TECHNICAL PROVE THAT MUSCLE PROPERTIES CAN HELP TO STABILIZE HOPPING GAITS

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INTRODUCTION

During human running, the apex height has to be held constant. This is apparently an easy task for humans but still a challenging task in state-of-the-art engineering. Simulations showed that muscle properties and afferent muscle feedback can stabilize periodic gaits [1]. Here we show that this stabilizing effect can be traced back to a special kind of energy supply.

METHODS

1) Mathematical model:

The vertical component of running motion, hopping, is described by the following differential equation:

$$m\, d^2y/dt^2 = -m\, g + F_m \qquad F_m = Act(t)\, F_l\, F_v\, F_{max}\,, \quad (1)$$

where F_m is the leg force produced by a Hill type muscle [1] during stance phase. F_m is composed of force-length curve F_l, force-velocity curve F_v, and Act(t) which describes muscle activation dynamics under delayed sensory (force?) feedback [1]. So, the muscular input combines force, contraction velocity and length of the muscle, all of these three signals being available via proprioception. Feedback strengths are optimized for maximum hopping height at 2 Hz hopping frequency using a genetic algorithm implemented in Matlab Simulink (The Mathworks, Inc.).

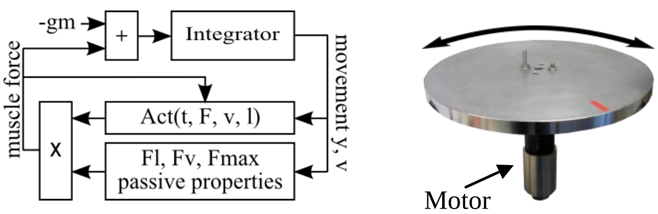

Figure 1: Left: Mathematical Model. Right: Robot model consists of a Maxon RE 30 DC motor, a aluminum disk with moment of inertia $J = 4.2 \times 10^{-3}$ Nm². The rotation speed is measured with a Mattke tacho generator T505.

2) Robot

The robot design in fig.1 R performs the integration indicated in the mathematical model outlined in fig.1 L, but now expressed in terms of torque, angular velocity and angular position instead of force, linear velocity and linear position. The robot is controlled a by Matlab/Simulink program carrying over the previously optimized parameters.

3) Stability analysis

The apex Poincaré maps (fig.2) reflect the hopping behavior of both the mathematical model and the hardware replacement. Each point shows the relation between release height (y_i) and subsequent apex height (y_{i+1}) for one step. The diagonal line is the line of fixpoints where $y_{i+1} = y_i = y_{fix}$. A fixpoint is stable when $|S| < 1$ with $S = dy_{i+1}/dy_i\, |y_{fix}$ [2].

RESULTS AND DISCUSSION

Robot and mathematical model both reveal stable hopping. Additionally, both Poincare return maps show a similar shape, because of friction and damping, however, the robot only reaches decreased hopping heights. Positive force feedback proves to be the most flexible and stable feedback. Activation pattern Act(t) can be adapted to diverse F_v and F_l shapes, but in any case the implementation of a force-velocity relation exhibiting a decreasing force with increasing velocity is crucial (necessary?) for stability.

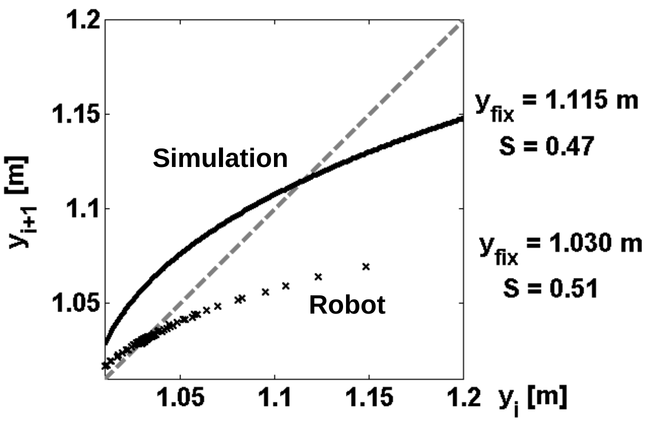

Figure 2: The apex Poincaré map for simulation (solid black) and the robot (black x) shows that the stability of the robot is similar to the models prediction but the fixpoint height differs. This model uses a linear F_v, constant F_l and is stimulated by Positive Force Feedback (PFF).

CONCLUSIONS

Positive Force Feedback (PFF) provides a scaleable and stable apex also in real world hopping, if combined with particular intrinsic muscle properties specified by F_v, F_l. Because the apex in hopping represents the total energy of the system, PFF reveals a method which just restores the energy lost by damping and friction.

ACKNOWLEDGEMENTS

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REFERENCES

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2. Rummel J, Seyfarth A, *International Journal of Robotics Research*, **27**:919-934, 2008