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POST-STROKE REHABILITATION: STICK EXERCISE MONITORING USING KALMAN FILTER

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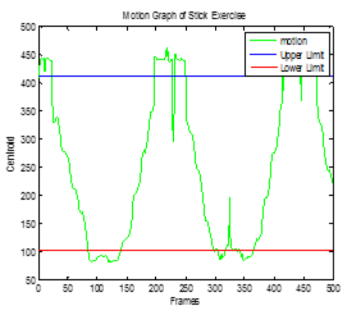
Graphical abstract



Abstract

Post-stroke rehabilitation is a necessary step to improve the function of motor and muscle of the patients. However, it is difficult for the patients to have one-to-one session with the physiotherapist at the rehabilitation center due to the constraint of money, location and time. Thus, there are many existing inventions that provide home-based physiotherapy monitoring to facilitate the patients in performing the rehabilitation exercises to restore the body functions and mechanical skills. This paper presents a novel approach to monitor the stick exercises, in which the system will count the number of exercise cycle performed by the patient for a certain period of time. By using Kalman filter approach, two inputs are observed based on the color of patient's cloth and length of the stick. The centroid coordinate obtained from the Kalman filter output is then used to map the motion graph. Two limits, upper and lower boundaries are set such that a complete cycle of exercise is confirmed if the patient passes both of the boundaries. Those limits are determined based on the ratio of human body proportion. Eight simulated videos of the stick exercise are used to validate the proposed method. The results show that the best performance with 100% correctly count is obtained from video 3 while the worst performance is taken from video 2 and 8. The system can be further improved by incorporating different types of shoulder exercises for post-stroke patient.

Keywords: Physiotherapy, counting exercise, post-stroke rehabilitation, Kalman Filter

Abstrak

Pemulihan pasca strok ialah satu langkah yang diperlukan bagi memperbaiki fungsi motor dan otot pesakit. Namun, ia sukar bagi pesakit bagi mendapatkan sesi perseorangan bersama ahli fisioterapi di pusat pemulihan disebabkan oleh kekangan kewangan, lokasi dan masa. Hal ini menyebabkan, terdapat banyak pengantaraan yang sedia ada yang boleh memberikan pengawasan fisioterapi di rumah bagi membantu pesakit menjalankan senaman pemulihan untuk mengembalikan fungsi badan dan kemahiran mekanikal. Kajian ini membentangkan satu pendekatan yang mengawas senaman menggunakan kayu, dimana sistem tersebut akan mengira jumlah kitaran senaman yang dilakukan oleh pesakit dalam sesuatu jangka masa tertentu. Dengan menggunakan pendekatan penapis Kalman, dua input diperhatikan berdasarkan warna baju pesakit dan panjang kayu. Koordinat titik tengah diperolehi daripada output penapis Kalman yang seterusnya digunakan bagi memetakan graf gerakan. Dua had, iaitu sempadan atas dan bawah disetkan supaya satu kitaran latihan penuh dapat disahkan sekiranya pesakit melepasi kedua-dua sempadan. Sempadan tersebut ditetapkan berdasarkan nisbah pecahan badan manusia. Lapan video simulasi senaman menggunakan kayu digunakan bagi mengesahkan kaedah yang dicadangkan. Keputusan menunjukkan prestasi yang terbaik dengan 100% pengiraan yang betul diperolehi dari video 3 manakala video 2 dan 8 menunjukkan prestasi yang rendah. Sistem ini boleh ditambah baik dengan menggabungkan pelbagai jenis senaman bahu bagi pesakit pasca strok.

Kata kunci: Fisioterapi, sistem pengiraan, pemulihan strok, penapis Kalman

1.0 INTRODUCTION

Physiotherapy is a rehabilitation treatment due to injuries or other problems that limit the patient capabilities to perform his/her daily activities. To monitor the physiotherapy process, the physiotherapist is needed to assist the patients to restore their original body functions, reduce the pain, and prevent further disabilities.[1] Normally, the physical exercises for post stroke are depend on the type of disease or injury. According to World Health Organization (WHO), stroke disease is the fifth leading cause of death and adult disabilities. [2] Stroke is defined as a clinical syndrome characterized by rapidly developing clinical symptoms of loss of cerebral function that last more than 24 hours. Every year, approximately 15 million peoples suffer from stroke worldwide. National Stroke Organization stated that every four minutes there is someone who will die from stroke, and up to 80% of stroke cases can be prevented.[3] Statistically, stroke is the top two leading cause of death reported by Malaysian National Burden of Disease Study.[4]

Therefore, recovery from stroke is a lifelong process that begins with formal rehabilitation session with the physiotherapist to restore patient independence in terms of physical, emotional, and mental functions.[2] Normally, physiotherapy activities are done in the hospital with the guidance from physiotherapist and doctor's supervision. However, due to the constraint of money, time, and limited human resources, it is difficult for the patient to have one-to-one session. Therefore, these challenges lead to the invention of home-based physiotherapy rehabilitation system to enable the physiotherapist to monitor the rehabilitation process remotely.

Recently, there is an emerging trend of computer assisted rehabilitation system among the researchers. In 2014, Ar and Akgul [5] proposed a robust and low cost vision based monitoring system for home-based physiotherapy by using Microsoft Kinect. This system can be divided into two main modules, which are exercise recognition and repetition count modules. The first module is using Bayesian network while the second module is using an approach based on the Bayesian network results. After that, the authors extended the original system by introducing hierarchical features of home-based physiotherapy exercises using an RGBD Camera. The system consists of three features: 1) motion patterns, 2) stance knowledge, and 3) exercise object.

Method in [6] used smartphone as a tool to monitor the rehabilitation exercises for patient who suffers from shoulder injury. The system was equipped with an accelerometer with Bluetooth communication protocol. Shoulder exercise is recognized by using Support Vector Machine method. Then, smart phone will be used to record the exercise's video. According to Zheng et al. [7], a web based monitoring system was proposed to monitor physical therapy activities by using both therapeutic instruction and support information. This system produced three-dimensional visual output and the exercise effectiveness is measured during the rehabilitation activities. Hence, the developed system allows the patients and health professionals to access and review the information.

Therefore, this study proposed a system which can help patient to monitor the number of cycles for the rehabilitation exercise in a certain period of time.

2.0 THE PROPOSED SYSTEM

The proposed methodology for this study consists of three main components, which are pre-processing, object detection and tracking to count the number of exercise cycle. Figure 1 shows the block diagram of the proposed system. The first stage involves background subtraction and color conversion from RGB to HSV colour model. The next stage is tracking, in which the video will undergo segmentation and centroid determination. Finally, the third stage is the counting process to determine the number of correctly done exercise. The system is validated by calculating the percentage of correctly done exercise over the total cycles of performed exercise.

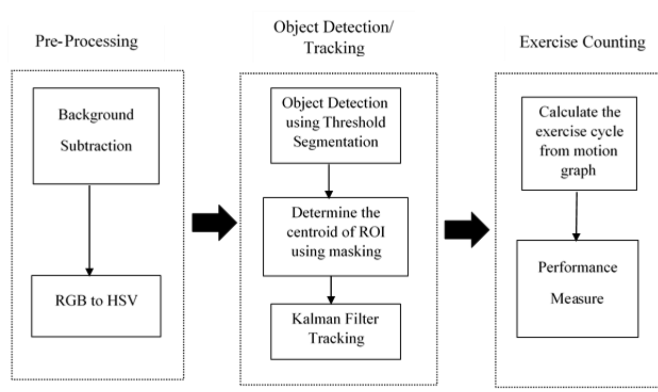


Figure 1 Block diagram of the physiotherapy exercise counting system.

2.1 Background Subtraction

In computer vision, background subtraction is one of the important parts that will significantly affect the overall system. The limitations are associated with challenges in background modelling, such as dynamic background, moving object, shadows and illumination changes[8][9].

Background subtraction is used as a pre-processing step to detect and track the object in surveillance system. There are several methods of background subtraction such as adaptive background and frame differencing. Thus, adaptive background subtraction will applied in this study to keep on updating frame by frame and more responsive to the illumination change and camera movement. The process of adaptive background subtraction is as follow[10];

- The current image will be combined together with the background model with parameter a.
- a = 0 yields simple background subtraction, a = 1 yields frame differencing.
- The a value that has been chosen is 0.5

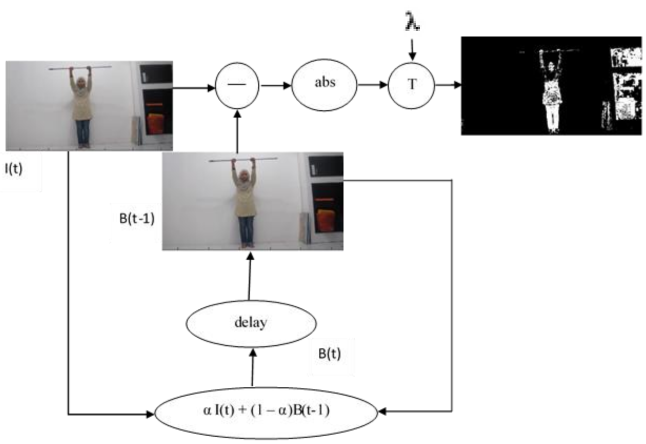


Figure 2 Block diagram of adaptive background subtraction

2.2 Color Space Conversion

After the background subtraction, the image will undergo the color conversion from RGB to HSV. This stage is important because of illumination changes and shadow existence. In order to overcome those limitations, HSV color model has been used since it is more robust. HSV color space is able to identify the difference between chromaticity and luminance and hence the lighting change can be negated[11]. Cucchiara stated that the lighting changes will only affect the hue component slightly, but saturation component significantly.[12]

RGB image　　Saturation Channel

Figure 3 Conversion of RGB to HSV

However, from the observation in Figure 3, saturation channel is able to reduce the shadow effect. Meanwhile, hue and value channels do not give big impact to the video quality. Thus, the saturation channel has been chosen as the input, which will be converted to binary image.

2.3 Segmentation and masking

Segmentation is an important technique to distinguish between foreground and background. Threshold method is one of the most common segmentation methods that has been widely used in computer vision field. Threshold can be determined based on histogram distribution or Otsu's method. In this proposed method, Otsu's threshold has been chosen since it can determine the threshold values of each video adaptively.

On the other hand, masking method has been used to extract the required features, which are the patient's cloth and length of the exercise stick. Centroid coordinates are obtained from both features, but in this proposed method the length of the stick has been selected for the tracking purpose.

2.4 Tracking using Kalman Filter

Kalman filter is a predictive filter that is based on the state space technique and recursive algorithm. This filter estimates the process by using feedback control form as the filter estimates the process and gives feedback by considering the noise measurements. It also predicts the most probable location in the current frame, which the search location is within the gating are of the neighborhood. If Kalman filter receives measurement input , it will continue to predict the next frame state.[13] The main advantages of Kalman filter are 1) the variances of Kalman filter innovations are smaller than the variances of the deterministic innovations and 2) Kalman filter requires low computational burden[14]. There are two important stages in Kalman filter, which are prediction and update stages. The Kalman filter equations are as follows;

$$Motion\ equation,\ X_k = F.X_{k-1} + W_k \quad (1)$$

$$Observation\ equation, Z_k = H.X_k + V_k \quad (2)$$

According to Challa et al, prediction and update equations are defined as shown in equation 3 to 7[15].

Prediction equations;

$$\hat{X}_{k|k-1} = F\,\hat{X}_{k-1|k-1} \quad (3)$$

$$P_{k|k-1} = F\,P_{k-1|k-1}F^{T} + Q_k \quad (4)$$

Kalman gain;

$$K_k = P_{k|k-1}H^{T}(HP_{k|k-1}H^{T} + R_k)^{-1} \quad (5)$$

Update equations;

$$\hat{X}_k = \hat{X}_{k|k-1} + K_k(Z_k - HX_{k|k-1}) \quad (6)$$

$$P_{k|k} = P_{k|k-1} - K_k H_k P_{k|k-1} \quad (7)$$

2.5 Exercise Counting

Upper and lower boundaries are determined based on the ratio body proportion of human being according to B. Bogin and M.I.V.Silva [15]. The boundaries are required to validate the counting as they need to pass through both of the limits in order for that cycle to be counted. The upper limit is determined by the ratio of the highest point, which is set to 0.5, while the lower boundary is set to 0.1 from the centroid or center of the human body.

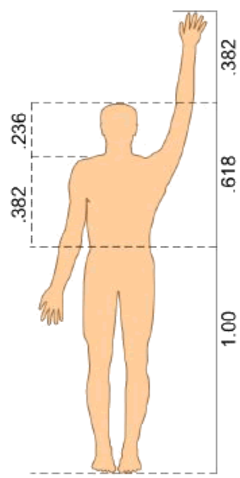


Figure 4 Human body proportion according to Golden Ratio

Figure 4 shows the human body proportion based on Golden Ratio [16] which has been used to determine the lower and upper boundaries for the counting system.

3.0 RESULTS AND DISCUSSION

The dataset used is recorded based on 4 patients from same class of ages to demonstrate shoulder rehabilitation exercises. Before data collection, the patients have been briefed on how to perform the exercise correctly. The videos are recorded using camera digital Canon G12. The specifications of the camera are as follows;

Table 1 Camera specification

Bil	Specification	Canon G12
1	Camera Pixel	10 –MP
2	Video Mode	HD: 1280 x 720 @24 fps

A total of 8 videos with duration of 30 seconds each have been recorded with the resolution of 1280 x 720 pixel. Figure 5 shows a patient doing stick exercise.

Figure 5 Stick exercise

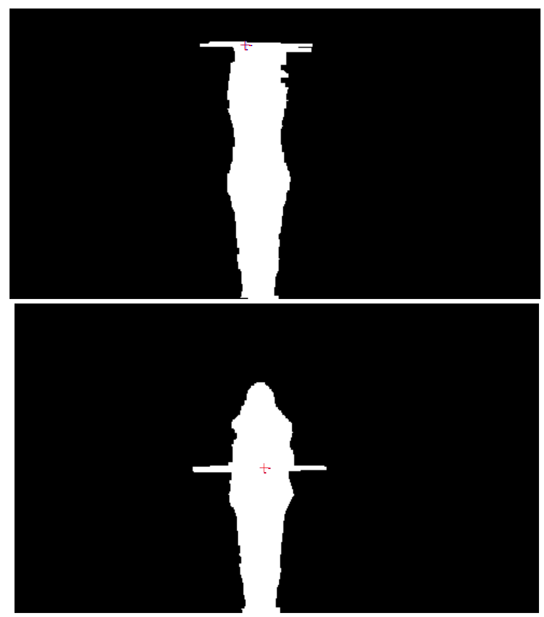


Figure 6 Segmentation of the subject based on output coordinate from Kalman filter.

The patient stands and holds stick as the object with her hands. The patient keeps her elbows in upright position and then raises the object slowly above her head before lowering the object back.

Figure 6 shows the segmentation image of the subject based on output coordinate from Kalman filter. The centroid coordinate of stick obtained is used to track the movement of moving region through Kalman filter algorithm.

The counting ground truth (GT) is obtained through observation from the original video by the trained experts. Then, percentage of correctly done exercise is calculated to validate the system performance.

$$\% \; of \; correct \; cycle = \frac{\text{Counting using KF Tracking}}{\text{Gound Truth Counting}} \; x \; 100$$

Table 2 Percentage of correct cycle

Video	No of Frame	Gound Truth Counting	Counting using Kalman Filter Tracking	% of correct cycle
Video 1	350	3	2	0.667
Video 2	240	3	1	0.333
Video 3	700	3	3	1.0
Video 4	430	3	2	0.667
Video 5	600	3	2	0.667
Video 6	500	3	2	0.667
Video 7	530	3	2.5	0.833
Video 8	250	3	1	0.333

Conversely, the simulation results show that the colour of the patient's cloth affects the output of Kalman filter. The colour influences the coordinate of the centroid in which a wrong bounding box might be calculated. This monitoring system counts the number of cycle of exercises that have been done by the patient in a certain period of time. Therefore, the noise can be neglected since the number of cycle is the only component that is taken into consideration.

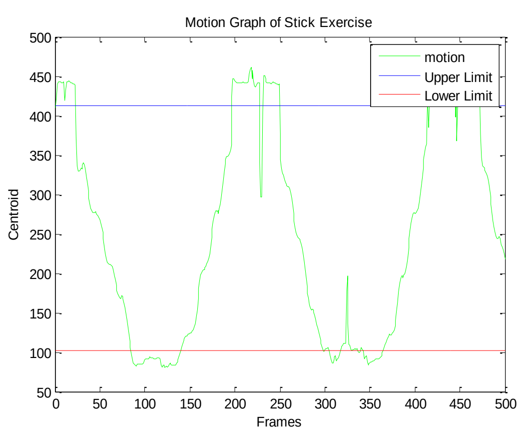


Figure 7 Sample of motion graph of stick exercise with centroid over frame time.

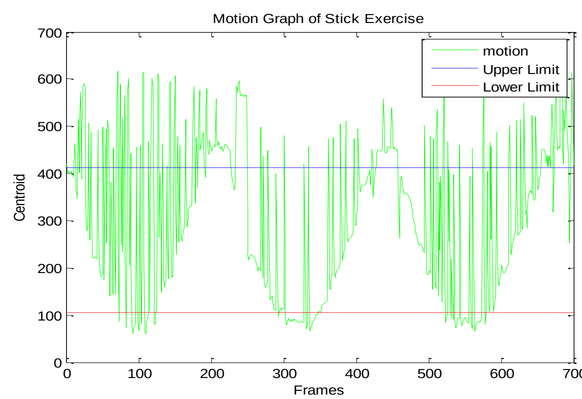


Figure 8 Motion graph of video 3

From the simulation results, video 3 and 5 shows the highest percentage of correctly done exercise while video 2 and 8 produce the lowest percentage of correctly done exercise with just 0.333%. Even though the motion graph in video 3 detects the noise but it still contains the highest percentage of correctly done exercise. This noise happened due to the color of the patient's cloth, yet it does not affect the tracking performance as seen in the motion graph.

4.0 CONCLUSION

This proposed method is implemented using Kalman filter approach to monitor the number of cycles of stick exercise. It counts the correctly done exercise in a certain period of time. This is important since the exercise needs to pace for the patient to recover effectively. This approach tracks the centroid coordinate by using Kalman filter, which is then mapped to the motion graph. This system can be further improved by using better tracker such as extended Kalman filter or particle filter.

Acknowledgement

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