Journal of Scientific & Industrial Research
Vol. 69, August 2010, pp. 600-605

Active marker based kinematic and spatio-temporal gait measurement system using LabVIEW vision

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Received 26 March 2010; revised 20 May 2010; accepted 02 June 2010

This study presents an automated, easy to use, cost-effective, patient-friendly, active marker based gait measurement (GM) system for 2-D tracking and extraction of spatio-temporal parameters of human gait. Active markers, consisting of visible light-emitting diodes (LEDs), were positioned at anatomical landmarks to measure coordinated kinematics of human joints. Acquired image data were processed and analyzed using LabVIEW vision for determination of spatio-temporal parameters.

Keywords: Active markers, GM system, Kinematics, Spatio-temporal parameters

Introduction

Visual observation method, used for assessing gait by measuring spatio-temporal parameters of human gait, had several limitation and inaccuracies[1-3]. Gait measurement (GM) system incorporates timed measurement of data for calculating mean values of gait speed, stride length and cadence[4,5]. Footstep measurement systems are cumbersome and time consuming[6-]Accurate estimation of human kinematics requires interdisciplinary domain knowledge of biomedical engineering, biomechanics, mechatronics, and human anatomy sciences[10]. In kinematics, instrumentation is required to estimate positions, angles, velocities and accelerations of body segments and joints during motion[11]. Gait analysis provides a scientific basis in monitoring anomalies in walking pattern[12]. Movement parameters are synchronized with kinetic parameters (body forces) to generate quantitative description of gait or human dynamics in the form of time-distance parameters and variations in joint angles, joint moments and joint powers[13].

Kinematic gait analysis[14,15] may be subdivided into direct measurement (contact) techniques [goniometers (mechanical and electronic), accelerometers, footswitches etc.] and imaging (noncontact) based measurement techniques. New imaging techniques using markers (active or passive) were developed to perform real time kinematic gait analysis[16]. Active markers use light-emitting diodes (LEDs) to generate image information. Passive markers are spheres covered with reflective Scotchlite tape, specifically designed to reflect incident light directly back along its line of incidence[17]. Manual analysis of marker images is error prone, labor intensive and a tiresome process.

This study presents development of a simple, cost effective and easier detection novel automated software algorithm to analyze spatio-temporal features of human gait kinematics using LabVIEW vision.

Experimental Section

Experiments were conducted on 9 healthy males (age group, 21-30 y; height, 1.56-1.77 m; wt, 48-71 kg). Image acquisition (total captured volume, 1.57 m^3) was done in partial dark (minimum light) environment for better image contrast ratio. Each marker was made up of an array of 4 red LEDs (peak wavelength, 660 nm; luminous intensity, 380.25 mcd; viewing angle, 120°) connected in series and attached to a battery. Power dissipated (450 mW), ensured that marker set can be used for a lot many number of trials. Cost for one marker was estimated to be around $ 4.5 only. LEDs were arranged to appear as a single big bright circle from distance. Marker set for full body kinematic analysis (Fig. 1a) were pasted on landmarks (hip, knee and ankle) using

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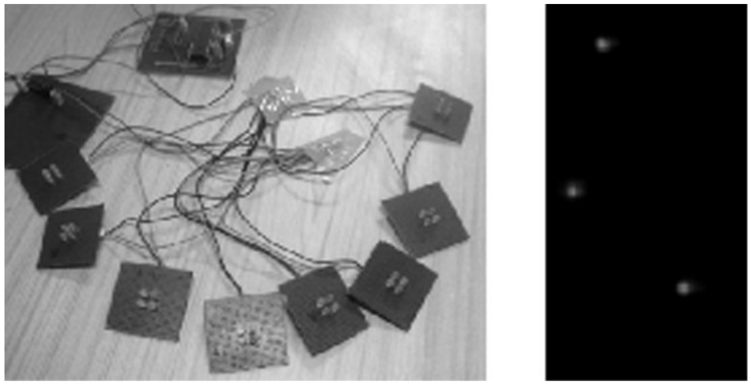


(a) (b)

Fig. 1— (a) Active marker set for full body Gait analysis (b) Subject wearing markers

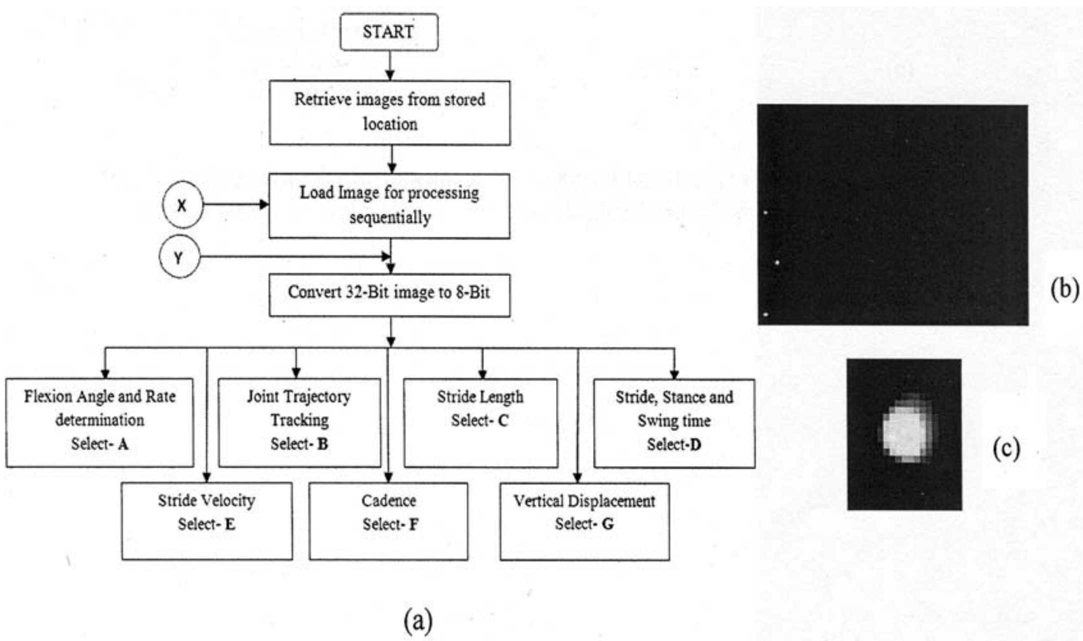


Fig. 2— (a) Flow chart for kinematics measurement algorithm, (b) Acquired image for processing, (c) Marker template

both-sided adhesive tapes (Fig. 1b). Relative distance between markers varied depending on limb length. Marker position was identified by physically feeling bone joints and deciding exact joint location. For proper fixture of markers and zero relative movement among them, markers were further fixed using non reflective adhesive tapes.

Image Acquisition

Lumenera LU120M series, 1.3 Mega-pixel, USB-2 camera (lens, 8.5 mm) was used. Resolution was fixed at 640x480 with frame rate of 50 FPS. Sequence acquisition mode was used to capture 225 frames for one walk. Acquired images were saved in National Instruments proprietary .apd file format. GM system (Fig. 2a) enables user to select desired measurement functions. In pre-processing of images, acquired 32 bit images (Fig. 2b) were converted to 8-bit grayscale image, intensity values of which corresponds to plane extracted using color plane extraction function (extracted plane being red here). A marker template was created (Fig. 2c) to act as a reference ROI (region of interest).

Software Measurement Functions

Flexion Angle Determination Function

Flexion angle measurement function includes pattern matching based on intensity measurement. Preprocessed data image is introduced to a pattern matching algorithm available with LabVIEW vision for

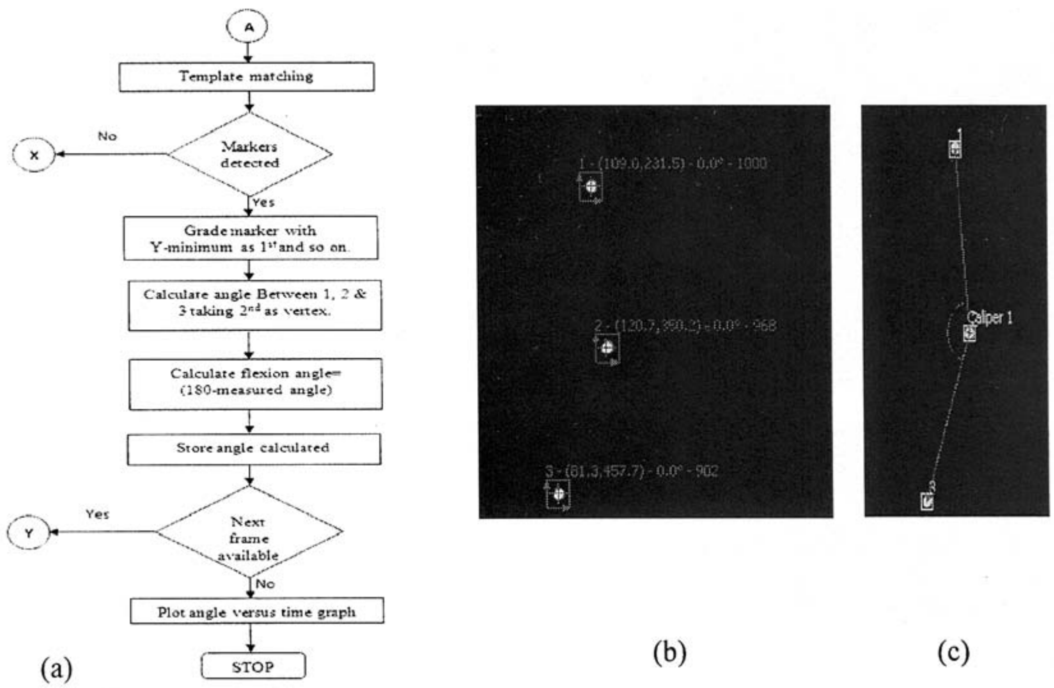


Fig. 3—(a) Flowchart for flexion angle measurement function, (b) Markers detected and their corresponding co ordinates and scores (c) Angle measured between detected markers

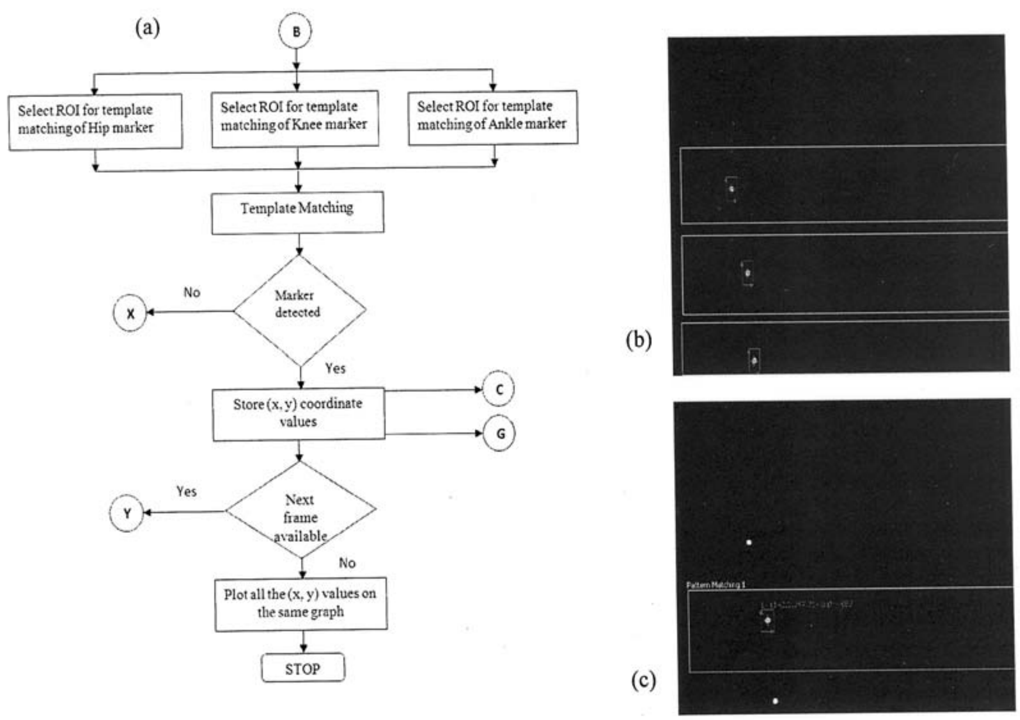


Fig.4 (a)—Flow Diagram for trajectory tracking, (b) ROI for template matching, (c) X, Y coordinates detected for knee marker

determining number of matches for markers in given image. Using flexion angle measurement function (Fig. 3a), required number of matches (3; each for hip, knee and ankle) was specified. Minimum score of 750 (matching threshold) was assigned to discard chance of any other reflective object to be considered for analysis. Software determines number of matched patterns along with their X-center, Y-center and score of each valid match (Fig. 3b). To determine angle between three markers, Y-coordinates of detected

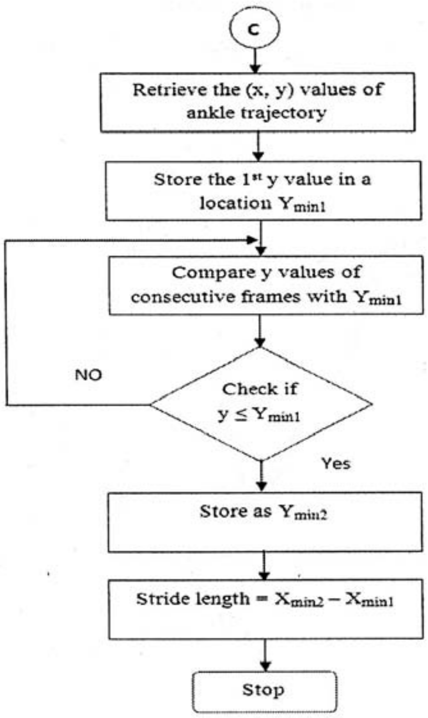


Fig.5—Flow diagram for stride length function

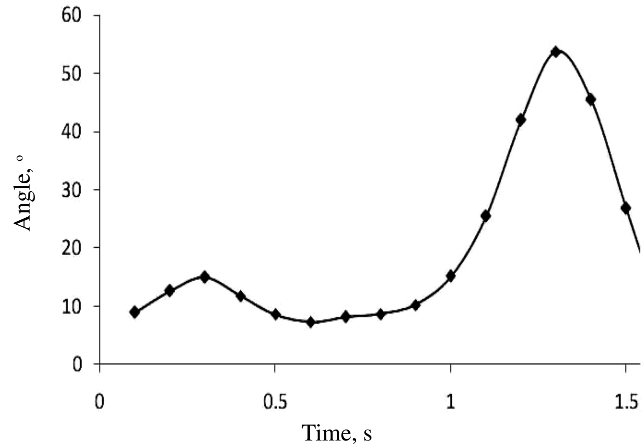


Fig. 6—Variation in knee-flexion angle for one gait cycle

markers were obtained from pattern matching results. Markers were then graded as M1, M2, and M3 in ascending order of their Y coordinate values. This was done by comparing Y coordinate values of any two markers to get lower Y value, then again comparing the one with lower Y value with Y value of third marker to get the lower of latter two. Marker with lowest Y coordinate value was graded M1. Similarly, M2 and M3 were determined. Angle M1M2M3 between markers M1, M2 and M3 with M2 as vertex was determined (Fig. 3c). Knee flexion angle was then calculated as

$$\text{Knee flexion angle} = \{180^\circ - (\text{Angle M1M2M3})\} \quad \ldots(1)$$

Trajectory Tracking of Joint Movement Function

Flow diagram (Fig. 4a) is shown for trajectory tracking of joint movement function. Image was pre-processed, after pattern matching with previously created template is done. For this function, different ROI was selected than the one in angle determination function. For each of three markers, ROI was defined in frame through which marker was most likely to traverse while walking of the subject (Fig. 4b). When markers in all images were detected, one get (X, Y) coordinates (Fig 4c). Coordinates (X, Y) of three markers at separate locations were stored and plotted on same graph to get trajectory of motion of marker/joint in field of view (FoV) of camera. Since frame rate, total distance of walkway in FoV of camera and total number of frames captured for walking trials were known, position of markers at any instant of time was determined subsequently.

Stride Length Function

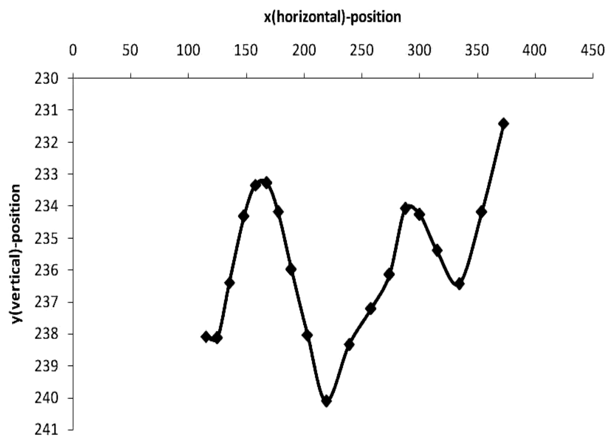
Stride length was determined using imaging algorithm by measuring distance between two successive minima's of ankle marker trajectory. This concept was utilized in determination of stride length from imaging data. In flow chart for stride length algorithm (Fig. 5), Y coordinate value of first image was stored as Y_{min1} and Y coordinate values of consecutive images were compared with Y_{min1}. If new value is $=Y_{min1}$, store it in a new location as Y_{min2}. In order to find stride length, difference between X co-ordinates of Y_{min2} and Y_{min1}, i.e. X_{min2} and X_{min1} respectively, was determined as

$$\text{Stride length} = X_{min2} - X_{min1} \quad \ldots(2)$$

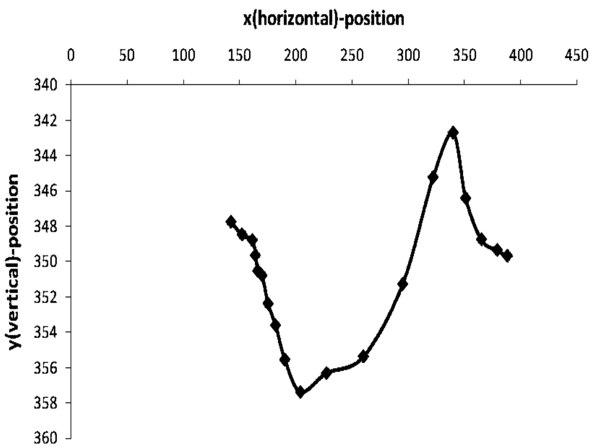
For stride length calculation, total frame width (640 pixels) represented 4.5 m of walk way.

Stride Time Function

Stride time was calculated using data available for frame rate and total walkway distance in FoV of camera. Total number of images with all markers visible in frame was 225. With frame rate of 50 fps, time to cover full walk in frame of 640 pixels was 4.5s. Stride time was calculated using available data of total distance covered in frame and time taken to cover this distance. Stance phase and swing phase comprise 60% and 40% of total gait cycle respectively. Thus stance and swing time was calculated.



a)



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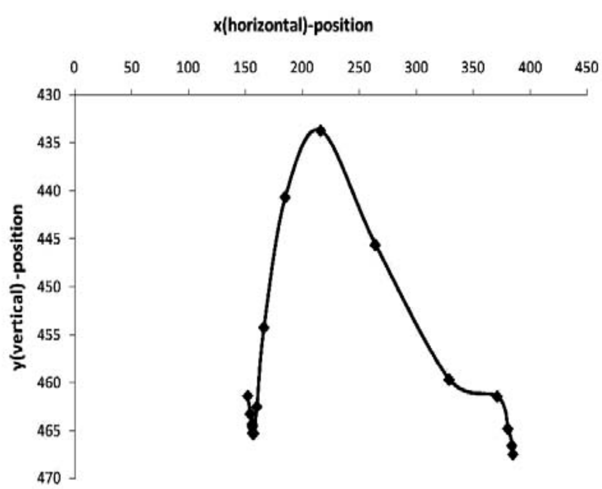

c)

Fig 7—Trajectory movement of: a) hip; b) knee; and c) ankle

Table 1—Spatio-temporal parameters using GM system

Gait Parameters	Calculated values by developed GM system for two walking	
	Normal	Slow
Knee flexion angle range, °	56	44
Stride length, m	1.41	1.19
Stride time, s	0.82	0.98
Swing time, s	0.32	0.39
Stance time, s	0.49	0.59
Stride velocity, m/s	1.72	1.21
Cadence, steps/min	146.34	120
Vertical displacement, m	0.09	0.08

Stride Velocity Function

From available data, stride velocity is calculated by dividing stride length with stride time.

Cadence Function

Step length is half of stride length, and calculated. Similarly, with known stride time values, time taken to cover a step was determined. Cadence (number of steps per min) was also calculated.

Vertical Displacement Function

Vertical displacement is range of variation in vertical position of individual during a walk cycle. Hip displacement was assumed to represent range of height covered by individual during walk as upper torso was almost constant in height when compared to lower half. Range of displacement was determined by calculating difference between Y_{max} and Y_{min}, from data obtained for trajectory traced by hip joint.

Results and Discussion

Algorithm was used for determination of various spatio-temporal parameters for subjects walking at their self selected speed. Knee flexion angle with respect to time for one gait cycle was found to be 44° for slow walk (Fig. 6). Resulted curve was akin to flexion angle curve for angles determined using other methods[18]. Results of knee flexion calculated using electro-goniometer were comparable with present system. All spatio-temporal parameters for healthy individual walking at self selected speeds were calculated (Table 1). Expected variation was distinguishable of gait parameters with change in walking speed. Joint trajectory movement is shown for hip (Fig. 7a), knee (Fig. 7b) and ankle joint (Fig. 7c).

Conclusions

GM system, developed using LED based active marker, utilized advanced digital image processing techniques for kinematic analysis of human gait. An algorithm using LabVIEW vision platform determined spatio-temporal parameters of human gait. This algorithm can be used for full body kinematic analysis or for specific limb motion analysis with little or no changes. Imaging algorithm was automated, easy to use, cost-effective tool for assessment of deviation in normal walk for quantification of prosthetic performance. Proposed development is unique as it used active markers detection in video image environment. This ensured simpler acquisition setup, cost effective and easier detection algorithms with better accuracy as compared to conventional systems.

References

1 Eastlack M E, Arvidson J, Snyder-Mackler L, Danoff J V & McGarvey C L, Interrater reliability of videotaped observational gait-analysis assessments, *Phys Ther*, **71** (1991) 465-472.

2 Krebs D E, Edelstein J E & Fishman S, Reliability of observational kinematic gait analysis, *Phys Ther*, **65** (1985) 1027-1033

3 Saleh M & Murdoch G, In defence of gait analysis Observation and measurement in gait assessment, *J Bone Joint Surg Br*, **67** (1985) 237-241

4 Youndas J W & Atwood, Measurement of temporal aspects of gait obtained with a multi memory stopwatch, *J Orthop Sports PhysTher*, **30** (2000) 279-286

5 Wall J C & Scarbrough J, Use of a multimemory stopwatch to measure the temporal gait parameters, *J Orthop Sports Phys Ther*, **25** (1997) 277-281

6 McDonough A L, Batavia M S, Chen Kwon S & Chen F, The concurrent validity of the functional ambulation profile and the GAITRite system, *Phys Ther*, **78** (1998) S68.

7 Selby-Silverstein L & Besser M, Accuracy of the GAITRite system for measuring temporal-spatial parameters of gait, *Phys Ther*, **79** (1999) S59.

8 Gaudet G, Goodman R, Landry M, Russell G & Wall J C, Measurement of step length and step width: a comparison of videotape and direct measurements, *Physiotherapy Can*, **42** (1990) 12-17.

9 Clarkson B, Absorbent paper method for recording foot placement during gait: suggestions from the field, *Phys Ther*, **63** (1983) 345351.

10 Maletsky L P, Sun J & Morton N A, Accuracy of an optical active-marker system to track the relative motion of rigid bodies, *J Biomech*, **40** (2007) 682-685.

11 Gautam S, Abu-Faraj Z O, Smith P A. & Harris G F, Design and development of an active marker based system for, analysis of 3-d pediatric foot and ankle motion, in *Proc 20th Annu Int Conf IEEE Engg in Med & Biol Soc*, **20** (1998) 2415-2417.

12 Bogart J V, *Motion Analysis Technologies, 0-7803-6469-4/00/ $10.00* (IEEE) 2000, 167-172.

13 Shi C & Youxing G, An invariant appearance model for gait recognition, 1-4244-1017-7/07/$25.00 ICME (IEEE) 2007, 1375-1378.

14 Boulgouris N V, Plataniotis K N & Hatzinakos D, Gait analysis and recognition using angular transforms, 0-7803-8253-IEEE6/ 04/, CCGEI (2004) 857-860.

15 Mallye M O, Lynn D & de Paor A M, Kinematic analysis of human walking gait using digital image processing, *Med Biol Engg Comput*, (1993) 392-402.

16 Bouchrika I & Nixon M S. Model-based feature extraction for gait analysis and recognition, *MIRAGE*, (2007) 150-160.

17 Whittle M W, Clinical gait analysis: A review, *Hum Movement Sci*, **15** (1996) 369-387.

18 Lee Seon-W, Mase K & Kogure K, Detection of Spatio-Temporal Gait Parameters by Using Wearable Motion Sensors, in *Proc 2005 IEEE Engg in Med & Biol 27th Annu Conf* (Shanghai, China) 1-4 September 2005.