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Embedded Platform Performance of Image Based Abnormal Gait Detection

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ABSTRACT

Abnormal gait analysis can be used as one of the surveillance method, medical rehabilitation monitoring and early detection in possible gait related symptom. Existing manual observation can only be done by professional and might cause misidentification about the real condition or situation of the subject. Additionally, gait laboratory utilises costly motion system for gait acquisition as research database. Hence there is a need to produce a low cost abnormal gait detection system. Thus in this study, evaluating an approach of markerless front view modelling, image based abnormal gait detection that utilised Linux based embedded board such as Raspberry Pi and Beaglebone, with Python software programming for recognising the differences between normal and abnormal gait based on gait image as input sequences captured from camera was carried on. Next, the extracted gait features is evaluated and validates using K-Nearest Neighbour (KNN) and Support Vector Machine (SVM) as classifier.

Keywords: Pendulum theory, front view gait, abnormal gait, K-Nearest neighbour, Support Vector Machine.

1. INTRODUCTION

Nowadays, abnormal recognition of gait has been carried out by professional or medical officer usually through an observation of patient's behaviour and mostly by manual. Thus, this might cause misidentification about a real condition of the patient and lead to difficulties for proper treatment and further subsequent therapies. However with gait analysis technology, gait database can be stored as references for gait monitoring. It is hope that with the patient gait data, it can be utilised as rehabilitation method in gait pattern treatment and intervention program as well as early detection of other gait symptoms due to fall and injuries or strange/suspicious movement in surveillance system. It is already known that markers method is frequently used in detecting abnormality gait tasks by capturing the motion of the subject during their walking gait. For instance, previous work used gyroscope and accelerometers on smart shoes implemented as discussed by Joonbum et al. [1] and Meng et al. [2]. Then, Zero Moment Point (ZMP) locus captured from signal of low-cost Force Sensitive Resistors (FSRs) can be utilised on falling possibilities and abnormal gait pattern analysis [3]. Additionally, model sensitivity of abnormal gait patterns by prediction knee joint contact forces numerical model from TKR's stance phase of subjects gait was laos investigated by Lundberg [4].

Consequently, the present markers technique that required hardware to be attached directly to the subject's body would limit the mobility, required dedicated laboratory environment only and costly too. Additionally, if the subjects involved are under age child/patient and others type of uncontrolled behavior such as autism, cerebral palsy and others related, marker method can be considered challenging to be implemented. Hence, for mobility and markerless method of gait analysis, image based studies is more suitable. As elaborated by Liang [5], silhouette-masked flow of motion metrics on histogram form and eigenspace transformation of human silhouettes extraction utilised frame-to-frame optical flows computation of computer vision approach.

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Instability condition gait of Parkinson patient explored by Manap et. al [6] which analyse on basic, kinematic and kinetic parameters of gait such as cadence, step length, walking speed and mean of stride time while walking involved is computed. Then, vector space embedding of segmented body silhouettes from homeomorphisms between 2D lattices and binary shapes implemented in unusual gait pattern movement [7]. Therefore, this study deemed further to evaluate and validate front view gait analysis by development of algorithms for human abnormal detection. Real time system prototype of gait abnormality recognition using ARM 4 processor equipped with Raspberry Pi board. In comparing performances of the algorithms on real board, ARM Cortex 8 processor equipped Beaglebone board is chosen for Python programming environment.

In the paper, front view markerless model is used with pendulum theory as feature extraction method whilst K-Nearest neighbor (KNN) and Support Vector Machine (SVM) as classifiers for abnormal gait detection. Additionally it is then embedded into Linux operating system based ARM board for further analysis.

The remainder of this paper is organized as follows. In section II, the proposed front view markerless model for gait is presented. Then we discuss features extraction method using pendulum theory in section III. The implementation of hardware and their performance on Raspberry Pi and Beaglebone are simulated in section IV. Finally, conclusion is presented in section V.

2. PROPOSED MARKERLESS FRONT VIEW MODEL

The proposed front view modelling is generated from lower leg skeleton model which is then used in computing the gait features of thigh and knee for both legs as described in earlier paper by Ismail and Tahir [8]. In the paper, the thigh rotation, $\theta T(t)$, is described by Eq. (1), where AT is the amplitude of the thigh rotation, ωT is the frequency, CT is the phase shift and CT is the offset.

$$\theta_T(t) = A_T \cos\left(\omega_T^t + \phi_T\right) + C_T \tag{1}$$

Meanwhile, the knee rotation, $\theta_K(t)$, can be described as

$$\theta_K(t) = \begin{cases} A_{K1} \sin^2\left(\omega_{K1} t\right) + C_K & 0 \le t \le p, \\ A_{K1} \sin^2\left(\omega_{K1} t + \phi_K\right) + C_K & p \le t < 1, \end{cases} \tag{2}$$

where A_{K1} and A_{K2} are the amplitudes of the knee rotation, ω_{K1} and ω_{K2} are the frequencies, C_K is the offset, ϕ_K is the phase shift and p is the time [2]. From the calculation, the stick figure for side view gait angle calculation is developed as depicted in Figure. 1.

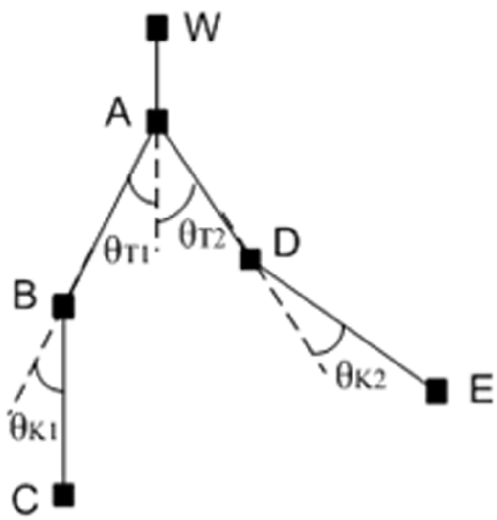


Figure 1: Stick figure for side view leg joint

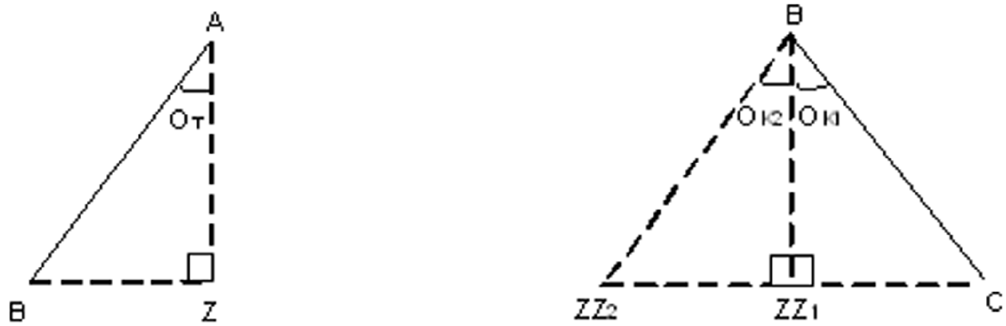


Figure 2: Triangular joint.

Then, it has been developed front view modeling concept by expanding the side view model. The first stage is using triangular for angle calculation for joint *A*, *B* and *C*, and *Z*, ZZ_1 and ZZ_2 represented for virtual point as shown in Figure 2, it can be conclude that:

$$AB = \frac{BZ}{\sin\theta_T} \tag{3}$$

$$BC = \sqrt{\left(\sin\theta_{K1}.BC\right)^2 + \left(\frac{ZZ_1.ZZ_2}{\sin\theta_{K2}}\right)^2} \tag{4}$$

Next, by utilizing equation (3) and (4), front view gait is calculated and the stick figure for proposed front view gait model comprised of seven joint angles as A1 for left leg hip joint, A2 for right leg hip joint**,** *B* for left knee, *C* for left ankle, *D* for right knee, *E* for right ankle and *W* for hip, respectively.

As in Figure. 3, thigh angle for left leg and right leg is represented by θ_{T1} and θ_{T2} respectively, and the angle of the knee by θ_{K1} and θ_{K2} which described joint angles of human stick figure from front side view. Finally, the complete stick figure used for front view gait angle calculation is introduced.

From the proposed front view model, it assembled correctly on silhouettes of normal and abnormal human gait cycle as depicted in Figure 4 and Figure 5, respectively.

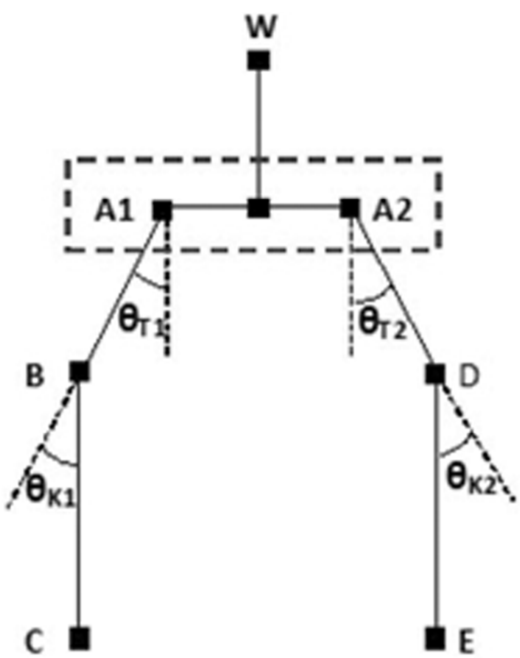


Figure 3: Stick figure for front view leg joint.

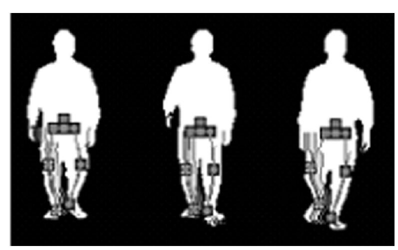


Figure 4: Sample of Normal walking.

Figure 5: From Left: Sample of abnormal condition as drunken condition, dragging leg and tiptoed leg gait by gait patterns.

3. FEATURES EXTRACTION USING PENDULUM METHOD

The angles features data is extracted using pendulum theory that further calculate the thigh and knee joint angle for both right and left leg [8]. The whole sequences of one complete cycles is based on front view gait modeling as shown in the stick figure form in Figure. 6.

Consequently, four sets of joint angles for both leg which consist of 70 features each sketched is depicted in Figure. 7 labelled as left and right thigh along with left and right knee accordingly. In addition, both normal and abnormal silhouettes images from the video gait sequences are extracted into angles form data features and utilised for the development of abnormal gait classifier. Firstly, the algorithms are developed, evaluated and validated in Matlab and next translated to Python coding in embedded board.

4. HARDWARE IMPLEMENTATION USING RASPBERRY PI AND BEAGLEBONE

This section will discussed the abnormal gait recognition performance analysis on front view hexagonal method [9]. The overall hardware implementation of abnormality gait using front view markerless modeling is as detailed in Figure. 8.

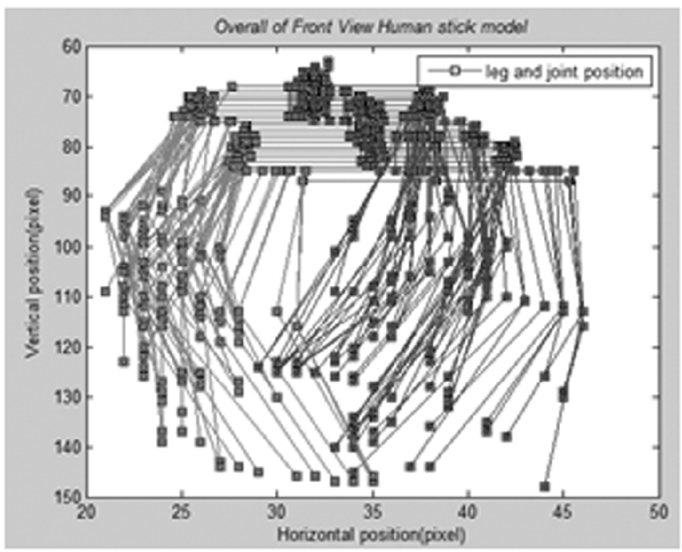


Figure 6: Overall sequences for one complete cycle using pendulum method

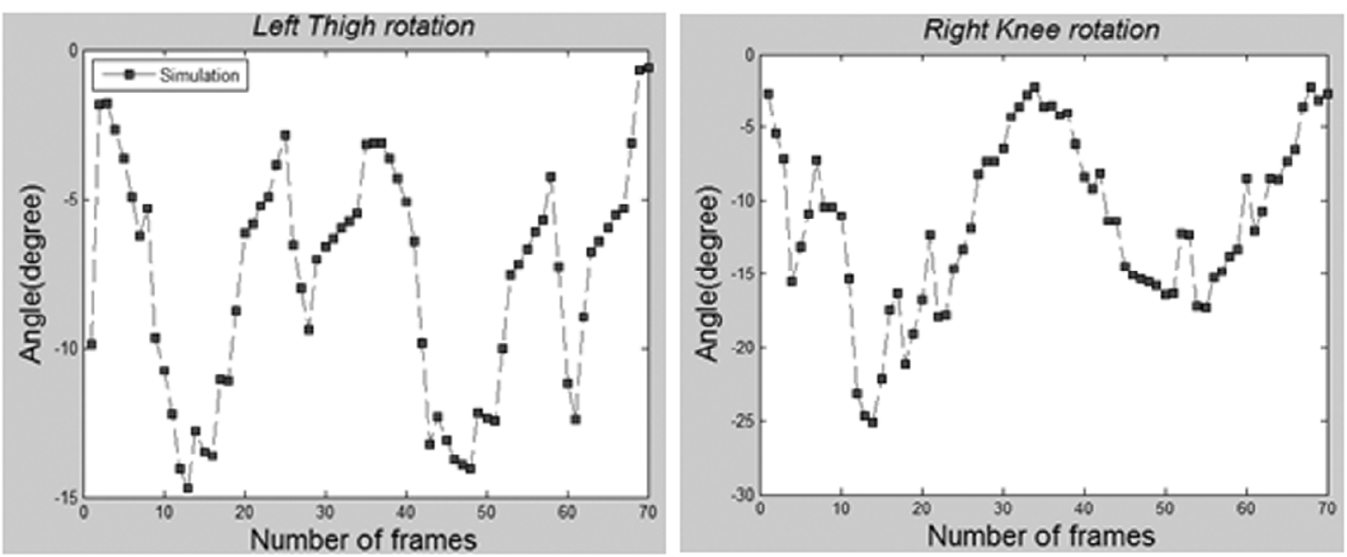


Figure 7: Overall samples of gait data based on 70 gait sequences extracted using pendulum method as features from knee and thigh angles of both left and right foot.

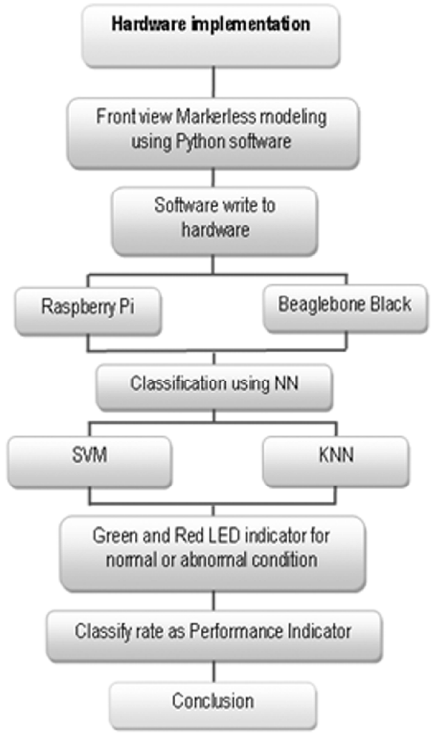


Figure 8: Schematic Diagram of Hardware Implementation for Front view gait modeling

The flow of classification method using Python [10] software embedded in Raspberry Pi board [11] and Beaglebone Black board is as follow:

1) Firstly, gait image sequences of subject "*A*" is saved into Folder in Raspberry Pi board. It consists of 70 images in *.png format.
2) Next the images is to be loaded one by one into Python software.
3) Feature extraction done using earlier proposed method that generated the knee and thigh angles for both left and right legs are set as test input data.
4) SVM and KNN as classifying machine in classifying between normal and abnormal gait.
5) SVM and KNN trained using previously generated gait data that consist of normal gait, drunken condition, tiptoed and dragging leg condition; and also from CASIA database.

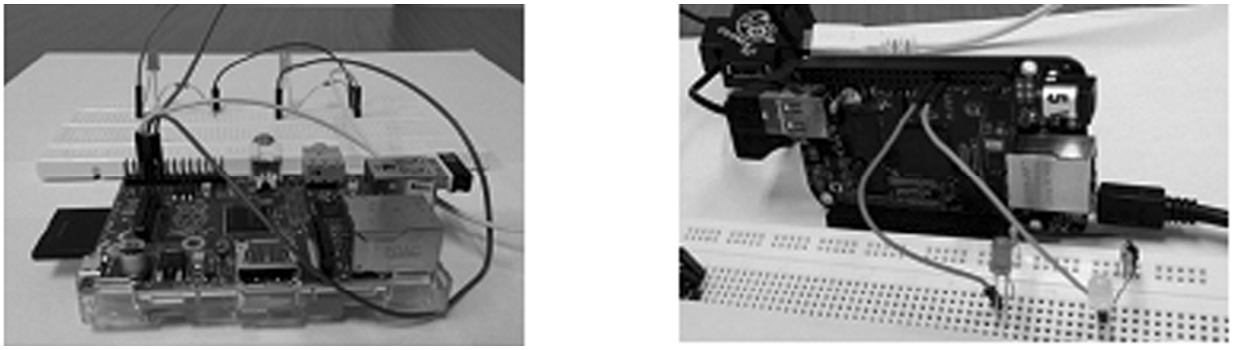
4.1. Raspberry Pi (RP) board

The RP is a credit-card-sized single-board computer which includes an ARM1176JZF-S 700 MHz processor, VideoCore IV GPU, and was originally shipped with 256 megabytes of RAM, later upgraded to 512 MB.

Combination of board, wires, resistor and LEDs on breadboard is the main part of hardware implementation used in this research as depicted in Figure. 9(a). Additionally, python programming language as main part of software development output result will be elaborated in the next part.

4.2. Beaglebone Black (BB) board

The BeagleBoard measures approximately 75 mm by 75 mm and has all the functionality of a basic computer which includes an ARM Cortex-A8 CPU, a DSP for accelerated video and audio decoding, and an Imagination Technologies to provide accelerated 2D and 3D rendering that supports OpenGL ES 2.0. Video out is provided through separate S-Video and HDMI connections.



(a) Raspberry Pi board **(b) Beaglebone Black Board**

Figure 9: Embedded board and it LEDs connection.

Two (2) colours LEDs, wires and two resistors are connected to the breadboard that is then attached to P9 pin out header as output of classification programming as described in [12]. Python is the main software in developing the features extraction algorithms and finally performing the abnormal gait classification task. Hardware used can be illustrated as in Figure 9(b).

5. RESULTS AND DISCUSSION

This section will discussed the implementation of using Raspberry Pi and Beaglebone Black along with the output attained.

5.1. Programming Output of Raspberry Pi (RP) and Beaglebone (BB)

5.1.1. Feature extraction

Features are extracted from each sequence of gait images and generate gait features; right thigh angle, right knee angle, left thigh angle and left knee angle. Time elapsed for overall 70 silhouettes images feature extraction was 231.75 sec using RP and 65.47 sec using BB as shown in Figure. 10 respectively. The features extracted are similar with features during simulation specifically 70 by 280 matrixes of features data generated from the python programming.

Using SVM classifier that is programmed and downloaded into the board, the generated gait database is then loaded into the program and classification is set into two category namely as "0" or "1" condition as depicted in Figure 11 and Figure 12 respectively where "0" represent normal gait and "1" for abnormal gait.

(a) RP board extraction time **(b) BB board extraction time**

Figure 10: Time taken for sequences of sample data features extraction

(a) Output as "0" – Normal Gait for RP **(b) Normal condition as in BB board**

Figure 11: Samples of k-NN classifier training and testing database for normal condition

The time required for overall recognition processing was approximately 230 second for SVM and 226 second for KNN since the board used ARM11 processor as in Figure. 13(a). The time required for overall recognition processing using SVM and KNN was improved which approximately 66 second for both method that used BB Cortex 8 processor.

5.2. LED output

The LED is to indicate the output as normal gait or otherwise. When the output recognised as normal gait, green LED will blink as in Figure. 14 while for recognition of abnormal gait, red LED will activate.

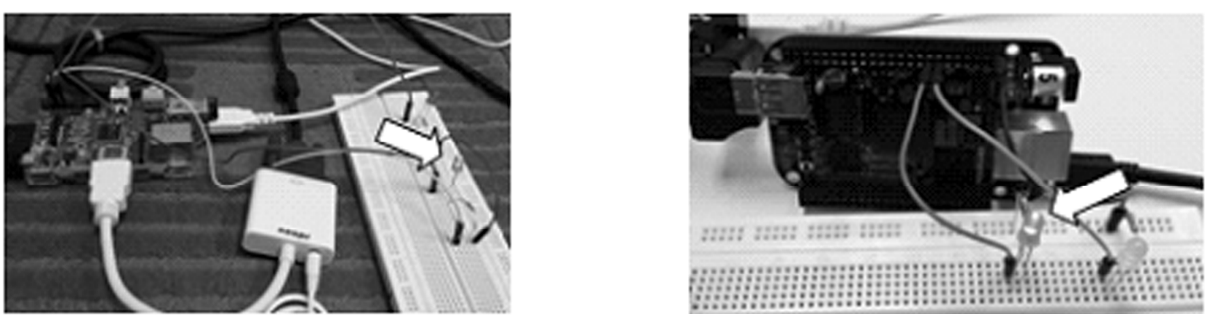
Results attained from both board demonstrated that hardware implementation is feasible with different processing speed and interestingly similar classification rate for both SVM and k-NN classifiers as tabulated in Table 1.

(a) Output as “1” – Abnormal Gait for RP (b) Abnormal condition as in BB board

Figure 12: Samples of k-NN classifier training and testing database for abnormal condition

(a) RP board time output (b) BB board time output

Figure 13: Sample of Classification Processing Time



(a) Green LED on RP board (b) Red LED blink on BB board

Figure 14: Sample of LED blink –Yellow/Green for Normal and Red for Abnormal using both board

Table 1
Overall performances of two different hardware used

Parameter	*Raspberry Pi*	*Beaglebone Black*
Feature extraction Processing Time (sec)	220.8	65.47
Classification Rate		
SVM	84.2%	84.2%
KNN	89.5%	89.5%
Processing Speed (sec)		
SVM	230	66
KNN	226	66

Features extraction time and overall processing time slightly improved using Beaglebone black which around 163 second shorter for SVM and 160 second for KNN. The result is nearly less than one minute processing time, proven that it can be improved with implementation of more higher speed processor and capable to be used in real time classification. Also, using both type of board, classification rate are similar that is 84.2% and 89.5% for SVM and KNN classifier.

6. CONCLUSION

As a conclusion, results attained using hardware implementation is successful based on promising classification rate attained as compared to simulation solely. Additionally, processing time can be enhanced since the present processing time is due to translating programming language from simulation stage and transferring to hardware stage. Further the built hardware prototype capable to recognize abnormal gait and vice versa which is based on front view markerless modelling. Hence this could be the alternative for markerless model that is lower in cost as compared to marker based approach.

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