Imitating Humans
Humanoid Fall Avoidance and Stable Gait Design using Biomimicry

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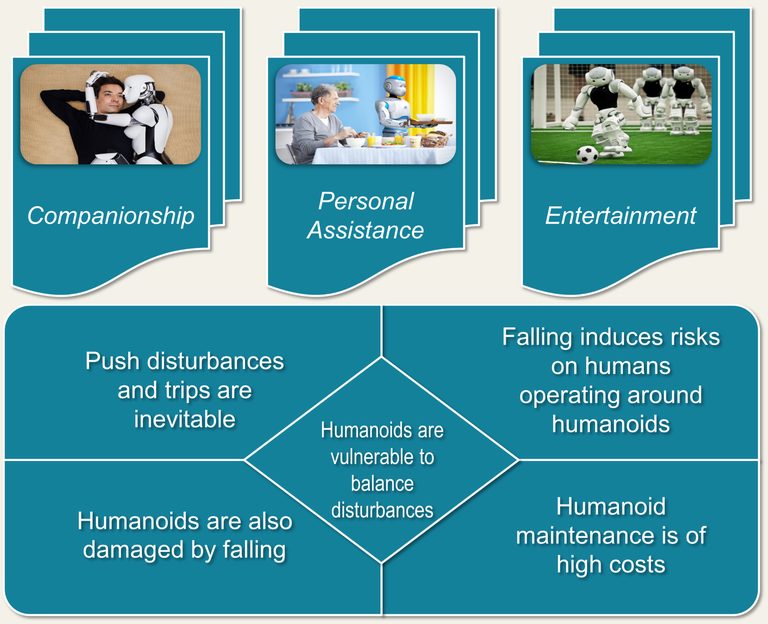
Introduction

Humanoid Robot Applications & Motivation



Objectives

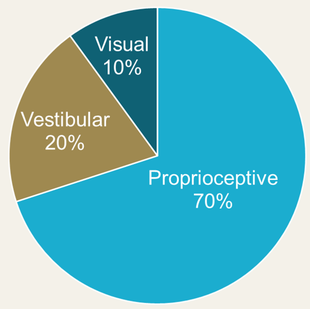
1. Humanoid fall avoidance during quiet standing that follows human-like strategies while considering dynamic changes in the environment
2. Humanoid fall avoidance during quiet standing that could be implemented on different humanoids, i.e. model-independent
3. Humanoid gait that applies human-inspired strategies specially in energy-efficiency and robustness against push disturbances

Posture Assessment

To assess their pose humans rely on

1. **Proprioceptive Sensors** Foot pressure and joint torques
2. **Vestibular Sensors** Located in the inner ear
3. **Visual Sensors** Ego-motion vs moving environment

Human Sensor Information



■ Proprioceptive ■ Vestibular ■ Visual

Humanoid Fall Avoidance – Quiet Standing

Sensor Reweighting

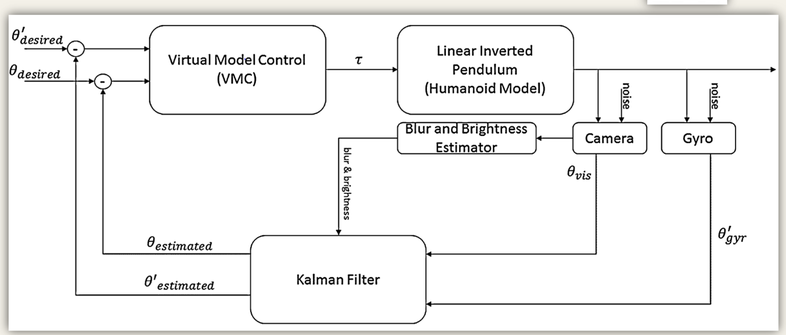


Figure 1: Control Loop of the overall system. The Kalman Filter fuses the measurements along with the blur and brightness metric and sends the predicted angular position and velocity to the Virtual Model Controller which in turn sends the appropriate ankle torque (τ) in order to maintain postural balance [1]

Scenario Number	Max. Torque (N)	Max. Angle Displacement (rad.)	Settling Time (sec.)
(1) Sensory Reweighting (normal conditions)	1.5	0.33	1.17
(2) Gyro alone (normal conditions)	3.75	0.17	1.95
(3) Camera alone (normal conditions)	2.14	0.42	1.29
(4) Sensory Reweighting (noisy gyro)	6.44	0.39	0.36
(5) Gyro alone (noisy gyro)	2	0.17	1.98
(6) Sensory Reweighting (lights out)	2.24	0.16	2.41
(7) Camera alone (lights out)	0.06	No recovery	No recovery

Table 1: Performance parameters for 7 scenarios (maximum torque, maximum displacement angle, and settling time) - Values are averages of the 10 repetitions [1]

Model-Free Push Recovery

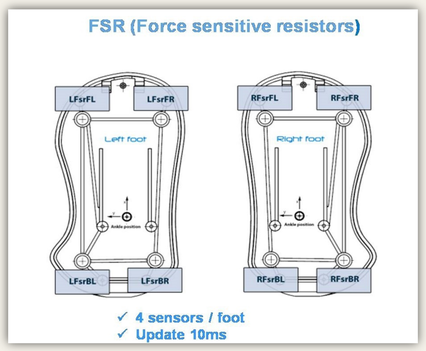


Figure 2: Force Sensitive Resistors located on Nao's feet

- Reliance on proprioceptive sensors (foot pressure)
- Difference between sensor readings indicates the degree of inclination
- Give weight to previous readings $r_{i+1} = w * r_{i+1} + (1 - w) * r_i$

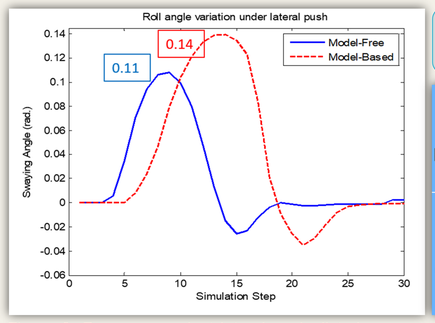
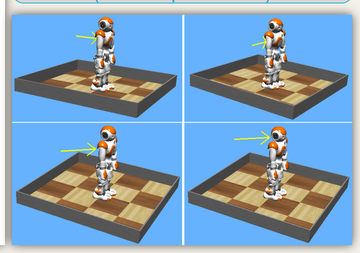


Figure 3: Recovery against lateral push disturbances – Simulation [2]

Model-Free handles up to 26N push (8.3% improvement)



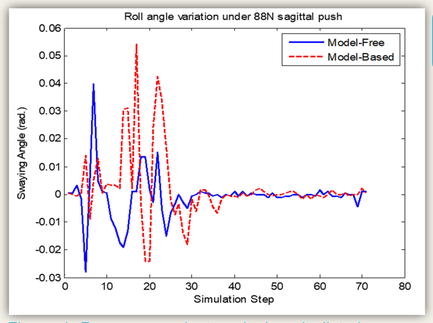
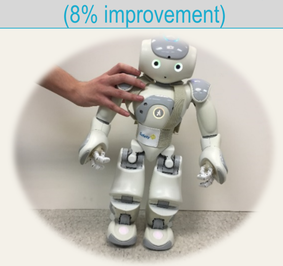


Figure 4: Recovery against sagittal push disturbances – Experiment [2]

Model-Free handles up to 95N push (8% improvement)



Humanoid Stable Gait Design based on Energy-Exchange

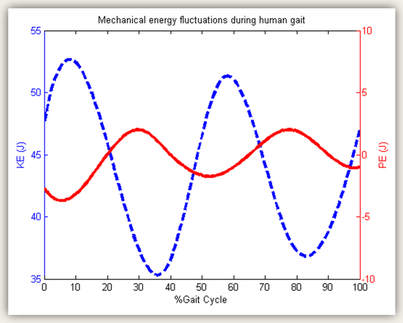
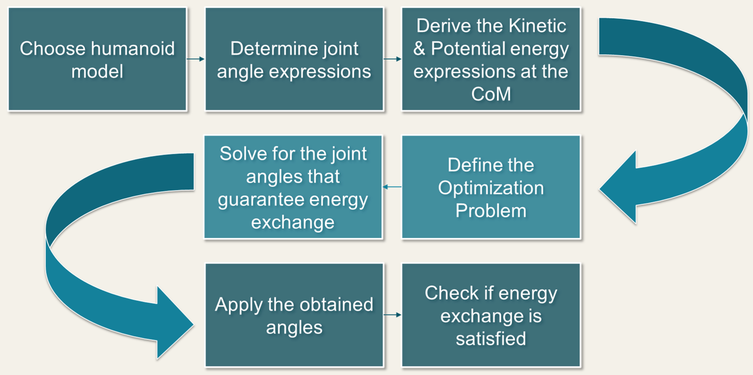


Figure 3: Mechanical energy fluctuations showing Kinetic Energy (KE in blue-dashed) and Potential Energy (PE in red) out-of-phase during a human gait

- During gait at constant speed, KE and PE of the human's CoM oscillate in an out-of-phase fashion
- Around 70% of external mechanical energy can be recovered [3]
- Not yet used in humanoid gait design

Gait Design Roadmap



Push Recovery During Gait

1. 49% more energy efficient than standard gait per total mechanical energy metric
2. Withstands up to 36.4% higher push disturbance magnitudes than standard gait

Conclusion

- Human-like posture assessment and push recovery during quiet standing
- Adaptable to environment changes using sensory reweighting
- Model-Free push recovery – increased versatility with changing humanoid models and disturbance direction
- Human-like humanoid walking inspired by energy-exchange – withstands higher push magnitudes during single stance

References

[1] N. Maalouf, I. H. Elhajj, E. Shammas, and D. Asmar, "Humanoid push recovery using sensory reweighting," *Robotics and Autonomous Systems*, vol. 94, pp. 208-218, 2017.

[2] N. Maalouf, I. Elhajj, D. Asmar, and E. Shammas, "Model-free human-like humanoid push recovery," in *RObotics and BIOmimetics (ROBIO), 2015 IEEE International Conference on*. IEEE, 2015.

[3] N. Maalouf, I. H. Elhajj, E. Shammas, and D. Asmar, "Imitating humans: Humanoid gait design based on energy exchange," in *Robotics and Biomimetics (ROBIO), 2017 IEEE International Conference on*, 2017, pp. 2599-2604: IEEE.

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