

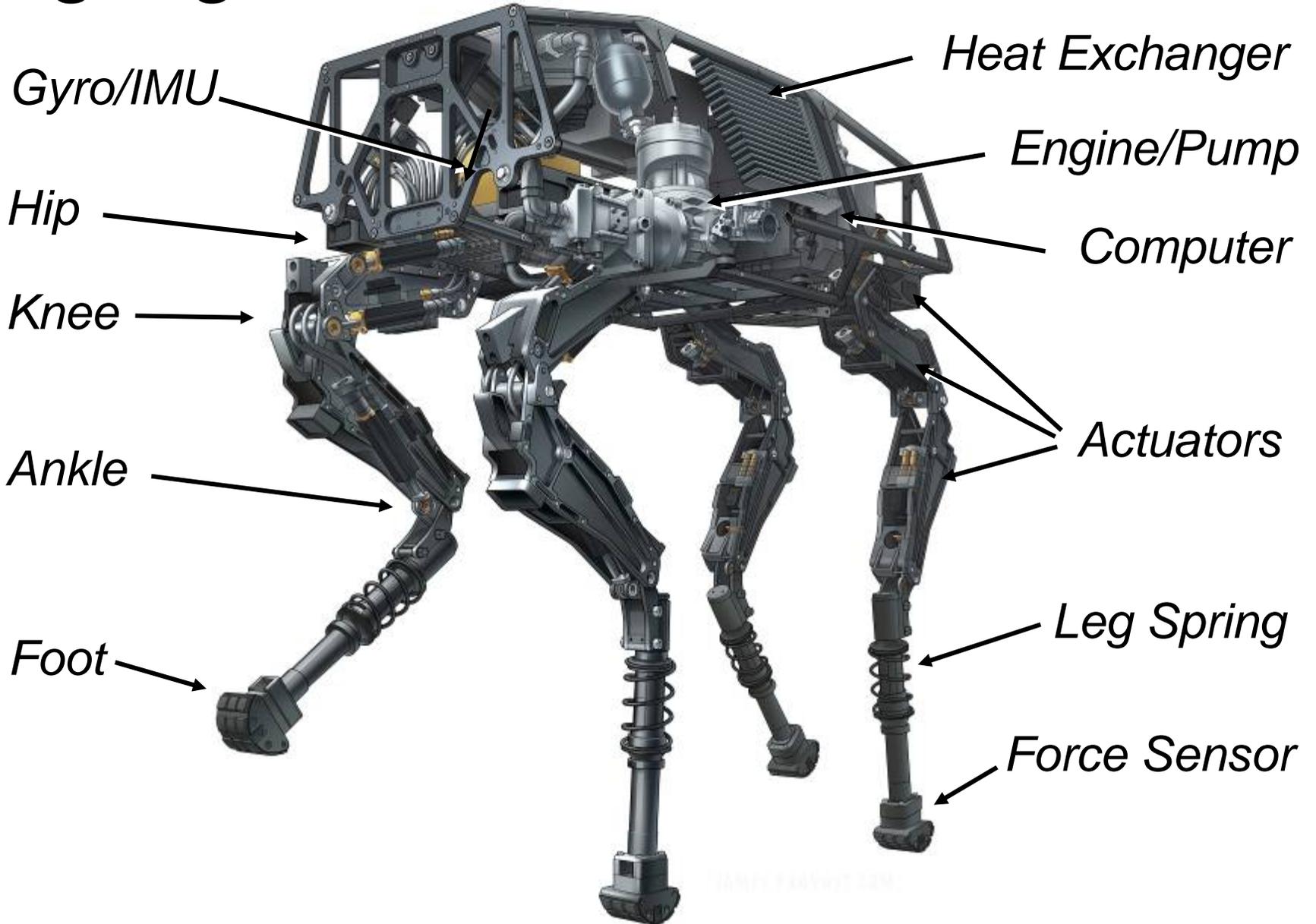


BigDog Overview

November 22, 2008



BigDog Architecture



Engine

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- Leopard go-kart engine
- One cylinder
- Two stroke
- Water cooled
- 9,000 rpm
- ~15 hp
- Electric starter



Hydraulic System

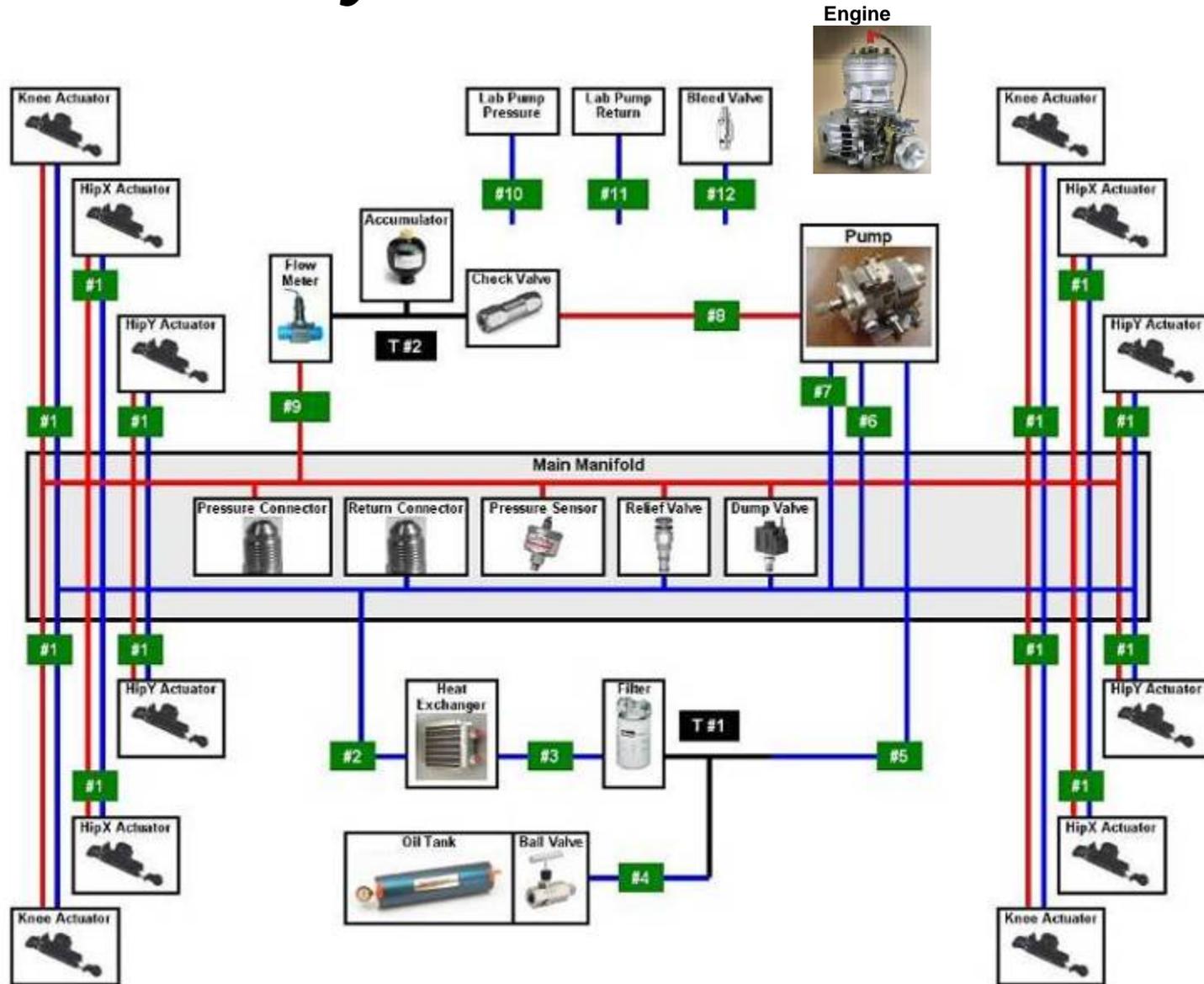
- Variable displacement hydraulic pump (3,000 psi)
- Custom actuator package (x16)
 - Low-friction hydrodynamic seals
 - 2-stage electro-hydraulic servovalve
 - Position sensor
 - Force sensor
- Heat exchanger
- Various filters, manifolds, accumulators, and valves

Hydraulic Actuator Package



Hydraulic System

Boston Dynamics



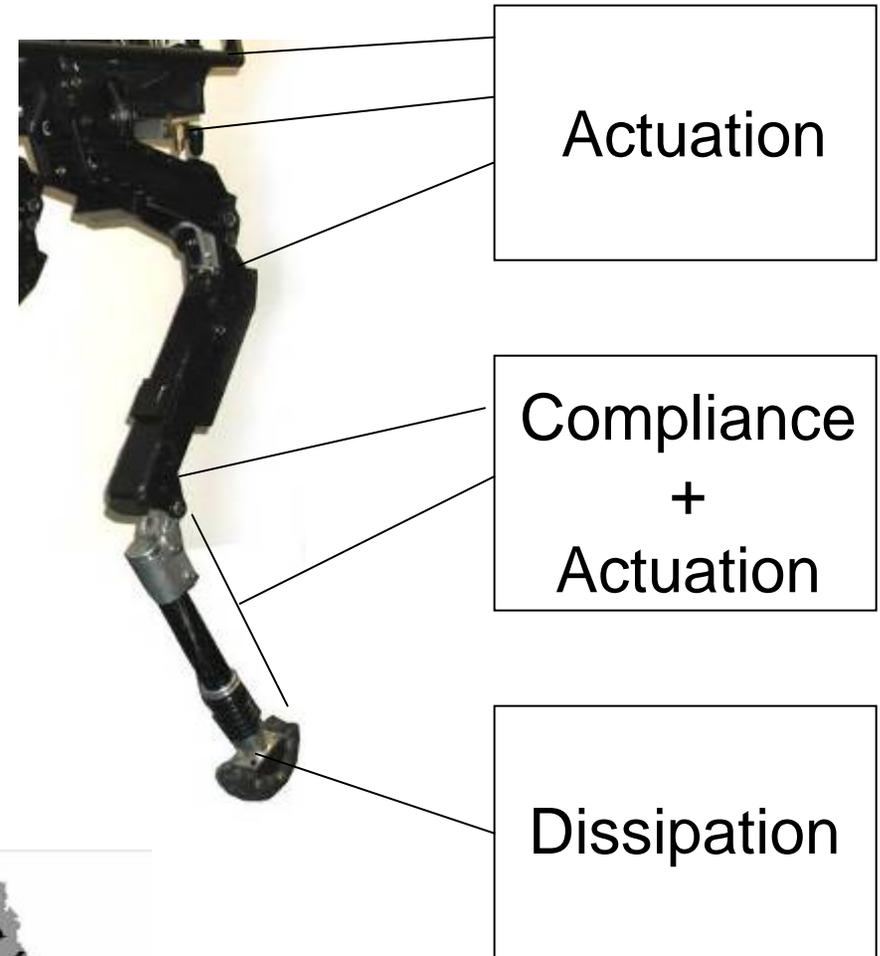
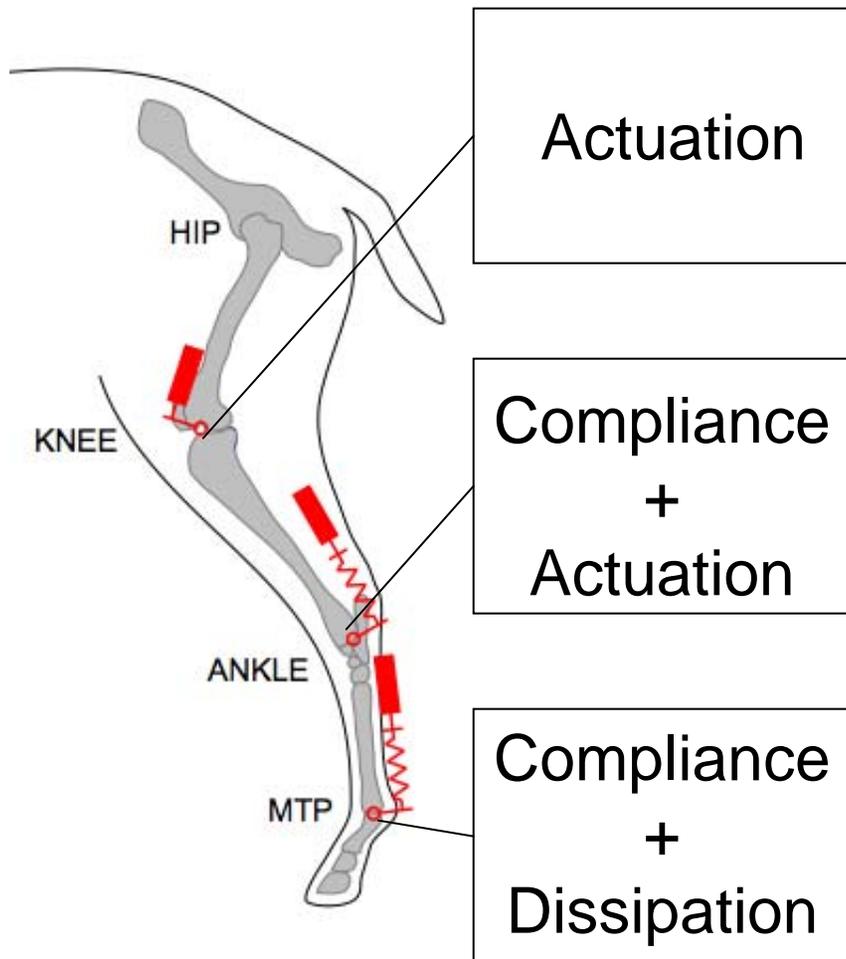
Multi-jointed Legs

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Animal

BigDog

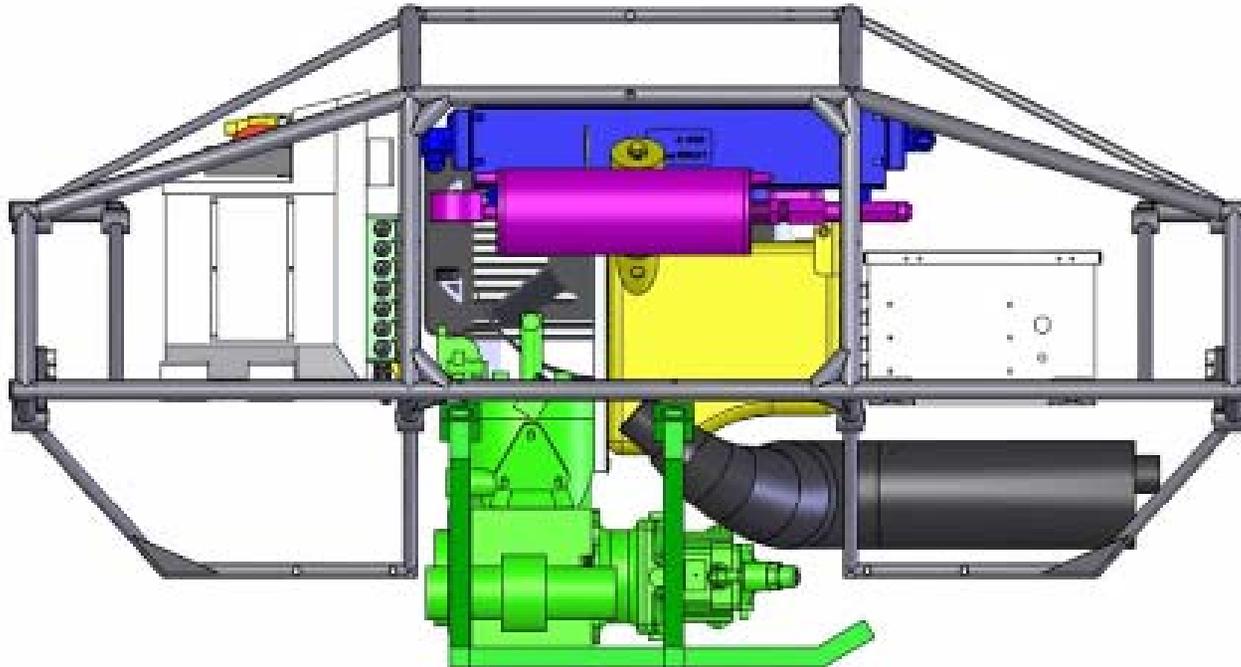


Less actuation
More compliance



Component Layout

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Component

Heat Exchanger

Engine / Drive / Pump:

Fuel tank / Fuel:

Oil tank:

Weight

9.62 lbs

26 lbs / 1.42 lbs / 6.5 lbs

2.1 lbs / 10.4 lbs

3.6 lbs

Sensors

GPS

Battery Voltage

Ring Laser
Gyro & Linear
Accelerometers

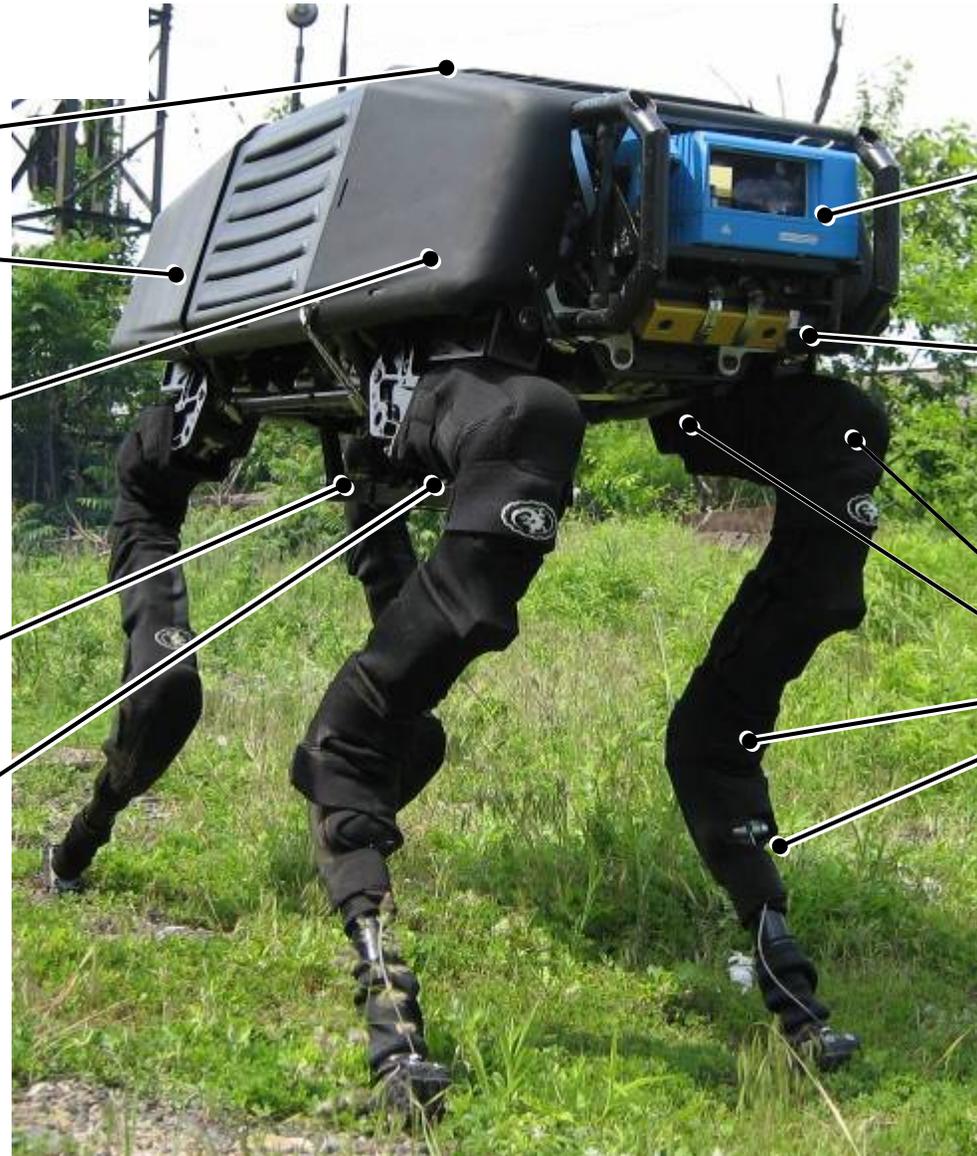
Engine Temp
& Speed

Hydraulic
Pressure, Flow
& Temp

LIDAR

Stereo Vision

Joint angles
& forces



BigDog Sensors

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Type	Measurement Quantity	Location	N
Linear Pot	Joint displacements	Knee, Hip (2), Ankle	16
Load Cell	Actuator, ankle force	Legs	16
Current Sensor	Servo valve current	eBox	16
Stereo Vision	Obstacles, Optic Flow Ground Slope	Body	3
LIDAR	Human Tracking	Body	1
Gyro	3 angular rates 3 linear accelerations	Body	6
Temperature	Engine, Oil temperature	Body	3
Flow	Oil flow	Body	4
Pressure	Oil pressure	Body	2
Governor	Engine RPM Battery voltage	Body	2
Total			69

Proprioception

Exteroception

Homeostasis

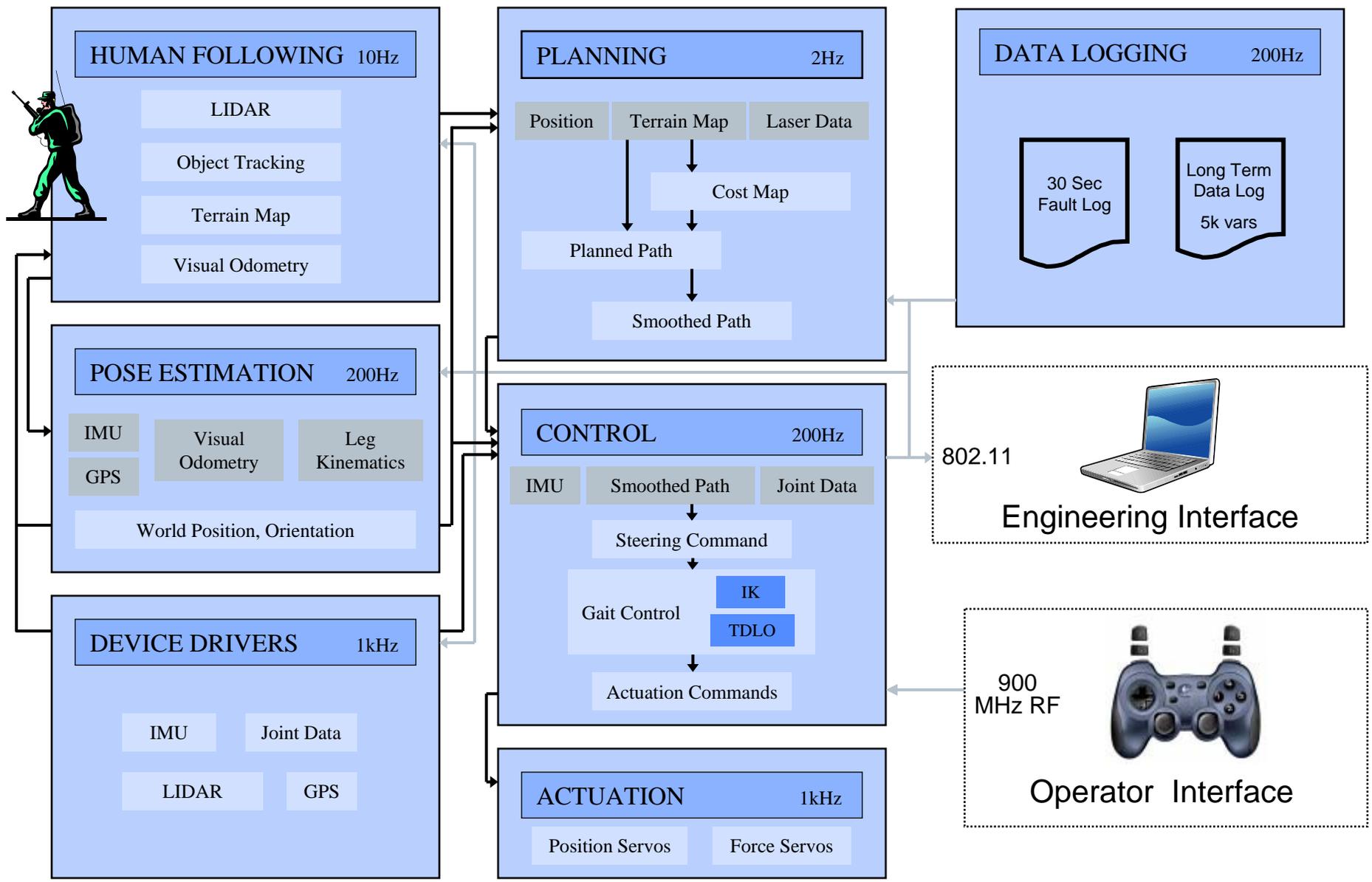


Onboard Computer

- PC104 stack
- Pentium CPU
- QNX real-time OS
- Code: C++
- Custom I/O interface boards
- Functions Performed:
 - Control
 - Sensing
 - Data Collection
 - Communications
 - Electric Power Distribution



Software Architecture



Software Processes

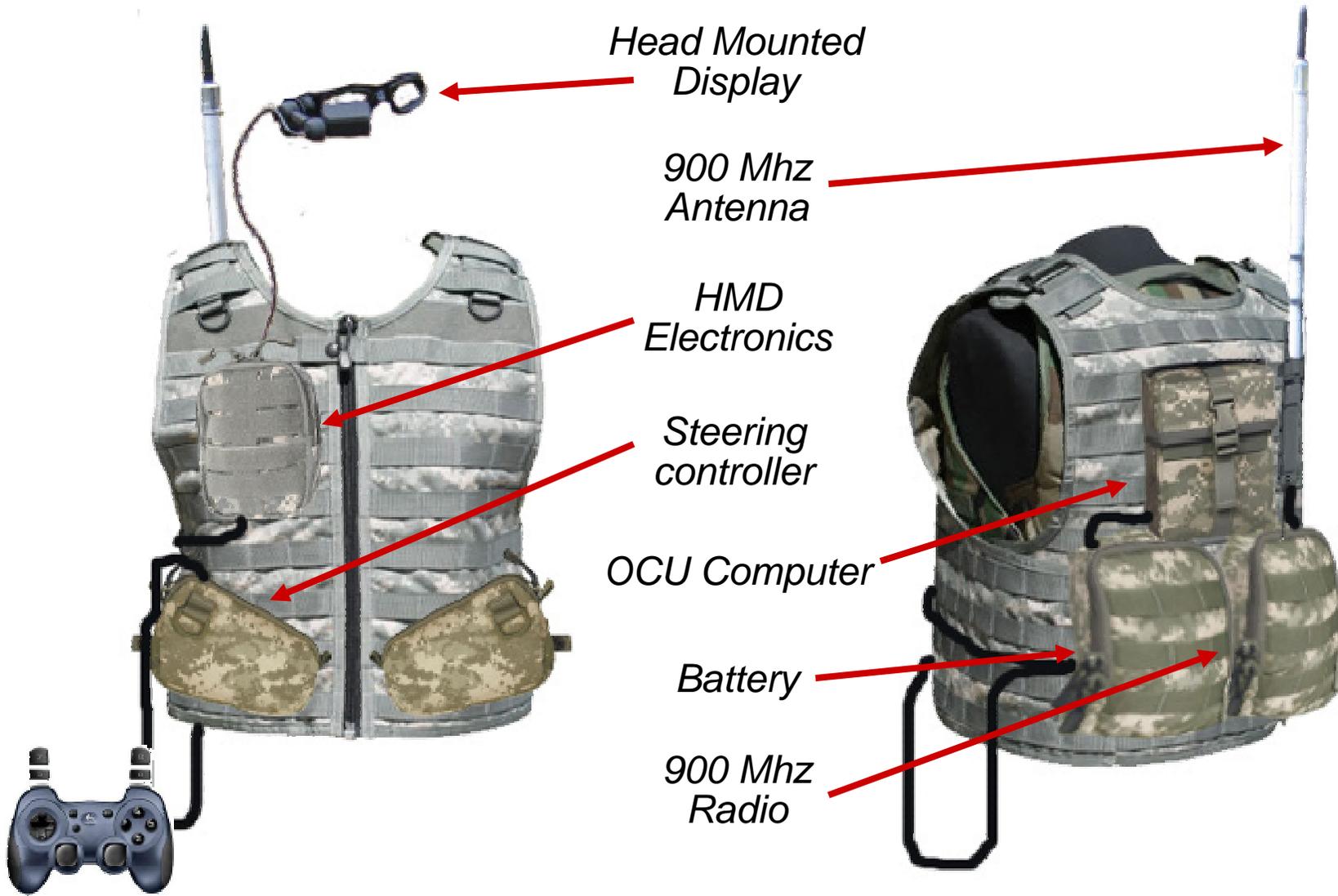
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Function:	Control	Servo	Logging
Description:	Main process. Balances and steers robot, odometry, communicates with operator.	Joint control, read sensors, command actuators, engine control.	Log engineering data for performance development and failure analysis.
Update Frequency:	200 Hz	1,000 Hz	200 Hz

Vest Operator Control Unit (OCU)

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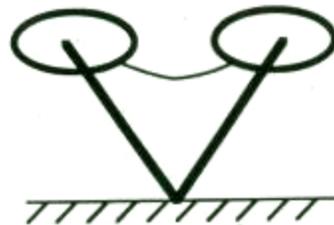


Control Principles

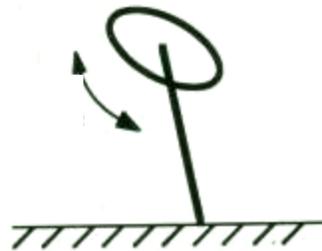
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Support - Bounce on springy legs



Balance - Move legs with symmetry to achieve balance



Posture - Keep body level using stance legs

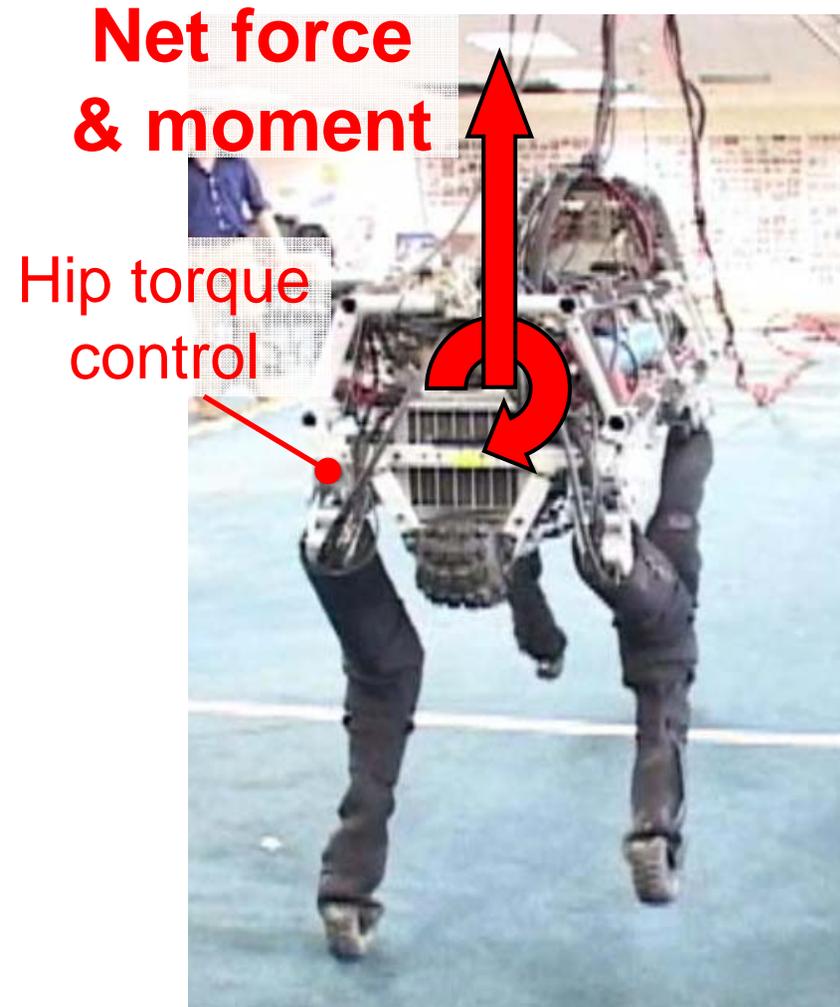
Control – BigDog

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Maintain Body Posture

- Control of body posture through force control



Control – BigDog

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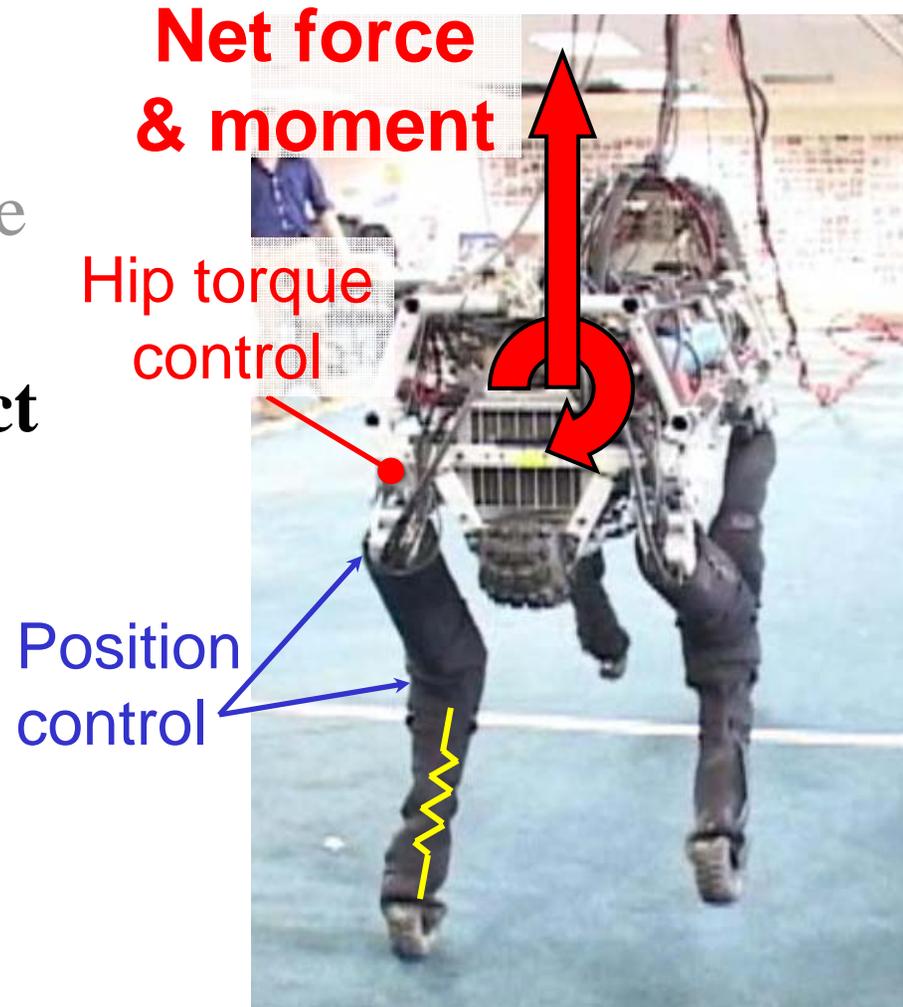


Maintain Body Posture

- Control of body posture through force control

Maintain Ground Contact

- Force control through compliant leg shock



Control – BigDog

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Maintain Body Posture

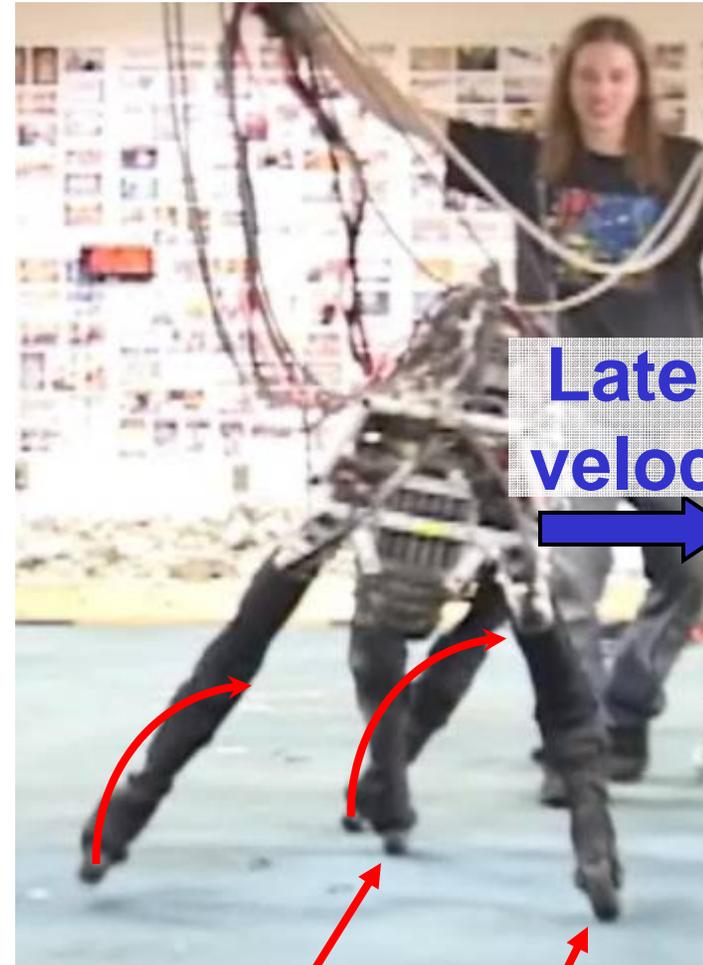
- Control of body posture through force control

Maintain Ground Contact

- Force control through compliant leg shock

Maintain Lateral Balance

- Place feet to control body lateral velocity
Stance leg motion provides lateral veloc. and angle for swing leg placement





Additional Controls

- *Estimate ground plane using history of leg kinematic data and odometry*
- *Adjust posture to optimize leg strength while maintaining reach on terrain*
- *Use traction control to avoid, detect and recover from foot slips*
- *Move legs to avoid leg collisions*
- *Determine ego-motion using kinematic, inertial and visual odometry*

Trot Control Features

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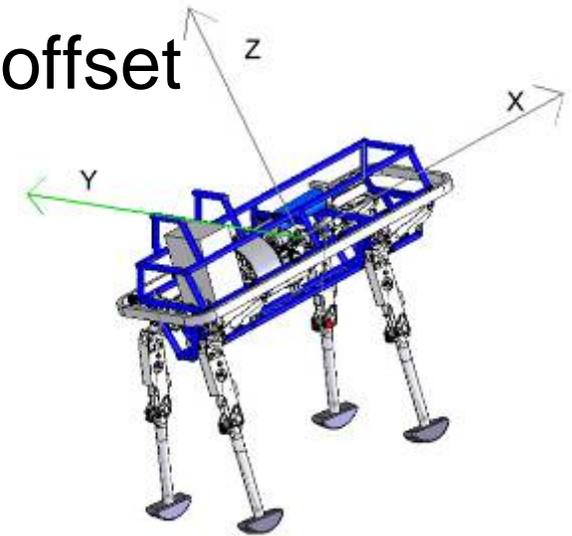


- Engine Power Control.
 - Engine RPM regulated in response to actual and predicted load.
 - Ground steepness, ground roughness, and lateral body velocity predict demand.
- Leg Collision Avoidance.
 - Adjacent legs have overlapping workspace.
 - Swing leg trajectories avoid hitting adjacent stance legs.



Trot Control

- **X** – Closed loop. Speed error corrected by x direction foot forces.
- **Y** – Lateral foot position chosen to offset unwanted lateral body velocity.



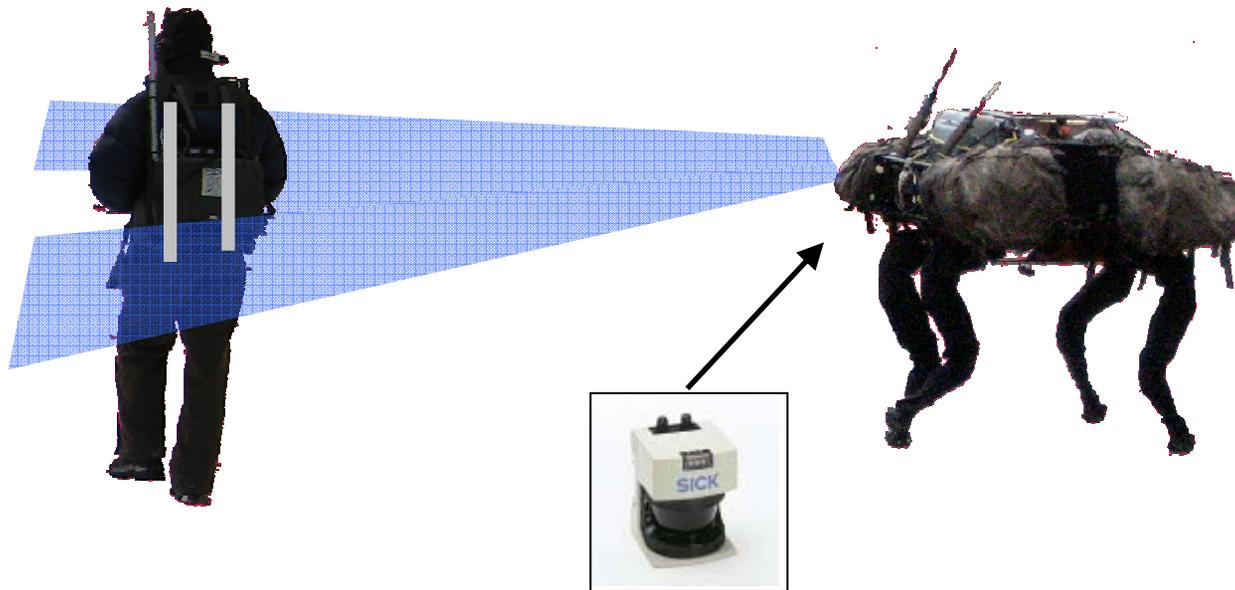
- **Z**
 - **Roll**
 - **Pitch**
 - **Yaw**
- Coupled Controller.
Corrections for height and Euler errors map to y and z direction foot forces.

LIDAR Leader Tracking

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- Follow leader without direct driving and without GPS:
 - Leader wears retro-reflective marker
 - SICK LIDAR used to locate leader and generate steering signals
 - BigDog follows at approximate fixed distance



End

