Digital Human Modeling and Applied Optimization, Vol. 46, 2022, 99–106
https://doi.org/10.54941/ahfe1001905

ARAT Test with Multisensory Information

Jesus Fernando Padilla-Magaña[1], Esteban Peña-Pitarch[1], Neus Ticó Falguera[2], Anas Al Omar[1], and Iñaki Alcelay Larrión[1]

[1]Escola Politècnica Superior d'Enginyeria de Manresa (UPC), Manresa, Spain
[2]Xarxa Assistencial Althaia, Manresa, Spain

ABSTRACT

The Action Research Arm Test (ARAT) is a tool widely used by physical therapists to evaluate the performance of the upper extremities in people who have suffered a stroke, brain injury, or multiple sclerosis. The ARAT consists of 19 items grouped into four subtests: grasp, grip, pinch, and gross movement. Nevertheless, it is a subjective test because the score is only based on the interpretation of the therapist who performs it. Therefore, in this work, the integration of a Multi-sensory System to the ARAT test is presented. The System developed consists in: an application developed in the software Unity® and in two sensors (an instrumental Glove with bend sensors (CyberGlove II ®) and five force sensing resistors (FSR)). The application records the Human Hand Motion data at the moment of performing the ARAT activities in real-time (joint angles and fingertip forces) and the data is stored in a database. The application also includes a hand simulation module for monitoring purposes. An experimental study was carried out with ten healthy volunteers with the purpose of testing and evaluating the performance of the proposed system. Inclusion criteria: over eighteen years old, right-handed, without any injury in their hands, collaborative patients. The results presented in this paper correspond to the Grasp subtest and analyze the correlation between fingertip force and the flexion angle of each joint. The proposed system allows therapists and health care professionals to perform a more objective and accurate evaluation. It also serves as the basis for future projects and applications of augmented reality (AR) and virtual reality (VR) for hand rehabilitation due to the compatibility of the Unity®.

Keywords: ARAT, Multisensory, CyberGlove II®, Force sensor, Rehabilitation

INTRODUCTION

Stroke remains the second-leading cause of death and the third-leading cause of death and disability combined (as expressed by disability-adjusted life-years lost-DALYs) in the world (Feigin et al., 2022). A large number of people who survive have important sequels that limit their activities of daily life (ADL). One of the main sequels produced by Stroke is the loss of functionality in the upper extremities (Arm, wrist, hand). The human hand is one of the most complex structures in the human body consisting of 27 bones, including eight carpal bones, five metacarpals, and 14 phalanges (Maw, Wong, & Gillespie, 2016). Moreover, it is one of the most important parts as it is used in most ADL. The rehabilitation process in the upper extremities after stroke is of great importance for the recovery of hand movements, rehabilitation is traditionally carried out by a physical therapist specialized in in the treatment of disabilities related to motor and sensory impairments(Whitehead & Baalbergen, 2019). Physical therapist help restore physical functioning by assessing and treating problems regarding movement, balance, and coordination. In order to evaluate the effectiveness of a stroke rehabilitation program it is crucial to perform a correct evaluation through the use of valid, standardized and reliable assessment tools. The Action Research Arm Test (ARAT) is a standardized and validated test that evaluates the performance of the upper extremities and is commonly used by physical therapists and another health professionals for the evaluation of stroke patients (Hsieh, C. L., Hsueh, I. P., Chiang, F. M., & Lin, 1998) (Koh et al., 2006) (Chen, Lin, Wu, & Chen, 2012). ARAT was first described by (Lyle, 1981) the test evaluates 19 tests of arm motor function, divided into 4 subtests (grasp, grip, pinch, and gross arm movement). Each test is given an ordinal score of 0, 1, 2, or 3, with higher values indicating better arm motor status. The total ARAT score is the sum of the 19 tests, and thus the maximum score is 57 (Yozbatiran, Der-Yeghiaian, & Cramer, 2008). The evaluation is based in an examiner's observations as well as other motor assessments that determine the corresponding score. The human factor can cause variability in the score process because it is an observational measure. The use of multiple sensors for the analysis of human hand motion allows to know: hand position, finger joint angles, angular velocity and finger force detection in real time. In recent years, research using multisensory information has been developed to analyze hand motion. A Data-Glove and force sensitive resistors (FSRs) were used during eating activities (Hussain, Zainul Azlan, & Yusof, 2018). (Ju & Liu, 2014) Developed an integrated framework with Three different types of sensors: CyberGlove® for angle trajectories, FingerTPS® for contact forces, and electromyography (EMG) sensor for forearm signals. A data-glove-based system embedded with 9-axis inertial sensors and FSRs were designed for evaluation of hand function (Hsiao, Yang, Lin, Lee, & Chou, 2015). An arm rehabilitation monitoring device was developed using an Arduino-based microcontroller, a flex sensor to detect arm bending movement, two FSRs to detect muscle force, and an Inertial Measurement Unit (IMU) (Ambar, Ahmad, Mohd Ali, & Abdul Jamil, 2011). Data from a Microsoft Kinect sensor (kinematic upper limb) and an FSRs glove to predict muscle forces in stroke patients were used by (Hoda, Hoda, Hafidh, & El Saddik, 2018).

Therefore, this paper presents a multisensory system for human hand motion analysis. The aim of this study is to measure the flexion/extension angles of hand finger joints and the fingertip force during the performance of Grasp subtest (ARAT) with the multisensory system. The multisensory information allows physical therapists to make more objective assessments.

MATERIAL AND METHODS

Multisensory System

The multisensory system designed is composed by a data glove CyberGlove II®, Force Sensing Module and a graphical user interface (GUI) developed in Unity® software. CyberGlove II® has 18 resistive flex sensors and 8-bit digital signal output, sensor has a resolution: <1 degree and a sensor repeatability: 3 degrees (CyberGlove Systems Inc.©, 2017). A previously calibration protocol (Peña-Pitarch et al., 2018) was used in this paper to convert raw data obtained from the glove in finger joints angles. The data glove provided the angles flexion/extension(F/E) of distal interphalangeal joint (DIP), proximal interphalangeal joint (PIP), metacarpophalangeal joints (MCP) of the fingers (index, middle, ring, and little), interphalangeal joint (IP), and MCP for the thumb. Data from the glove was transmitted wireless to a PC via Bluetooth. Force sensing module consist in five force sensing sensors (FSRs), FSRs are devices that allow measuring static and/or dynamic forces applied to a contact surface. The model selected was the (FSR07CE Ohmite) with an active area diameter of 14.7 mm. The FSR sensors were calibrated under static conditions before application in order to reduce inaccuracies, similar processes were used in other investigations (Hsu, Sugiarto, Chen, & Lin, 2018) (Flórez & Velásquez, 2010)(Ye, Seyedi, Cai, & Lai, 2015). An Arduino Nano microcontroller was used to convert analog data from FSRs into digital data. Then, digital data is converted into a force using a linear equation obtained during the calibration process. The data from Arduino was transmitted wirelessly via Bluetooth. A graphical user interface (GUI) was created using the software Unity engine version 2020.2.2f1. The GUI includes Icons for each activity of the ARAT, a score box, timer buttons, instructions of each activity, and a hand simulation window. GUI stores the personal data and the multisensory information of each subject in CSV files for further analysis.

Participants

This study included 10 healthy subjects (six females and four males, mean age: 33 ± 11.9 years, HL: 183.2 ± 10.74, HB: 78.8 ± 8.59). The subjects were selected under the criteria of being right-handed, over 18 years old, and not having suffered any hand disorders or lesions. All participants provided written informed consent and all experiments were performed in accordance with the declaration of Helsinki.

Experimental Setup

The study was performed at the Manresa School of Engineering (EPSEM-UPC). Before the experiment, subjects were instructed about the Standard positioning of the ARAT (Yozbatiran et al., 2008) and encouraged to perform the task in the most natural way possible. Five FSRs were attached to the finger tip of the fingers (thumb, index, middle, ring, little). A silk glove was placed taking care that the sensor's wires passed through the dorsal part of the hand, then the CyberGlove II® was put on in the hand (see Figure 1). Finally, the connection to the GUI was tested. Equipped with the multisensory system in the right hand, the subjects executed the subtest Grasp of the ARAT. The Subject is asked to grasp the objects for each activity which were placed on the table in front of them, one at a time: lift vertically, place, and then release each onto the top of the shelf. The experiment was repeated three times in order to decrease random errors. In the present study, only Grasp subtest activities

Figure 1: A participant wearing the multisensory system.

were performed, the subtest consists in six items: block 10cm, block 2.5 cm, block 5 cm, block 7.5cm, cricket ball and sharpening stone.

RESULTS

Statistical analysis was conducted by using Software R 4.1.0, an Analysis of variance (ANOVA) a well-known statistical test was used to check if the means of two or more groups were significantly different from each other. The DIP angle joint of fingers was not considered in the analysis because there is a linear relationship with the proximal joint PIP, distal joint was assumed as DIP = 2/3 * PIP. However, the information of this joint is in the database.

The flexion angle for all finger Joints (IP, MCP, PIP) captured by the Multisensory system during the six activities of the Grasp Subtest are shown in Figure 2. In activity 1, few differences were observed in the MCP joint angle of the index, middle, ring and little fingers. The mean flexion angle of the Thumb IP was 26.08°, Index PIP 30.71°, Middle PIP 45.87°, Ring PIP 43.94° and Little PIP 22.22°. In contrast, the mean flexion angle of the thumb MCP was 12.98°. In Activity 2, the maximum mean flexion angles were found at the MCP 30.76° and PIP 31.64° joints of the index, the MCP 29.36° and PIP 35.18° joints of the middle, and MCP 16.48° and PIP 27.60° joints of the ring. In Activity 3, maximum mean flexion angles were found in the MCP 16.10° and PIP 33.66° joints of the index, the MCP 29.25° and PIP 37.79° joints of the middle, and the MCP 15.92° and PIP 32.03° joints of the ring. In Activity 4 the maximum mean flexion angles were found in the index PIP 36.75°, middle PIP 41.94° and ring PIP 36.71°. In Activity 5, the maximum mean flexion angles were found in the index PIP 31.5°, middle PIP 34.28° and ring PIP 33.21°. In Activity 6, the maximum angles were found

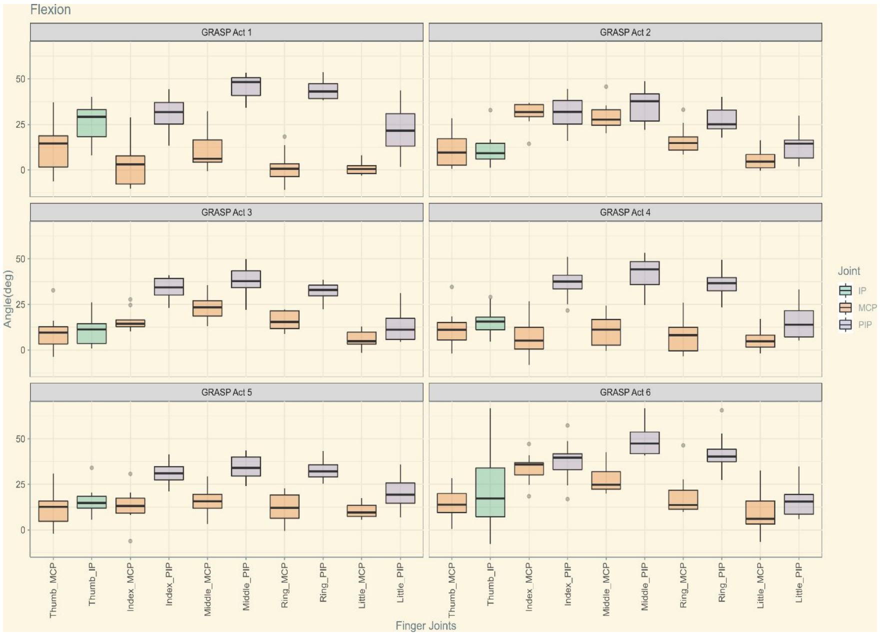

Figure 2: Boxplots of the flexion values of all the joints measured with the CyberGlove II® sensor.

in the MCP 34.05° and PIP 37.97° joints of the index, MCP 28.06° and PIP 49.34° joints of the middle, and the MCP 18.57° and PIP 42.41° joints of the ring.

On the other hand, the maximum forces of the fingertips (Thumb, Index, Middle, Ring, Little) captured during each ARAT activity are shown in Figure 3. In Activity 1, mean maximum forces were found in the thumb fingertip 6.18 N and middle fingertip 4.43 N. In the case of Activity 2, maximum forces were found in the fingertip of the thumb 1.33 N and 1.40 N in the index fingertip. In Activity 3, maximum forces were found in the thumb fingertip 2.29 N and middle fingertip 1.40 N. In Activity 4, maximum forces were found in thumb fingertip 2.90 N, index fingertip 1.63 N and middle fingertip 2.24 N. In Activity 5, maximum forces were found in the thumb fingertip 2.43 N and middle fingertip 2.27 N. Finally, maximum forces were found in the index 1.56 N and middle fingertip 1.70 N in the Activity 6. The total fingertip force in the Activity 1 is 17.6 N, in Activity 2 3.54 N, Activity 3 is 5.65 N, Activity 4 is 8.98 N, Activity 5 is 5.75 N, and Activity 6 is 4.28 N.

In this work, an ANOVA One-way was performed to determine if there is a statistically significant difference in the mean flexion angle of the finger joints (IP, MCP, PIP) based on the different activities of the Grasp Subtest. Table 1. showed a significant difference ($p < .05$) in the flexion angles of the index MCP, middle MCP, middle PIP, ring MCP and ring PIP between at least two Grasp activities. In contrast, no significant differences were found in the mean flexion angle of the other finger joints; therefore, these finger joints were not affected by the type of activity.

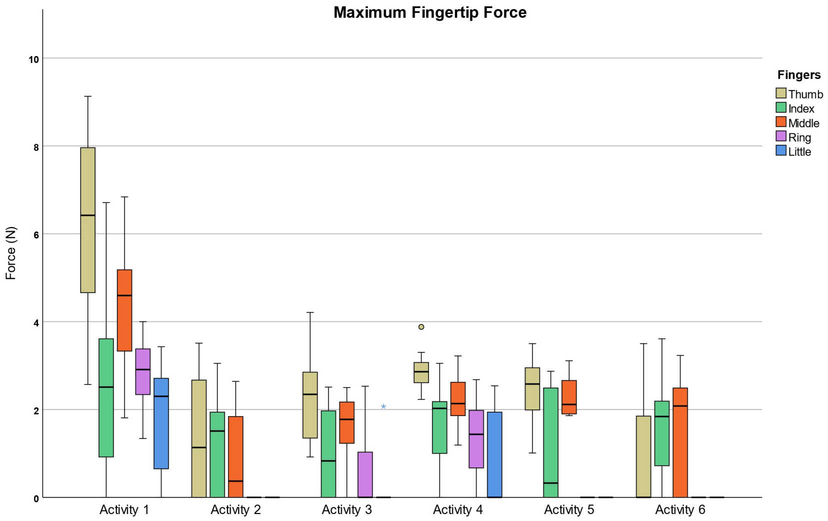

Figure 3: Boxplots of the maximal force values of all the fingers measured with the FSRs sensors.

Table 1. Anova one-way summary table.

Finger Joints	Sum of Squares	df	Mean Square	F	Sig.
Index MCP	7670.660	5	1534.32	15.772	<.001
Middle MCP	3582.137	5	716.427	10.030	<.001
Middle PIP	1828.869	5	365.774	5.661	<.001
Ring MCP	2054.937	5	410.987	5.463	<.001
Ring PIP	1987.493	5	397.499	7.659	<.001

DISCUSSION

The results obtained in the Anova showed that there is a strong relationship when an object is grasped between the size of the object and the flexion angle of the finger joints, similar results were found (Lee & Rim, 1991) (Peña-Pitarch et al., 2020) . The MCP and PIP finger joints increased during the performance of the Activity 2 and Activity 6 due to the size of the objects used in each activity. Activity 2 = 2.5 cm block and Activity 6 = stone (10 × 2.5 × 1 cm). Activity 4 and Activity 5 have similar size objects but with different shape, a block 7.5cm and a cricket ball $\phi = 6.5$ cm respectively. At the moment that the cricket ball was grasped, we found an increment of the mean flexion angle in the index MCP 7.13°, middle MCP 4.96°, ring MCP 4.6° and little MCP 5.3° but also a decrease in the angles of index PIP 5.25° middle PIP 7.66° and ring PIP 3.5°. This is due to the fact that when a precision grasp is used the fingertip position tends to form a circle independent from the object's shape, therefore the cricket ball fits better the hand shape. The maximum forces of the fingertips allow to know the number of fingers used at the moment of grasping an object. We found a correlation between the size of the object and the fingers used. Similar observations were found in (Peña-Pitarch et al., 2020) where the number of fingers used to grasping an object depends on the objects radius (ρ) e.g. for $5 \leq \rho \leq 12.5$ mm were used 2 fingers, $12.5 \leq \rho \leq 20$ mm were used 3 fingers, $20 \leq \rho \leq 35$ mm were used 4 fingers and $35 \leq \rho \leq 70$ mm were used 5 fingers. The results obtained showed that for the item (10 cm) corresponding to Activity 1 five fingers were used, in Activity 2 item (2.5 cm) results showed that subjects used two fingers and other three fingers. Activity 3 item (5 cm) results showed that subjects used in general three fingers and only a few four fingers. In Activity 4 item (7.5 cm) four and five fingers were used. Activity 5 item ($\phi = 4.5$ cm) and Activity 6 (2.5 cm) three fingers were used.

CONCLUSION

In this paper we present a novel multisensory system to asses hand motion. The system allows to know the range of motion (ROM) of the finger joints and the fingertip forces during the execution of the ARAT test. The information obtained by the system will allow health care professionals and physical therapists to make a more objective assessment with the ARAT in stroke patients. Although measurements with post stroke patients must be performed, these first results are promising.

ACKNOWLEDGMENT

This work was partially supported for Spanish government by the project PID2020-114819GB-I00.

REFERENCES

Ambar, R., Ahmad, M., Mohd Ali, A., & Abdul Jamil, M. (2011). Arduino based arm rehabilitation assistive device. *Journal of Engineering Technology*, *1*(October 2017), 5–13.

Chen, H. F., Lin, K. C., Wu, C. Y., & Chen, C. L. (2012). Rasch validation and predictive validity of the action research arm test in patients receiving stroke rehabilitation. *Archives of Physical Medicine and Rehabilitation*, *93*(6), 1039–1045. https://doi.org/10.1016/j.apmr.2011.11.033

CyberGlove Systems Inc.©. (2017). CyberGlove II. Retrieved June 21, 2019, from http://www.cyberglovesystems.com/cyberglove-ii

Feigin, V. L., Brainin, M., Norrving, B., Martins, S., Sacco, R. L., Hacke, W., … Lindsay, P. (2022). World Stroke Organization (WSO): Global Stroke Fact Sheet 2022. *International Journal of Stroke*, *17*(1), 18–29. https://doi.org/10.1177/17474930211065917

Flórez, J. A., & Velásquez, A. (2010). Calibration of force sensing resistors (fsr) for static and dynamic applications. *2010 IEEE ANDESCON Conference Proceedings, ANDESCON 2010*, 2–7. https://doi.org/10.1109/ANDESCON.2010.5633120

Hoda, M., Hoda, Y., Hafidh, B., & El Saddik, A. (2018). Predicting muscle forces measurements from kinematics data using kinect in stroke rehabilitation. *Multimedia Tools and Applications*, *77*(2), 1885–1903. https://doi.org/10.1007/s11042-016-4274-5

Hsiao, P. C., Yang, S. Y., Lin, B. S., Lee, I. J., & Chou, W. (2015). Data glove embedded with 9-axis IMU and force sensing sensors for evaluation of hand function. *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*, *2015-Novem*, 4631–4634. https://doi.org/10.1109/EMBC.2015.7319426

Hsieh, C. L., Hsueh, I. P., Chiang, F. M., & Lin, P. H. (1998). Inter-rater reliability and validity of the Action Research arm test in stroke patients. *Age and Ageing*, *27*(2), 107–113. https://doi.org/10.1093/ageing/27.2.107

Hsu, W. C., Sugiarto, T., Chen, J. W., & Lin, Y. J. (2018). The design and application of simplified insole-based prototypes with plantar pressure measurement for fast screening of flat-foot. *Sensors (Switzerland)*, *18*(11). https://doi.org/10.3390/s18113617

Hussain, Z., Zainul Azlan, N., & Yusof, A. Z. Bin. (2018). Human Hand Motion Analysis during Different Eating Activities. *Applied Bionics and Biomechanics*, *2018*. https://doi.org/10.1155/2018/8567648

Ju, Z., & Liu, H. (2014). Human hand motion analysis with multisensory information. *IEEE/ASME Transactions on Mechatronics*, *19*(2), 456–466. https://doi.org/10.1109/TMECH.2013.2240312

Koh, C.-L., Hsueh, I.-P., Wang, W.-C., Sheu, C.-F., Yu, T.-Y., Wang, C.-H., & Hsieh, C.-L. (2006). Validation of the action research arm test using item response theory in patients after stroke. *Journal of Rehabilitation Medicine*, *38*(6), 375–380. https://doi.org/10.1080/16501970600803252

Lee, J. W., & Rim, K. (1991). Measurement of finger joint angles and maximum finger forces during cylinder grip activity. *Journal of Biomedical Engineering*, *13*(2), 152–162. https://doi.org/10.1016/0141-5425(91)90062-C

Lyle, R. C. (1981). A performance test for assessment of upper limb function in physical rehabilitation treatment and research. *International Journal of Rehabilitation Research*, *4*(4), 483–492. https://doi.org/10.1097/00004356-198112000-00001

Maw, J., Wong, K. Y., & Gillespie, P. (2016). Hand anatomy. *British Journal of Hospital Medicine*, *77*(3), C34–C40. https://doi.org/10.12968/hmed.2016.77.3.C34

Peña-Pitarch, E., Costa, J. V., Martinez, J. L., Al Omar, A., Larrión, I. A., & Tico-Falguera, N. (2018). Introductory Analysis of Human Upper Extremity After Stroke. *International Journal of Privacy and Health Information Management*, *7*(1), 45–60. https://doi.org/10.4018/ijphim.2019010103

Peña-Pitarch, E., Magaña, J. F. P., Ticó-Falguera, N., Omar, A. Al, Larrión, I. A., & Costa, J. V. (2020). Virtual human hand: Grasps and fingertip deformation. *Advances in Intelligent Systems and Computing*, Vol. 975, pp. 484–492. https://doi.org/10.1007/978-3-030-20216-3_45

Whitehead, S., & Baalbergen, E. (2019). Post-stroke rehabilitation. *South African Medical Journal*, *109*(2), 81–83. https://doi.org/10.7196/SAMJ.2019.v109i2.00011

Ye, Q., Seyedi, M., Cai, Z., & Lai, D. T. H. (2015). Force-sensing glove system for measurement of hand forces during motorbike riding. *International Journal of Distributed Sensor Networks*, *2015*. https://doi.org/10.1155/2015/545643

Yozbatiran, N., Der-Yeghiaian, L., & Cramer, S. C. (2008). A standardized approach to performing the action research arm test. *Neurorehabilitation and Neural Repair*, *22*(1), 78–90. https://doi.org/10.1177/1545968307305353