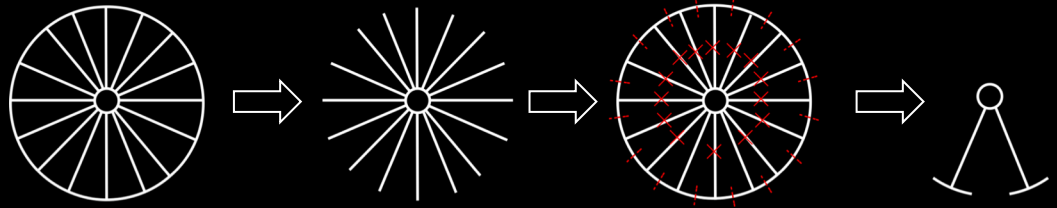
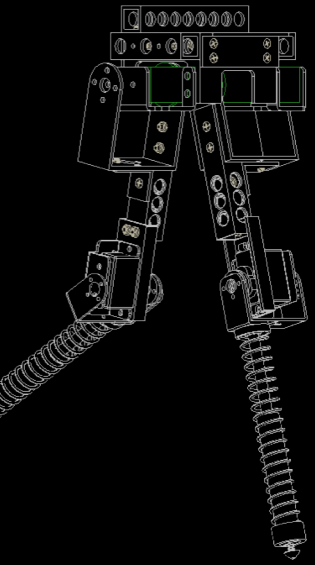
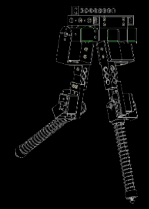




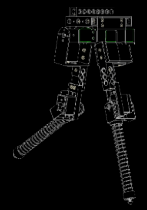


Passive Dynamic Walkers

IN2352 “Applied Biorobotics”

Coordinator: Dr. Daniel Renjewski

Presenters:
N. Paredes, G. Reiersen, J. Martinez-Moritz, J. Mirzai, F. Lay, R. Petereit



Properties

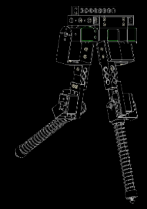
- ❏ Actuation mainly through gravity and inertia, limited *active* control
- ❏ Exploit inverted pendulum effect through coupling of joints
- ❏ Stable single gait but limited to slopes and gravitational field
- ❏ Prone to perturbations since no or limited actuation to counter

Source: T. McGeer et al. [1]

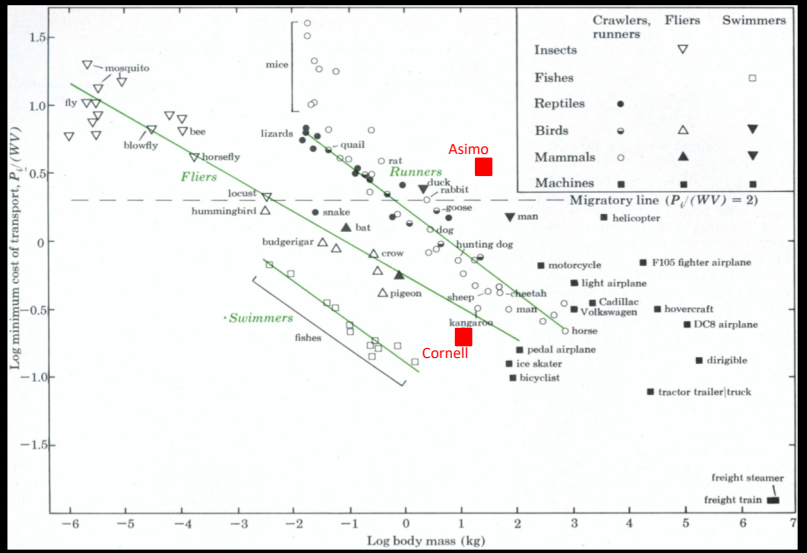
Passive walking toy
https://www.youtube.com/watch?v=anbPG6lpP1w

McGeer‘s passive walker
https://www.youtube.com/watch?v=WOPED7I5Lac

Motivation

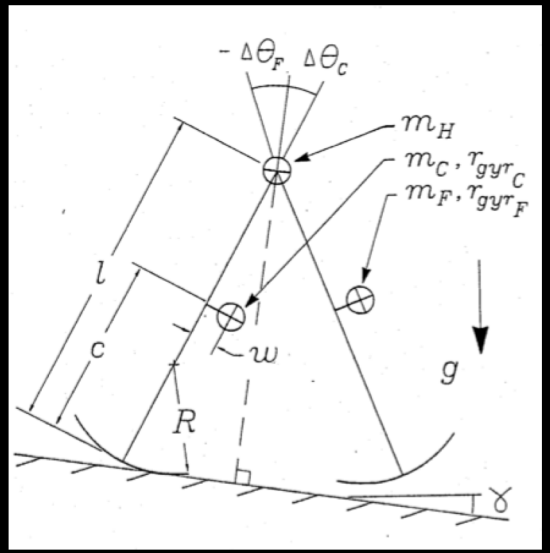


Efficiency



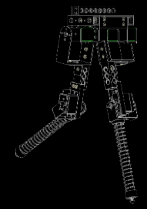
Minimum costs of transport [2, 3]

Simplicity



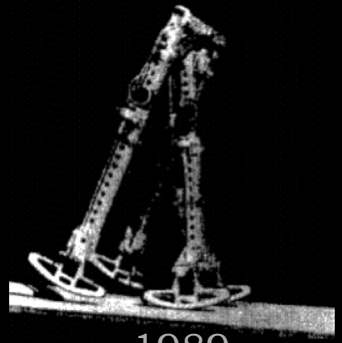
2D biped model [1]

Historic Development



Early Developments

Toys that could mechanically walk down a inclined slope with no motors.



Passive Walking with Knees

Knees solve the problem of feet colliding with the ground when the leg swings forward [5]

Recently

~1888

1989

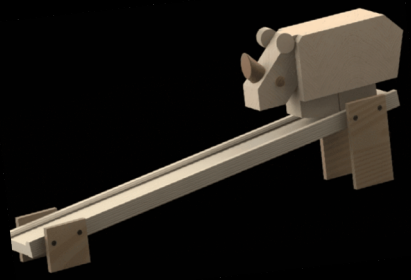
1990

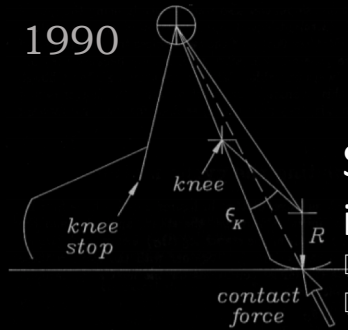
1999

Dr. Tad McGeer

Introduce the term Passive Dynamic Walkers

McGeer's early passive-dynamic machines relied only on gravity and the natural swinging of their limbs to move forward down a slope. [1, 4]





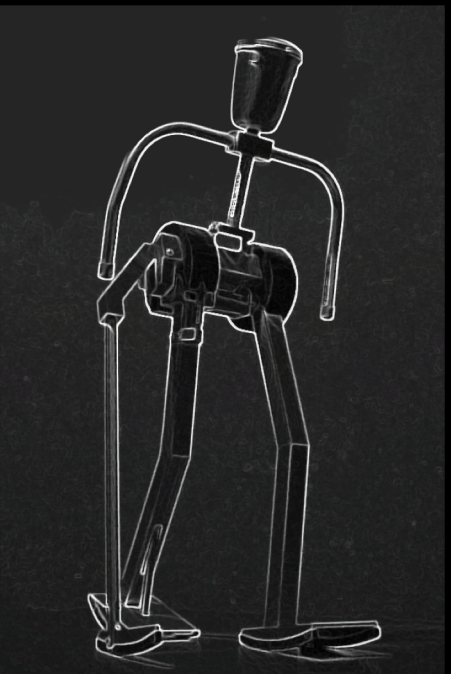
Stabilization of lateral motion in passive dynamic walking

- ❑ Art Kuo (University of Michigan) [6]
- ❑ Anti-foot scuffing mechanism (A. Ruina)[7]
- ❑ Dynamic arm swinging (2009) [8]

Design: Roberto Lou Ma

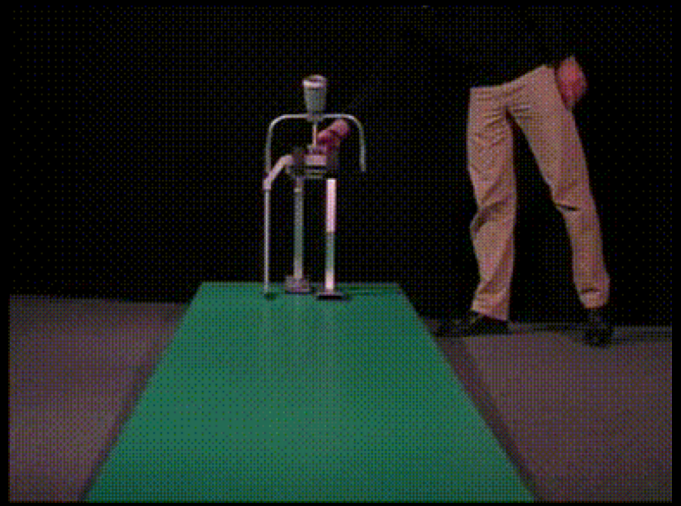
Passive Dynamic Walkers

Museon Walker (2001)



Source: website of T.U. Delft Biorobotics Lab

- Developed at the Delft University of Technology
- Fully passive walking robot (McGeer) -Anti-foot scuffing (A. Ruina)
- 80 cm tall and weight of about 3.5 kg.
- Used to demonstrate the basic principle behind passive dynamic walking.
- “Requires a sloped walking surface and obtains its swing leg acceleration from a mechanism at the hip joint which effectively lowers the center of mass to provide energy to the swing leg” [9] (natural frequency)



Denise - T.U. Delft (2004)[14]

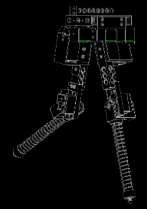
- Pneumatically actuated humanoid robot[13] (McKibben muscles)[10] with simple control (on/off) and foot sensor
- *Purpose:* extend the passive dynamic walking legs with an upper body to increase sideways stability[12]

- *Height:* ~ 160cm
- *Weight*: ~ 10kg
- *Speed:* max 1,3 m/s
- *DOF*: 5 in total
  2 ankles, 2 knees
  and 1 at the hip
  [10,11]

Source: website of T.U. Delft Biorobotics Lab, visited 23.01.2018

Source: M Wisse and R. Q. van der Linde, "Delf Pneumatic Bipeds" 2007, p. 106

Cornell Ranger - Cornell University (2006)



The first robot that was **reliable** in walking distance and **efficient**

- reliable walking distance: 65 km (2011)
- Total Cost of Transport (TCOT) = 0,28

Principle: Simplicity

- 6 logical states in 2 phases

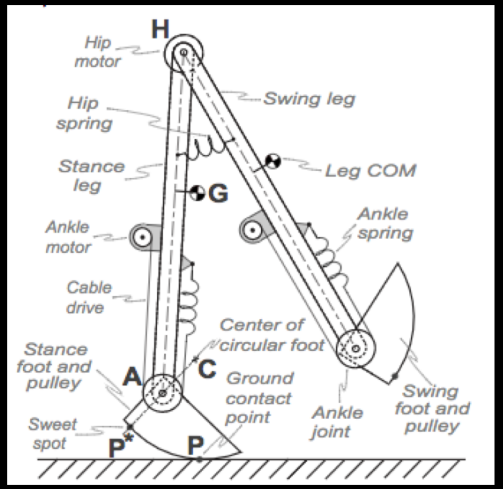
[15],[16]

Specifications

- Degrees of Freedom: 6
- Weights: 9,9 kg
- Height: 1m
- Speed: 2 km/h
- Battery powered
- Radio controlled direction

[17]

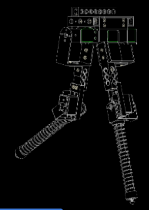
Source: Youtube: Cornell Ranger 2011 - Marathon Walking Robot, visited: 23.04.18



Source: Pranav A. Bhounsule et. al, Low-bandwidth reflex-based control for lower power walking: 65 km on a single battery charge, Figure 1b, 2006

Passive Dynamic Walkers

BlueBiped (2008)



No motors or hydraulics, no sensors, no computers, the legs are completely passive. The momentum of each step is enough to throw it into another step.

- Fujimoto Lab - Nagoya Institute of Technology in Japan
- Appearance: 2008 Good Design Award Winner
- Record: walked for 13 hours continuously, 100,000 consecutive steps, 15km. Mass ~10 Kg
  - Research
  - Understanding Human Physiology
  - Future Commercial development

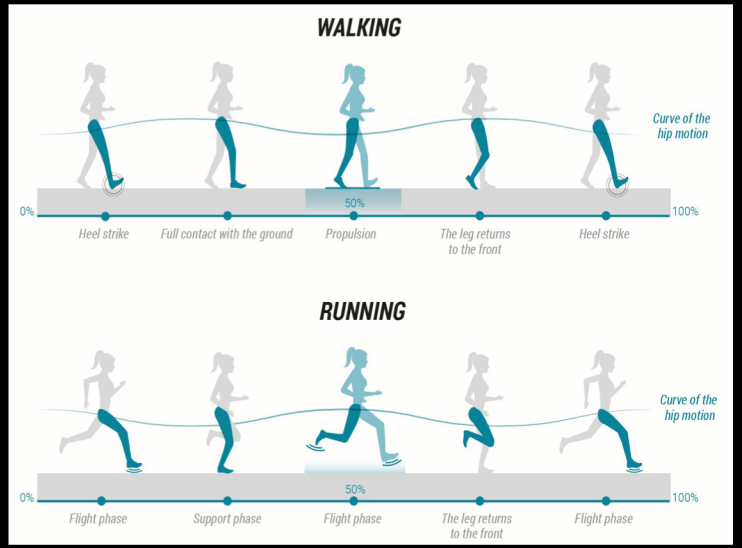
[18],[19]

Source: Comparison with Human Gait Movie
http://drei.mech.nitech.ac.jp/~fujimoto/sano/walk_jpn.html

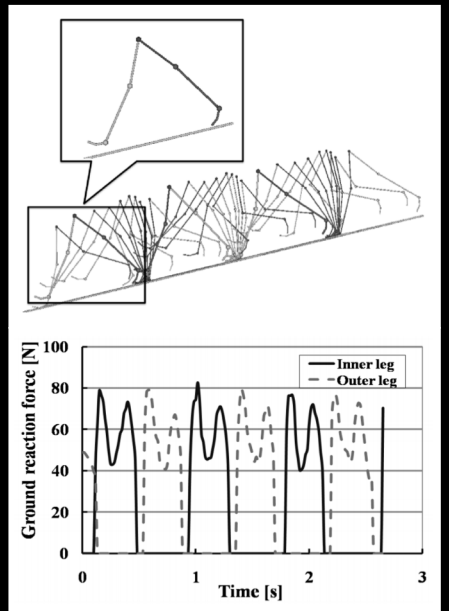
Passive Dynamic Walkers

PDR400 (2010)

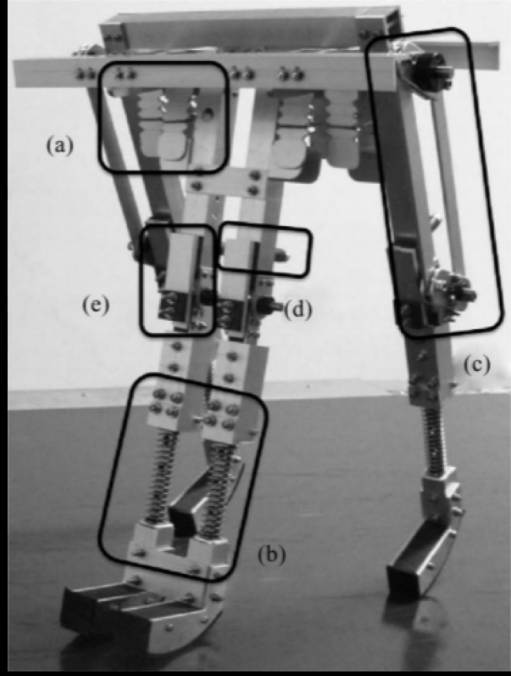
- ❑ Uses elastic elements for passive control
- ❑ Animal inspired hyperextension of the knee
- ❑ 36 steps maximum recorded
- ❑ 0.83 m/s on a 0.22 rad slope
- ❑ Record speed in 2010



Source: newfeel [20]

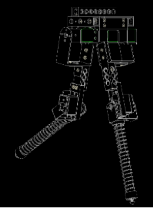


Source: Owaki et al. [21]



a) Torsion springs in the hip joints
b) Linear springs in the legs
c) Parallel-link mechanism
d) Shock absorbers
e) Hyperextension mechanism

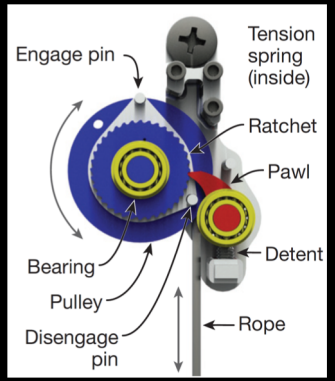
Source: Kurowski [22]



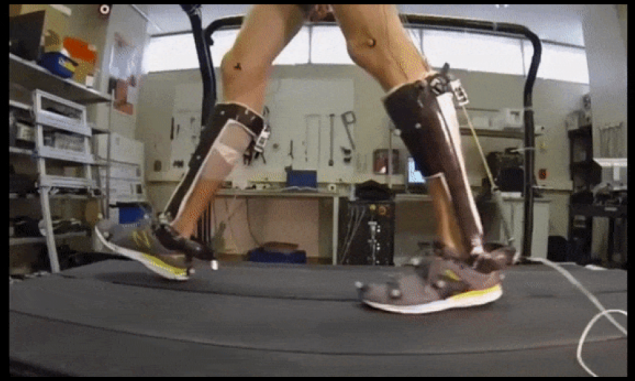
Unpowered ankle exoskeleton (2015)

Source: Collins et al. [23]

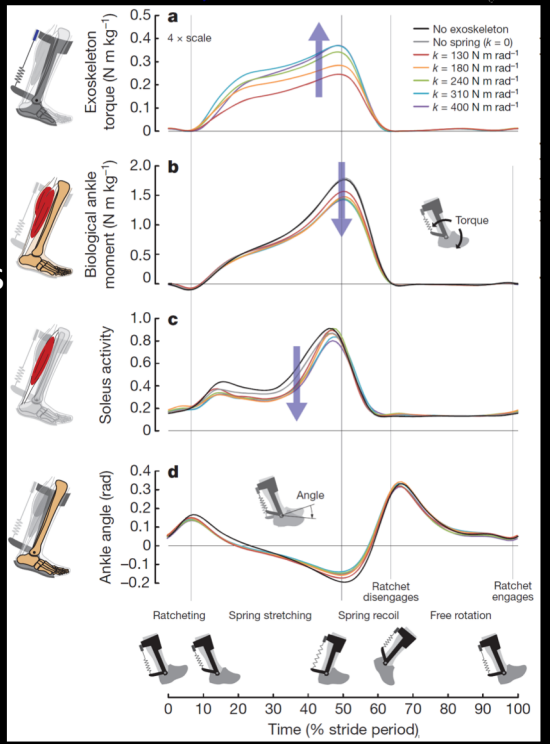
- ❑ Published by Carnegie Mellon and North Carolina State Uni.
- ❑ Mechanical clutch to support calf muscles and Achilles tendon
- ❑ Metabolic rate reduction of ~7.2% (N_{study} = 9)
- ❑ Mass of around 400 - 500 g
- ❑ Passive dynamics can further increase efficiency of actuated gaits



Design

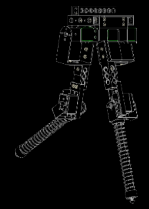


Source:
https://www.youtube.com/watch?v=9weJw2b0qfM



Step-to-Step analysis

Reference List A



[1] T. McGeer et al., “Passive dynamic walking,” I. J. Robotic Res., vol. 9, no. 2, pp. 62–82, 1990.

[2] V. A. Tucker, “The Energetic Cost of Moving About: Walking and running are extremely inefficient forms of locomotion. Much greater efficiency is achieved by birds, fish and bicyclists,” American Scientist, vol. 63, no. 4, pp. 413–419, 1975.

[3] T. McGreer, “W-Prize Challenge,” 2009, Link: http://www.wprize.org/aboutus.html. (Accessed: 22/04/2018)

[4] T. McGeer, "Powered flight, child's play, silly wheels and walking machines," Proceedings, 1989 International Conference on Robotics and Automation, Scottsdale, AZ, 1989, pp. 1592-1597 vol.3.

[5] T. McGeer, "Passive walking with knees," Proceedings., IEEE International Conference on Robotics and Automation, Cincinnati, OH, 1990, pp. 1640-1645 vol.3.

[6] A. D. Kuo, “Stabilization of lateral motion in passive dynamic walking,” The International Journal of Robotics Research, vol. 18, no. 9, pp. 917–930, 1999.

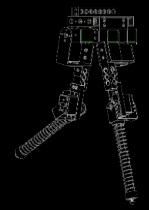
[7] M. W. Gomes and A. Ruina, “A Walking Model with No Energy Cost,” 2010.

[8] S. H. Collins, P. G. Adamczyk, and A. D. Kuo, “Dynamic arm swinging in human walking,” Proc. R. Soc. B Biol. Sci., vol. 276, no. 1673, pp. 3679–3688, 2009.

[9] M. Wisse, "Three additions to passive dynamic walking; actuation, an upper body, and 3D stability," 4th IEEE/RAS International Conference on Humanoid Robots, 2004., 2004, pp. 113-132 Vol. 1.

[10] M. Wisse and R. Q. van der Linde, Delft Pneumatic Bipeds. Springer Berlin Heidelberg, 2007.

Reference List B



[11] S. H. Collins, “Efficient Bipedal Robots Based on Passive-Dynamic Walkers,” Science (80-.)., vol. 307, no. 5712, pp. 1082–1085, Feb. 2005

[12] S. H. Collins and A. Ruina, “A Bipedal Walking Robot with Efficient and Human-Like Gait,” in Proceedings of the 2005 {IEEE} International Conference on Robotics and Automation

[13] S. O. Anderson, M. Wisse, C. G. Atkeson, J. K. Hodgins, G. J. Zeglin, and B. Moyer, “Powered bipeds based on passive dynamic principles,” in 5th {IEEE}-{RAS} International Conference on Humanoid Robots, 2005

[14] M. Wisse, A. L. Schwab and F. C. T. van der Helm,“Passive dynamic walking model with upper body”, Robotica, Cambridge University Press (CUP), 2004, 22, 681-688

[15] Bhounsule, Pranav A., et al. "Low-bandwidth reflex-based control for lower power walking: 65 km on a single battery charge." *The International Journal of Robotics Research* 33.10, 2014

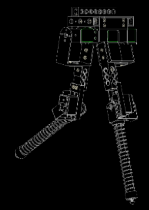
[16] Karssen, JG Daniël. "Design and construction of the Cornell Ranger, a world record distance walking robot." ,*Internship Final Report* ,2007

[17] Cornell University, Andy Ruina, Ruina.tam: http://ruina.tam.cornell.edu , visited: 23.04.18

[18] BlueBiped. Website Fujimoto Lab - Nagoya Institute of Technology in Japan. Link: http://drei.mech.nitech.ac.jp/~fujimoto/sano/walk_jpn.html . Accessed: 21/04/2018

[19] T. Singh. Inhabitat. *BlueBiped: The Zero-Energy Robot That Can Walk Just Like a Human.* Link: https://inhabitat.com/bluebiped-the-zero-energy-robot-that-can-walk-just-like-a-human/ . Accessed: 21/04/2018

Reference List C



[20] newfeel, Power Walking and Running: What's the Difference?: Fast walking steps and running strides. [Online] Available: https://www.newfeel.co.uk/advice/power-walking-and-runningwhats-difference-a_16798. Accessed on: Apr. 22 2018.

[21] D. Owaki, M. Koyama, S. Yamaguchi, S. Kubo, and A. Ishiguro, A Two-Dimensional Passive Dynamic Running Biped with Knees: 3 - 7 [i.e. 3 - 8] May 2010, Anchorage, Alaska, USA. Piscataway, NJ: IEEE, 2010.

[22] S. Kurowski, “A Systematic Approach to the Design of Embodiment with Application to Bio-Inspired Compliant Legged Robots,” Dissertation, Universitäts- und Landesbibliothek Darmstadt, Darmstadt, 2016.

[23] S. H. Collins, M. B. Wiggin, and G. S. Sawicki, “Reducing the energy cost of human walking using an unpowered exoskeleton,” Nature, vol. 522, no. 7555, p. 212, 2015.