Quadroped Hopper, Marc Raibert

MAKE IT HOP

How do you put life in legs? Ivan's friend, Marc Raibert, decided to use springs.

"Mechanical machines have a mind of their own. If you look at a mechanism that has a spring in the leg and a mass in the body, such a spring and mass forms an oscillator. There is a sharing of responsibility for producing a motion between what the control system does and what the mechanical system does"
-Marc Raibert

At around the same time that Ivan was working on his cockroach, Marc Raibert founded the Leg Laboratory. The Leg Lab's current website cites the founding moment of the research, reproduced below.

Ivan and Marc met with Dr. Craig I. Fields, the director of DARPA, and he purportedly "salivated at the mouth" when Raibert pulled a small hopping machine out of a box. Some of the reasons cited by Raibert to develop robotic legs were mobility, an understanding of human locomotion, and expanding the accessibility of the world. The Leg Laboratory was based at Carnegie Mellon University from 1980-1986. Marc went to MIT in 1987, and started another Leg Laboratory there. At the lab they developed dynamically stable running monopods, bipeds, quadrupeds, hoppers, and more. The springs used in the legs of

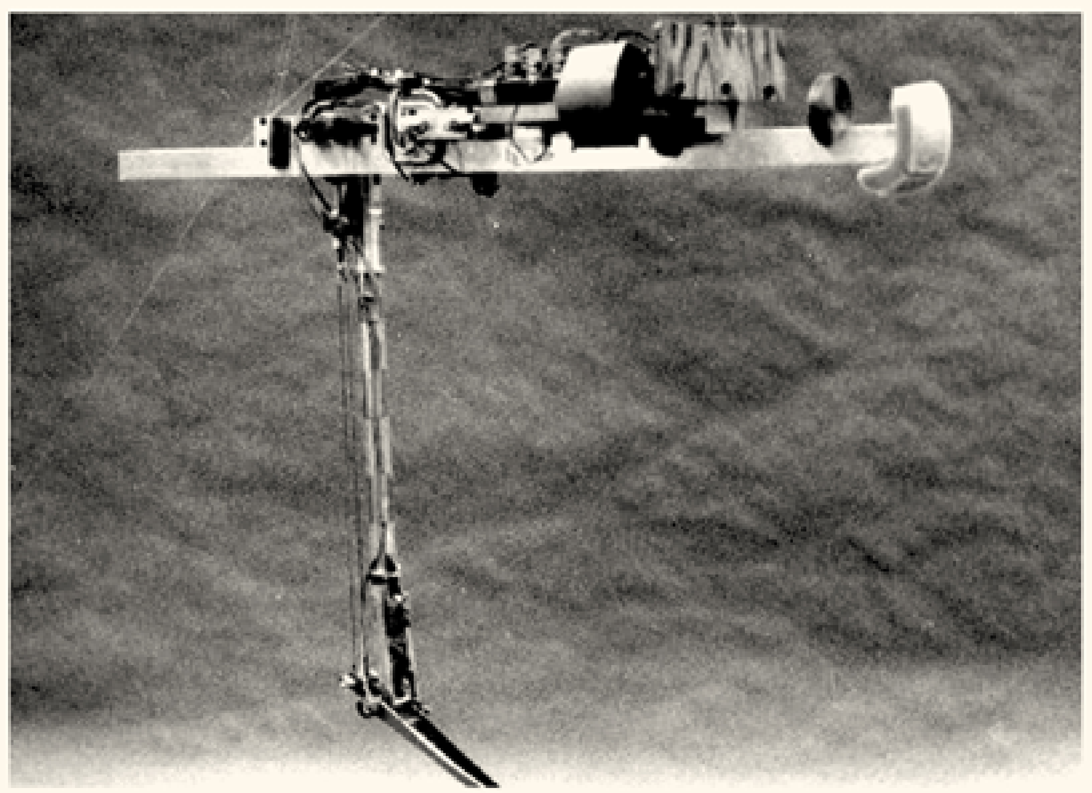
Leg Laboratory Vitrine at Posner Center

these machines allowed for a “passive rebound” during the stance phase, and they used hydraulic actuators for the thrusting motion and angle control. (Raibert 1986).

Ivan and Marc’s dream began to grow. An ad was put in the paper “looking for someone to work in a robotics lab”. Ben Brown responded, and met with Ivan and Marc for an interview. Mike Chepponis was hired, and Jessica Hodgins joined in 1983. Jeff Koechling, Karl Murphy, Eugene Hastings, and others also worked in the lab.

The team at the leg lab discovered that control could be done with a few simple algorithms, in part because the mechanical system itself was responsible for a share of the computing. They applied Ivan’s idea of the “virtual leg”. The control mechanism would coordinate groups of legs simultaneously that shared support, making them all act like a single leg.

This is a foot from one of the Leg Laboratory’s planar bipeds, featuring an internal binary foot switch used to detect ground contact. The switch was taken from dead HP calculators, and at one point, the lab ran out of calculators of the necessary model, causing panic. Also, next to the foot is one of Ben Brown’s earliest bow legged hoppers. Garth Zeglin continued this research with Ben during his time at CMU.



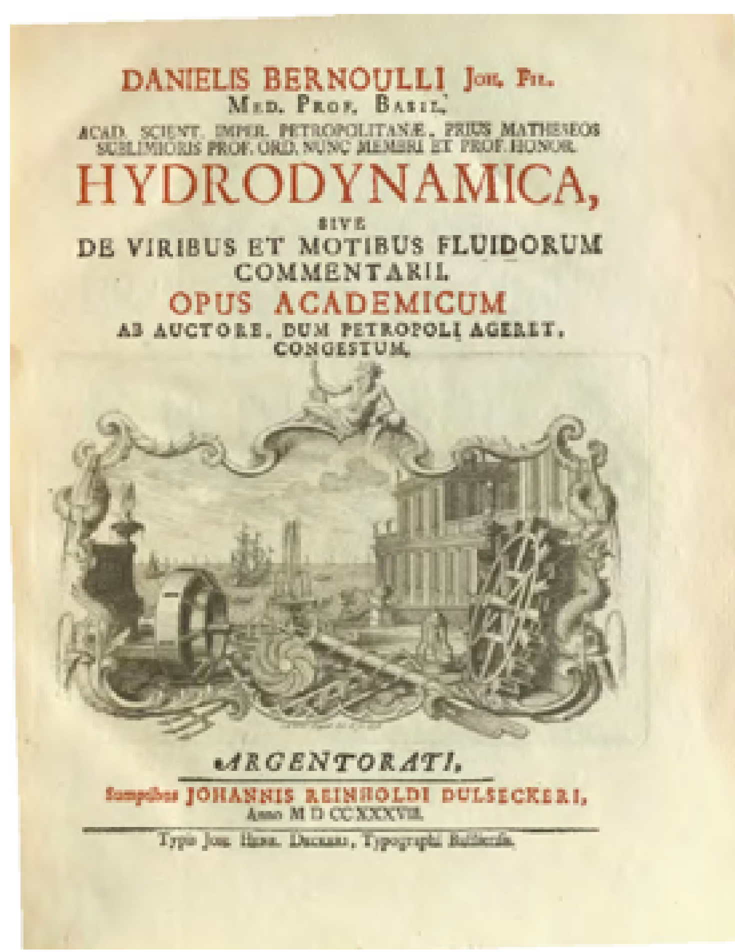
A One Legged Hopper from the Leg Laboratory

YOU WALK WITH ONE LEG AT A TIME

Studies at the Leg Lab emphasized the kinetic energy of the mass of walking machines. Raibert's lab developed actively balanced systems, which were unique in their ability to tip and maintain balance. Their designs allow for a sufficient base of support to be maintained in motion. The "polygon of support" is more free, and so these machines have increased mobility, as they can move all their legs to new footholds at a time. This takes into account the energy stored in each spring and the center of mass to deal with the potential speed and movement of the machine. The idea of active balance was central to figuring out a means of replicating animal locomotion.

RESEARCH ON ACTIVE BALANCE

Active balance as a concept has an interesting history, which goes back to the work of Claude Shannon, Ivan's advisor at MIT and the father of information theory. In 1951, Shannon used parts from an erector set to build a machine that balanced an inverted pendulum atop a small powered cart. The "Inverted Pendulum" idea used here proved crucial to understanding balance in legged systems. It is also crucial for launching rockets such as the Saturn V that went to the moon. Rockets are balanced on their thrusters in the same way an inverted pendulum is balanced on a cart.



DANIELIS BERNOULLI Joh. Fil.
Med. Prof. Basil.
ACAD. SCIENT. IMPER. PETROPOLITANÆ, PRIUS MATHESEOS SUBLIMIORIS PROF. ORD. NUNC MEMBRI ET PROF. HONOR.
HYDRODYNAMICA,
SIVE
DE VIRIBUS ET MOTIBUS FLUIDORUM COMMENTARII.
OPUS ACADEMICUM
AB AUCTORE, DUM PETROPOLI AGERET, CONGESTUM.

ARGENTORATI,
Sumptibus JOHANNIS REINHOLDI DULSECKERI,
Anno M D CC XXXVIII.
Typis Joh. Henr. Deckeri, Typographi Basiliensis.

Front page from Daniel Bernouilli's Hyrdronamica

BREATHING

Daniel Bernoulli wrote his doctoral dissertation on breathing.

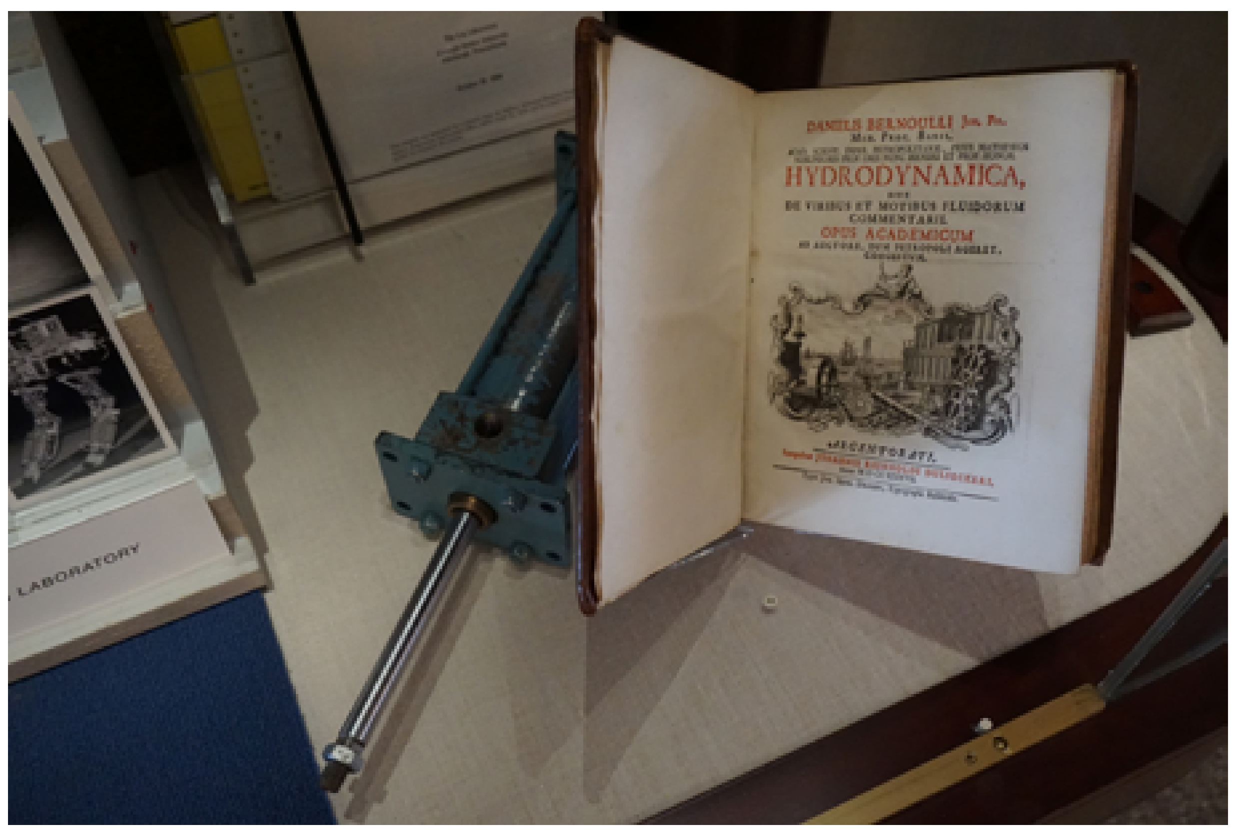
Born in 1700 to a family of mathematicians, Daniel's father, Johann Bernoulli, was one of the early developers of calculus.

Bernoulli's study of anatomy and medicine led him to be inspired by William Harvey's On the Movement of Heat and Blood in Animals, which stated that "The heart is like a pump which forces blood to flow like a fluid through the arteries".

This metaphor between the mechanical and the natural inspired much of Daniel's work in the rules of fluid movement. Daniel designed an hour glass that would work while at sea. The trickle of sand remained constant even when the ship was turbulent. He designed it while ill in Venice when he was 23.

Daniel punctured the wall of a horizontal pipe with an open ended straw. The height to which the fluid rose was noted as an outcome of the fluid's pressure in the pipe. Soon, doctors throughout Europe began sticking pointed glass tubes directly into patients veins to measure blood pressure. For 170 years, this was how blood pressure was measured. Daniel realized kinetic energy in a fluid is exchanged for pressure. This is now how we measure the speed of air as it passes a plane.

Daniel's most important work was written in St Petersburg,



Hydronamica next to a hydraulic cylnder from the Trojan Cockroach

Hydronamica. Hydronamica is the first correct analysis of water flowing from a hole in a container.

This was based on an application of the the Law of Conservation of Energy. In this work, Daniel developed the idea of potential energy. Bernoulli's equation is a foundational element of physics, fluid mechanics, and aeronautical science. Daniel developed theories that led to the development of watermills, windmills, water pumps and water propellers.

THE HYDRAULIC SYSTEM

The principles Daniel Bernoulli developed led to the innovations necessary for modern hydraulic equipment, a fundamental power source for many walking robots.

The hydraulic system of the Trojan Cockroach or any other walking machine can be thought of as a machines internal infrastructure, where the valves and hydraulics are the muscles, and the central hydraulic pump is the heart.

A metaphor to use for understanding hydraulics is to think of oil flow as current and pressure as voltage

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PUMPS

The pumps used in the Trojan Cockroach's hydraulic systems are used for flow and not for pressure. As the shaft turns the