Development of an Affordable, Accessible, and Available (3As) IoT-Enabled Motion Analysis System for Stroke Recovery Monitoring – An Introductory Approach

Yu Zheng CHONG1*, Peng Yee NG1

1 Department of Mechatronics and Biomedical Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Sungai Long Campus, MALAYSIA.

*chongyz@utar.edu.my

Abstract. According to the United Nations Sustainable Development Goals (SDGs) formulated in 2015, there are seventeen (17) identified goals aimed to be achieved by 2030. This project was focussed on SDG 3, SDG 10, and SDG 11 [1]. The developed motion analysis system adopted principles of Affordability, Accessibility, and Availability of this system for monitoring of stroke patients who are undergoing physical therapy (PT). Such system will enable stakeholders involved in rehabilitation of these communities to monitor the progress of PT regime that will be vital in determining efficacy of the regime. Furthermore, the proposed system has the capabilities of remote monitoring, and data acquisition via the IoT platform. The cost of developing this modular system was less than RM 1,000 (approximately USD 243) [2]. Hence, it is anticipated that this project will be a stepping stone towards 3As of motion analysis for stroke patients.

1. Introduction

Stroke is a disease that well defined in numerous literatures, and it will happen when blood delivered to brain tissue is disrupted [4]. According to statistics obtained from United Nations, there are approximately 15 million peoples suffer from stroke globally [3]. In the local Malaysian context, stroke is one of the leading causes of disability, and the third highest cause of mortality. National Stroke Association of Malaysia has estimated some 40,000 Malaysians suffer from stroke annually [4]. These figures grow annually at the rate of 29.5 % and 18.7 % for ischemic and haemorrhagic stroke yearly [4]. Hence, it is vital to have proper post-stroke treatments to enable recovery, and enhancing the quality of life of this community. The Ministry of Health Malaysia has proposed various treatment plans [4].

1.1. Clinical Gait Analysis and Applications of Depth Sensors

Clinical Gait Analysis (CGA) have been widely used in analysing gait for various purposes, from gait monitoring to intervention studies [5]. The adoption of such technologies in Malaysia is still in its infancies due to various factors, and one of the identified factors are the cost of adopting these technologies. Based on 2016 statistics, median monthly household income stands at RM 5,228 [6], hence, under these circumstances the affordability of household to own such monitoring devices at home will be a great financial challenge. In line with this, the project aims to develop a gait monitoring system that costs around RM1,000 which fulfil requirements of 3As.
Three-dimensional gait analysis (3DGA) has been widely used in analysis of human motion joint kinematics [7]. This quantitative assessment of human motion has been utilised specifically in clinical setting whereby various joint kinematics were measured and further analysed to obtain gait parameters that are useful in determination of various clinical considerations from diagnosing to analysing the effectiveness of rehabilitation regimes [7]. These technologies are considerably high cost, hence the 3As of such system is still not widely utilised [7].

With rapid advancement in technologies, there are various readily-available products in the market could be adopted to datalog human joint kinematics. The availabilities of depth sensors technology have enabled motion tracking possible. This adoption may be considered as the supplementary applications of the systems due to the primary functions are for electronic-gaming purposes [8]. Various studies have been conducted on different depth sensors available in the market, namely the Microsoft® Kinect XBox 360, Asus XTion sensors. Functional assessment of human gait have been investigated in various studies [5][8]. One study noted that the Kinect XBox 360 sensor is affordable, highly portable, and user-friendly to enable clinicians to integrate the system into their clinical practice in assisting human motion monitoring and assessments, particularly in the field of rehabilitation [8][9].

1.2. Motivation
The primary aim of this project is to develop an Internet-of-Things (IoT)-enabled markerless human motion analysis system based on the Kinect XBox 360 sensor to monitor movement of patients with hemiplegia during physical rehabilitation sessions. The system also incorporated joint force reaction feedbacks to act as feedback aiming to provide motivation to the patient during rehabilitation sessions. In the nutshell there are three (3) objectives identified for this study as the following:

- Development of testing protocol for marker-less motion analysis system for stroke rehabilitation monitoring
- Integration of IoT features to the Motion Analysis System
- Interactive feedback system as motivation to stroke patient

2. Methodology
This section describes methodology design and implementation for the system.

2.1. SWOT Analysis for the Proposed System
The strengths, weaknesses, opportunities, and threats (SWOT) analysis were conducted to evaluate integration of Kinect XBox 360 in stroke rehabilitation.

2.2 System Architecture
The proposed system architecture is shown in Figure 2. Firstly, the patient is required to perform sit-to-stand exercise. The manoeuvre will be recorded by camera system facing the frontal plane of the patient. Skeleton modelling was directly generated by via the Kinect System Development Kit (SDK) which is interfaced with a dedicated program installed in the computer. Joint landmarks were recorded in real-time for all movement performed by the patient. All information recorded will be stored in an encrypted secured database. This is essential due to the lack of standard database in public-domain utilising the Kinect System. The database is stored in a remote database which will enable retrieval of data from remote location which serves as part of the IoT technology.
Figure 1. The System Architecture

2.2. Subjects Selection
Total of thirty (30) healthy subjects (as control) were recruited for the studies, and one (1) stroke patient volunteered for testing the prototype developed. The study protocol has been approved by the University Ethical Committee prior to data collection. All participants were briefed thoroughly on the study protocol before obtaining informed consent. Selected participants will need to fulfil some requirements prior selection to participate. The participant should be able to stand up from sitting position on their own, ability to understand instructions and understand commands. Exclusion criteria will be tetraplegic or non-independent participants that requiring assistance in accomplishing sit-to-stand manoeuvre.

2.3. Experimental Setup
Figure 2 shows the experimental setup for the sit-to-stand protocol.

Figure 2. Experimental Setup for the sit-to-stand Motion Analysis

The Kinect Xbox 360 sensor was placed 2.60 meter away from the chair. The camera is affixed to a tripod at the height of 0.8 m from the ground as shown in Figure 2. The armless chair selected is of 0.4 cm high. According to [10], majority of movement involved in the sit-to-stand manoeuvre involves sagittal plane movement such as flexion and extension of both hip and knee joint; plantar-and-dorsi-flexion of the ankle joint. Furthermore, the orientation of the camera is placed in front of the subject to detect differences of both sides of the body.

Detailed protocol is summarised in Table 1.

| No. | Details |
|-----|---------|
| 1   | The Kinect Xbox 360 is placed at 0.8m from the ground level; |
Distance between The Kinect Xbox 360 is 2.6m away from the frontal plane of the subject;

Subject is seated on an armless chair with backrest. Fifty percent of the thigh length is sustained by the chair;

The original feet position and the height of chair are adjusted to ensure the position of knee and hip angle is 90 degrees.;

Subject is requested to rise from the chair in his/ her usual manner with self-paced and comfortable speed and sit down. This is to be repeated for three times.

2.4 Skeletal Tracking

Based on the capabilities of the camera system, total of twenty (20) anatomical landmarks coordinates were collected by the system. Three-dimensional coordinates were tracked in real-time to determine respective movement parameters of the movement. Dedicated datalogging system were developed utilising the Microsoft™ Visual Basic Studio 2012. Estimation of body position was performed by depth map computation, which is a proprietary machine learning capability embedded in the camera system.

Mathematical modelling of the lower limb has been performed utilising the link-segment model to model the moment of forces of respective lower extremities joints. In addition, the joint reaction forces were simulated utilising anthropometric data sourced from [11]. Figure 3 shows the link-segment model and anthropometric data adopted in the mathematical modelling.

2.6 IoT Platform

Data acquired from camera system is filtered via the dedicated interface with the Joint Reaction Forces were tabulated and exported in Microsoft Excel (.xlsx) format before being stored in Microsoft OneDrive cloud storage. Data update and retrieval were handled by the Microsoft PowerApps as the back-end interface of the IoT platform. Dedicated mobile application known as `TeleK` was developed utilising PowerApps Studio which enables distributions on mobile devices. Figure 4 shows the development process in TeleK.-

![Figure 4. IoT Platform Development](image-url)
3. Results and Discussions
Lower extremities joints kinematics and kinetics were obtained from the system which agree with [10][12]. As the data collection is still on-going, the results reported in this paper will form the preliminary results obtained from the system.

During the sitting phase of testing, lower extremities of the subject remained in neutral original position whereby the ankle, knee, and hip joints reaction forces are near to zero. When the subject started to change position from sitting to standing, it was noted that large forces were exerted on both knee and hip joints. This were due to the transfer of loading due to weight and balancing mechanism of the lower extremities in reaction to the dynamical changes in the upper extremities. The next event will be transition between sitting to full standing posture. Whilst the subject is standing in the upright position, both extremities will be transiting from dynamic situation to static situation, hence, the joint reaction forces will be back to equilibrium i.e. in static situation. Dynamical changes were recorded once again when the subject transited from standing position back to sitting position. During these changes, the knee joint will exert higher force to support the upper body weight of the subject, and at the same instances, hip will be lowered down until the subject fully resting on the chair. Figure 5 shows an example of the transition of joint reaction forces in the testing cycle.

![Figure 5. The joint reaction forces of Hip, Knee, and Ankle during sit-to-stand testing](image)

It was found that the kinematics and kinetics of the test subjects are in accordance to results obtained in [10][12]. Figure 6 shows samples of joint kinematics collected by the system. In addition, it should be noted that these results are still in its preliminary stages, therefore, more testing will be performed to further validate the efficacy of the developed system.

![Figure 6. Sample Kinematics Parameters Collected by the System](image)

As for the IoT-enabled platform, apps named as TeleK has been developed. The feature of the system enables secured remote access of gait parameters of patients. This will enable remote access to this vital data for the purposes of monitoring, and even diagnosing by healthcare professionals in determining the progress, modification of rehabilitation regime, and home monitoring by the patient caretakers. User profiles, training records, and comments are also made available in the apps. Figure 7 shows the screenshot of the developed apps.
4. Conclusions and Future Recommendations

This paper demonstrates that with the currently available depth camera system, it will be possible to develop a motion analysis system that may assist in improving the quality of life of stroke patients especially in rehabilitation. More importantly, this will be a stepping stone in the development of 3As in the broad area of clinical motion analysis. With the forthcoming technologies in wireless communications, such as 5G, the future will be very exciting especially in making biomechanical assessment technologies to be 3As and in-turn would be able to fulfil the SDGs [1].

References

[1] United Nations. About the Sustainable Development Goals https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (accessed 10 June 2019).
[2] Bank Negara Malaysia. Exchange rates. http://www.bnm.gov.my/index.php?ch=statistic&pg=stats_exchangerates (accessed 10 June 2019).
[3] Aziz ZA, Lee YYL, Ngah BA, Sidek NN, Looi I, Hanip MR, et al. Acute Stroke Registry Malaysia, 2010-2014: Results from the National Neurology Registry. J Stroke Cerebrovasc Dis 2015; 24(12): . https://linkinghub.elsevier.com/retrieve/pii/S1052305715004280 (accessed 10 June 2019).
[4] Islam MR. Rights of the People with Disabilities and Social Exclusion in Malaysia. Int J Soc Sci Humanit 2015; 15(2): . http://www.ijssh.org/index.php?m=content&c=index&a=show&catid=52&id=763 (accessed 16 April 2019).
[5] Taborri J, Palermo E, Rossi S, Cappa P. Gait partitioning methods: A systematic review. Sensors 2016; 16(1):40-2 .
[6] Statistics Department Malaysia. Findings of the Household Income Survey https://www.dosm.gov.my/v1/index.php?r=column/cthemByCat&catid=120&hul_id=RUZ5REweUt1r a1hGCI21JWViPRmU2Zz09&menu_id=amVoWU54UTI0u21NWmdhMjFMMWcyZzc09 (accessed 10 June 2019).
[7] Tucker CA, Wren TAL, Gorton GE, O S. Efficacy of clinical gait analysis: A systematic review. Gait & Posture 2011; 34(2):149-53 .
[8] Clark RA, Pua Y-H, Oliveira CC, Bower KJ, Thilarajah S, McGaw R, et al. Reliability and concurrent validity of the Microsoft Kinect V2 for assessing standing balance and postural control. Gait & Posture 2015; 42(2): . http://linkinghub.elsevier.com/retrieve/pii/S0966636215000740 (accessed 16 April 2019).
[9] Ruff J, Wang TL, Quatman-Yates CC, Phieffer LS, Quatman CE. Commercially available gaming systems as clinical assessment tools to improve value in the orthopaedic setting: A systematic review. Injury. Gait & Posture 2015; 46(2):179-83 . http://linkinghub.elsevier.com/retrieve/pii/S0966636215000740 (accessed 16 April 2019).
[10] Frykberg GE, Häger CK. Movement analysis of sit-to-stand – research informing clinical practice. Phys Ther Rev 2015; 20(3): . http://www.tandfonline.com/doi/full/10.1179/1743288X15Y.0000000005 (accessed 16 April 2019).
[11] David A. Winter. Biomechanics and Motor Control of Human Movement, 4th ed. New York: John Wiley & Sons Inc; 2009.
[12] Crockett K, Ardell K, Hermanson M, Penner A, Lanovaz J, Farthing J, et al. The Relationship of Knee-Extensor Strength and Rate of Torque Development to Sit-to-Stand Performance in Older Adults. Physiother Canada 2013; 65(3): . https://utpjournals.press/doi/10.3138/ptc.2012-04 (accessed 16 April 2019).