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Human Motion Detection for Rehabilitation

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ABSTRACT

Marker-less human motion tracking is becoming popular recently to avoid occlusion and discomfort for user during rehabilitation. This paper proposed utilizing an algorithm for marker-less tracking of human motion followed by gait analysis for rehabilitation purpose. This paper involves several steps including preprocessing, detection, tracking and behavior understanding. Preprocessing involves morphological process and detecting involves skeletonization process to obtain the leg point for detection process. Angle parameters were obtained from tracking process and was used to determine the frequency of the gait cycle. As the result, this approach successfully detect the leg and tracking it based on angle of the leg. Besides, by providing frequency of the cycle and image of the patient in border image form to describe leg point. From the experiment carried out, average frequency of normal and abnormal is 16.42 and 8.35 respectively which is frequency for normal gait is lower and faster than abnormal gait.

1. Introduction

Gait is the pattern of movement of the limbs of animals, including humans, during locomotion over a solid substrate [1]. Gait is a unique characteristic of human being. Everyone has different kind of gait pattern. Besides, gait is a kind of biometrics like fingerprints because different person have different gait pattern [2]. Normality of gait is significant to one because body moves from one place to another with gait. Thus, analysis for abnormality of gait is becoming interesting area to be studied. Gait disorder is diagnosed by analysing on slow gait or/and aesthetically abnormal [3].

Therapist required to measure time and speed to analyse the progress of a patient. However, at the same time, therapist also assist the patient in order to do the physiotherapy. Thus, more than one therapist are required in each session. It would be inefficient if only one therapist carried out both tasks and lead to unsynchronized result especially when number of patient increasing gradually. Thus, interpretation of patient's condition could be wrong. Due to the above problems,

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this paper proposed to develop an approach for tracking and detecting patient and it can give more information for helping therapist to diagnose and interpret patient's progression.

2. Literature Review

Human motion analysis can be divided into three parts [4], detection, tracking and behavior understanding. In this paper, all the three parts will be reviewed in the following sub sections.

2.1 Detection

Motion segmentation is a process detecting the changes of the pixels in a frame sequence. This is because in video sequence images of moving object, each frame will have different pixel value or/and coordinate between the images. The most widely used method by researchers is background subtraction. This technique will find the pixel changes between the background image and motion image sequence in order but this is very sensitive even small change could be detected. Therefore, many of the researchers that used background subtraction will make it adaptive into dynamic environment such as lighting changes. Several researchers used median value of several images to determine the threshold value [5].

In addition, there are several methods are widely been used such as statistical methods, temporal differencing and optical flow. Statistical method was done by updating statistic background dynamically then classified each pixel either is a background pixel or object pixel [6]. This is robust to noise and shadow changes. Temporal differencing was conducted by finding the difference between two or three consecutive frames in an image sequence to extract moving region [7]. This method showed a good performance for dynamic environment but did not extract the whole feature. Optical flow can detect moving object even in moving camera condition but it involves complex computational and very sensitive to noise. Therefore, optical flow is not appropriate method to be applied in real-time situation.

Object classification is a process after motion segmentation in human motion analysis. However, this technique required video sequence of several or different moving objects at a time. For human motion analysis, this step will detect human out of other motion such as moving vehicle and flying bird. In addition, there are several techniques that widely been used among researchers such as shape classification and motion-based classification. Shape classification is a description of moving object by using shape such as point, silhouette, blob and box. For instance, box is classified into four classes namely single human, group human, vehicles and clutter [8]. For motion-based classification, human motion is a periodic property which is can be used to detect human motion out of other motions. From the detected motion self-similarity measure will be carried out followed by time frequency analysis to characterize the motion [5].

In this paper, the environment is indoor and involves single human moving. The video is recorded by using a single camera. Thus, motion segmentation with background subtraction would be the best technique to be applied.

2.2 Tracking

The model-based tracking is a technique that applies geometric structure to describe human motion. The model could be in 2-D model for example stick figure [9] and 2-D contour. 3-D model is called as volumetric model [10,11]. Region-based tracking will search for moving object image sequences that have connected region, then tracking that region over time by using crosscorrelation. Recently, this technique is widely been used but may produce occluded image in condition that video sequences have long shadow [12].

Active contour-based tracking is also known as snake can be used to extract subject's shape [13]. This technique had been focused by researchers several years ago. It shows a representation of object contour bounding and keep dynamically updating it over time. Feature-based tracking is conducted by using sub-feature of the moving object to realize that tracking process. Sub-features for instance are distinguishable points or lines. This method is good since it shows the tracking in real time but produce occlusion. To overcome this problem, the feature based data is amplified because the signal obtained would be very low energy and then auto-correlated to determine the connectivity of the feature [14]. Therefore, in this paper, feature-based tracking is suitable technique to track human image in order to determine its gait cycle time.

2.3 Behaviour Understanding

Analysis and recognition process on human motion pattern have been carried out by researchers using general techniques, active recognition or semantic description. General technique is conducted for action recognition analysis in time-varying data by using dynamic time warping, Hidden Markov models or neural network [15-16]. For active recognition, several well-known methods are available such as template matching and state-space approach. Template matching is low complex computational and simple implementation but affected by variation of time interval of the motion and more susceptible to noise [7]. State-space method is an alternative method to overcome the disadvantage of template matching method but involve complex iterative computational. Semantic description is new technique that use natural language concept to vision system and recently obtained attention. Thus, in order to recognize either the subject is having normal or abnormal gait, action recognition technique by using template matching method is more practical in order to provide information for therapist.

2.4 Tracking for Rehabilitation

For normal person, gait analysis consist of two phases which are stance and swing [17]. Generally, in gait analysis there are several gait parameters which are cycle time/cadence, stride length and speed. In this research, only cycle time will be used. By using the cycle time, abnormality of the gait can be determined. Determination of angle on leg and gait cycle is important part for action description [18]. By referring to a normal gait cycle [19], a normal gait cycle will be in between 1.03-1.17 second for male and 0.98-1.10 second for female as shown in Table 1.

Table 1
Cycle time for Normal person

Gender	Cycle Time (s)
Male	1.03-1.17
Female	0.98-1.10

On the other hand, human motion cycle was classified into running and walking frequency after obtaining angle value of a leg for each image frames [18]. By using normal subject, average walking frequency value was determined as 1.75 Hz and for average running frequency value was 2.875 Hz.

Thus, behavior understanding will be applied based on angle data as stated in Fujiyoshi and Lipton [18] and the average time of a gait was determined by using average frequency value.

3. Methodology

From the video, the background and image sequence is determined. The overall methodology is denoted in Figure 2.

3.1 Background Subtraction

Background subtraction is the subtraction process between background image and each image sequence. The subtraction is denoted in equation 1 below:

Image (i) = background_image – image_seqecuence (i) (1)

where, i = 1,2,3….N and N= Number of image sequences. From this process, image of moving object in this case is the subject can be obtained.

3.2 Tracking

From local maxima points obtained from the above, determination of the desired points relevant to the objective which is about gait cycle, local maxima point of leg should be determined. However, the head point and right leg point is negligible and just focus on the left leg only for the next process. This is because; from the referred paper [2], the author stated that lower extremal point is used as the cyclic point since it can yield cyclic structure of the motion although not guarantee that the analysis is being performed on the same physical leg at all times.

The left leg of local maxima points is determined by:

$$(lx, ly) = \min_{y_i^s < Yc} x_i^s \tag{2}$$

From equation 2 left legs is determined by selecting minimum value of x-coordinate (x_i^s) from local maxima points (l_x, l_y) and y-coordinate (y_i^s) should be lesser value than y-coordinate of centroid point (Yc). From the left leg coordinate and center coordinate, angle can be calculated by using tangent concept.

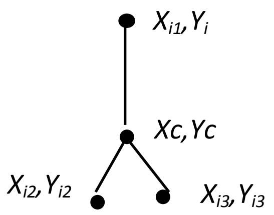

Fig. 1. Angle calculated from tangent concept on (X_c, Y_c) and leg point (left) to determine gait cyclic frequency

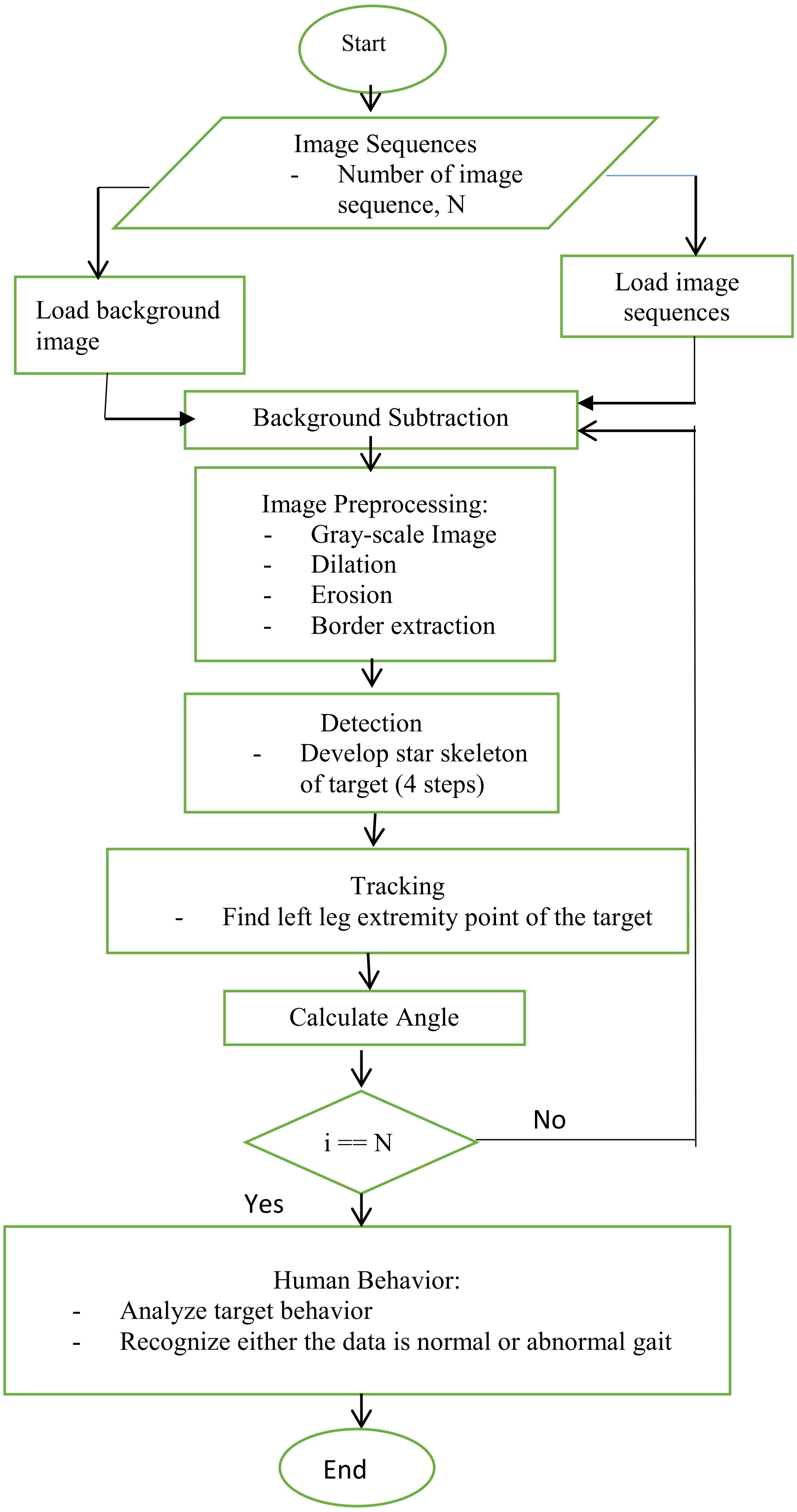

Fig. 2. Flow chart of the proposed approach

3.3 Behavior Understanding

After obtaining angle data from each frame, the data was analyzed. The signal data must be inverted from time domain to frequency domain to quantify the signal by using DFT (Discrete Fourier Transform). However, DFT alone does not enough to yield useful result. Thus, autocorrelation was applied. But this could result bias which required applying pre-amp before auto-correlation process. Next, obtaining leg frequency was started by performing pre-emphasis filter on angle signal of every frames by using function as denoted in equation 3 with α chosen empirically to be around 1.0 then autocorrelation was done on θn to emphasis the cycle by using equation 4 to yield new signals. Lastly DFT transform was carried out to quantify the signal resulting signals.

Finally, frequency of the half cycle can be determined, and time for a gait cycle is inverse proportional of the frequency value and followed by multiplication of 2. Finally, from the previous section, it is stated that cycle time for normal people is male 1.03 to 1.17 second and for female is 0.98 to 1.10 second.

$$H(z) = 1 - \alpha z^{-1} \tag{3}$$

$$Ri = \frac{1}{N+1-i} \sum_{n=1}^{N} \theta n \, \theta n - 1 \tag{4}$$

4. Results and Discussion

Preparation for obtaining data was a significant part because any destruction of a video sequence would affect angle value and consequently would be interpreted wrongly. Therefore the subject for this work need to wear black clothes so that it could maximize pixel difference between subject and background. For purposed of rehabilitation, subject need to walk at a flat surface with two condition which were normal and abnormal gait condition. Subject was asked to walk five times for every condition so that the best video sequence for obtaining normal and abnormal video sequences can be obtained. Besides, video sequence was recorded by using Webcam (320 x 240 resolution) with Intel Core i3 processor CPU with the help from Matlab software. By using image acquisition toolbox, time interval from a frame to another frame is 0.03 second.

For experimental data, there were 20 video sequences were used and analyzed. 10 of the video sequences were normal gait and another video sequences is abnormal gait. For normal gait, subjects were asked to walk with normal walking pattern and normal speed used in daily life. On the other hand, for abnormal gait, subject was asked to walk with abnormal pattern which is stoked like patient (weighting the body more for left side of the body). If lower limb is not in black, the image border extraction will be affected. Frame per trigger should be in infinite selection so that image from subject started entering the webcam area until out of that area could be recorded fully. Before subject started walking, webcam should 'on' first and allow it capturing several initial frames of the background image. Forty image sequences excluded background frame was used from each video sequences. Each frame sequence was subtracted with background frame before performing gray-scale to the result image. Then, followed by dilation process, erosion process (Figure 3) and lastly edge detection process. Sobel edge detection with vertical and horizontal direction was used to find the boundary.

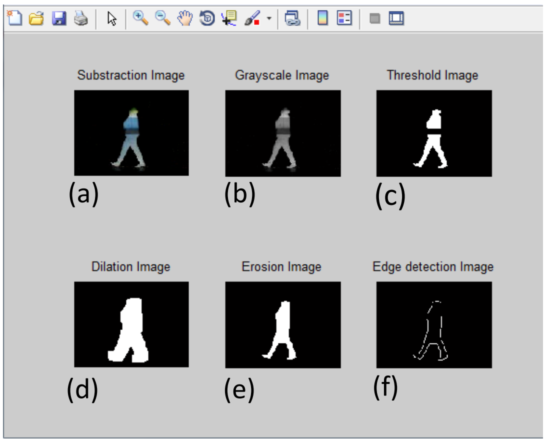

Fig. 3. Result of pre-processing stages

Next, for obtaining the leg points, distance data from every white pixel coordinate and centroid coordinate. The data was then filtered by using Low Pass Filter (LPF) to smooth the data. Difference function was adopted to produce local maxima point / extrema point as shown in Figure 4.

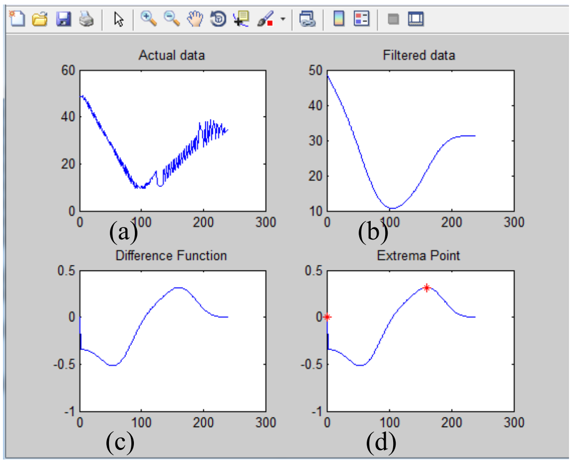

Fig. 4. Steps for leg detection

Local maxima point was detected and plotted on edge detection image as shown in Figure 5. Angle was obtained by using tangent mathematical formula of leg point and centroid point. Each image sequence will follow the same procedure to produce a set of angle data.

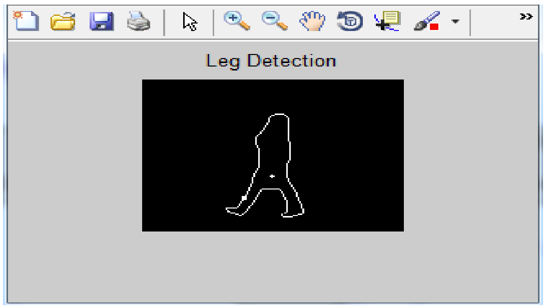

Fig. 5. Successful detected leg

Average frequency of a gait was determined from angle data after several processes. The data should transform into frequency domain by Discrete Fourier Transform (DFT) to analyze the signal.

Due to background noise, autocorrelation was used before DFT for emphasizing cyclic component of that image sequences.

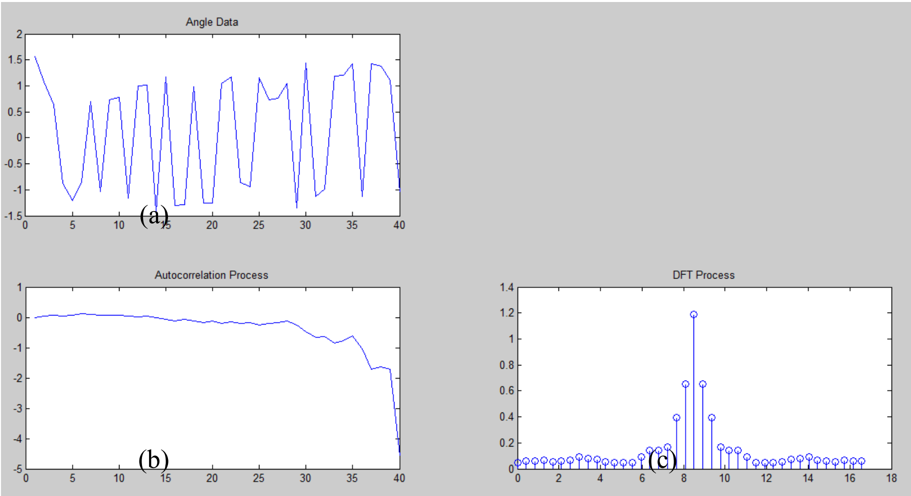

Fig. 6. Gait analysis to obtained average frequency. (a) Horizontal axis is number of frames and vertical axis is angle value in radian. (b) Horizontal axis is number of frames and vertical axis is angle value after autocorrelation process (c) Horizontal axis is number of frames in frequency domain and vertical axis is result from DFT process

From Table 2, it shows that the average frequency from normal video sequences is 16.42 Hz and average frequency from abnormal video sequences is 8.35 Hz. For every subject, frequency of the normal gait is higher than frequency of the abnormal gait.

Table 2
Result of frequency normal and abnormal video sequences

Subject	Frequency of Normal Video Sequence (Hz)	Frequency of Abnormal Video Sequence (Hz)
1	16.5	8.5
2	15.7	8.5
3	16.5	8.5
4	16.5	8.5
5	16.5	8.0
6	16.5	8.5
7	16.5	8.5
8	16.5	8.0
9	16.5	8.0
10	16.5	8.5
Average	**16.42**	**8.35**

From the tracking image, leg point was detected in order to calculate angle and classify image sequences into normal or abnormal gait. However, due to several factors, not all images show the accurate angle of leg thus affecting image cycle graph. Environmental factor is important. If the pixel value of background image and subject image is not in significant different and in range of background image, thus the approach will detect that pixel as background image. Besides, illumination is the common problem in preprocessing stage. Illumination distracted object image eventually after subtraction steps. Thus, image of subject after angle detection is not completely describe the real subject image. Other than that, during analyzing data, the peak frequency is almost same for all subjects. This condition happened due to edge detection image is inaccurate thus affecting angle data. It is stated that average walking frequency is 1.75 Hz and average running frequency is 2.875 Hz [18]. It shows that speed of running is higher than walking and average time for running is lesser than walking. Walking and running is also consists of gait cycle but in different speed with relationship when speed is decrease, time is increase and number of cycle is also decrease.

In this paper, the above condition is assimilated to classify between normal gait and abnormal gait. Normal gait will shows higher speed than abnormal gait besides, time for a normal gait taken for a cycle will be lower than abnormal gait. However, for classifying normal or abnormal gait, algorithm should perform pre-emphasis first before autocorrelation. However, by following pre-emphasis equation as stated at methodology, graft of angle verses frequency could not obtained correctly. Therefore, this paper was conducted on experiment excluded pre-emphasis process.

5. Conclusion

From developed approach, human motion could be tracked and detected. However, gait analysis of behavior understanding seems more complicated. Fortunately, by using this approach, normal and abnormal gait able to classify after some modification on methodology when performing experiment. Result of the experiment is acceptable but there is problem when all frequency of normal gait sequence is quite similar. In future, there are several improvement that can be developed on human detection and tracking in order to detect accurate edge detection image, leg point, angle of the leg and classifying algorithm.

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