B-COV:Bio-inspired Virtual Interaction for 3D Articulated Robotic Arm for Post-stroke Rehabilitation during Pandemic of COVID-19

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Summary

The Coronavirus or COVID-19 is contagiousness virus that infected almost every single part of the world. This pandemic forced a major country did lockdown and stay at a home policy to reduce virus spread and the number of victims. Interactions between humans and robots form a popular subject of research worldwide. In medical robotics, the primary challenge is to implement natural interactions between robots and human users. Human communication consists of dynamic processes that involve joint attention and attracting each other. Coordinated care involves sharing among agents of behaviours, events, interests, and contexts in the world from time to time. The robotics arm is an expensive and complicated system because robot simulators are widely used instead of for rehabilitation purposes in medicine. Interaction in natural ways is necessary for disabled persons to work with the robot simulator. This article proposes a low-cost rehabilitation system by building an arm gesture tracking system based on a depth camera that can capture and interpret human gestures and use them as interactive commands for a robot simulator to perform specific tasks on the 3D block. The results show that the proposed system can help patients control the rotation and movement of the 3D arm using their hands. The pilot testing with healthy subjects yielded encouraging results. They could synchronize their actions with a 3D robotic arm to perform several repetitive tasks and exerting 19920 J of energy ($kg.m^2.S^{-2}$). The average of consumed energy mentioned before is in medium scale. Therefore, we relate this energy with rehabilitation performance as an initial stage and can be improved further with extra repetitive exercise to speed up the recovery process.

Keywords: *bio-inspired interaction, robotics, medical, post-stroke rehabilitation, gesture tracking.*

1. Introduction

In recent years, many modern therapeutic procedures and techniques have been proposed to incorporate developments from technology and other areas of science into medicine[1,2]. It is now widely acknowledged that people's physical health is related to their psychological health as well as their resilience to diseases. Numerous investigations have explored this resilience. That is why if circumstances like this occur, job-related rehabilitation is added to improve and stimulate healthiness by awarding people to accomplish significant and resolute livelihoods. It's can be loving when they do their daily lifecycle, being communally and cautiously useful, tangled in public or group events[3]. The importance of using multimedia and gaming tools along with Virtual and Augmented Reality has been recognized in research as helpful for physical therapy and rehabilitation among children and adults suffering from mobility-related issues, particularly neurological issues or trauma cases[4].In this context, the requisite control of mobile robots consists of computing paths for them to follow, with or without the capability for collision avoidance. The robots are typically operated using an operative panel or computer as the first interface[5]. The other researcher also focused on analyzing the humanoid robot walking and emotion classification of human as weel as their intuition to find the wayfinding in the virtual environment[6-9]. This paper consists of several sections, section 1 present motivation of the research, while segment 2 fouses on current and past works. Section 3 describe the methodology of the researach, while chapter 4 will describe the result of the study. Finally, part 5 is the conclude the whole research and future work of the upcoming research.

2. Related Works

In most cases, the process of changing the objective of a moving robot involves stopping and reprogramming it using an on-board interface or computer. The articulated robotic arm is used by physicians to help patients recover from physical injuries and ailments. It is costly, however, and many medical facilities cannot afford to buy or even rent it. The communication between robot and human trough skeletal tracking might be delayed or slightly change when the position of sensor not aligned properly[10-12].

Microsoft's Kinect was developed as a gaming tool but can be applied to stroke therapy. Therapeutic diagnostics

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can be improved by using joint tracking. Doctors can use the Kinect camera along with the appropriate software to interpret the actions and monitor the progress of patients. Therapy professionals can use it to determine areas where the patient's movement requires more work by inspecting movements of the joints. Feedback provided by the system can help the patient focus on problematic parts of their body when moving. The Kinect camera has extended functionality as a home-based therapy and treatment tool as neural reactivation requires frequent exercise for subtle control movements[13-14].

The equipment and technologies for rehabilitation in hospitals are generally too expensive to be affordable for personal use. However, the Kinect camera is cheap, effective, and easily available. Rehabilitation software based on the Kinect can be used to track patients' movements and provide appropriate feedback. For instance, if a user during a rehabilitation workout moves too far to the right while standing upright, the application notifies him/her of this and guides movement to the left.

Research has revealed that only 31% of patients with motor disabilities perform the recommended exercises[15-18]. Home rehabilitation systems and the programs can make it easier for patients to exercise regularly. This study focuses on exercises related to mobility therapy for stroke patients, although it is also applicable to other areas of therapeutics—cerebral palsy, Parkinson's, and multiple sclerosis. The Kinect camera is also applicable to treat sports injuries and post-surgery treatment. Some areas of therapy dealing with helping regain balance and movement may benefit from using the Kinect to track and observe the patient's motion. Before the development of the Kinect camera, motion-capture devices were employed by doctors in stroke therapy workouts. White et al. developed a virtual world for stroke therapy that can track the patient's arm while he/she performs a workout[19-20].In the virtual world, images were incident against three walls of an area mimicking a kitchen containing various items for the user to pick up using the arm. The patient's activities were tracked using a sensor attached to the skin. This system has drawbacks related to the motion-capture system as the sensors attached to the patient restrict mobility, and such devices are usually costly and unsuitable for personal use.

The Kinect camera is small and cheap, and thus is suitable for personal use. It does not need to be worn by the patient and thus does not restrict movement. Studies have noted that the Kinect can be used for physical treatment. It introduced a rehabilitation system based on the Kinect to support physical therapists working with patients with motor infirmities. The system contains motion tracking data to help monitor the patient's movements according to the relevant rehabilitation standards. Audio and video feedback are known to help improve the results of rehabilitative workouts. They introduced a 3D virtual environment based on the Kinect that features a virtual arm mimicking the patient's arm. This enables the patient to use the arm to pick up 3D objects[21]. By employing the game world, the level of strain of tasks can be attuned to the capabilities of the patient, which helps engage and maintain his/her interest. The system also allows the patient to assess the movement of the virtual arm. The other researcher used the Kinect camera to create a home-based therapy program for patients suffering from chronic pain[22,23].

Medical staff can use the Kinect as tool for physical therapy. It has been.investigated how video games requiring participant movement could motivate people at risk of obesity to engage in physical activities[24,25]. A Kinect-based system has developed to demonstrate the concept and use of gestures for the popular computer game World of Warcraft instead of the computer mouse, joystick, and keyboard. Gallo et al. introduced a Kinect camera system that allows users to freely control and operate a medical image without a controller so it can be used in a surgery room where everything needs to be sterile, and such conventional means of input such as mouse and keyboard are prohibited[22].

Natural interaction with gesture tracking also being practiced for controlling the presentation, game,AR. They also focused on appearance of the virtual human cloth[26-29]. The Kinect has been employed to manipulate particle visualization, enable robots to navigate hurdles, and recognize the meanings of hand gestures. Researchers have proposed a framework to measure the kinematics of gait using a wearable sensor that has an accelerometer and a gyroscope for each part of the body. Body-assisted rehabilitation has also been studied in this regard. Some researchers have studied applications of the Kinect to balancing games to help stroke patients regain strength[30-34]. While other research that focused on external force of hair might become a concern once they need a realistic virtual human[35]. Table 1 presents a detailed comparison of previously proposed techniques for stroke rehabilitation.

Table 1. Contribution technique with previous works

Proposed techniques	Authors
Focus on synchronization between robotic hand and human arm They used several sensors attached to human body to get accurate position of human body during the interaction.	G.Gioioso et. al [23] Mayagoitia et.al [22]
They proposed new approach for reconstruction to monitor the progress of patient's joint movement. It can be used for continuous progress monitoring for patients who are under therapy.	Lorussi et.al [17]
Provide balancing game application to assist chronic stroke patient. They are asked to do stepping movement while kinect are capturing the gesture and the force that released by patient	Lloréns R et. al[16]
They are invented game-based application that can be used by stroke patient to do home therapy. However, this system little bit complex due to most of stroke patient are dominated by elderly and most of them cannot play game.	Gerling K et. Al [25] and Lange B et al.[26]
The proposed solution will provide simple kinesthetic movement by synchronizing the tracked upper limb arm with 3D articulated arm. The repetitive task will be asked toward the patient to enhance their recovery process. The simple task such as moving 3D blocks from initial position to the destination.	**Proposed Solution**

3. Research Method and Material

Stroke patients usually suffer from several disabilities, such as impaired speech and memory, and even limited motion. The goal of stroke rehabilitation is to use physical exercise to help patients recover physical mobility, typically in their arms. This involves the patients performing simple tasks from daily life. This is challenging because the user/patient needs to synchronize the movement of his/her arm with that of a 3D robotic arm. Table 2 provides the task description in detail.

Table 2. Task Description

Task	Task Description
Task 1	Stretching arm
Task 2	Rotating palm
Task 3	Pulling arm
Task 4	Rotating arm

This section details the methodology used to develop the proposed system, and Figure 1 renders it in a flowchart.

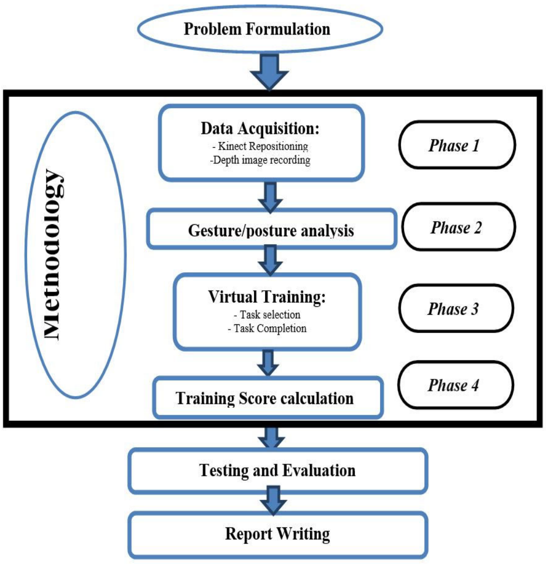


Fig 1. Project Methodology.

The process is initiated by adjusting the position of the Kinect, which recognizes the location of the user. The user acquires a depth image that is converted into a sequence of videos to be analyzed further. The posture is examined according to the requirements of the task. The system gives specific instructions regarding gestures and asks the user to perform the task. When the user has completed it, he/she is awarded a score. At the end of the entire procedure, it displays the overall results of training. The Kinect camera captures the coordinate of the human body and transforms them to manipulate the 3D robotic arm. The detailed synchronization between the human arm and the robotic arm is explained in section 4. The system was designed to train the user to move in coordination with the robotic arm. The user was asked perform a task repeatedly to move a particular joint of the robotic arm with his/her own arm. Even though the movement was simple, hand–eye coordination with the Kinect required focus. The task was determined to help stroke patients recover strength (refer to the task list in Table 2).

The gesture/posture analysis required a coordinate mapping of the results of the Kinect camera concerning the orientation of the joint. The Kinect used a quaternion orientation equation for synchronization between the human joint and the robotic arm joint. The quaternion has four set values (a, b, c, d), where the third is a complex number and one of the other values is real.

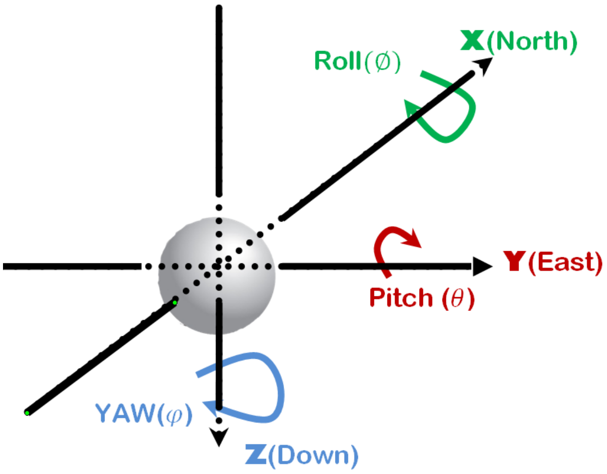


Fig. 2 Join rotation Axis.

Fig. 2 shows that the rotation of the robotic arm was in an inertial frame, where x is the point to north, Y to the east, and Z pointed downward. We define vector q_i^b as a quaternion vector for rotation in the inertial frame, $q_i^b(a\ \mathrm{b}\ \mathrm{c}\ \mathrm{d})^T$, T is a transpose vector, and b, c, and d are vector elements of the quaternion matrix that are used for rotation. “a” is the scalar rate controlling the degree of rotation of the vector elements. If θ is the angle of rotation and vector $(v_x\ v_y\ v_z)^T$ is a vector element for the rotational axis, the quaternion component can be identified as Equation 1:

$$\begin{pmatrix} a \\ b \\ c \\ d \end{pmatrix} = \begin{pmatrix} \cos(0.5\theta) \\ v_x \sin(0.5\theta) \\ v_y \sin(0.5\theta) \\ v_z \sin(0.5\theta) \end{pmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The quaternion q_i^b is used as rotation of the inertial frame relative to the main body using Equation 2:

$$v_B = q_i^b \begin{pmatrix} 0 \\ v_I \end{pmatrix} (q_i^b)^{-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Vector V_B can be rotated by using the quaternion that has zero real elements, and multiplying it by the stance quaternion and its inverse. If we define the quaternion $q_1 = (a_1\ b_1\ c_1\ d_1)^T$ and $q_2 = (a_2\ b_2\ c_2\ d_2)^T$, the quaternion multiplication q_1q_2 is specified by Equation 3:

$$q_1q_2 = \begin{pmatrix} a_1a_2 - b_1b_2 - c_1c_2 - d_1d_2 \\ a_1b_2 + b_1a_2 + c_1d_2 - d_1c_2 \\ a_1c_2 - b_1d_2 + c_1a_2 + d_1b_2 \\ a_1d_2 + b_1c_2 - c_1b_2 + d_1a_2 \end{pmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The matrix of rotation from the inertial frame to that of the body through quaternion factors can be computed using Equation 4:

$$R_i^b(q_i^b) = \begin{pmatrix} a^2+b^2-c^2-d^2 & 2bc - 2ad & 2bd+2ac \\ 2bc+2ad & a^2 - b^2 + c^2 - d^2 & 2cd\ -\ 2ab \\ 2bd-2ac & \mathrm{2cd+2ab} & \mathrm{a}^2 - \mathrm{b}^2 - \mathrm{c}^2 + d^2 \end{pmatrix} (4)$$

Therefore, a rotation of the inertial frame → body frame can be represented by multiplying the matrix as shown in Equation 5:

$$v_B = R_i^b(q_i^b)v_I \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

The process of conversion of the quaternion to the Euler angle depends on the sorting of the rotation. This process can be represented using Equations 6, 7, and 8.

$$\Phi = \arctan\left(\frac{2(ab+cd)}{a^2-b^2-c^2+d^2}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$\theta = -\arcsin\left(2(bd-ac)\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

$$\psi = \arctan\left(\frac{2(ad+bc)}{a^2+b^2-c^2-d^2}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

4 Result and Discussion

An arm gesture tracking system was setup using a depth camera to capture and interpret human gestures to use as interactive commands for the robot simulator. The human subject was expected to act naturally using the proposed robotic arm while controlling the relevant joint of his/her body. The proposed system is based on the OpenGL3D library and Kinect for Windows to communicate with the Kinect sensor. Fig. 3 illustrates the main interface of the 3D articulated arm.

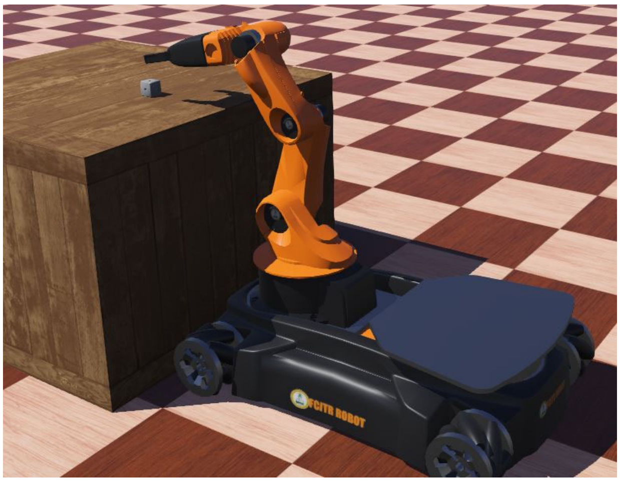
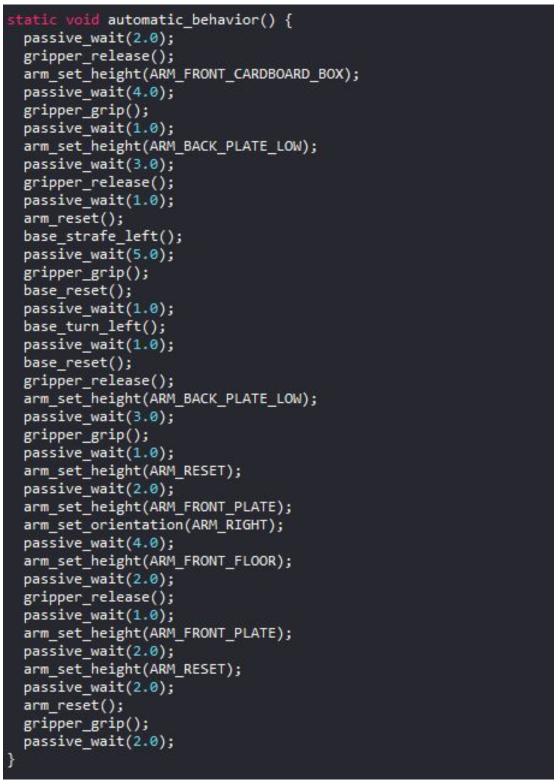


Fig 3. Controlling Mobile Robot to take the cube

Fig 4. shows the procedure of controlling the robot's state by switching the joint using numeric keys arrow up, down, left and right of the keyboard, or by using the Kinect to imitate functions of the mouse through gesture tracking.



```
static void automatic_behavior() {
  passive_wait(2.0);
  gripper_release();
  arm_set_height(ARM_FRONT_CARDBOARD_BOX);
  passive_wait(4.0);
  gripper_grip();
  passive_wait(1.0);
  arm_set_height(ARM_BACK_PLATE_LOW);
  passive_wait(3.0);
  gripper_release();
  passive_wait(1.0);
  arm_reset();
  base_strafe_left();
  passive_wait(5.0);
  gripper_grip();
  base_reset();
  passive_wait(1.0);
  base_turn_left();
  passive_wait(1.0);
  base_reset();
  gripper_release();
  arm_set_height(ARM_BACK_PLATE_LOW);
  passive_wait(3.0);
  gripper_grip();
  passive_wait(1.0);
  arm_set_height(ARM_RESET);
  passive_wait(2.0);
  arm_set_height(ARM_FRONT_PLATE);
  arm_set_orientation(ARM_RIGHT);
  passive_wait(4.0);
  arm_set_height(ARM_FRONT_FLOOR);
  passive_wait(2.0);
  gripper_release();
  passive_wait(1.0);
  arm_set_height(ARM_FRONT_PLATE);
  passive_wait(2.0);
  arm_set_height(ARM_RESET);
  passive_wait(2.0);
  arm_reset();
  gripper_grip();
  passive_wait(2.0);
}
```

Fig 4. Robotic arm movement

This research present two main phases of testing: Gesture tracking and initial testing toward a healthy subject. The first test involved the management of the tracker to control the hand, and began by adjusting the vision sensor to read the joints of the human body and synchronizing the 3D arm with a hand motion.

4.1 Gesture tracking and system evaluation

The gesture tracking featured detecting the motion of the human hand based on visual tracking. The human arm was classified into three joints, all of which were connected to the robotic 3D arm as shown in the following figures (Figure 5). While Figure 6 User has been asked to hold the cube and move to the car, then put the cube in different location. This updated version has attracted user attention and receives a positive response from then as depicted in section 4.2.

Fig 5. Controlling mobile robot to put the cube on the cart

Fig 6. shows the movement of the articulated arm controlled by the human hand.

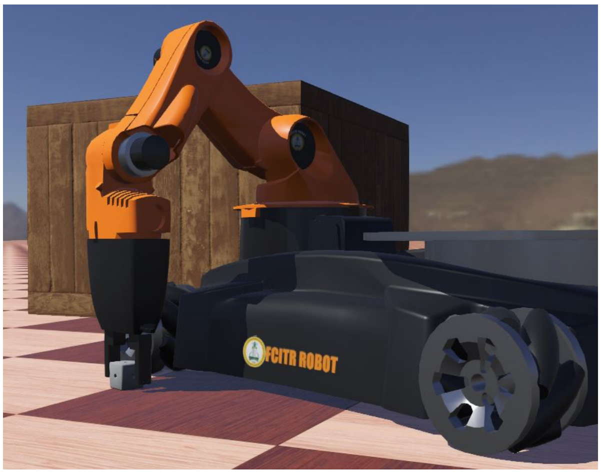
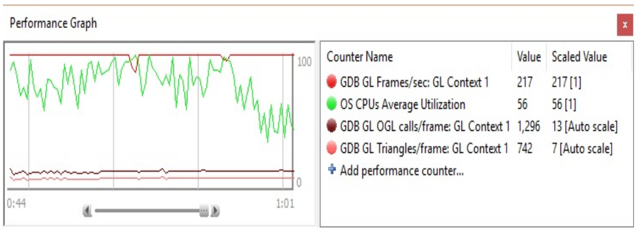


Fig 6. Controlling mobile robot to lay the cube on the floor

The proposed system was developed using OpenGL, and the robotic arm was synchronized with the patient's arm through skeletal tracking in the Kinect. The proposed method was evaluated for efficiency in terms of CPU and memory processing as it is a real-time application. A subjective evaluation considering usability for the patient will be conducted in a future study. Fig 7 and 8 show that on average, the system used CPU resources below a given threshold, which means that the simulation could provide real-time feedback to the user without delay. The GDB/Gl triangle also had a low value that shows that the 3D model provided modeling but used little memory.



Counter Name	Value	Scaled Value
🟥 GDB GL Frames/sec: GL Context 1	217	217 [1]
🟩 OS CPUs Average Utilization	56	56 [1]
🟥 GDB GL OGL calls/frame: GL Context 1	1,296	13 [Auto scale]
🟥 GDB GL Triangles/frame: GL Context 1	742	7 [Auto scale]
✚ Add performance counter...		

Fig 7. The cpu and memory performance monitoring

Fig 8 shows the performance of the system in terms of hardware utilization. The average CPU usage was high but acceptable, whereas the number of frames rendered per second were also high. This means that the rendering process was detailed and led to high-resolution 3D modeling.

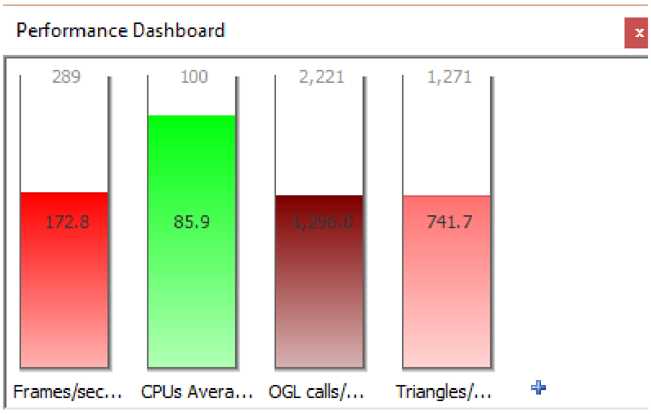


Fig 8. Performance dashboard

Fig 9 shows the overall statistical measurement of CPU usage and frame rendering, and shows a positive outcome. Even though the number of frames rendered was large, CPU utilization remained low.

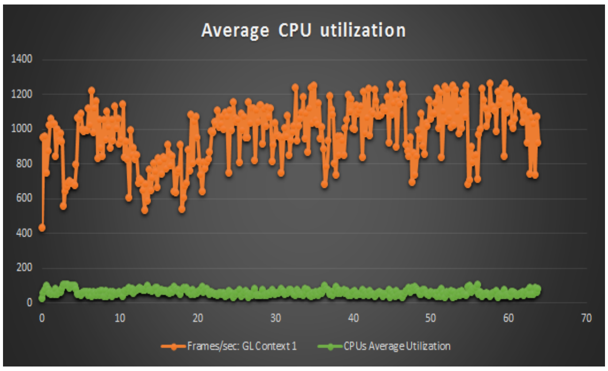


Fig 9. CPU vs Frames/sec.

4.2. Initial testing of healthy subjects

Initial testing was conducted on five healthy subjects, whereas experiments on stroke patients will be undertaken in future research. The subjects were asked to perform several tasks as shown in Table 2. Figure 17 shows a subject stretching, rotating, and pulling an arm, and rotating the palm.

Fig 17. User acceptanceerformance

A. Experiment toward user energy consumption

The subjects were successfully tracked, and their movement coordinates were transferred and synchronized with those of the 3D robotic arm. The amount of energy exerted by the users was computed as kinetic energy using Equation 9.

$$KineticEnergy(KE) = 0.5 \times mv^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

$$m = mass$$

$$v = velocity$$

$$Velocity(V) = \frac{\text{distance}(d)}{time(t)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

We used the energy release computation in Palade's work (2013) to calculate the amount of energy exerted by the subject during interaction with the system as shown in Equation 11, with the assumption that the mass of arm was 5% of that of the body.

$$M_{arm} = M_{body} * 0.05 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

It’s has mentioned that shoulder seizure front comparable with the stretching and pulling arm motion has average energy ±382 Joules(kg.m2.S-2). While rotating hand motion similar is with shoulder abduction side with ±214 Joules. Finally, the rotating palm is similar to the movement of arm by following certain line or pattern which cause motion energy release with ±36 Joules. Therefore, the average energy spend for the exercise for 20 times repetitive task is described in Table 3.

Table 3. Average Energy Consumption per subjects

Task	**Task Description**	**Repetition**	**Total energy**
Task 1	Arm Stretching	20	7640 Joules(kg.m^2.S^{-2})
Task 2	Palm Rotation	10	360 Joules(kg.m^2.S^{-2})
Task 3	Arm Pull	20	7640 Joules(kg.m^2.S^{-2})
Task 4	Arm Rotation	20	4280 Joules(kg.m^2.S^{-2})
Total energy			19920 Joules(kg.m^2.S^{-2})

The energy exerted by the subjects varied according to age, level of health, and gender. Therefore, a more extensive pilot study will be conducted in future work, in addition to testing subjects on more complicated tasks.

B. Experiment on user acceptance

In order to strengthen the evaluation of our initial testing we did provide user acceptance testing. There are two main hypothesis that derived in this research, refer to Table 4.

H1: Condition in which the user has got a training toward the system and familiar with the user interface for stroke rehabilitation

H2: Condition in which the user run the system for the first time and didn’t have prior background about how the stroke therapy is conducted

We run two statistical analysis testing such as Z test and Anova to find the correlation between two hypotheses. Table 5 represents the z test between two theories. Because the value of z which is -0.348117229 < 1.959963985(z Critical two-tail). So we cannot reject the hypothesis that means even without training our proposed system is very used and compatible even with the beginner.

Table 4. User acceptance test

Criteria	User 1	User 2	User 3	User 4	User 4	User 5	User 6	User 7	User 7	User 8	User 9	User 10	User 11
1. User acceptance on how to do Arm Stretching (LC)	H	L	H	L	L	H	H	L	H	L	L	L	L
2. User acceptance on how to Rotate the palm (HC)	H	H	H	H	L	L	H	H	H	H	H	H	H
3.User acceptance on how to Pull the Arm (LC)	H	H	L	H	H	H	H	L	L	L	L	H	H
4.User acceptance on how to rotate the Arm (HC)	H	L	H	L	H	L	H	H	H	L	H	H	H

Table 5. Z Test analysis for user acceptance test

z-Test: Two Sample for Means		
	Variable 1 (with training)	*Variable 2 (Without training)*
Mean	82.56	83.69
Known Variance	51.9084	53.4589
Observations	10	10
Hypothesized Mean Difference	0	
z	-0.348117229	
P(Z<=z) one-tail	0.363876073	
z Critical one-tail	1.644853627	
P(Z<=z) two-tail	0.727752146	
z Critical two-tail	1.959963985	

A similar trend also is shown in Table 6, and the Anova test also proves that we cannot reject the null hypothesis because of F value: 0.109067045 < 4.413873419 (F crit value). Anova demonstrates that training toward our proposed system not affect the knowledge of the user on how to use the system. The user quickly can adapt and use the application without further problem.

Table 6. Anova analysis for user acceptance test

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6.3845	1	6.3845	0.109067	0.745022	4.413873
Within Groups	1053.673	18	58.53739			
Total	1060.0575	19				

5 Conclusion

The pandemic has changed most people live, and they are spending most of their time at home for their daily activities. This study focused on providing Kinect system as a low-cost home-based rehabilitation system to train the upper arm, especially for post-stroke therapy. It is obtained by tracking human joints connected to a robotic arm synchronized in real-time. Subjects were asked to carry out such simple movements as stretching, rotation, pushing, pulling the arm, and rotating the palm. The users were encouraged to move their arms and check to see whether the 3D arm moved. At the end of the training session, the system provided the exercise and recommendations or targets for the next training. A pilot test with five healthy subjects was conducted. They were able to synchronize their movements with those of a 3D robotic arm to perform several repetitive tasks while exerting 19920 J(kg.m^2.S^{-2}) of energy. This energy is a significant amount for planned exercise, and increasing the intensity of training is expected to increase the success rate of stroke rehabilitation. We plan to use the proposed mechanism for clinical tests on stroke patients in future work.

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