# A METHOD FOR AUTOMATIC RELOCATION OF SKIN MARKERS IN REARFOOT MOTION ANALYSIS

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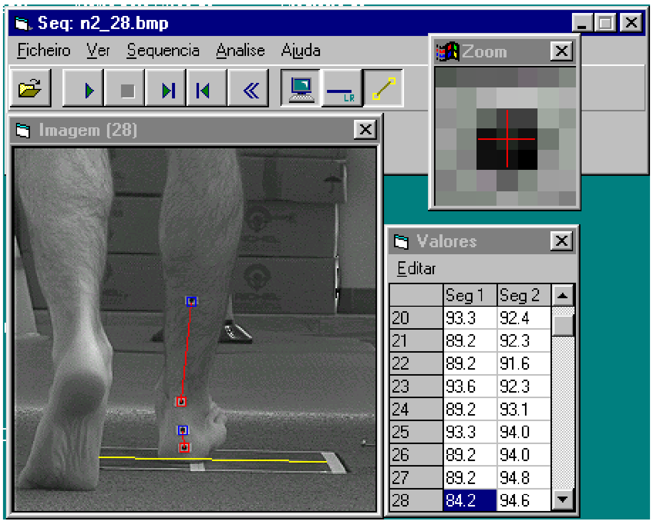
**INTRODUCTION:** In bipedal locomotion, in daily life activities as well in sport, there is frequently a need to alter the plane of displacement. However, the modification of the plane of displacement may cause some difficulties, because it frequently requires a side cut change of direction. That movement exposes the ankle to inverting/everting moments. Acute injuries, such as fractures and sprains, occur most commonly as a result of cutting or side-to-side movements, in sports such as basketball, soccer and football (Grana, 1994). Similarly, bipedal locomotion that utilizes some type of device in both feet to produce a gliding motion (e.g., skiing, ice and in-line skating) requires athletes to execute lateral maneuvers (Groot *et al*, 1985; Koning *et al.*, 1994) which are identical to side cut change of direction. Research on rearfoot motion during lateral side cut change of direction may help us understand the behavior of the ankle and devise strategies to reduce the incidence of injuries to this joint. The purpose of this study is to offer a method for automatic relocation of skin markers in rearfoot motion analysis during lateral side cut change of direction while walking. The choice of walking is justified by the fact that it is a basic standard motor pattern, letting us presuppose that it is subject to ontogenetic processes which are common to a major part of bipedal locomotion activities.

**METHODS AND PROCEDURES:** One normal adult male, 33 years old, with a body weight of 774.2 Newtons and height of 1.85 meters, participated in the experiments on a voluntary basis. The subject satisfies the following criteria: pain-free motion of both ankle and subtalar joints, no history of arthritic or neuromuscular disorders, no history of major trauma to the ankle or subtalar joint (including fractures, dislocations and sprains). The Nyquist sampling theorem states that a signal must be sampled at least twice as fast as its fastest frequency component. Some gait analysis systems use 25 Hz (or 30 Hz) sampling rates, which provide interpretable data for some aspects of slow walking (Krebs, 1995), but are not adequate for the analysis of running (Freychat *et al*, 1995). There is evidence that normal gait has some kinematics components with frequencies of 10 to 30 Hz (Krebs, 1995). However, to avoid aliasing problems the visual signal was acquired using a high-speed digital camera (DALSA CA-D1) at 225 Hz (frames per second). A prototype system was built, based on an IBM PC running the Windows NT operating system, with a windows interface to facilitate data analysis (Fig. 1). Data shown in the *Valores* box (Fig. 1) was exported to a spreadsheet and also to a statistical package for further processing. The prototype system was used to analyze recorded data of angular motion of the ankle joint complex during two walking tasks.

In the first task, the subject was asked to walk barefoot at the most comfortable speed along a 12 meter pathway. He started from a point which allowed him to place his right foot, at the middle of the pathway, on a rectangular surface (40 cm width and 60 cm length), properly, without any modification of direction, cadence or stride length. In the second task, the subject performed a 90º side cut change of walking direction. This cut of direction was made as long as possible, at the middle of the pathway, on the same rectangular surface indicated on the first task, being the right foot the supporting one. Ten trials were recorded for each of the two walking tasks. A total of 20 complete stance phases of the subject were analyzed. The experiments were focused on the observation of the kinematics behavior of the ankle joint complex, on the posterior aspect of the frontal plane, during the stance phase of both tasks, while walking barefoot. The high-speed camera was positioned at right angles to the plane of motion and as far away as possible (7 meters) to minimize the distortion introduced by perspective. The angles measured from the image sequence are the projection of three-dimensional angles on a two-dimensional plane, and any part of angulation that occurs out of that plane is ignored. The high-speed camera was focused at a point 0.5 m above the fore edge of the rectangular surface. Four skin markers were clearly marked on the heel and on the rear part of the leg (black ink on a white stripe of tape). They were located (Figure 1, from bottom to top): (1) on the right distal point of the posterior aspect of the calcaneus; (2) on the right insertion of the Achilles tendon on the calcaneus; (3) on the right mid-point between the medial and the lateral malleolus; (4) on the right line joining the marker number (3) with the bisection of the leg, at the level of the popliteal fossa, 15 cm above the marker number (3).

To improve the *accuracy* of the automatic relocation, these markers are localized in the computer screen by hand with help of a *Zoom* box (Fig. 1) using the mouse in the first frame of the sequence. The markers are automatically located in the other image frames of the sequence, using the proposed method, based on optimized block matching. To perform subsequent rigid body cinematic calculation, two body segments were defined from the marker trajectories: foot and leg. The foot segment was defined by a vector from the marker number (1) to the marker number (2). The leg segment was defined by a vector from the marker number (3) to the marker number (4). The space calibration procedure uses a scale marked by two targets located perpendicularly on the camera axis. These two points mark the horizontal. Comparison between the real measures of one well-know rigid body and measures calculated by the computer help prevent some poor performance of the automatic analysis. Angles between each segment and the horizontal were considered positive in the counter-clock-wise direction for a person analyzed from his right side. The ankle angle ($\theta a$) on the frontal plan was estimated considering the inversion position as positive and the eversion position as negative ($\theta a$ = leg angle - foot angle). The ankle angle during the stance phase was normalized over the total stance duration. Linear interpolation was applied to the original data about the angular position of the ankle to obtain 200 samples per stance phase independently of the stance duration. The resulting points go from 0 to 100, spaced at 0.5 units. These points were averaged over all recorded trials in each walking task. A ratio of variability (RV) was estimated, using an expression proposed by Frigo *et al.* (1996). This parameter leads the calculation of the mean standard deviation over the trials, in percentage of the mean ensemble signal range. The *t of* *pairs* was applied to compare the average values of the repetitive trials in each task. The resulting level of statistical significance was $P < 0.05$.



| | Seg 1 | Seg 2 |
|---|---|---|
| 20 | 93.3 | 92.4 |
| 21 | 89.2 | 92.3 |
| 22 | 89.2 | 91.6 |
| 23 | 93.6 | 92.3 |
| 24 | 89.2 | 93.1 |
| 25 | 93.3 | 94.0 |
| 26 | 89.2 | 94.0 |
| 27 | 89.2 | 94.8 |
| 28 | 84.2 | 94.6 |

**Figure 1-** The prototype windows interface, developed to facilitate data analysis.

**RESULTS AND DISCUSSION:** The proposed automatic relocation method was successfully used in the detailed motion analysis of the described motor tasks, with great economy to the operator. The angular behavior of the performer ankle of this study during walking without a change of direction (Fig. 2) is identical to the behavior referred to by the Winter *et al*. (1995) for the frontal plane.

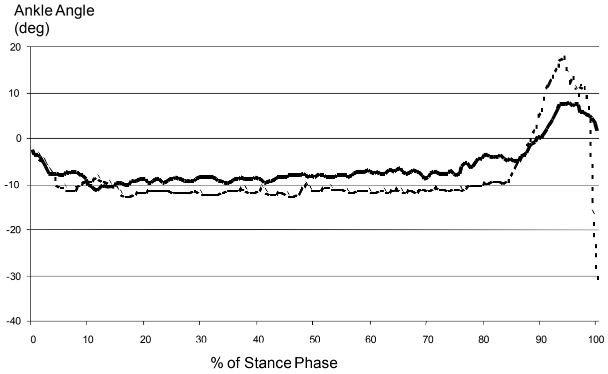


**Figure 2 –** Comparison of average curves of the ankle angle, across subject, between first (dotted line) and second task, normalized to stance phase.

The RV, as an index of the variability of the ankle angle, was in the first task 17.7% and 33.3% in the second task. Differences were found for average curve values between both tasks. The performer seems to try, in both tasks, to immobilize the articulation in the frontal plane, executing an alteration of the relative position among the leg and the foot just in the last third of the stance period (Fig. 2).

However, in the second task, the eversion position and the inversion peak position are not so intense as in first task.

**CONCLUSIONS:** The automatic localization solution represents a step towards the analysis of sequences acquired with high frame rates, justified by the fact that image acquisition with standard equipment (25 or 30 frames per second) presents strong aliasing problems. The results of the experiments in the present study indicate that the prototype system can be used in rearfoot motion analysis. The results suggest that during walking side cut change of direction the control at the ankle has the objective of restricting the eversion/inversion movement. Because this is an intra-subject study, more extensive biomechanical experimentation are necessary to validate these conclusions. The method presented here is expected to be a useful tool for other kinematics behavior studies.

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