BIPEDAL ROBOTS

(original presentation by Tony Belpaeme and Séverin Lemaignan)

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INTRODUCTION

- fails at the DARPA challenge in 2015

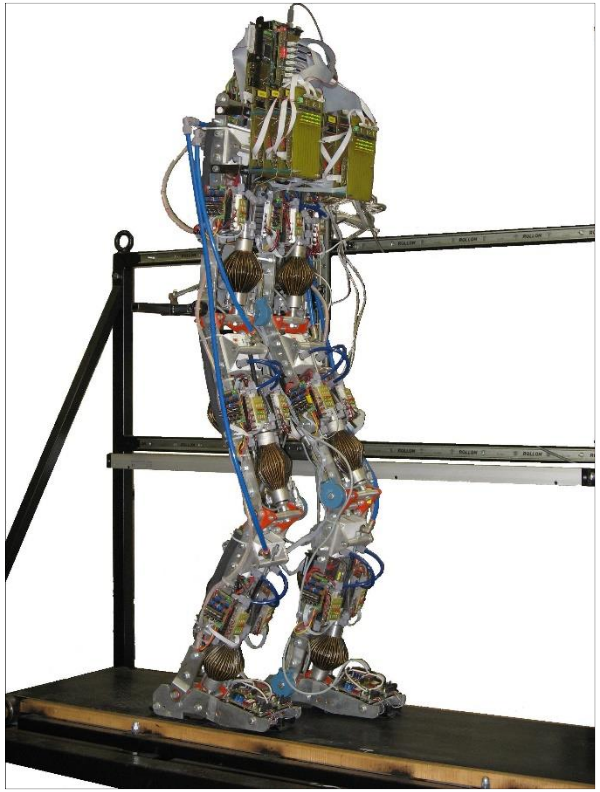
  https://www.youtube.com/watch?v=g0TaYhjpOfo

WHY WALKING ROBOTS?

- mobility
  - wheeled robots only function on prepared surfaces (roads, rails, …)
  - legged robots can negotiate difficult terrain, which wheeled robots cannot reach
- understanding
  - understanding animal legged motion

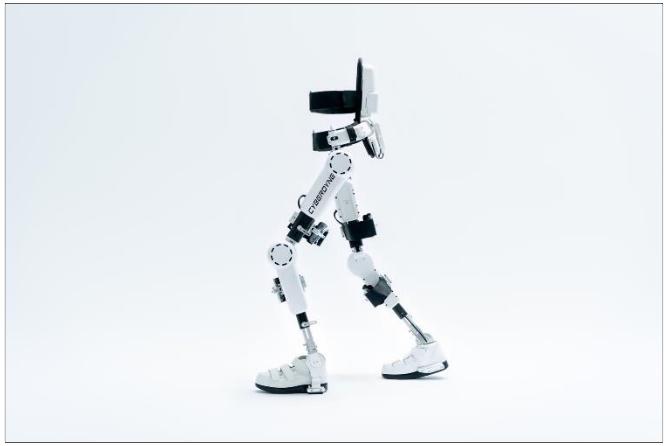
WHY BIPEDAL WALKING?

- because humanoid robots only have two legs
  - better mobility over rough terrain
  - active suspension that stabilizes the load
  - overcoming obstacles, i.e. avoiding or moving over or under obstacles
- humans relate to humanoid robots much more readily
- lower hardware complexity



WHY BIPEDAL WALKING? (2)

- as a tool for understanding human gait disorders
- active prosthetics
  - Hugh Herr's prosthetic legs
- exoskeletons
  - Cyberdyne HAL
- the human environment has been adapted profoundly to bipedal locomotion
- *just because it's cool!*

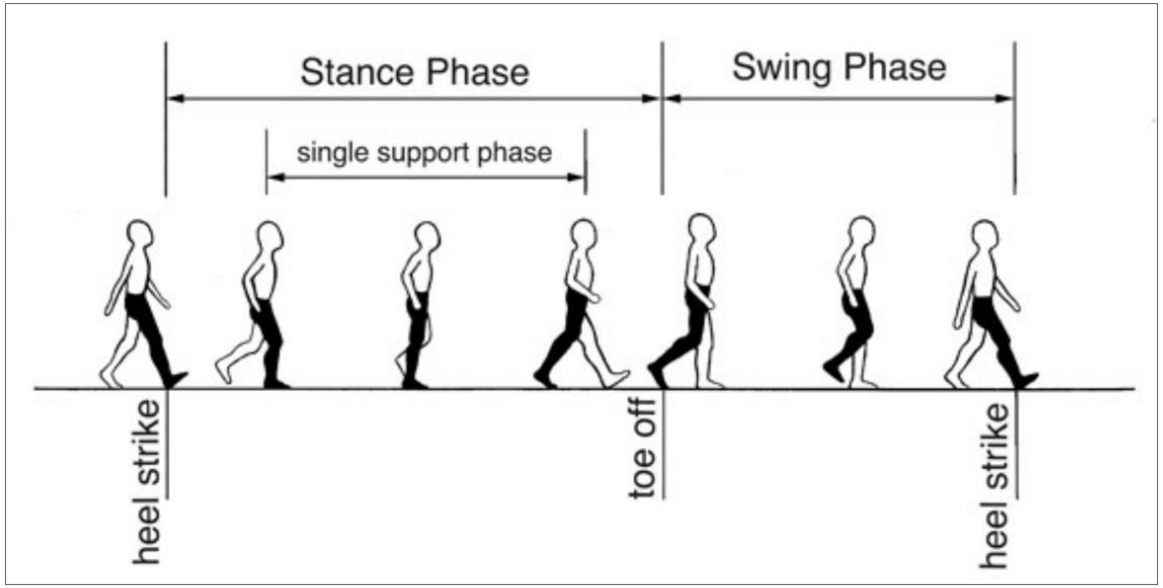


WHAT IS BIPEDAL WALKING?

- a ***gait cycle*** starts with an initial contact of the foot with the ground, and ends at the next contact of the same foot with the ground.
- ***walking:*** the two feet are simultaneously in contact with the ground at some point during the gait cycle.
- ***running:*** one foot at maximum touches the ground at any point in the gait cycle.

WHAT IS BIPEDAL WALKING? (2)

- two phases to a gait cycle:
  - ***stance phase*** – when the foot is in contact with the ground (also called ***support phase***);
  - ***swing phase*** – when the foot is lifted of the ground



ACTIVE VS PASSIVE WALK

- an active walk is when the robot is internally powered. This is usually through electrical servos, pneumatics or hydraulics
- versatile
- continuous high bandwidth control
- fully actuated, resulting in high energy consumption
- e.g. BigDog, Honda Asimo (2), Bioloid, …

ACTIVE VS PASSIVE WALK (2)

- a passive walk is when a robot is not internally powered. This is usually driven by an initial push or through gravity (downhill)
- fixed walking sped, no starting, stopping or turning
- no actuation
- no control
- very low energy consumption
- Passive walker example, University of Tsukuba

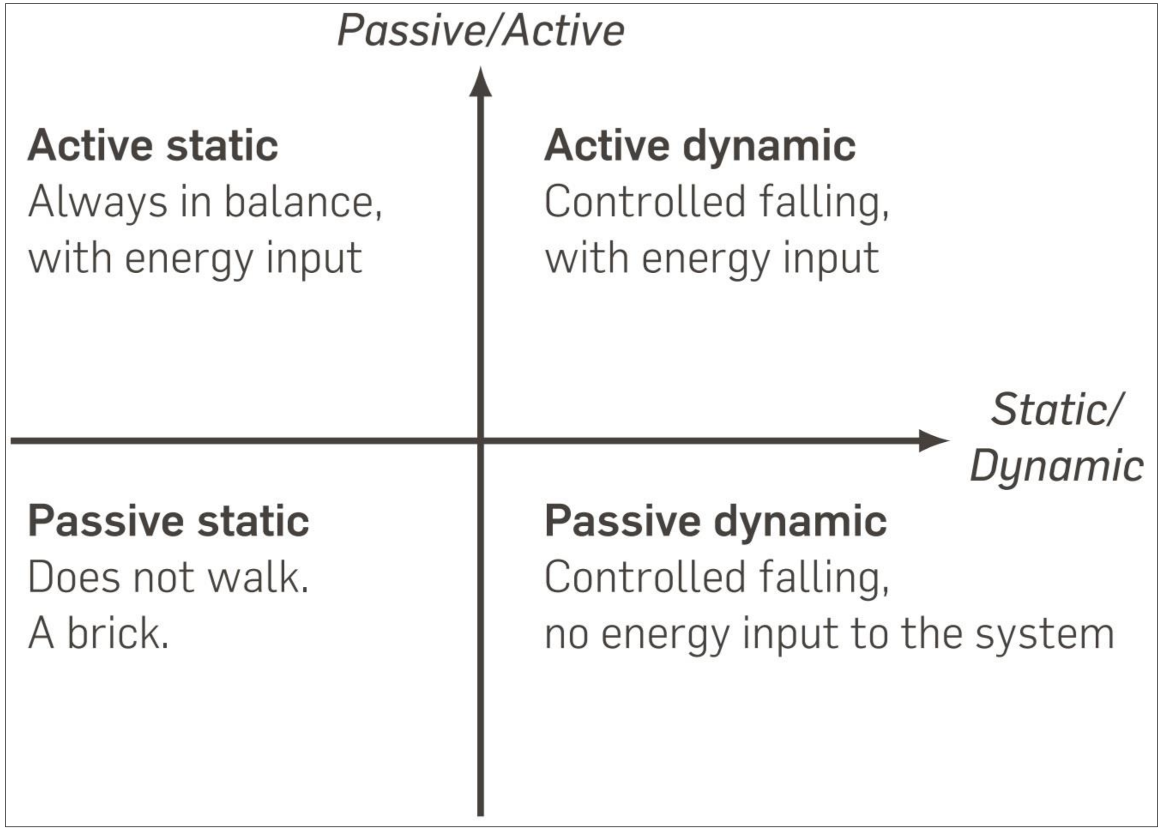
STATIC VS DYNAMIC WALK

- static walk
  - a static walk is when the robot is ***always balanced***. If the robot was to stop at any point in the gait cycle then it would not fall over
  - control is easy
  - movements are slow
  - NAO (crazy NAO), LittleDog

STATIC VS DYNAMIC WALK (2)

- dynamic walk
  - a dynamic walk when the robot is ***not always balanced***. If the robot was to stop at any point in the gait cycle then it would fall over. ***Controlled "falling"***.
  - control is hard
  - fast(er) motion
  - Honda Asimo, Cornell walkers, Delft walkers, Schaft robot

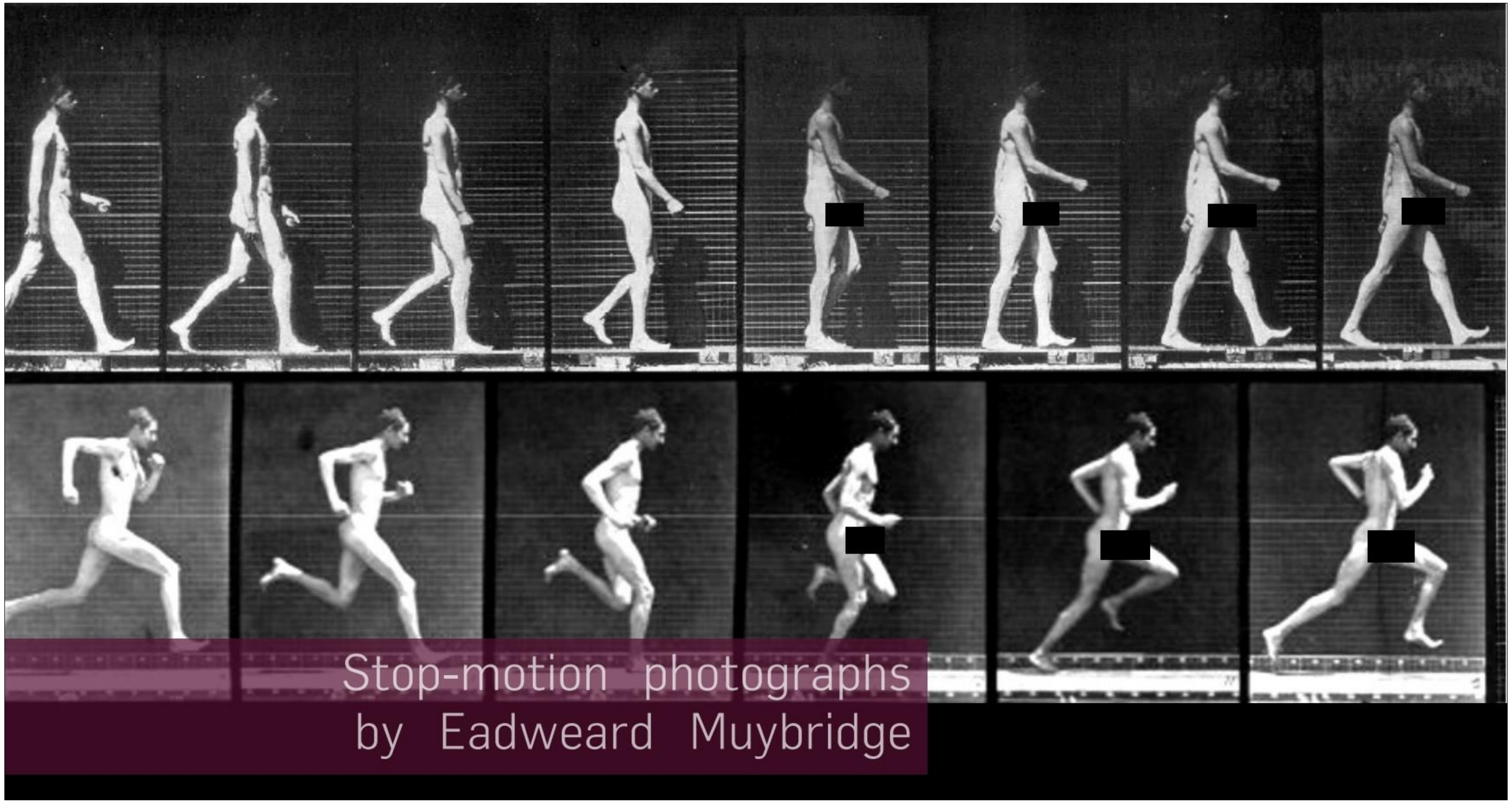
ROBOT WALK TYPOLOGY - SUMMARY



HOW DO PEOPLE WALK?

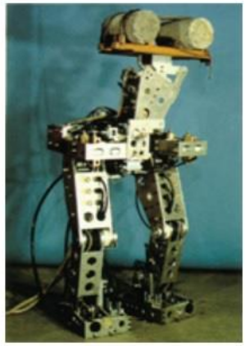
- human perspective
  - humans use a mixture of active/passive and static/dynamic walking
  - walking requires generating energy (active) but the energy is also conserved where possible (passive)
  - humans can balance (static) although this requires more energy therefore they use an efficient unbalanced gait (dynamic)
- robot perspective
  - most robot research has focused on either an active static gait, an active dynamic gait or a passive dynamic gait

HOW DO PEOPLE WALK?



SPEED OF ROBOTS

Walking person ±*5km/h*



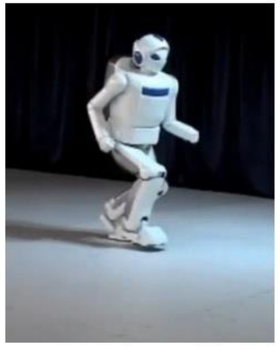
WL-5 ('70) *45s/step*

E2 ('91) *1.2km/h*

Nao *1.6km/h*

Asimo *6km/h*

Atlas robot *7km/h*

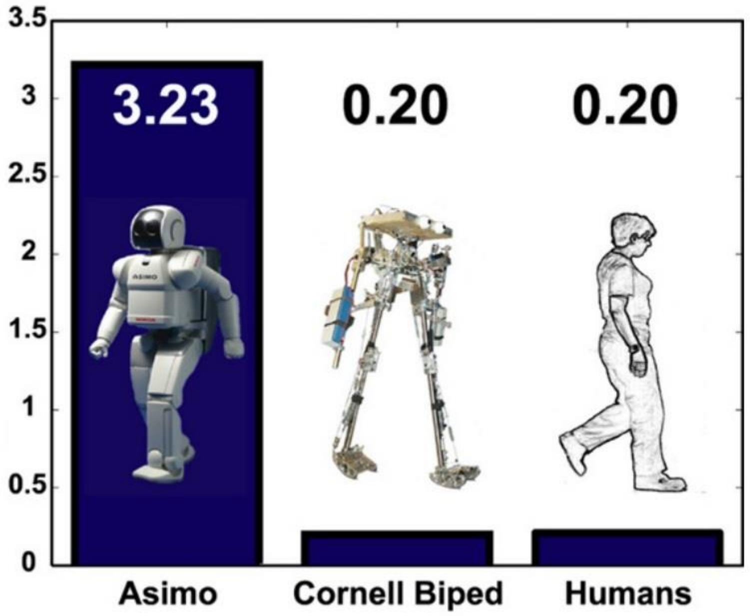


Partner *7km/h*

SPEED OF HUMANS

ENERGY CONSUMPTION: COST OF TRANSPORT

- $COT = \frac{E}{m*g*d}$
- energy E to move a system of mass m over a distance d

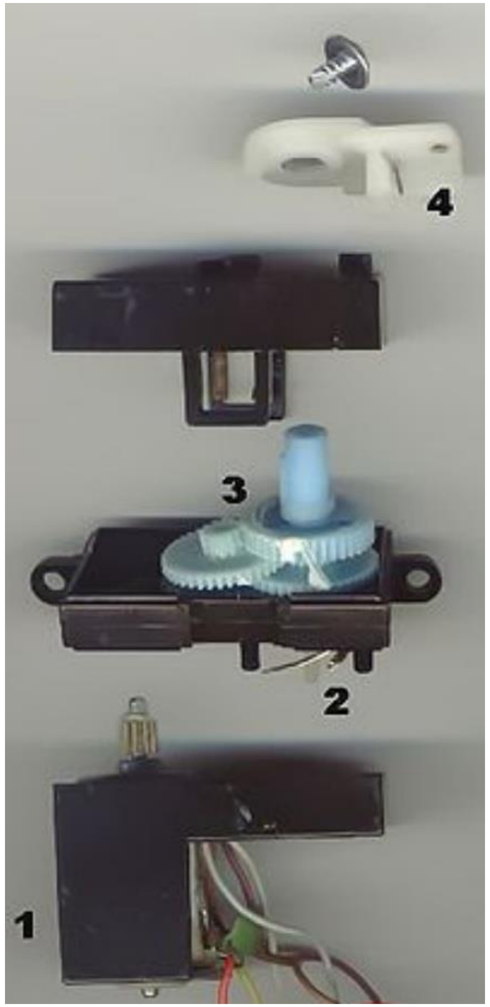


ACTUATION

- hydraulics
  - pressurized liquid
  - BigDog, Petman, Atlas
- pneumatics
  - air powered: high energy, powerful
- DC motors
  - can be combined with spring to have compliant motors
  - iCub
- servo motors
  - DC motors with gears and positioning electronics

WHAT IS A SERVO MOTOR?

- a servo motor is a combination of a DC motor, gearing and a position measurement
- position measurement is used for negative feedback to decrease error between current position and demanded position



WHY SERVO MOTORS?

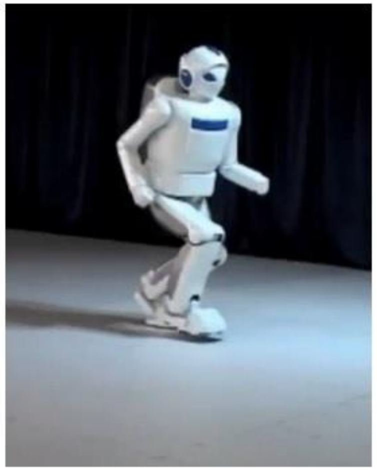
- a large percentage of humanoid robots use servo motors
  - traditional method of powering a robot. The vast majority of industrial robots use motors to control their movement
  - large knowledge base for servo motor control
  - can be scaled for larger or smaller robots
  - powered by electricity via a fixed or portable power supply
  - accurate control of position
  - large range of movement
  - good power to weight ratio
  - good speed characteristics
  - cost effective solution

HUMANOIDS AND SERVOS

- from industrial robots to humanoid robots
  - many of the first humanoid robots were developed from existing technology used in industrial robots
  - car manufacturers use large numbers of industrial robots and were amongst the first companies to invest heavily in the development of new technologies to produce a humanoid robot

HUMANOIDS AND SERVOS (2)

- examples of humanoid robots using servo motors
  - Honda Asimo
  - Toyota humanoid
  - NAO
  - Bioloid
  - Team Osaka football player


SERVO-BASED HUMANOIDS

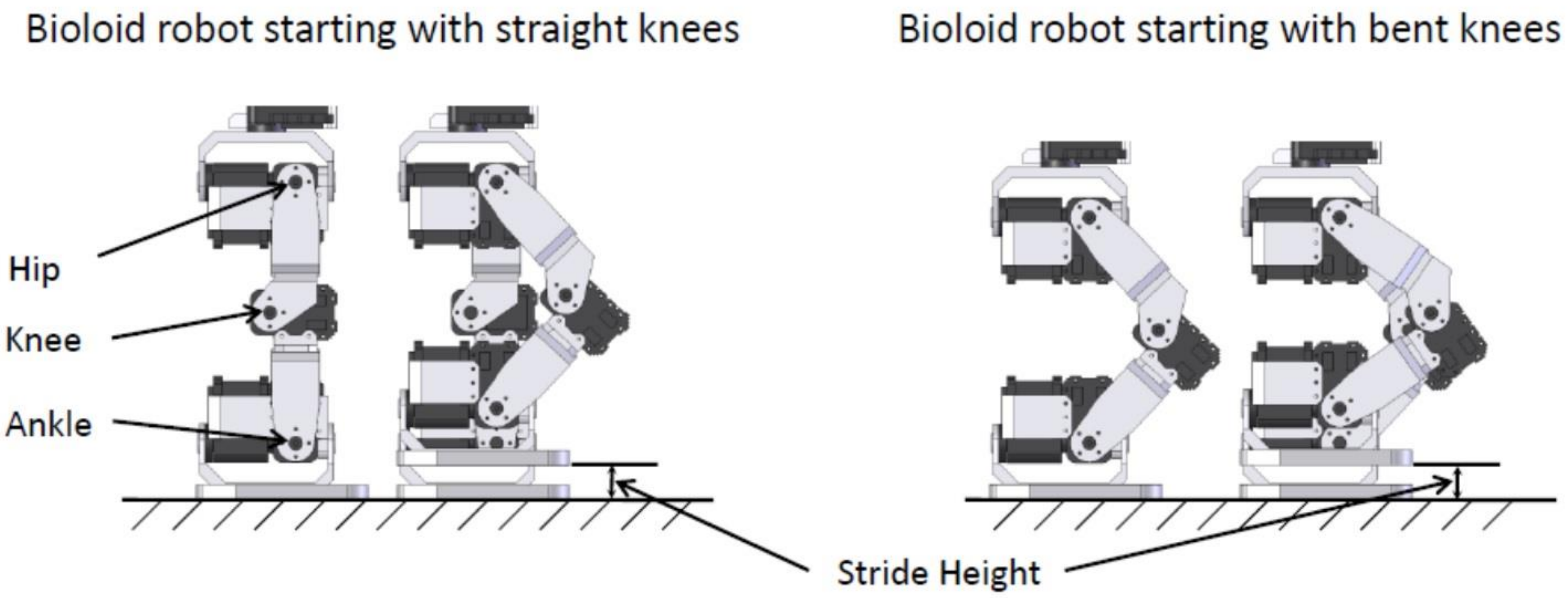
- what do servo powered humanoid robots have in common?
  - they never straighten their legs!
  - most servo powered robots either walk or run with their legs slightly bent
  - produces a non-human like gait
  - same for either statically or dynamically balanced robots
  - results from the physical restrictions of using servo motors

BIOLOID GAIT ANALYSIS

- manufactured by Robotis in South Korea
- has 18 degrees of Freedom (=motors)
- designed to be reconfigured into different forms
- robust
- easy to assemble
- 40 cm tall
- weighs 1.7 kg

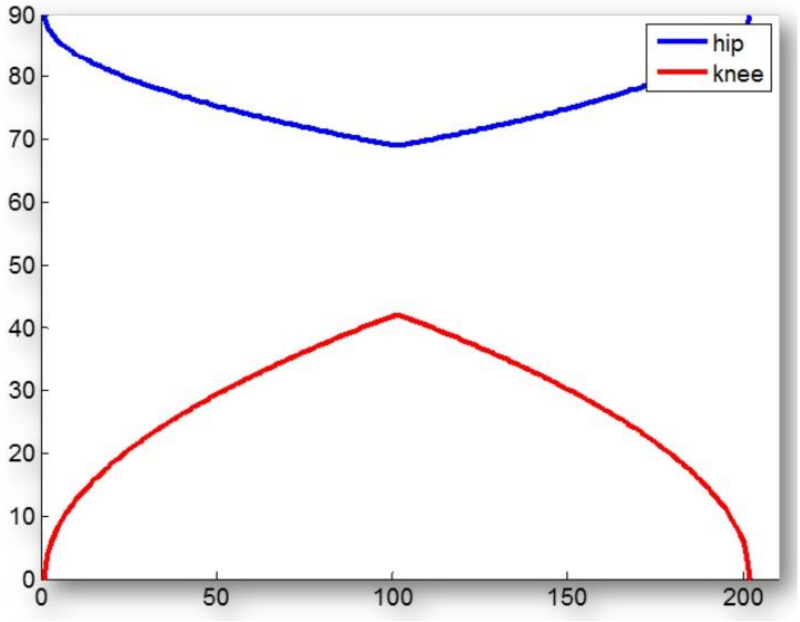
BIOLOID GAIT ANALYSIS (2)

- starting with slightly bent knees means the knee servo motor is used more effectively resulting in the foot being lifted a greater distance and in a more controlled manner

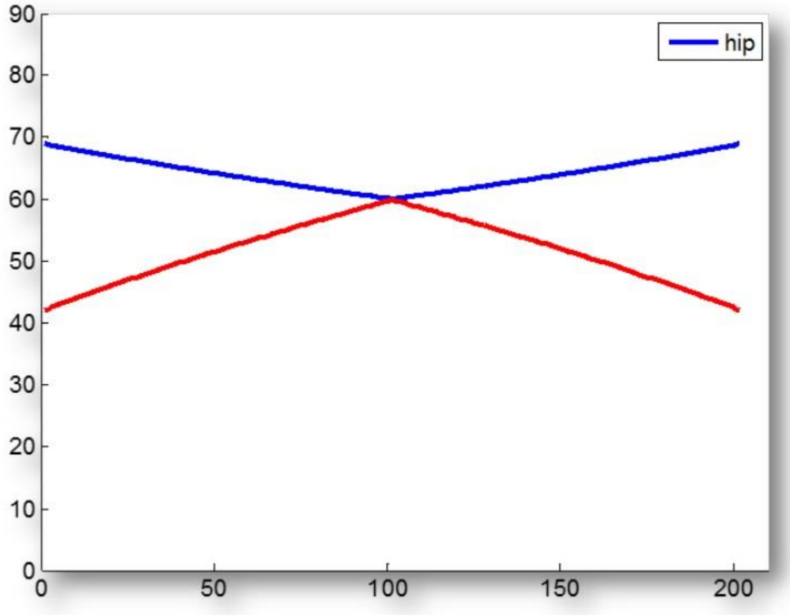


EFFORT TO LIFT FOOT 1CM?

- ***stretched leg***
- hip moves 21.0°, knee moves 42°



- ***bent knees***
- hip moves 8.9°, knee moves 17.8°

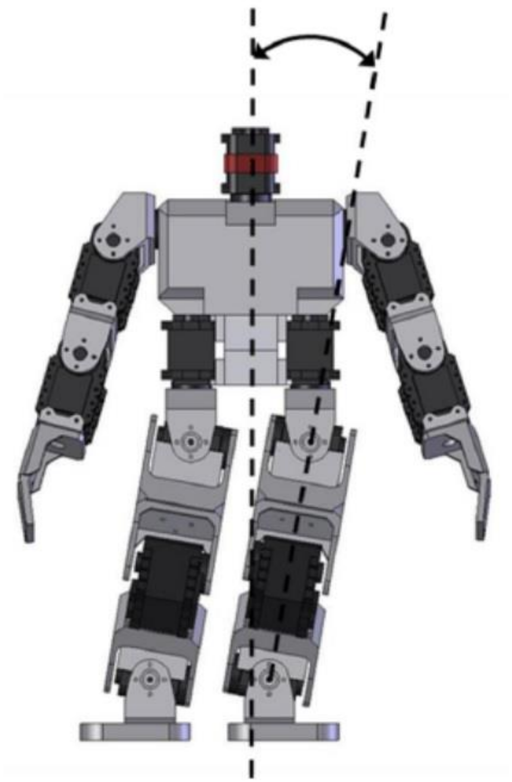


BIOLOID DYNAMIC GAIT GENERATOR

- there is also a Bioloid dynamic gait generator, which takes the following parameters to generate a series of robot poses

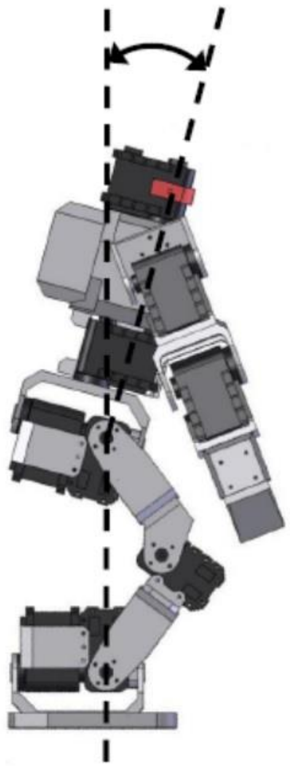
BIOLOID DYNAMIC GAIT GENERATOR

- swing – hip movement (sideways)



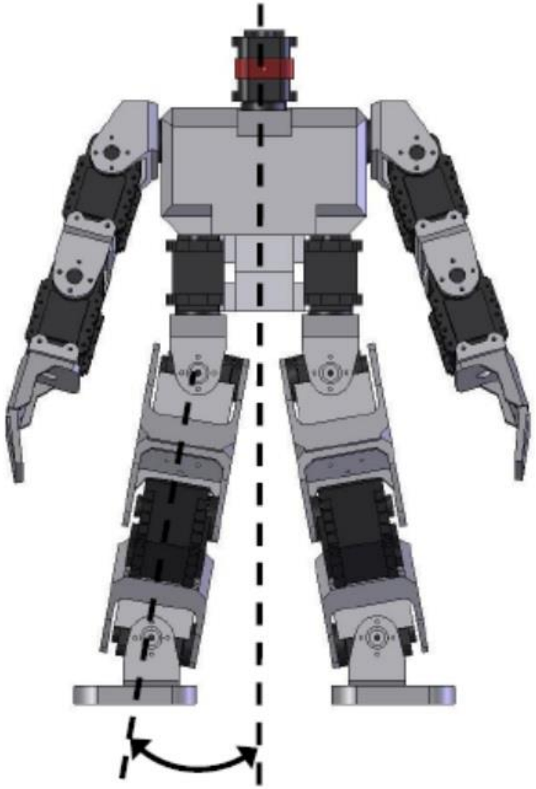
BIOLOID DYNAMIC GAIT GENERATOR

- tilt – hip (used to balance the robot)



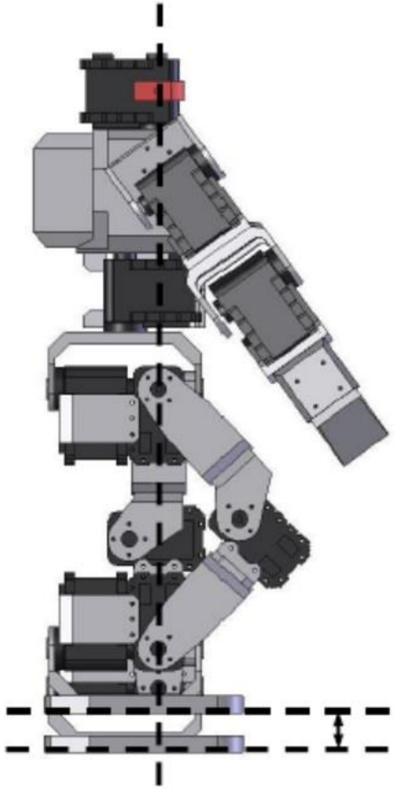
BIOLOID DYNAMIC GAIT GENERATOR

- camber (splaying legs)



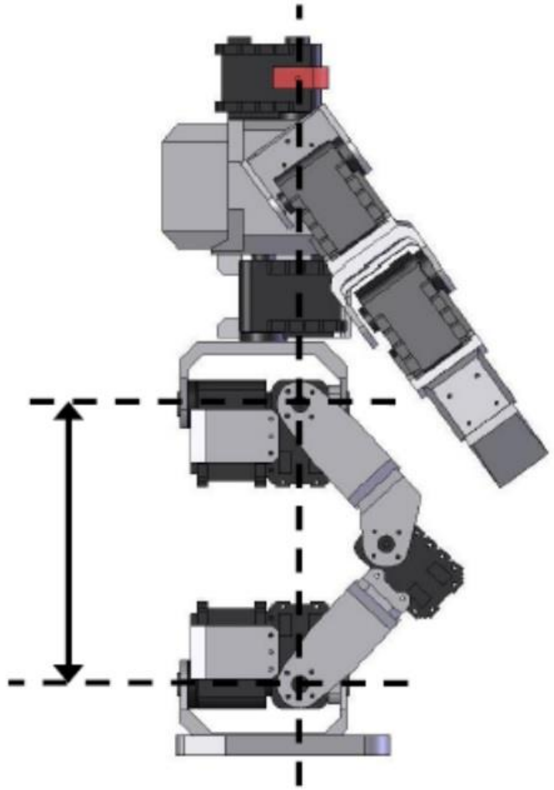
BIOLOID DYNAMIC GAIT GENERATOR

- stride height (foot lift)



BIOLOID DYNAMIC GAIT GENERATOR

- y-offset (starting position for knees)

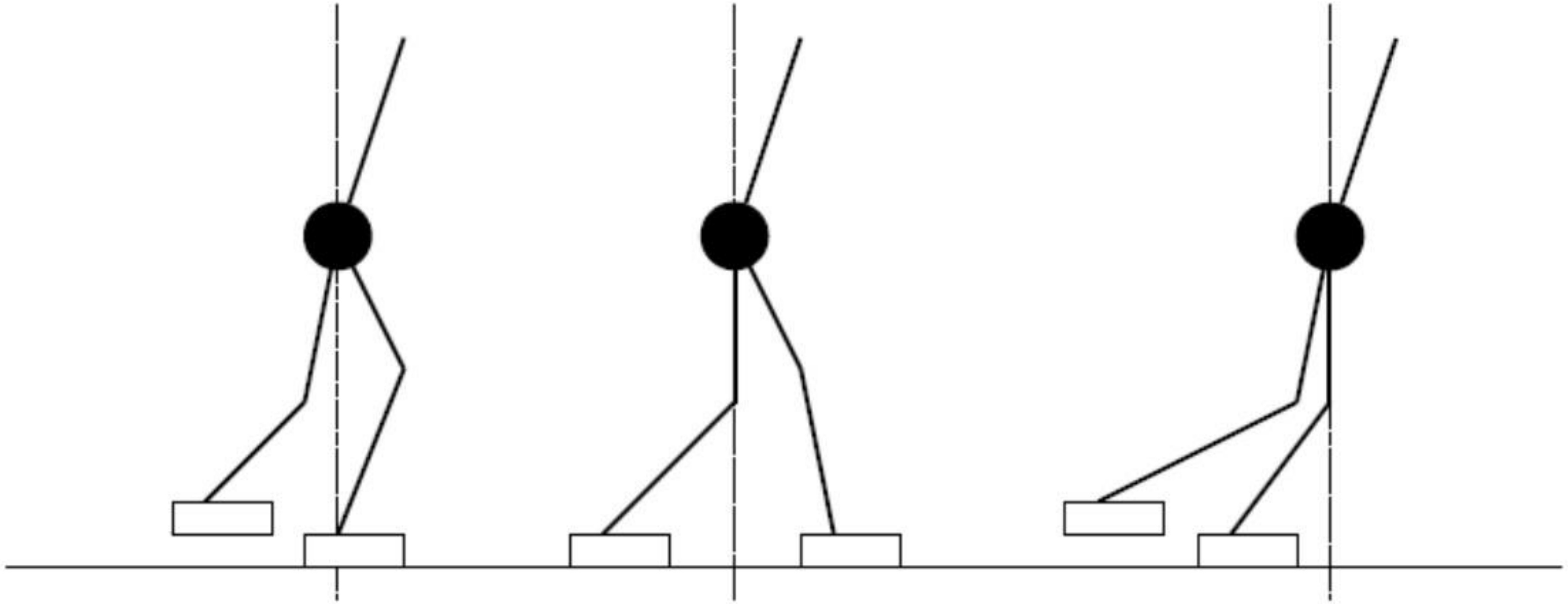


SUPPORT POLYGON

- the ***support polygon*** is a horizontal region over which the center of mass must lie to achieve static stability
- for example, for an object resting on a horizontal surface (e.g. a table), the support polygon is the ***convex hull of its "footprint"*** on the table
- for bipedal robots, the support polygon is ***the convex hull of the contact points with the ground***
  - might be a single foot!
  - changes over time

STATIC WALKING

- based on keeping ***Centre of Gravity over the support polygon***

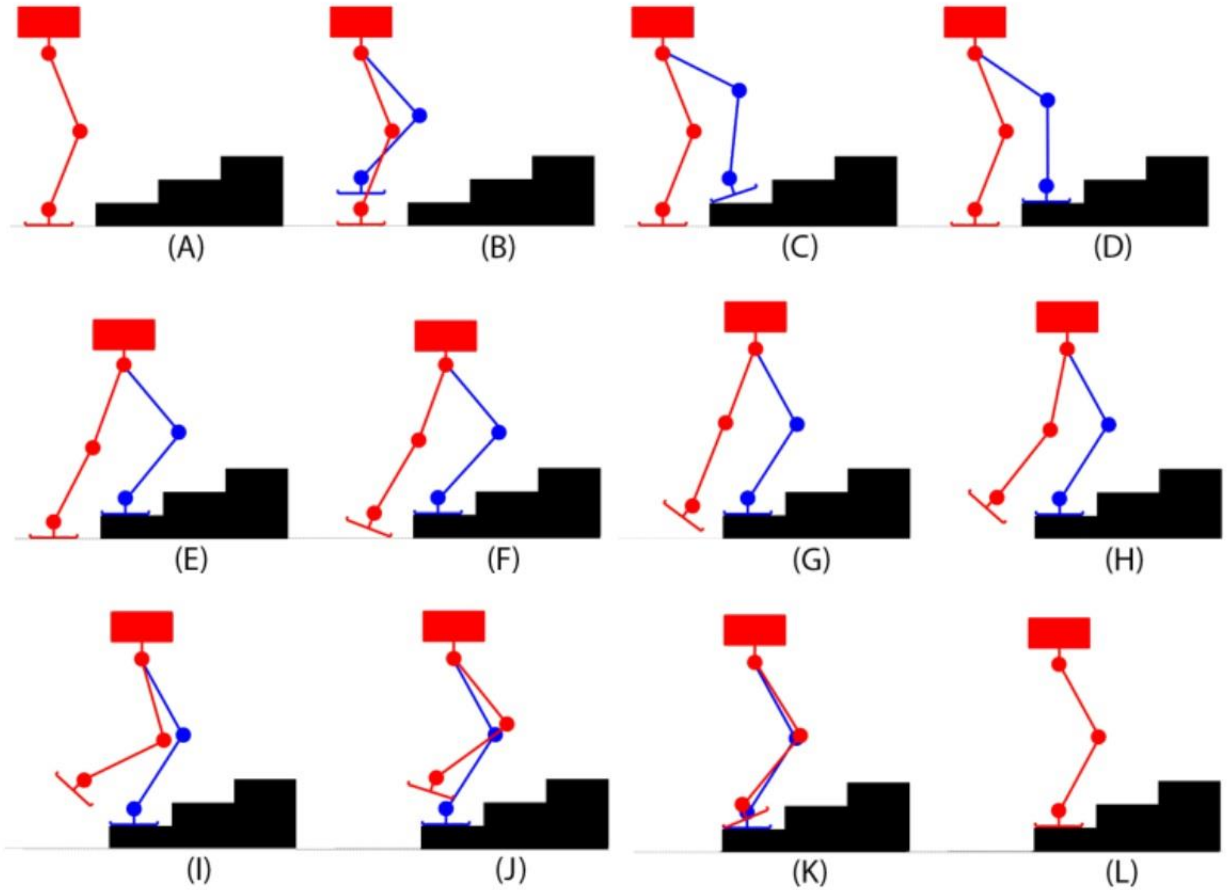


Single support phase
Stable position

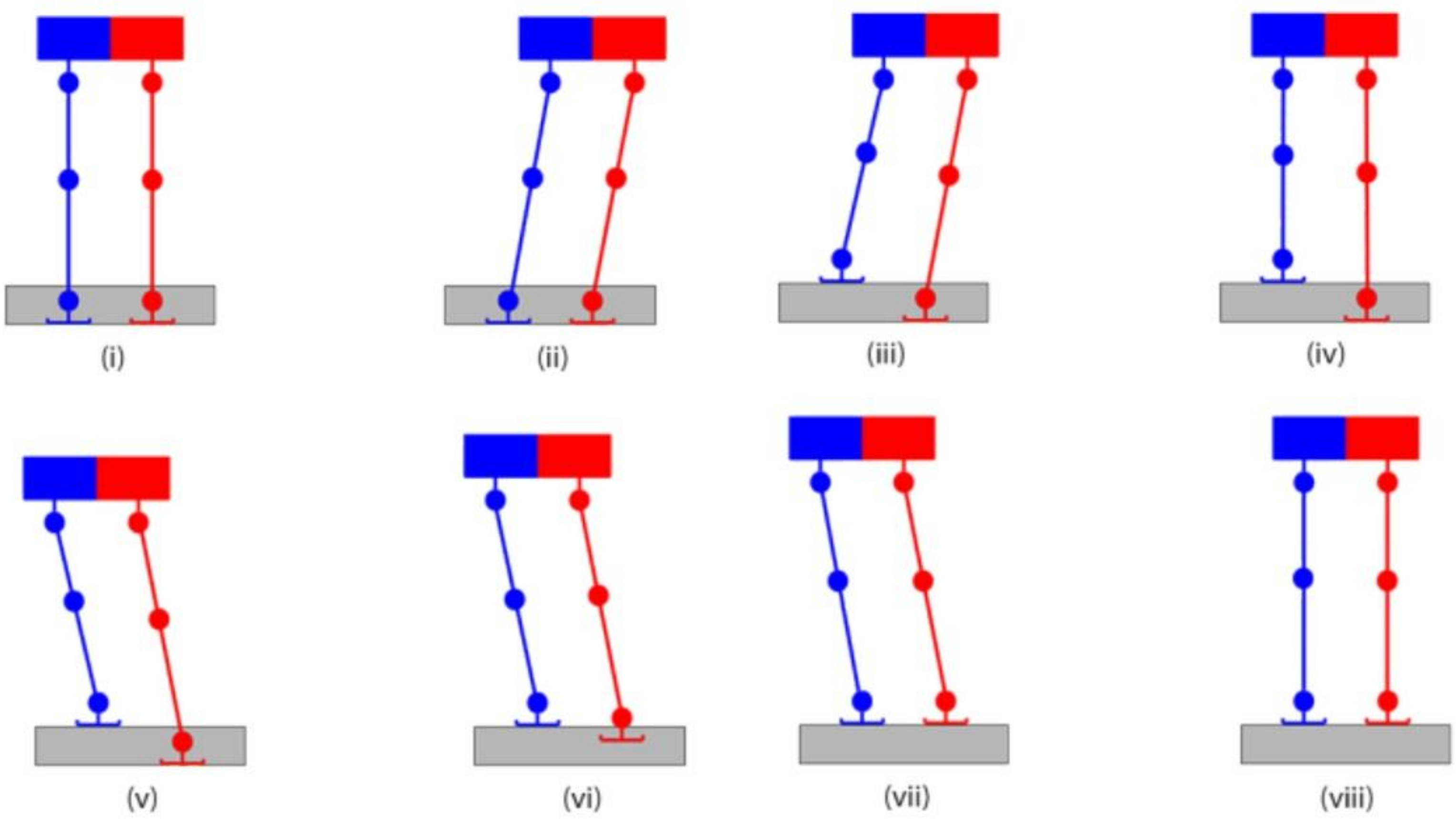
Double support phase
Stable position

Unstable position

STATIC WALKING

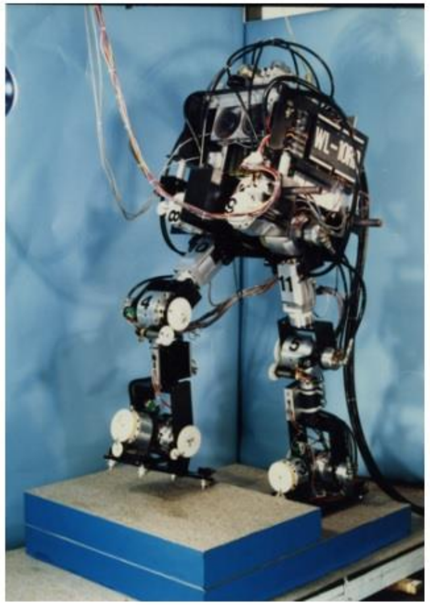


STATIC WALKING



DYNAMIC WALKING

- based on keeping ***<u>Zero Moment Point over the support polygon</u>***

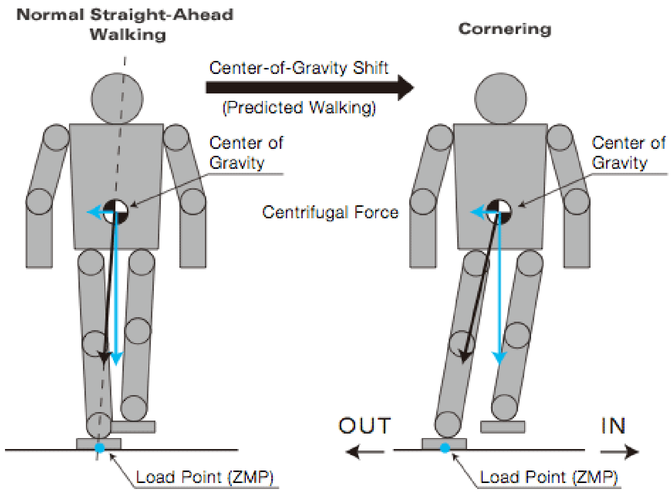


WL-10RD. First dynamic walker using the ZMP scheme (1985).

Honda Asimo, uses ZMP scheme for walking as deduced from papers and patents (2000-).

ZERO MOMENT POINT

- the point where the total of horizontal inertia and gravity forces equals 0 (zero).
- The concept assumes the contact area is planar and has sufficiently high friction to keep the feet from sliding



REQUIREMENTS OF ZMP BIPEDS

- the fundamental requirements for ZMP-based walking
  - at least six fully actuated joints for each leg: hip (3), knee (1), foot (2)
  - joint are position controlled
  - feet are equipped with force sensors, used to measure ZMP

ZMP - THE PROBLEM

- in theory, it works. In practice, it doesn’t always.
- requires a precise knowledge of where the center of gravity is, what the forces are acting on the point of contact, and what the rate of angular momentum of the robot is.

WHY IS WALKING HARD FOR ROBOTS?

- number of possible gaits is enormous
  - finding a gait that works (a “robust” gait) is hard
  - one set of parameter settings will typically work for only one type of surface under one set of conditions
  - example: genetic algorithms to find the right parameters

WHY IS WALKING HARD FOR ROBOTS?

- ***floor reaction control is very hard***: human feet senses and changes to the structure of the surface. Robots don't yet.
- ***sensing for walking challenging***: gyroscopes, accelerometers, cameras, … we don't yet understand how to use their readings to make robust gaits
- ***power requirements are high***