist to evaluate the accuracy and coordination of movements during the filling. In fact, pouring water into a glass is a real challenge for motor deficient stroke patients. The patient has to grasp the bottle and the glass, raise the bottle above the glass and control the amount of liquid poured into the glass. Monitoring the orientation of the glass allows the therapist to understand the way the patient held the glass (vertically or not). This could highlight some motor or neurological troubles. Tracking the glass position when it is placed on the table allows the therapist to asses the motor precision of the patient. The therapist generally indicates to the patient a target to reach on the table. Finally, monitoring the evolution of tremors frequency along with their power is a good indicator of the patient's recovery [16]. It allows also the detection of the occurrence of neurological disorders.

Sensory Feedback

The sensory feedback is referring to a signal that lets the patient know if he is doing something correctly or not. Providing alert and guidance information during the filling and drinking steps enhances the performances and the motivation of patients. Indeed, several research highlighted the direct impact of positive or negative feedbacks on the motivation of patients [22]. With SyMPATHy platform, we focus on providing information on (1) liquid level, (2) glass orientation and (3) detection of reaching spatial target. The tremor was not considered since the patient can not act on it. The identification of suitable sensory modalities and relevant information representation is important for the guidance of stroke patients.

The feedback selected for the glass orientation is a visual feedback on the top of the glass to highlight the tilt angle and direction. Indeed, audio feedback can not provide angle and direction information easily. Technically, we used circles of leds placed on the top of the glass. The leds displayed colors according to the tilt angle of the glass. We selected discriminable colors (green, red, etc.) to display the tilts levels in order to avoid a perception ambiguity. Leds are lighted up in green if the glass is held correctly (0-20°), red if the glass is very tilt (> 50°), and yellow or orange for intermediate configurations (yellow: 20-35°, orange: 35-50°). Moreover, 3 leds are lighted in white in the direction of the tilt (Figure 1). In order to avoid the occultation of leds due to the glass material, we placed one circle of leds on the outer side of the glass and one circle of leds on the inner side of the glass.

Towards the liquid level, an informal study led us to use the visual modality by displaying colors vertically along the glass. Colors simplify the information display by providing a discrete representation of the liquid level. From a technical point of view, we used a column of 5 leds. According to the European culture, we lighted up the leds from red to green including orange and yellow from the bottom to the top of the glass.

Regarding the glass position, we focus in this work on reaching a given spatial target. To indicate to the patient that the target is reached, we used a binary audio feedback. This enables to unload the visual modality. From a technical point of view, a speaker was integrated to the glass. It plays a tone when the patient brings the glass to the correct position.

HARDWARE DESIGN

Monitored Data

SyMPATHy prototype comprises embedded sensors to access to the required data: (1) glass orientation, (2) liquid level, (3) detection if the spatial target is reached, (4) tremor detection.

Orientation tracking

We used an Inertial Measurement Unit (IMU) to measure the movement and the orientation of the glass. We selected the 9-axis Motion Tracking device "Invensense MPU-9150". It presents a good compromise between performance, energy efficiency, size and cost. The "Invensense MPU-9150" embeds an accelerometer, a gyroscope and a magnetometer. Each of these sensors returns 3 values on the 3 axis x, y, z.

Table 1. IMU Specifications.

Sensor	Value	FSR
Accelerometer	Acceleration	± 2 m.s^{-2} (g)
Gyroscope	Angular velocity	± 1000 °.s^{-1}
Magnetometer	Magnetic field	± 1200 μT

FSR (Full-Scale Range) maps the raw data from registers from $[-2^{15}, 2^{15}-1]$ to $\pm$ FSR value. At 25 °C, the gyroscope has a sensitivity scale factor tolerance of $\pm 3\%$. The accelerometer Initial Calibration tolerance is also $\pm 3\%$. Moreover, we sample data at 30Hz in order to have a smooth leds lightning.

Liquid level tracking

Due to the constraints of industrial liquid level sensors (low-reactivity, size, etc.), we designed a specific sensor for SyMPATHy. The sensor is based on the detection of the liquid conductivity. We placed five conductive electrodes vertically inside the glass. The electrodes were spaced of 1 cm. Each discrete level corresponds to a volume of 100 ml. The electrodes were connected to tension divider bridges to measure the electric tensions. After empirical measures with different liquids, the resistances were set to 100KΩ except for the first one which was set to 200KΩ. These values allow to detect the presence or absence of liquids.

Detection of reached target

To detect if the patient reach correctly the target positioned on the table, we equipped the SyMPATHy prototype with a Near Field Communication (NFC) shield and use a NFC Tag as a target. The NFC shield detects in a very short range the NFC Tag, and thus if the glass reach the target. We used a PN532 NFC controller. The antenna shape is a rectangle of 45 x 55 mm which means that the NFC Tag can be detected in a range of 25 mm to 30 mm on the horizontal plane. The minimum vertical detection distance is around 10 mm. We used a Mifare classic Tag which provide 7 bytes ID.

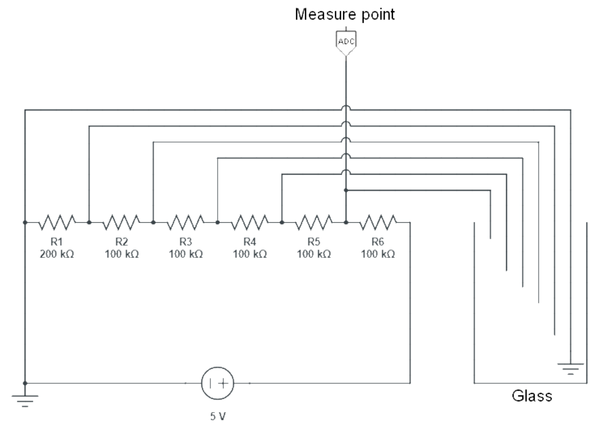

Figure 2. Wiring of the level water sensor.

Tremor detection

From a technical point of view, tremors correspond to low amplitudes oscillations. Previous work highlighted that post-stroke tremors have a frequency under 5Hz and are perpendicular to the direction of movement [24]. Based on this finding, we used the three axis of the gyroscope to measure tremors. A processing is applied on the retrieved data to detect and characterize the tremors (See section "Data processing").

Electronic design

The electronic part of SyMPATHy is based on the TinyDuino platform. It is a miniature open-source electronic component based on the Arduino platform. The platform is comprised of a TinyDuino processor board and multiple TinyShields which add special functions such as sensors, communications and display options. In order to avoid to overload the system and cause stack-overflows due to the low Flash and RAM memory of the Tiny processor (32Kb of Flash and 2Kb of RAM memory), we divided the electronic functions on 2 different processor boards. The first processor board handles the IMU sensor as well as the fusion algorithm. Moreover, this board deals with the circle of leds for the orientation. It also manages the I2C (Inter-Integrated Circuit) communication with the second board. The second board handles the NFC shield with the speaker, the liquid level sensor along with the 5 leds and a SD card connected with SPI (Serial Peripheral Interface) in order to log data from the the different sensors.

Glass design

The design of the glass presented several challenges. First, the glass must be waterproof. We used a 3D printer to test sealing with different infill value. The optimal parameter to have a waterproof glass is a infill value set to 30%. Second, to integrate the electronic part, we designed a small space in the bottom of the glass. This space includes 1) the TinyDuino processors, 2) the IMU, 3) the SD Card TinyShield, 4) the battery and 5) the rest of electronics (speaker, tension divider bridges, etc.). The NFC shield was placed in the bottom of this space (fixed on the glass base) so that it can detect the NFC tag place on the table. The electrodes used to detect the liquid level are connected to the tension divider bridge

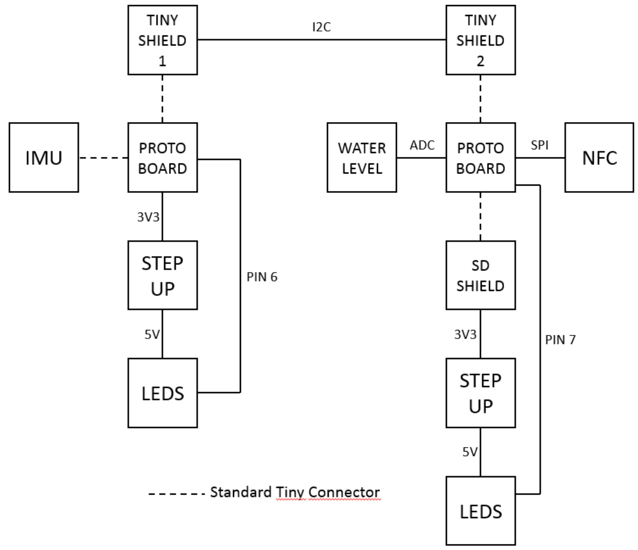

Figure 3. Hardware architecture.

located in the bottom of the glass. Regarding displays, we used strips of leds. Two strips were used to make the circles of leds placed on the top of the glass to display the glass tilt (i.e. outer and inner sides of the glass). One strips with five leds was placed on the side of the glass to display the liquid level. The parts of the glass that includes leds were realized with a semi-transparent material. Finally, in order to help the patient grasping the glass, we designed a handprint on the glass. Indeed, the handprint provide a relevant information to the patient on how to grasp the glass [20]. This affordance is particularity helpful for stroke-patients.

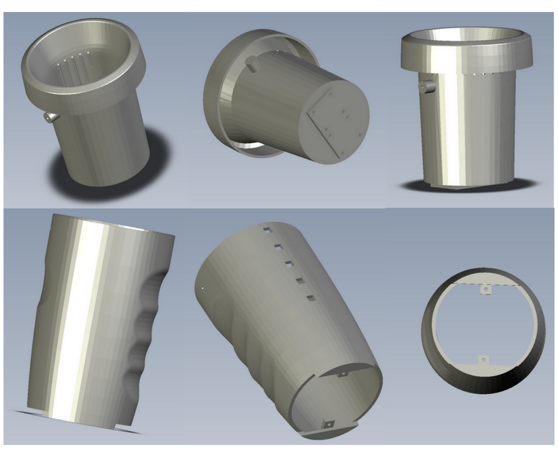

Figure 4. 3D glass design.

DATA ACQUISITION, LOGGING AND PROCESSING

Embedded processing and power consumption

Real-time wireless communication (Bluetooth and Wi-Fi) with a computer has been considered in order to log and process data. However, this solution presents several constraints in term of usability and reliability of communication. For instance, the Bluetooth communication requires a short distance from hotspot limiting the working space. In addition, Bluetooth communication can induce a loss of data making the platform less reliable for patient monitoring. The main constraint of a real-time wireless communication is power consumption. In fact, this kind of communication is a very power consuming process. This is an important challenge in the field of autonomous smart objects. To solve this issue with the SyMPATHy platform, we propose to log data locally on a file. The saved data are sent to the computer once a day or once a week allowing the therapist to visualize the history of data. The data file includes: pose quaternion, 3D vectors for accelerometer, gyroscope and magnetometer, discrete values of liquid level, and NFC Tag ID if detected. All these data are logged according to time with 6 significant numbers. For the SyMPATHy platform, we used 3.7V and 140mAh batteries on each TinyDuino processor board. The most energy-intensive parts are the leds lighting which require 1A to be lighted up. Although we added a step-up to boost the intensity to 1A. The power autonomy of SyMPATHy is of an half hour with the leds lighting, and of three hours without the leds lighting.

Fusion algorithm for glass orientation processing

IMU sensor returns nine values of acceleration, angular velocity and magnetic field. Based on theses values, the pose of the sensor is calculated, in other words the 3D orientation of the glass. The RTIMULib-Arduino [1] framework, from richards-tech, have been used to retrieve IMU data and apply fusion algorithm. RTIMULib uses RTQF fusion algorithm, a simplified version of a Kalman filter for an effective fusion of data. RTQF uses the gyroscope measures along with the time between samples to linearly extrapolate the previous orientation to the predicted current orientation of the IMU. In order to keep this prediction quite correct, the accelerometer and magnetometer provide an absolute reference (pitch and roll for the accelerometer, yaw for the magnetometer). RTQF calculates two quaternions at every step: a predicted quaternion from the gyroscope measures and a ground frame-referenced measured quaternion from the accelerometer and magnetometer. The predicted quaternion is stable but subject to drift whereas the measured quaternion is less stable but has no drift. Slerp (**S**pherical **L**inear Int**erp**olation) is a technique for finding an intermediate quaternion between two other quaternions. The Slerp power (between 0 and 1) controls towards which the predicted quaternion or the measured one the resulting quaternion is. If the value is 0, the measured quaternion is ignored and only the gyroscope is used effectively. If the value is 1, the predicted quaternion is ignored and only the measured state from the accelerometers and magnetometers is used. We set the Slerp power to 0.02. It results that the fusion works very well. Even if gyroscope and accelerometer measures exceed their FSR by motion, the algorithm will take a few seconds to close the gap between the predicted state and the measured state. RTIMULib also allows to apply a Low Pass Filter (LPF) in order to suppress noises. We added a LPF with a 20Hz cutoff frequency for the gyroscope and 21Hz for the accelerometer. These cutoff frequencies have been selected after empirical measures. Indeed, as stroke tremors are under 5Hz [24], signal data over 20Hz is not needed.

[1] https://github.com/richards-tech/RTIMULib-Arduino

The fusion algorithm returns a quaternion which corresponds to the 3D orientation of the glass. Based on this quaternion, it is possible to calculate the leds colors (green, yellow, orange, red, white) to provide the right visual sensory feedback to patients. The angle between the glass tilt and the vertical vector (0, 0, 1) in the earth reference frame is ϕ expressed in the spherical coordinate frame. According to the pose quaternion [qx, qy, qz, qw], we created the equivalent rotation matrix which transforms vector coordinates expressed into the earth frame to the glass frame.

$$\begin{bmatrix} 1-2(qy^2-qz^2) & 2(qx.qy-qw.qz) & 2(qx.qz+qw.qy) \\ 2(qx.qy+qw.qz) & 1-2(qx^2-qz^2) & 2(qy.qz-qw.qx) \\ 2(qx.qz-qw.qy) & 2(qy.qz+qw.qx) & 1-2(qx^2-qy^2) \end{bmatrix}$$

Figure 5. Rotation matrix generated from pose quaternion.

We rotated the vertical vector according to this matrix (Figure 5). Then, we projected the resultant vector on the horizontal plane. It corresponds to the θ angle in the spherical coordinate frame. The circle of leds includes 14 leds which means that the angular resolution is of 25.7°. We proceed to an integer division of the θ angle from the projection by the angle between 2 leds and we light up the corresponding leds in white.

Tremor detection and characterization

The tremor detection and characterization are based on a spectral analysis tool provided by the MatLab software: Fast Fourier Transform (FFT). FFT highlight the frequency components of a noisy time domain signal. After importing the gyroscope data into MatLab, we apply a FFT for the each axis. Next, we compute the Power Spectral Density (PSD) for each axis. The PSD is a measurement of the energy at various frequencies. It describes how power of the signal is distributed over frequency. Subsequently, we manually perform PSD analysis with the MatLab tools such as periodogram and look for the peaks of the frequency for each sample. The maximum value of PSD corresponds to the fundamental frequency of the signal. Finally, we display the graphic with the values in frequency and power of the fundamental frequency.

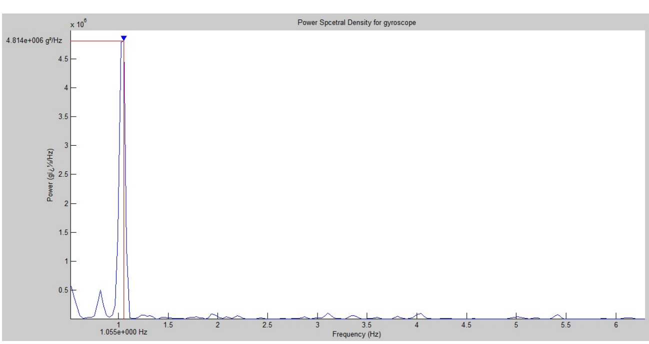

Figure 6. Tremor detection on the Z-axis of the gyroscope.

TECHNICAL STUDY

The study focuses on the assessment of the reliably and accuracy of the tremor detection. This information is very important for therapists in order to follow the patients' progresses and detect some health problems. The other data processing are widely addressed in the literature (i.e. orientation tracking and NFC based detection) [12, 19]. So their are not investigated in this paper.

Protocol

To generate controlled gyroscopic tremors, a stepper motor was used. A potentiometer was added on the motor to calibrate the tremor frequency and to generate a precise frequency. When the potentiometer detects the minimum (or maximum) value, the rotation is inverted. The time between two minimums (or maximums) allows the calculation the motor frequency: $1000/\Delta t$ (Δt expressed in ms). We performed thirty measures on each axis for five different tremor frequencies (1, 2, 3, 4, 5 Hz) according to the specifications highlighted by Smaga et al. [23].

Results

We computed the means of each sample (1 to 5 Hz on X, Y and Z) and calculated the error percentage. Then, we computed the general error percentage for each axis in order to compare it to the data-sheet error percentage.

Table 2. Error percentage measured for a specified $\pm 3\%$ error range.

	1Hz	2Hz	3Hz	4Hz	5Hz	Mean
X	3.12	4.00	3.55	3.96	3.71	3.66
Y	3.32	4.00	3.55	3.86	3.69	3.68
Z	2.93	4.00	3.61	3.8	3.77	3.66

The adjacent table (Table 5.2) show that the error percentage is independent from the axis. Moreover, the IMU is in accordance with the data-sheet which specifies an error range of $\pm 3\%$. The difference between our results and the data-sheet could be reduce by increasing the sample rate or using a DC Motor to avoid parasite vibrations.

CONCLUSION AND FUTURE WORK

The paper presents the smart glass SyMPATHy for the monitoring and guidance of stroke patients. The platform design was inspired by the Activities of the Daily Living allowing a transparent and continuous monitoring of patients that provides relevant information to therapists. The platform embeds a series of sensors, displays and electronic components to provide an autonomous and a self-content smart glass. The technical study highlight the accuracy and reliability of the tremors detection.

The future work will address several issues. First, based on the first SyMPATHy platform we plan to carry out a series of study in order to investigate the usability of the smart glass, in particular with stroke patients. We will work with therapists in rehabilitation center to verify the relevance of recorded data and applied processing. This work will probably highlight new information to improve the activity analysis of the therapist. From a technological point of view, several improvements will be explored. As shown by the different evaluation methods of the patient recovery, grasp and pinch is an important task for patient's independence. So we will integrate force sensors to detect the pinch and grasping forces. We will also work on the processing of IMU data to get information related to movement (linear acceleration, translation amplitude, etc.)

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REFERENCES

1. Craig Anderson, Sally Rubenach, Cliona Ni Mhurchu, Michael Clark, Carol Spencer, and Adrian Winsor. 2000. Home or hospital for stroke rehabilitation? Results of a randomized controlled trial I: Health outcomes at 6 months. *Stroke* 31, 5 (2000), 1024–1031.
2. Irene Aprile, Marco Rabuffetti, Luca Padua, Enrica Di Sipio, Chiara Simbolotti, and Maurizio Ferrarin. 2014. Kinematic analysis of the upper limb motor strategies in stroke patients as a tool towards advanced neurorehabilitation strategies: a preliminary study. *BioMed research international* 2014 (2014).
3. Naveen Bagalkot, Elena Nazzi, and Tomas Sokoler. 2010. Facilitating continuity: exploring the role of digital technology in physical rehabilitation. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*. ACM, 42–51.
4. Janet H Carr, Roberta B Shepherd, Lena Nordholm, and Denise Lynne. 1985. Investigation of a new motor assessment scale for stroke patients. *Physical therapy* 65, 2 (1985), 175–180.
5. Sophie Dethy, André Luxen, Luc M Bidaut, and Serge Goldman. 1993. Hemibody tremor related to stroke. *Stroke* 24, 12 (1993), 2094–2096.
6. A Ferbert and M Gerwig. 1993. Tremor due to stroke. *Movement disorders* 8, 2 (1993), 179–182.
7. 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. *Scandinavian journal of rehabilitation medicine* 7, 1 (1974), 13–31.
8. George D Fulk and Edward Sazonov. 2011. Using sensors to measure activity in people with stroke. *Topics in stroke rehabilitation* 18, 6 (2011), 746–757.
9. B Gialanella, R Santoro, and C Ferlucci. 2013. Predicting outcome after stroke: the role of basic activities of daily living predicting outcome after stroke. *European journal of physical and rehabilitation medicine* 49, 5 (2013), 629–637.
10. Alexandra Handley, Pippa Medcalf, Kate Hellier, and Dipankar Dutta. 2009. Movement disorders after stroke. *Age and ageing* 38, 3 (2009), 260–266.
11. M Iosa, G Morone, A Fusco, M Bragoni, P Coiro, M Multari, V Venturiero, D De Angelis, L Pratesi, and S Paolucci. 2012. Seven capital devices for the future of stroke rehabilitation. *Stroke research and treatment* 2012 (2012).
12. Anthony Kim and MF Golnaraghi. 2004. A quaternion-based orientation estimation algorithm using an inertial measurement unit. In *Position Location and Navigation Symposium, 2004. PLANS 2004*. IEEE, 268–272.
13. Jong Sung Kim. 1992. Delayed onset hand tremor caused by cerebral infarction. *Stroke* 23, 2 (1992), 292–294.
14. Jong S Kim. 2001. Delayed onset mixed involuntary movements after thalamic stroke. *Brain* 124, 2 (2001), 299–309.
15. S Lehericy, S Grand, P Pollak, F Poupon, J-F Le Bas, P Limousin, P Jedynak, C Marsault, Y Agid, and M Vidailhet. 2001. Clinical characteristics and topography of lesions in movement disorders due to thalamic lesions. *Neurology* 57, 6 (2001), 1055–1066.
16. Margit Alt Murphy, Carin Willén, and Katharina S Sunnerhagen. 2011. Kinematic variables quantifying upper-extremity performance after stroke during reaching and drinking from a glass. *Neurorehabilitation and neural repair* 25, 1 (2011), 71–80.
17. World Health Organization. 2002. World Health Report. Report. (2002). Retrieved December 29, 2015 from http://www.who.int/whr/2002/en/.
18. Shanta Pandian and Kamal Narayan Arya. 2014. Stroke-related motor outcome measures: Do they quantify the neurophysiological aspects of upper extremity recovery? *Journal of bodywork and movement therapies* 18, 3 (2014), 412–423.
19. Jose A Rios and Elecia White. 2002. Fusion filter algorithm enhancements for a MEMS GPS/IMU. *Crossbow Technology, Inc* (2002), 1–12.
20. Luisa Sartori, Elisa Straulino, Umberto Castiello, and Alessio Avenanti. 2011. How objects are grasped: the interplay between affordances and end-goals. *PloS one* 6, 9 (2011), e25203.
21. Kathryn A Sawner, Jeanne M LaVigne, and Signe Brunnstrom. 1992. *Brunnstrom's movement therapy in hemiplegia: a neurophysiological approach*. Lippincott.
22. Juliana Schroeder and Ayelet Fishbach. 2015. How to motivate yourself and others? Intended and unintended consequences. *Research in Organizational Behavior* 35 (2015), 123–141.
23. Sharon Smaga. 2003a. ESSENTIAL TREMOR. *American Family Physician* 68, 8 (2003).
24. Sharon Smaga. 2003b. Tremor-Problem-Oriented Diagnosis. *American Family Physician* 68 (2003), 1545–1552.
25. Annick AA Timmermans, Henk AM Seelen, Richard D Willmann, Wilbert Bakx, Boris De Ruyter, Gerd Lanfermann, and Herman Kingma. 2009. Arm and hand skills: training preferences after stroke. *Disability and rehabilitation* 31, 16 (2009), 1344–1352.