Dynamic stabilisation of the biped Lucy powered by actuators with controllable stiffness

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This dissertation reports on the developments of the bipedal walking robot Lucy. Special about it is that the biped is not actuated with the classical electrical drives but with pleated pneumatic artificial muscles. In an antagonistic setup of such muscles both the torque and the compliance are controllable. From human walking there is evidence that compliance plays an important role in energy efficient walking and running. Moreover pneumatic artificial muscles have a high power to weight ratio and can be coupled directly without complex gearing mechanism, which can be beneficial towards legged mechanisms. Additionally, they have the capability of absorbing impact shocks and store and release motion energy. This manuscript gives a complete description of Lucy: the hardware, the electronics and the software. A hybrid simulation program, combining the robot dynamics and muscle/valve thermodynamics, has been written to evaluate control strategies before implementing them in the real biped.

The current control architecture consists of a trajectory generator and a joint trajectory tracking controller. Two different trajectory generators have been explored. The first is based on an inverted pendulum model where the objective locomotion parameters can be changed from step to step. The second is an implementation of the preview control of the zero moment point developed by Kajita. The joint trajectory tracking unit controls the pressure inside the muscles so the desired motion is followed. It is based on a computed torque model and takes the torque-angle relation of the antagonistic muscle setup into account. With this strategy the robot is able to walk up to a speed of 0.15m/s. Higher walking speeds are difficult because the robot has to walk flat-feet and the valve system is not fast enough to follow the predescribed pressure courses.

On a single pendulum structure a strategy is developed to combine active trajectory control with the exploitation of the natural dynamics to reduce energy consumption. A mathematical formulation was found to find an optimal compliance setting depending on the trajectory and physical properties of the system. This strategy was not implemented on the real robot because the walking speed of the robot is currently too slow.