

# Gait Analysis for Rehabilitation Assessment System Simulator

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**Abstract:** Rehabilitation exercises are needed to help patients to recover from physical disability after experiences serious injuries, either due to illness or surgery. The recovery process usually conducted at the rehabilitation center under expert supervision and consultation with the physiotherapist. However, some patients might be having time constraints to go to the rehabilitation center or the center itself has a limited staff to conduct the therapy session. Therefore, recovery progression will take a longer time. This paper proposes an online rehabilitation monitoring system to help patient undergoing the therapy process without supervision with the aid of a Kinect sensor. Based on several exercises, Kinect joint point data is extracted and simulate in real-time basis. The developed assessment system simulator is tested with 12 subjects and the low-cost system is capable to provide the required date for rehabilitation. The movement data is analyzed based on the angle value simulation and display the overall therapy progress for further improvement.

**Keywords:** Gait analysis; Kinect; Rehabilitation; Simulator.

## 1. INTRODUCTION

According to the latest WHO data published in 2017, stroke deaths in Malaysia reached 15,642 or 11.31% of total deaths. The death rate is 71.50 per 100,000 of population, which ranks Malaysia to number 113 in the world [1]. Strokes can cause a person's movement is restricted and can be improved by a trained physical rehabilitation [2]. In addition to stroke, a factor that is the cause of physical disability that affects the ability of body systems to function correctly is a disorder of the brain such as multiple sclerosis, cerebral palsy, chronic pain, including back and neck pain, spinal cord injury and others. This physical disability can cause patients to lose the ability to be independent because they are unable to carry out the activities required for daily life [3]. Patients may experience problems such as loss of balance, lack of ability in terms of attention and concentration, pain, weakness, and paralysis, usually in the body. One way to restore the power of the system to the patient's body back to work is through the process of physical recovery.

Physical recovery is a typical medical method to help patients to restore their lost function of the body caused by illness or injury. It is also to restore the patient's ability to perform everyday tasks independently by conducting regular exercises. For stroke patients, the physical rehabilitation process is limited by pressure on the patient's body system [4]. The study showed that intensive therapy is carried out at an early stage that includes physical movement aspects of daily activities, showing more positive results for the recovery of the body caused by a stroke [5]. Perhaps the significant issues arising in connection with traditional therapies is the lack of motivation given to the patient, the time allotted to patients when physical activity is less, the exercise is too easy [6], and environmental conditions make patients uncomfortable and easily distracted [7].

The assessment of limb mobility for stroke patients is an essential part of post stroke rehabilitation. Recovery process and training monitoring can be used by the physiotherapist to provide feedback to the patients for training improvement. Clinical monitoring is manually performed using chart based ordinal scales. This conventional method is limited to a different chart scale for other exercises and stage of recovery. The manual evaluation is not reliable to a different aspect of body function and not accurately represent the real assessment outcome. Therefore, many researchers improve the efficiency, reliability and sensitivity of rehabilitation assessment method based on wearable sensor and visual-based sensors.

Initially, the study involved the development of a sensor-based application which attach a device to the subject and monitor the movement. A wearable inertial measurement unit (IMU) is commonly used in rehabilitation training supervision

applications. Wearable devices are cheaper, compact and easy to set up and operate. The wearable sensor, such as an accelerometer is used to emphasize the clinical applications of fall detection during rehabilitation treatment [9]. Zhang *et al.* used sensing devices such as accelerometer sensor, gyroscope and magnetic sensor to develop motion tracking system and model 3D animation for rehabilitation patients with chronic pulmonary disease and stroke [10]. Mazilu *et al.* used accelerometers to analyze the gait for Parkinson disease [11]. Bartalesi *et al.* suggested a kinesthetic wearable sensor in an upper limb gesture recognition system for stroke patients [12]. Pan *et al.* focused on upper part rehabilitation treatment for home-based monitoring online system [13]. Dobkin *et al.* classified activity pattern and speeds for healthy and hemiplegic patients by placing an accelerometer over the tibia, which is just above the ankle [14].

However, the wearable sensor method solely depends on the placement or positions of sensors during exercise. Users will move on control manner because they worried if the device will result in an error or damaged. The challenges of sequence variations among the subject might produce a different result. Therefore, a study in rehabilitation assessment opts for another option which is a vision-based sensor. The Kinect sensor has been widely used to perform an automatic evaluation in rehabilitation assessment. A study reported in [15] used a 3D view of the computer system for the assessment and rehabilitation of cognitive-based Kinect device. Kinect device used to detect connection joints in the human body and the detection of facial features (nose, eyes, ears) to exercise psychomotor ranging from touching the facial features by hand or movement of hands. Then, the subject can be monitored and assessed the exercise, whether the subject performed incorrect training. This system has been evaluated by a total of 15 users and achieved 92.28% accuracy. This performance is suitable for the integrated system in cognitive rehabilitation platform mode.

The Kinect sensor potential is shown by another achievement to assess the likelihood of recovering two teenagers with cerebral palsy (CP) in public schools [16]. This system allows physical therapists to develop a series based on the movement of upper limb exercise for the restoration of lasting motor impairment for each participant. This system also helps people to practice motor activity independently. Game-based approach for rehabilitation patients also utilized the Kinect sensor to perform a particular task and exercise for stroke patient recovery [17]. The game-based method allows users to control and interact with the game console without the need to touch a game controller and provide remedial training for stroke patients who have had a failure of the lower limbs [18]. The game-based method is simple in terms of functionality, and the game is useful for the recovery of the affected upper limb function. Meanwhile, patients were encouraged actively like to play games and reduce drastic movements of the body, thus avoiding stress on the cardiovascular system [19]. Vision-based rehabilitation exercise simulation system utilizes pattern recognition technique to achieve the objective in clinical assessment. Supervise classification techniques are often incorporate to measure the vital information from the sensor and produce valid result correlated with expert evaluation. For example, a support vector machine (SVM) was used to classify the severity of Parkinson's disease in [20].

This paper develops and evaluates a real-time home-based rehabilitation assessment using a low-cost assessment system with Kinect sensor data manipulation. Kinect joint point data is extracted and simulate in real-time basis for further assessment and analysis. Conventionally, the assessment is conducted manually by clinicians using a chart-based ordinal scale, which is inefficient and subjective. At the same time, the patient's needs to go to the therapy center weekly or monthly for progression analysis. A low cost sensing camera technology capable of providing a mark for the entire body on a conventional PC is used. The technique combines a variety of technologies to help people with disabilities in the process of physical recovery, and it is developed in a variety of situations. Using the Kinect system, it can be a method that can be used by patients for the therapy process. By using this system, the patient can carry out the recovery process without the presence of the therapist.

## 2. METHODOLOGY

Figure 1 shows the Kinect camera setup during the data acquisition process to record and capture the subject movements. Figure 2 emphasizes on the flowchart of the rehabilitation assessment simulator. After the subject is detected, the simulator will display each of the 25 body joint points and track the exercise movement in real-time. Hence, the subject needs to select which type of exercise they want to perform. The simulator will calculate the distance of the chosen joint point using Equation (1) and followed by the angle calculation utilizing the law of cosine formula. The simulator will plot and display the angle value for subject references. Further assessment is needed to evaluate the subject performance by calculating the average peak angle. Then, subject conditions will be determined and categorized into Weak, Average or Good conditions by analyzing the threshold setting value for each of the exercises.

The simulator is developed so that the patient can be trained by following the sequence of steps in the recovery process using the Kinect device. The patient will be instructed to do a correct exercise so that they can do the training at home and recorded the data of the movement at home by using a Kinect device.

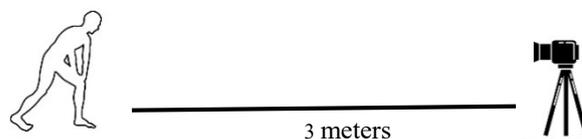


Figure 1. Kinect setup for data acquisition

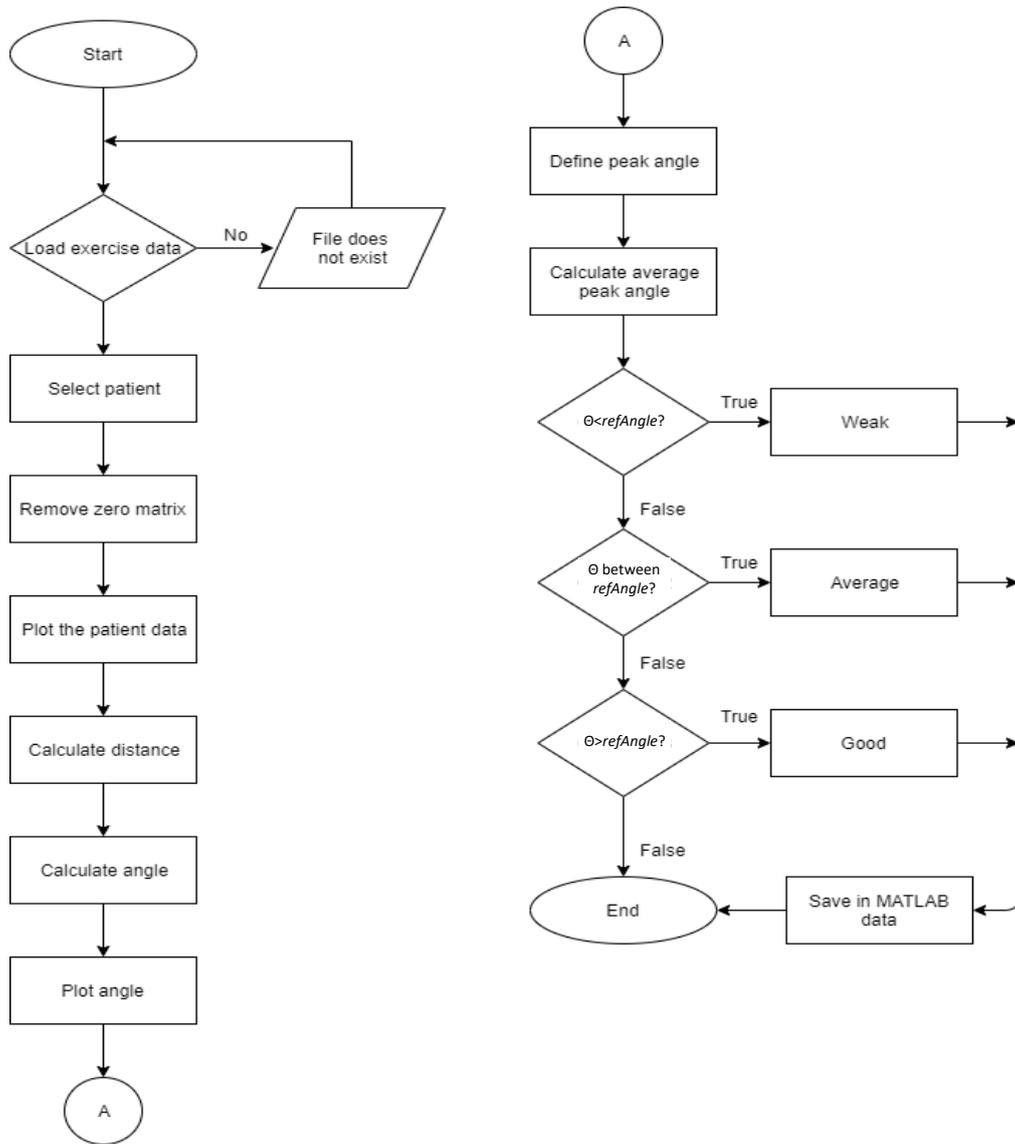


Figure 2. Proposed workflow for rehabilitation assessment simulator

**2.1 Joint Point Distance**

The joint point angle for selected skeleton data used to assess the progress of exercise movement. The angle was calculated based on a mathematical basis which depends on the length or distance for certain joints (x, y). The calculation distance, *d* is determined by the following:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{1}$$

where (x, y) is the coordinates of both points. Then the angle was determined using cosine rule formula, and each exercise is setting to different angle position. Figure 3 shows how the joint point angle is selected from the joint point distance. For hand raise exercise, the distance is calculated using hand tip and knee from the spine base joint point. The reference angle for sit up movement is calculated from the distance of the shoulder and knee from the spine base joint point. While for the squat exercise, the angle reference for sit up movement is calculated from the distance of knee and ankle from the spine base joint point. The hand raise and sit up exercises measure the subject condition for upper limb and lower limb, respectively. Only the squat exercise uses the analyze subject performance condition for both upper limb and lower limb.

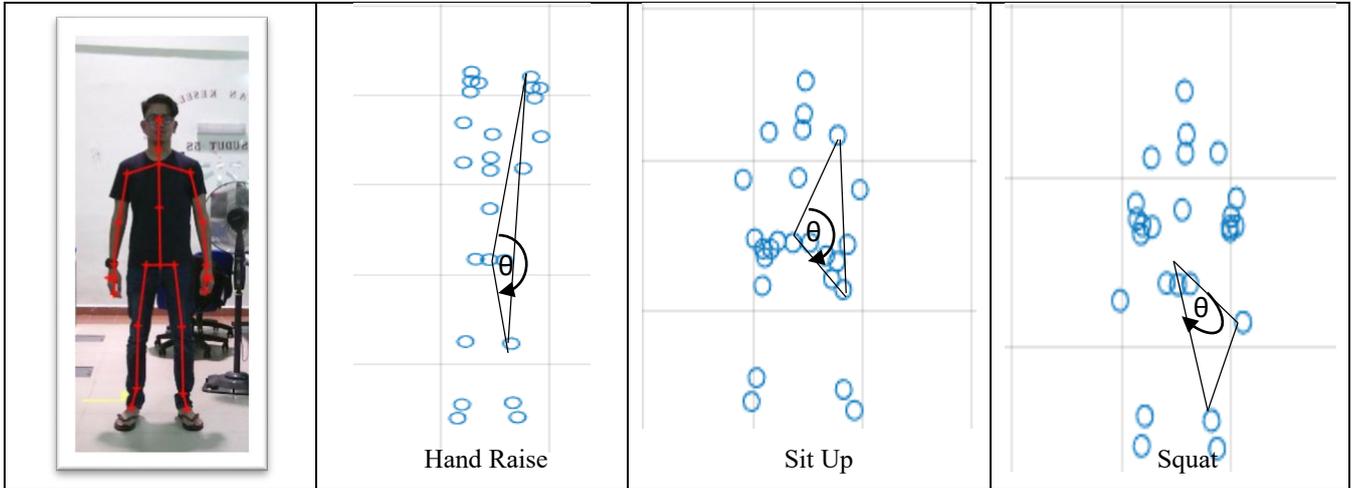


Figure 3. Reference angle for each exercise based on the joint point angle

Table 1. Reference angle and assessment conditions for all exercises

Type of exercises	Reference angle (refAngle) (degree)	Condition
Hand raise	$0 < \theta \leq 90$	WEAK
	$90 < \theta \leq 120$	AVERAGE
	$120 < \theta \leq 180$	GOOD
Sit and up	$150 > \theta \geq 180$	WEAK
	$110 > \theta \geq 150$	AVERAGE
	$90 > \theta \geq 110$	GOOD
Squat	$140 > \theta \geq 180$	WEAK
	$110 > \theta \geq 140$	AVERAGE
	$80 > \theta \geq 110$	GOOD

### 3. RESULT AND ANALYSIS

#### 3.1 Data Collection

The dataset is recorded using Kinect v2 at 30 fps under controlled laboratory environment for three types of exercise which are hand raise, squat, sit and up position. Then, data will be represented by 25 joint points in MATLAB software. There are twelve different subjects involves (seven males and five females) perform each of the exercises in 5 different sets of exercises. All subjects are healthy except that one male subject is a post-surgery subject.

#### 3.2 Assessment System Simulation

Table 1 shows the reference angle that has been chosen for exercise conditions during the analysis process. This reference angle has been set in the exercise code that will be calculated based on the average peaks angle. There are three different reference angles for every exercise. Every reference angle will have a specific condition. This reference angle is used to determine the patient's condition during the training. The patient needs to achieve a particular state to make sure they are fully recovered. If they do not complete a specific condition, they need to repeat this exercise for the next session.

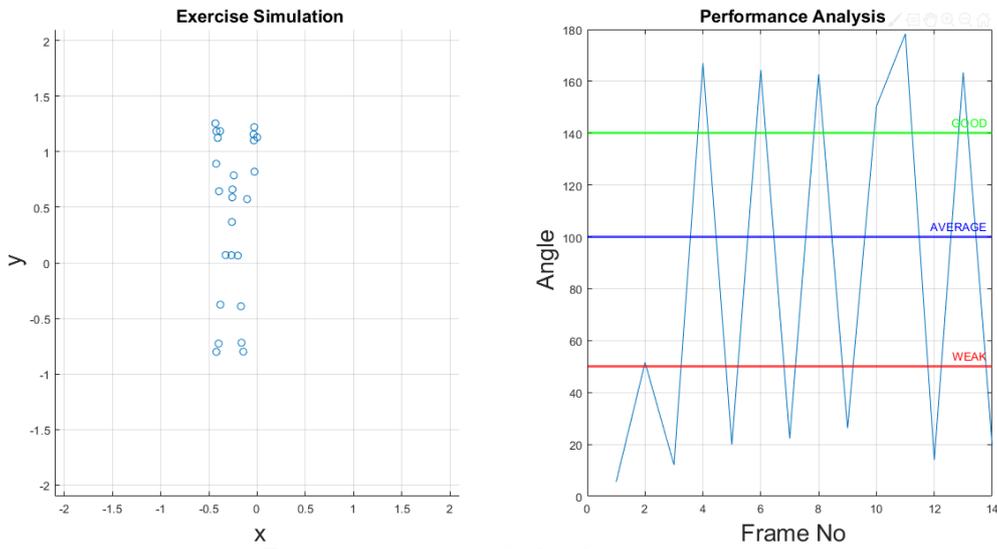


Figure 4. Assessment for hand raise exercise

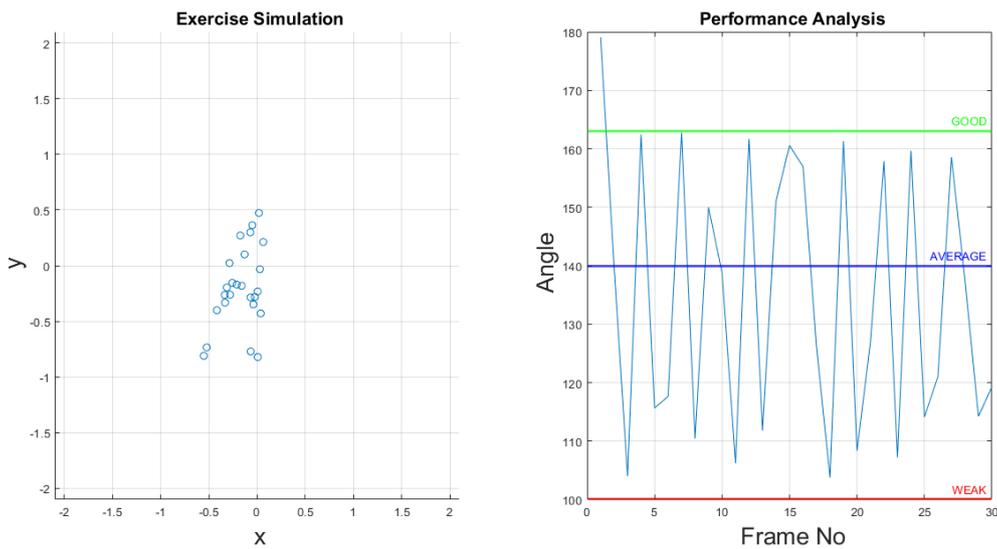


Figure 5. Assessment for sit up exercise

Figures 4-6 show samples for good, average and weak assessments on the graphical user interface (GUI). The progress or performance analysis can be monitored on a real-time basis. Each exercise is performed for 3-5 repeated sequences. Figure 4 shows the exercise simulation of the movement of the subject while doing hand raise exercise. This exercise focus on the upper limb condition. The performance analysis shows that subject performance is in good condition because the GUI indicator displays the maximum achievement of the reference angle value is more than 120 degree.

Figure 5 shows a sample of subject movement for sit up exercise. This exercise is capable of monitoring the performance conditions for the lower limb analysis. The GUI indicator displays that the overall performance conditions are on average. The reference angle for average condition achievement is between 110 and 150 degrees. Figure 6 shows a sample for subject performs in weak conditions while doing squat exercise. The accomplishment of the squat exercise used to analyze both upper and lower limb conditions. The GUI indicator displays that the overall performance conditions for this subject are weak. The reference angle for average condition achievement is above 140 degrees. Overall this system achieved the target to analyze the level of the upper limb and lower limb for the patient. Based on all experiments, 10 out of 12 subjects perform good upper limb and lower limb conditions. The differences between all healthy subjects are for squat positions. Some subject might not so familiar or unfit to perform squat positions.

This system can be one of the methods for a hospital, especially a physiotherapy department, to upgrade their system to be more flexible and more accessible. The proposed method which utilizing the joint point distance from skeleton joint manipulation can develop a low-cost simulator for rehabilitation assessment system.

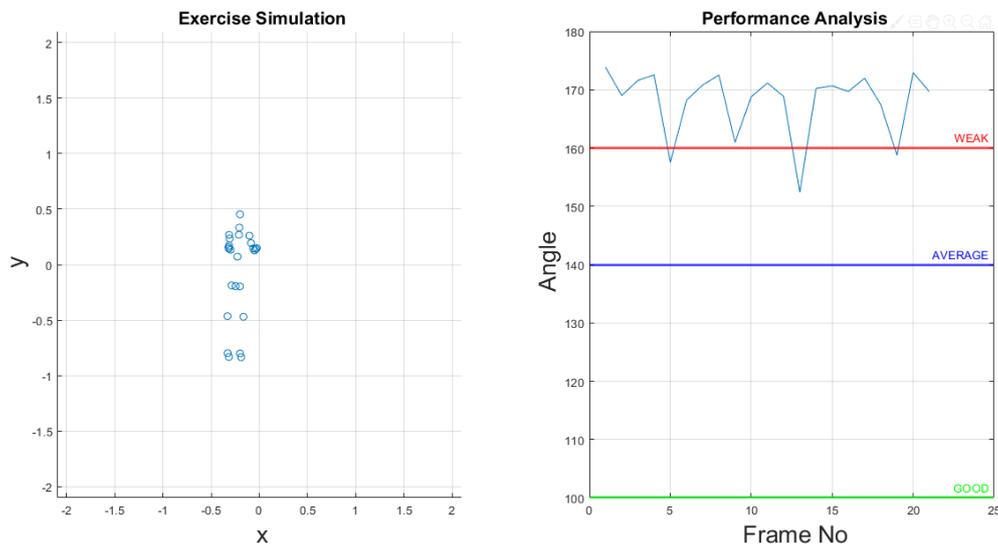


Figure 6. Assessment for squat exercise

#### 4. CONCLUSION

In this paper, a simplified limb mobility evaluation for home-based rehabilitation monitoring system has been proposed. The contribution of this study is to provide an efficient solution for a limb mobility assessment. It serves to improve the individual rehabilitation training in both supervised and unsupervised environments. The simulation system results have demonstrated that the proposed joint-point distance measure is capable of reflecting the training progress of individual subject or patient. The level of assessment based on the reference angle indicator has the potential to produce low cost and low computational rehabilitation assessment system. The evaluation of training progression for different subject ability can be integrated online with expert, clinician or therapist as intuitive feedback to guide patients for maintaining high standard training quality. It can also help the clinician to track patient recovery process and limb mobility without the need for them to present at the site and observed a full training session. In future, the proposed simulation work based on the Kinect sensor will be integrated with the wearable system to improve system validity and reliability further. The metric assessment measurement will be utilized and extended using deep learning which can predict low mobility and early disease diagnosis like cardiovascular disease or stroke.

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