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Articulated foot improves human likeliness of walking when compared to a flat foot

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KEYWORDS Gait synthesis; 3D simulation; articulated feet

1. Introduction
Simulations of human walking is a current subject of research in different areas. Between the different approaches for the synthesis of human walking (Xiang et al. 2010), two clearly distinguish: dynamical synthesis and data motion replay. The first approach allows for the study of the gait itself, without the bias of human data replay that can be found in the second case. This synthesis of walking is commonly found in the humanoid robotics field. However, the majority of robots present flat feet, which is a known drawback in the synthesis of human like gait.

We propose here to compare walking motions generated for human virtual models with and without articulated feet. We make the hypothesis that articulated feet increases the range of possible motions and improves the human likeness of the generated gait.

2. Methods
2.1. The virtual human
A first model, Model I, composed of 15 rigid segments (head, torso, 2 arms, 2 forearms, 2 hands, 2 legs, 2 shanks and 2 feet) linked together by 14 joints was developed. In order to evaluate the impact of articulated feet in the walking motion, a second model, Model II, is designed, by dividing the foot in two segments, articulated at the metatarsal level, with a one degree of freedom joint. This model is then composed of 17 segments and 16 joints. Body inertial parameters were adapted from (Dumas et al. 2007).

2.2. Linear Quadratic Programming Controller
The Linear Quadratic Programming developed by (Salini 2012) was used to control the walking motion for both models. The walking motion is generated by combining several objectives to be achieved simultaneously. These objectives are expressed as a task error $T_i$ between a desired acceleration $a_{i}^{des}$ and the system acceleration $a_i$ as follows:

$$T_i = a_i - a_{i}^{des}$$

The gait generation then consists in finding the system actuation torques, contact efforts and generalised acceleration, $X = (r, W, \dot{v})$, by minimizing a cost function resulting for the weighted $\omega_i$ sum of all $n_t$ squared tasks $T_i$, as follows:

$$\min_X \sum_{i=1}^{n_t} \omega_i T_i^2(X)$$

while respecting the equations of motion and inequality constraints expressed as joint limits, torque limits and non-slipping contact conditions.

2.3. Tasks for the walking motion
The tasks generated for the walking motion are:

- Left/Right Foot Tasks, controlling the foot frames during foot displacement;
- CoM Task, responsible for the control of the Centre of Mass acceleration, following the method of (Wieber 2006);
- Pelvis Height and Orientation Tasks, controlling the Pelvis Height and Orientation, for stability purposes;
- Torso and Head Tasks, responsible for maintaining these segments straight during the entire motion, for stability purposes.

The main differences between the control of the two models rely on the definition of the foot tasks and the CoM tasks:

- Model I – Foot displacement is defined with polynomials respecting a zero velocity and acceleration...
Videos of the corresponding walking motions can be found in the supplementary electronic data.

4. Conclusions

In this article, the impact of articulated feet in the generated walking motions for a virtual human is accessed. Walking patterns for different SPT are generated. The gaits generated for Model II increases about 200% the maximum of step lengths and almost 300% the maximum walking speed. Kinematics is greatly improved for the ankle, but also ankle joint moments vary more human likely.

Future work includes inverse optimization techniques to better identify the tasks needed to generate walking patterns, as possible way of improving walking patterns generation.

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