How to generate natural female walking with high heels?

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1 Motivation

People can differentiate walking patterns of women wearing high heels or flat shoes with little doubt. Now, how to generate high-heeled walking motion for female humanoid robots is another question. We can think of applying captured motion data of women wearing high heels directly on the robots. However, we believe that more natural motion would be produced by extracting characteristics of the motion and applying them to the humanoid robots.

Analysis of the motion capture data shows that walking patterns are changed by shoe heel heights. We conjecture that instability of the body and muscle discomfort by high heels cause these changes. These characteristics can be used to compose *natural* female walking on high heels.

2 State of the Art

Gait analysis of high-heeled walking has been studied in biomechanics, medical science, and rehabilitation. These studies are usually not for generation of walking motion, but for understanding of muscle activity or cause of disease. Stride patterns or joint angles are generally analyzed in these studies. In high-heeled walking, stride length becomes shorter [2, 3] and maximum knee flexion is smaller at the swing phase while larger at the stance phase [4].

Female walking motion on flat shoes is analyzed for female humanoid robot using motion capture system in [5]. In this approach, the characteristics such as single support time of toe, stretched knee joint at heel strike, and motion of swing leg are considered for creating natural walking of HRP-4C. Walking like fashion models is implemented in computer simulations [6]. In order to develop feminized robots for fashion shows or entertainment, the study used common features observed from the style of model walking. The predetermined trajectories for knee joints and arms are applied to generate model-like walking for simulated robot WABIAN-2.

3 Generation of high-heeled walking

Female walking with high heels and with flat shoes are captured to understand and implement natural female walking wearing high heels. The data are compared to analyze the characteristics of high-heeled walking. Finally, these characteristics can be adapted to humanoid walking motion.
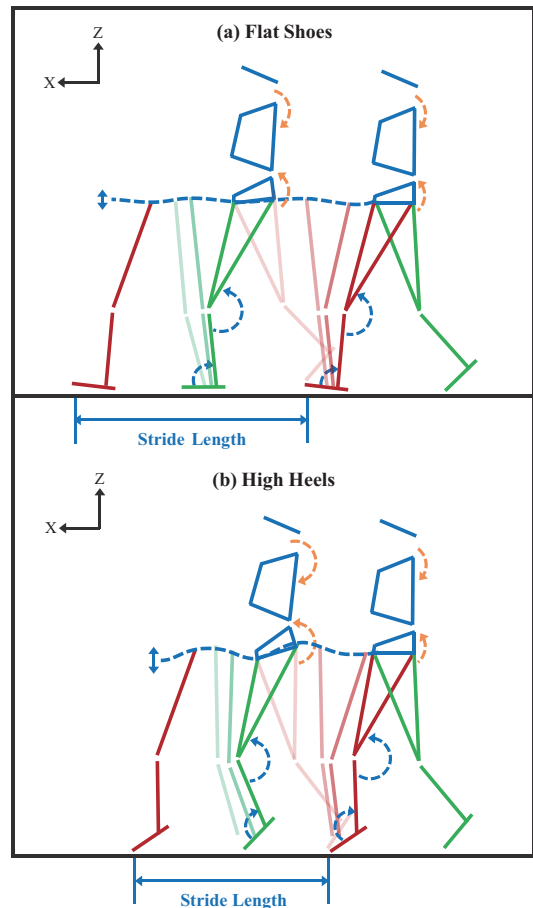

Figure 1: Gait changes in sagittal view depending on heel heights: (a) flat shoes (b) high heels

Motion capture

Twelve females participated in the experiment to walk 5m walkway for data collection. A Vicon 3D motion capture system with 12 cameras (Vicon T160 Camera, Oxford Metrics Ltd) was used to capture kinematic data at 100 Hz from 35 reflective markers (19 in the upper body and 16 in the lower limb). Two types of shoes which were different in heel height and shape (flat shoes with a 1 cm heel and high-heeled shoes with a 9.8 cm heel) were applied in this study. Stride patterns, joint angles, and trajectories of the body parts were obtained for two shoe conditions. The data range was fixed to 3 seconds starting from heel strike, which in-

cluded about 3 cycles of gait at 118 steps/min. Paired t-Test between the flat shoes and the high heels was performed for statistical analysis.

Experimental Results
The differences in stride patterns, joint angles and trajectories of the body parts are analyzed from the captured data. It is found that the average stride length of all subjects was shorter at high heels than that of flat shoes (flat: 127.02 ± 9.88 cm, high heels: 116.77 ± 8.57 cm, p-Value: 0.001). The average of double support time increased with high heels (flat: 0.10 ± 0.03 sec, high heels: 0.15 ± 0.03 sec, p-Value: 0.0002).

Knee flexion-extension in sagittal plane had a greater maximum point at the stance phase (flat: $14.55 \pm 9.56°$, high heels: $22.49 \pm 10.07°$, p-Value: <0.0001), but a smaller maximum point at the swing phase (flat: $61.22 \pm 10.87°$, high heels: $50.10 \pm 11.21°$, p-Value: <0.0001) with high heels than with flat shoes. Also, there were tendencies of greater tilt in sagittal plane (flat: $13.79 \pm 4.05°$, high heels: $16.23 \pm 3.83°$, p-Value: 0.0005) and slightly severer rotation of the spine (flat: $12.46 \pm 4.93°$, high heels: $15.72 \pm 6.29°$, p-Value: 0.0394) in the subjects wearing high heels.

The trajectories of the body parts such as the ankle, knee, pelvis, and head were analyzed. The trajectory of the ankle along the vertical direction in flat-shoes walking had a wider motion than that in high-heeled walking (flat: 180.66 ± 20.15 mm, high heels: 102.77 ± 17.24 mm, p-Value: <0.0001). On the other hand, the trajectory of the knee had an opposite trend compared to the trajectory of the ankle (flat: 84.49 ± 10.44 mm, high heels: 99.20 ± 15.46 mm, p-Value: <0.0001). The pelvis trajectory showed greater fluctuations with high-heeled walking, and this effect was continuously observed in the spine and head trajectories in the vertical direction.

Key characteristics of high-heeled walking
It was found that the double support time increases 1.5 times with high heels than flat shoes, and this implies that high-heeled walking motion becomes closer to static walking. The stride legnth decreases with high heels.

The more the knee joint is inflexed at the stance phase, the less the knee joint is inflexed at the swing phase with high heels. Due to this change, the upper body and the head trajectories in the vertical direction have more fluctuation with high heels. Also, the motion of the upper body has more vertical rotation and tilt in sagittal plane with high heels.

These findings may explain the reason why people generally think high-heeled walking looks like a gait with short, quick steps, and hips swaying.

4 Disccusion

The key characteristics of high-heeled walking in the previous section could be representative factors for generating female humanoid walking on high heels.

The found characteristics are the changes in double support time, stride length, knee joint angle, and vertical motion of the upper body. It is conjectured that double support time increases due to the instability of the body wearing high heels. Muscle discomfort, caused by raised heel position, affects stride length, knee joint angle, and vertical motion of the upper body.

We are now studying on how these characteristics can be effectively applied in synthesizing female humanoid motion.

Also, the effect of speed on high-heeled gait is currently being investigated.

5 Open question

Is high-heeled walking different with toe walking? Women wearing high heels walk without putting much weight on the heel, which is also refered as toe walking. What is the difference between toe walking and high-heeled walking and how to generate those motions in humanoid robots?

Keyword

High-heeled gait, Female walking

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