Welcome to
2.12 Introduction to Robotics

Objectives

- Reinforce the study of 2.004 and 2.003 materials
  - ***Kinematics and dynamics*** of multi-rigid body systems in the light of computer control
  - Application of the classical ***control theory*** to robotics problems
- Gain practical knowledge about control components and software
  - Actuators and drives, sensors, and networks
  - Imbedded software: PIC-C programming
- System design
  - System integration: mechanism, actuators and sensors, and software
  - Task strategy and human-machine interface

Reference and Lecture Notes

Asada, H., and Slotine, J.-J., "Robot Analysis and Control", Wiley 1986, ISBN 0-471-83029-1.

Newly written lecture notes will be provided at each lecture. These lecture notes are a preliminary version of the second edition of the above reference book, "Robot Analysis and Control". While the book was originally written for graduate-level courses, the new lecture notes are primarily for undergraduate juniors and seniors, assuming 2.003 and 2.004 level background knowledge about dynamics and control.

Mars Rover Project

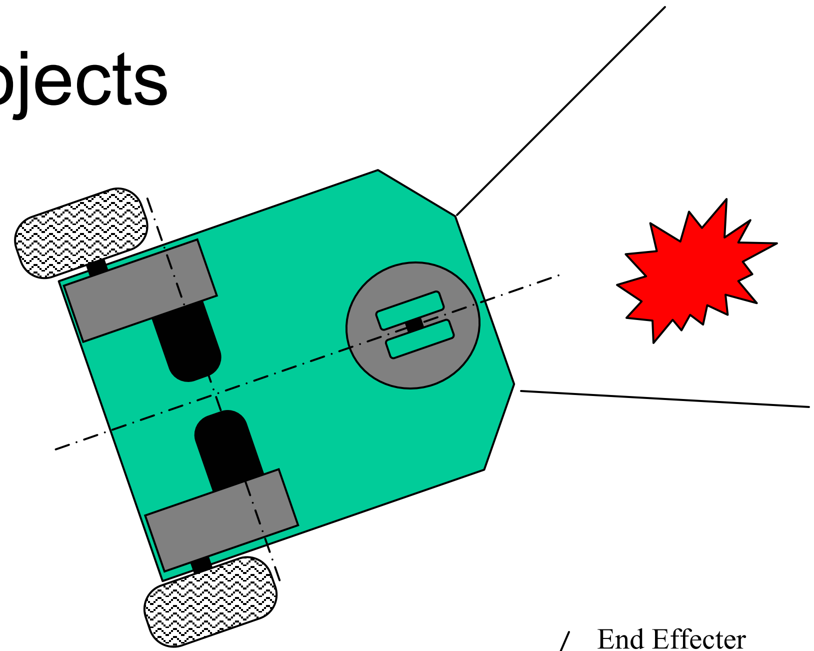
[OCW note: The projects planned for 2.12 changed during the term. The original plan called for three projects, with the final project being a Mars Rover styled robot (shown in the above photo from previous term's class.)]

Three Laboratory Projects

Project 1

De-mining robot control

Lab 1 ~ 3 (9/16 ~ 10/1)



Project 2

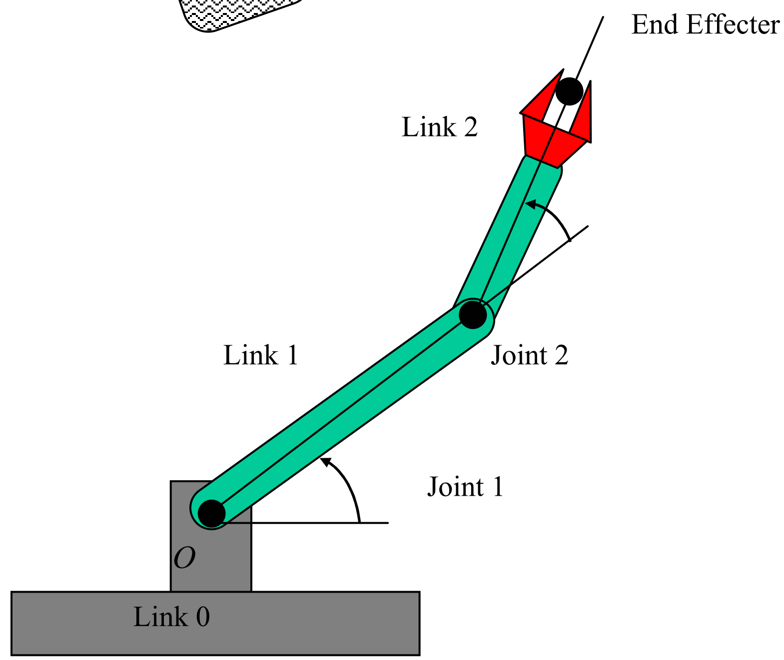
Tele-manipulator system

Lab 4 ~ 5 (10/7 ~ 10/15)

Project 3

Mars rover replica

Lab 6 ~10 (10/21 ~ 12/3)



[OCW note: This project plan changed midway through the term. The class actually did two projects. Project 1, the de-mining robot, took Labs 1-4; Project 2 became a Santa Claus robot, described in subsequent lecture and lab files.]

Mars Rover Design Project

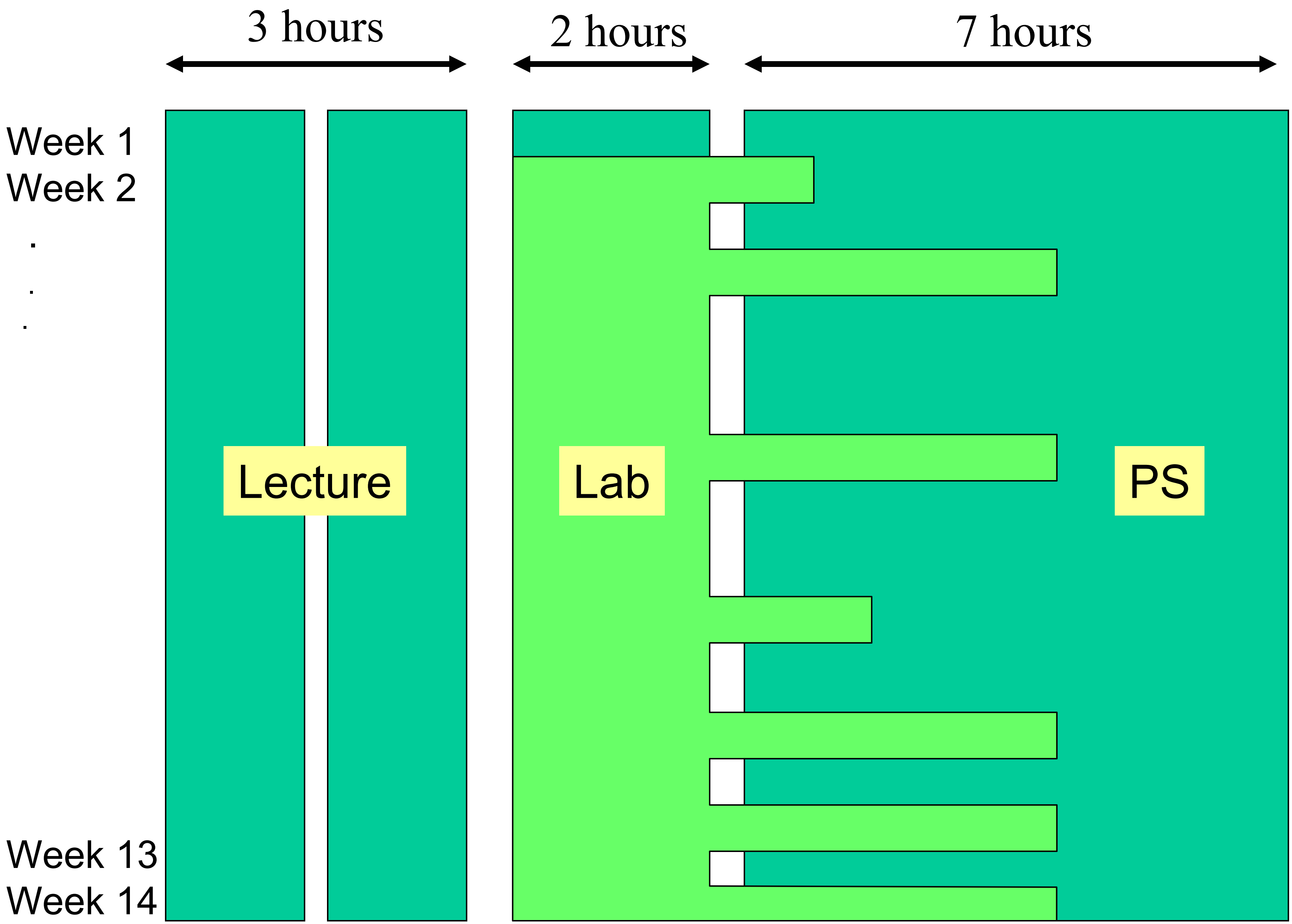
- Design and build replicas of the Mars Rovers.
- Components needed for the rovers, including DC motors, drives, on-board controls, laptop computers, wireless modems, and basic control software, will be provided.
- Before starting the development projects, students will learn in class fundamentals of kinematics, dynamics, servomechanisms, and controls, and will have hands-on experience of servomotors and computer control of a vehicle and an arm in the first two projects.

[OCW note: The Mars Rover final project was replaced by the Santa Claus robot design project.]

2.12 has been approved as a Restricted Elective (professional subject).

Weekly Study Plan

- Wednesday: Problem set given
- Saturday/Sunday: Reading lecture notes – 2 hours
- Monday: Work out the problem set (and get stuck!) – 3 hours
- Tuesday: Meet TA and/or discuss it with friends – 1 hour + 1 hour
- Wednesday: Problem set due


3 hours
2 hours
7 hours
Week 1
Week 2
.
.
.
Week 13
Week 14
Lecture
Lab
PS

Ethics

- Use of problem set solutions of previous terms is strictly prohibited.
- Collaboration is not permitted during quizzes.
- Students are encouraged to discuss problem assignments with one another. However, each student must submit his/her own solution to each problem set.

Grading

Mid-term exam, (2:30 – 4:30 pm, November 3, 2004)	30%
End-of-term exam (2:30 – 4:30 pm, December 1, 2004)	30%
Home work assignment (7~8 assignments)	20%
Laboratory and Term Project (See details below.)	20%
Total	100%

Overview of Robotics

1948 - 2004

Prehistory-1
Remote manipulators

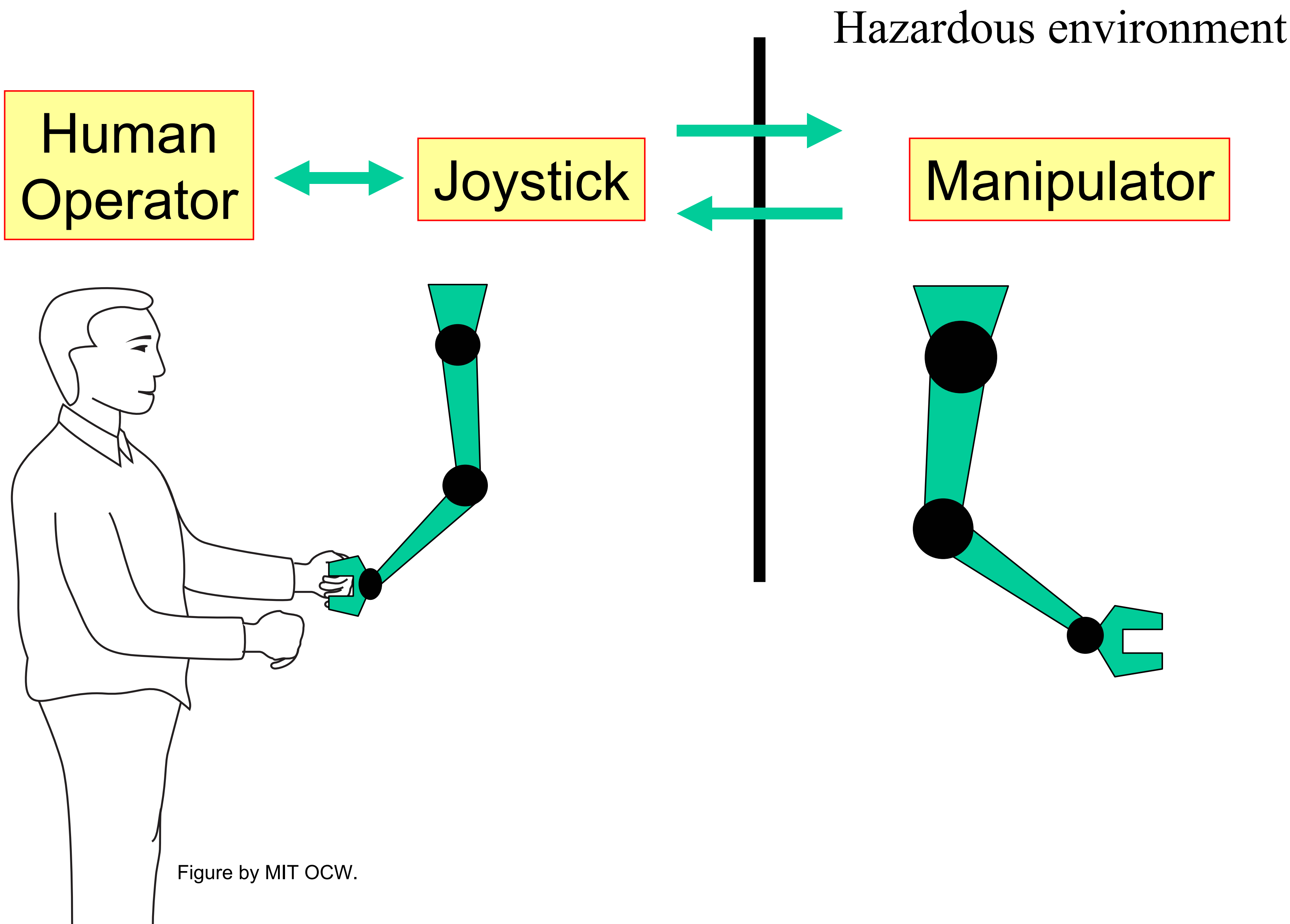


Figure by MIT OCW.

Prehistory-2

- Numerical Control
- Control based on stored data
- 1948 US patent
- 1953 First implementation at MIT

Pictures removed for copyright reasons.

Birth of Industrial Robots

1954 US patent by George C. Devol
Part transfer: Teach-in/Playback

1962 First industrial robot developed by Unimation, Inc., Joe Engelberger

1964 First installation at GM

Pictures removed for copyright reasons.

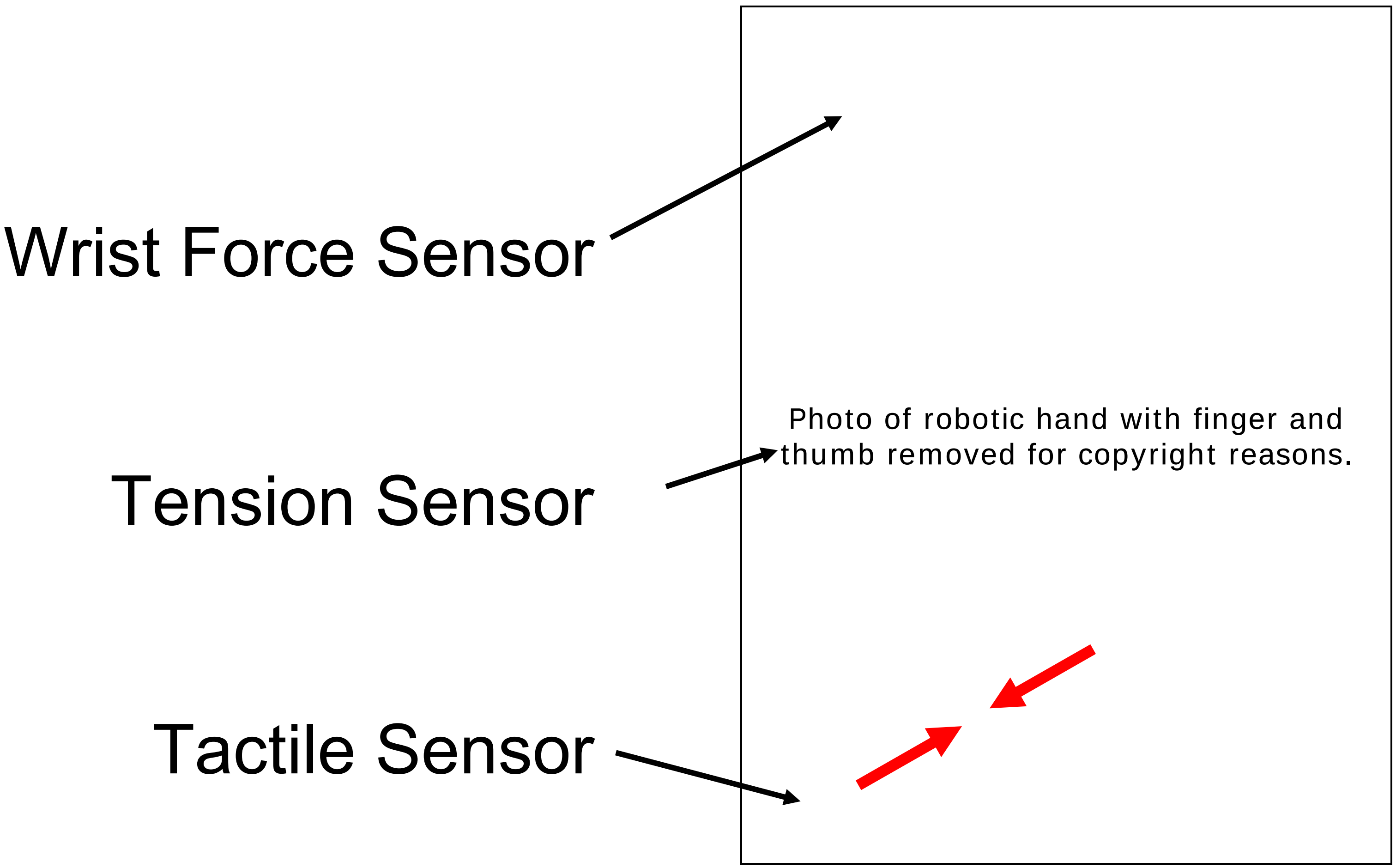
Robots must be dexterous and interactive: Sensor-based control

Skills and Dexterity

Pictures of robotic hands (human-style) removed for copyright reasons.

Intelligent control strategy
and behavior

We do not know what are dexterity and skills are:
Subconscious knowledge


Wrist Force Sensor
Tension Sensor
Tactile Sensor
Photo of robotic hand with finger and thumb removed for copyright reasons.

Touch Sensor

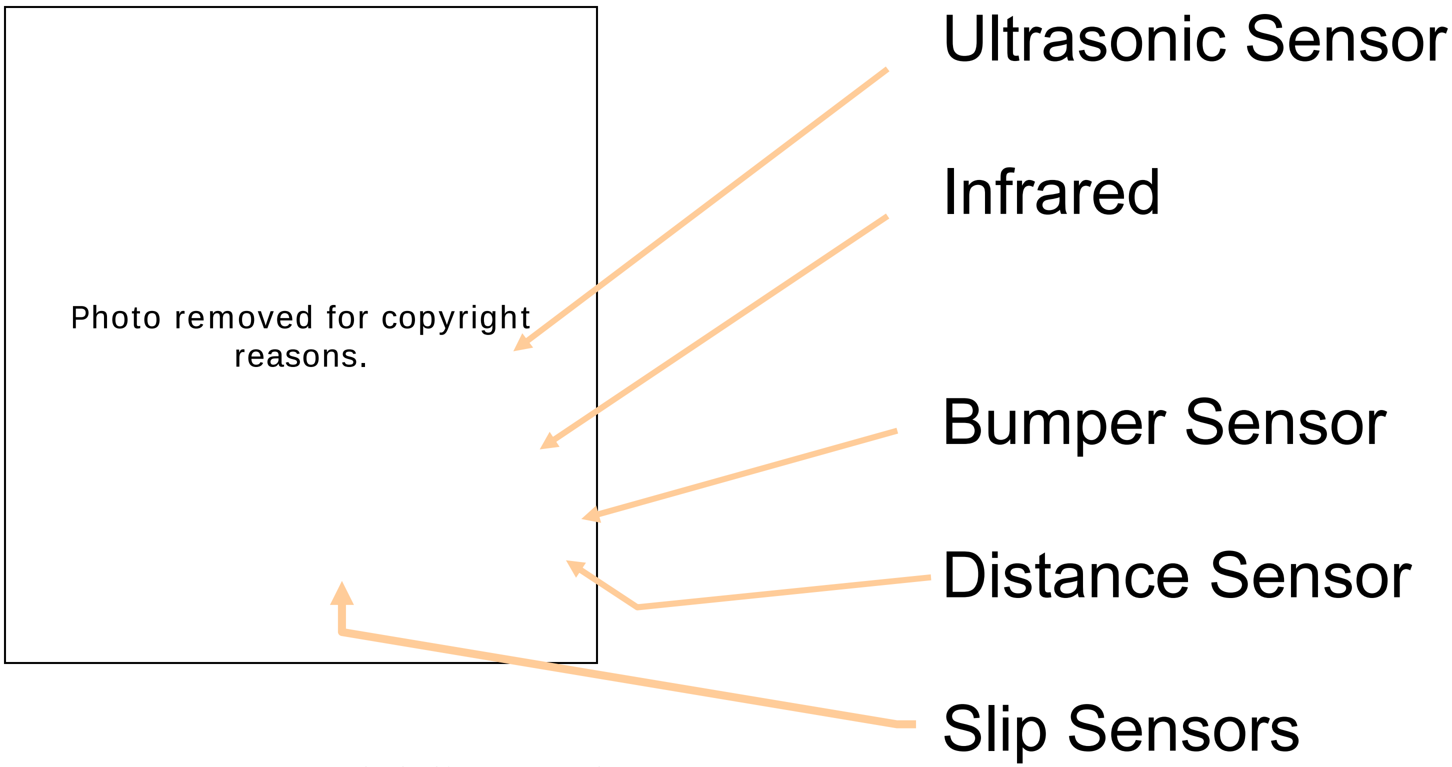
CCD Camera
Vision System

Photo of Sony Aibo™ robot (dog) removed for copyright reasons.

Ultrasonic Sensor

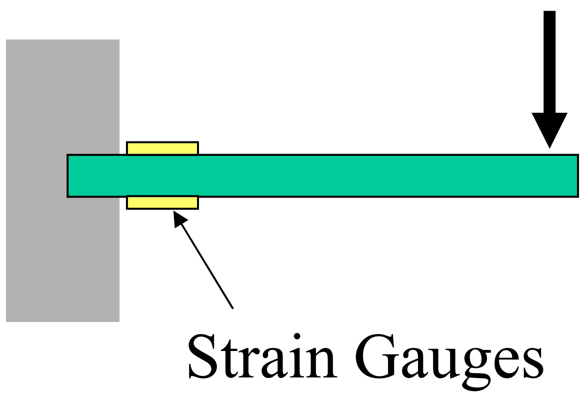
Torque Sensor

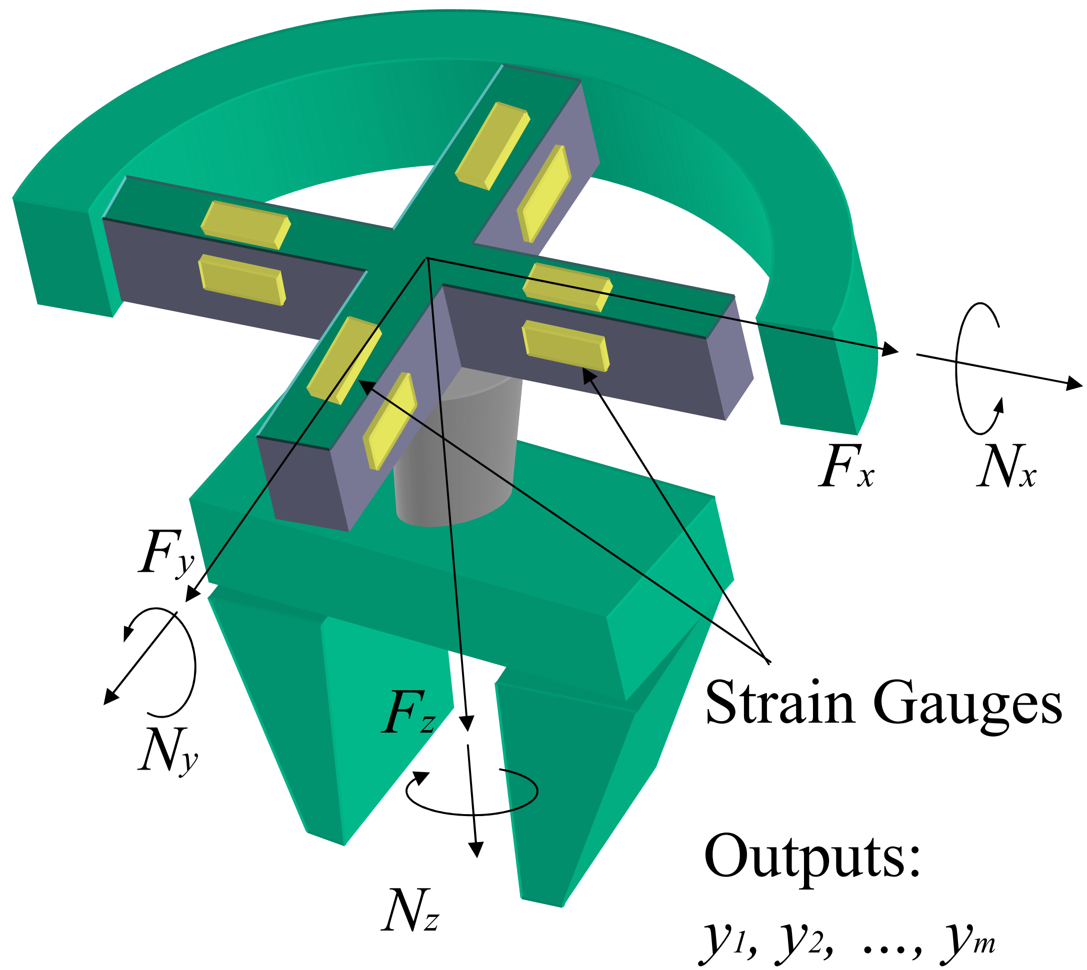
Touch Sensors



Meal delivery robot
Hospitals and nursing homes

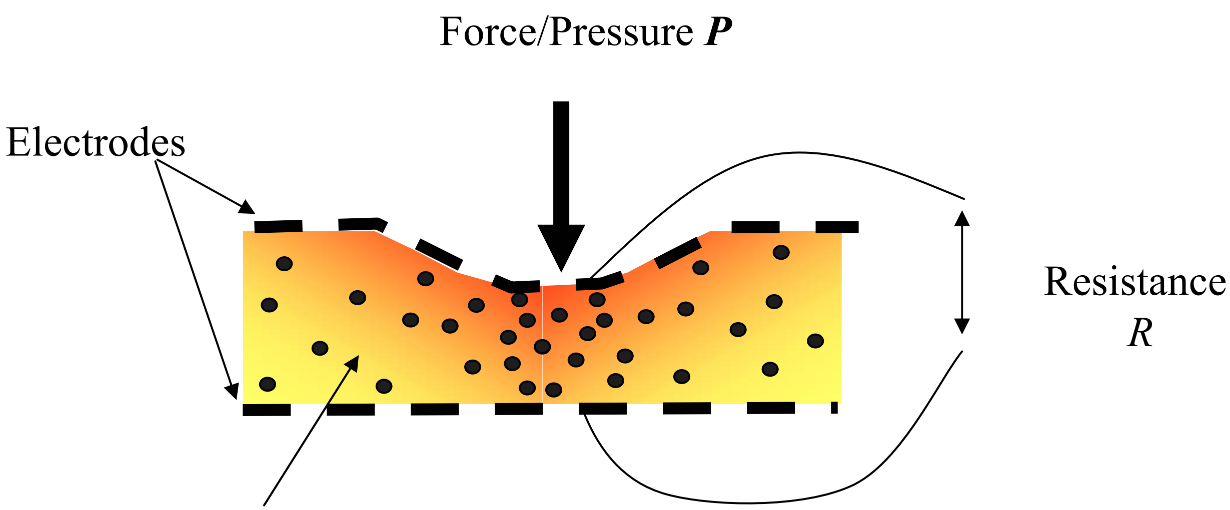
6-Axis Wrist Force/Torque Sensor



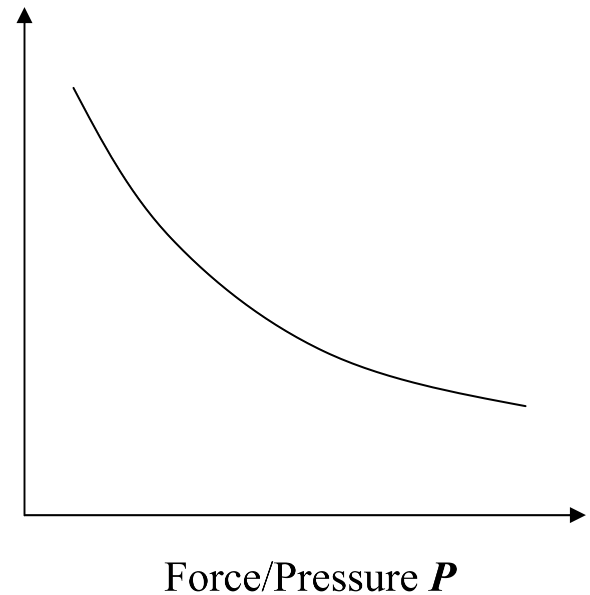


Tactile Sensors

Tactile Pad



Conductive Rubber:
Media impregnated with conductive dopants

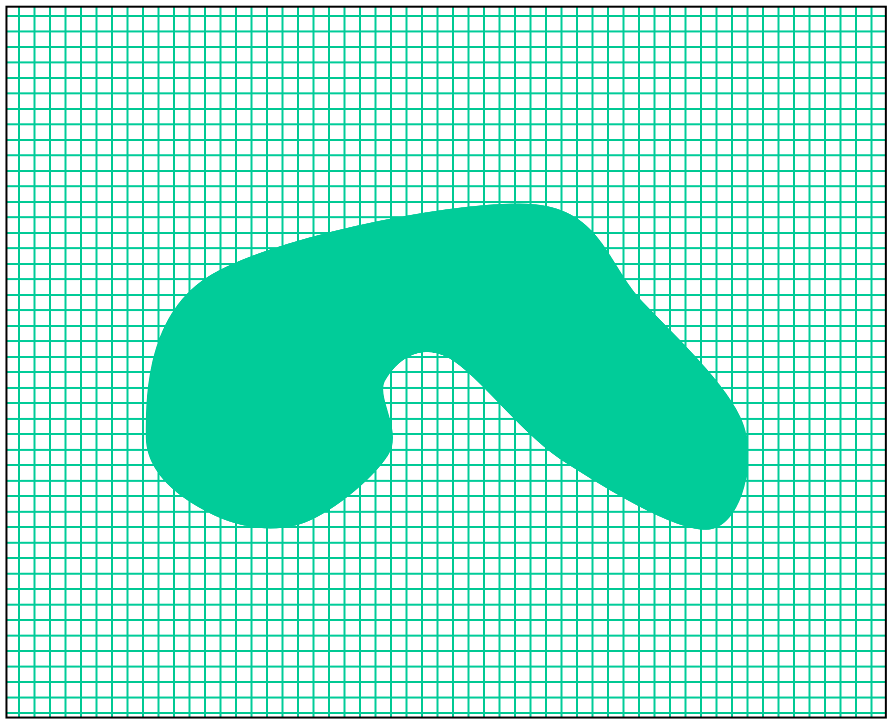


Other Methods:

- Capacitive
- Optical
- Piezoelectric
- Magneto-resistive
- Magneto-elastic

Sensor Pad:
2-D sensor array

Pressure distribution

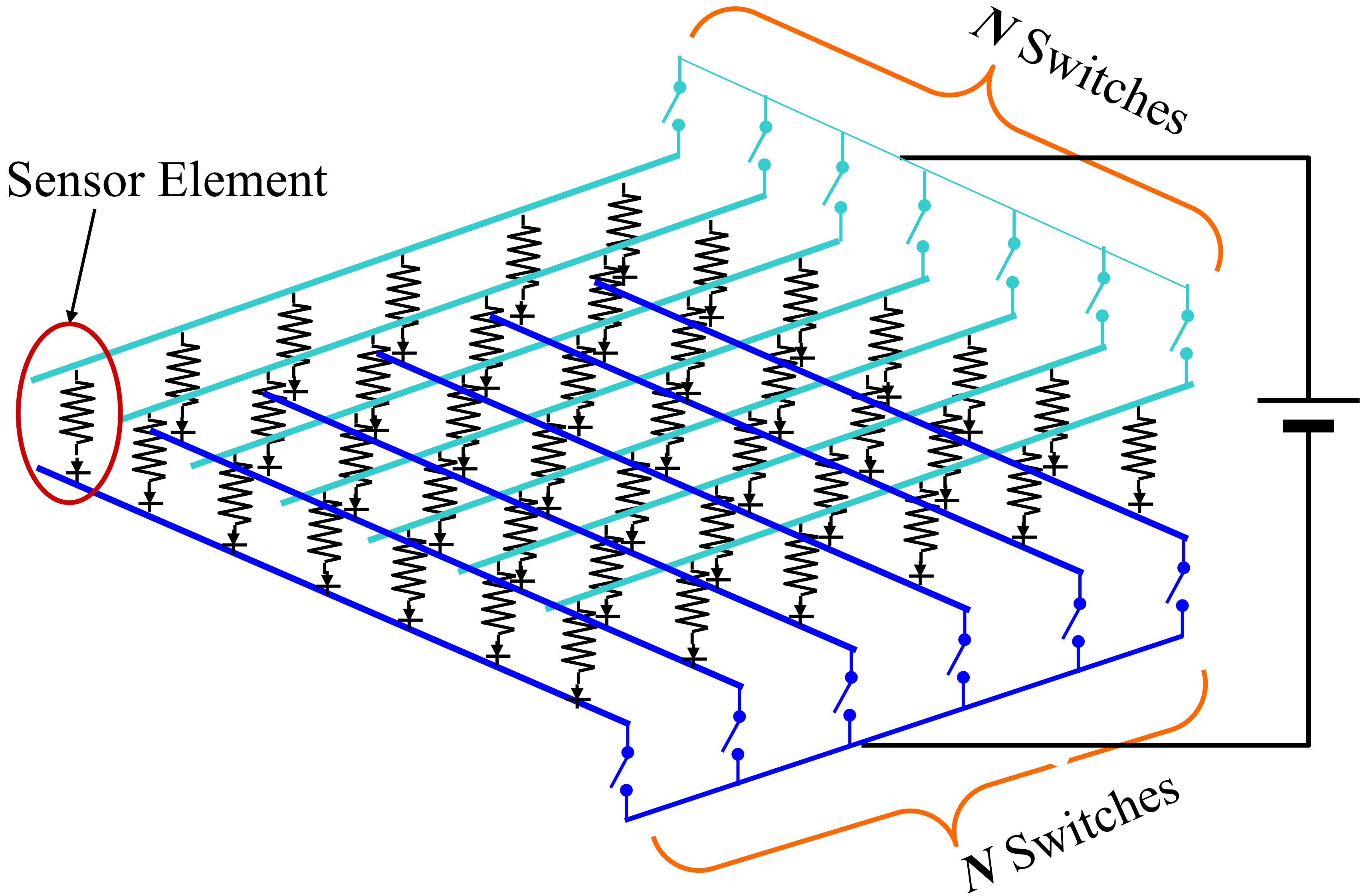


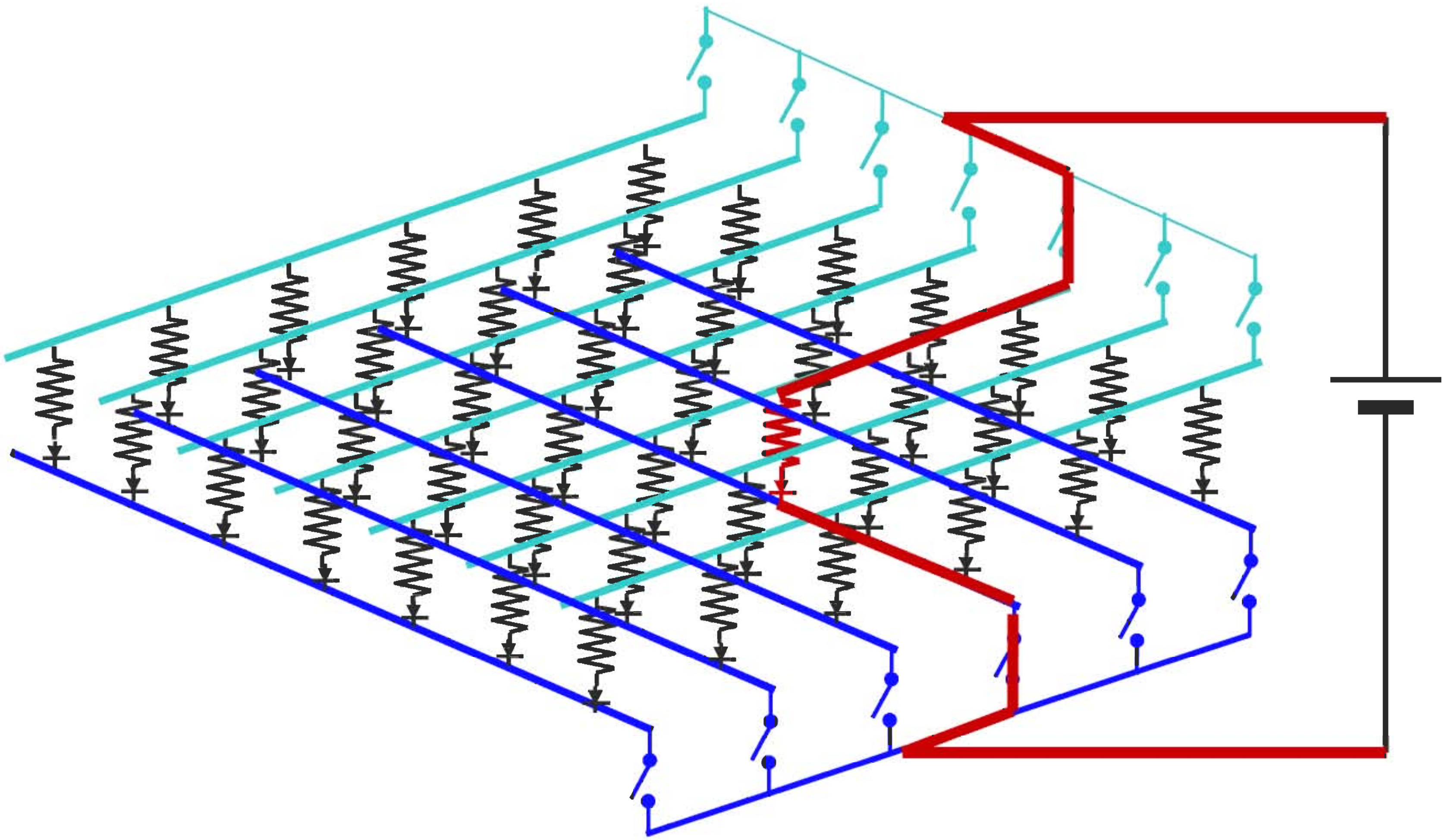
Technical Issues:

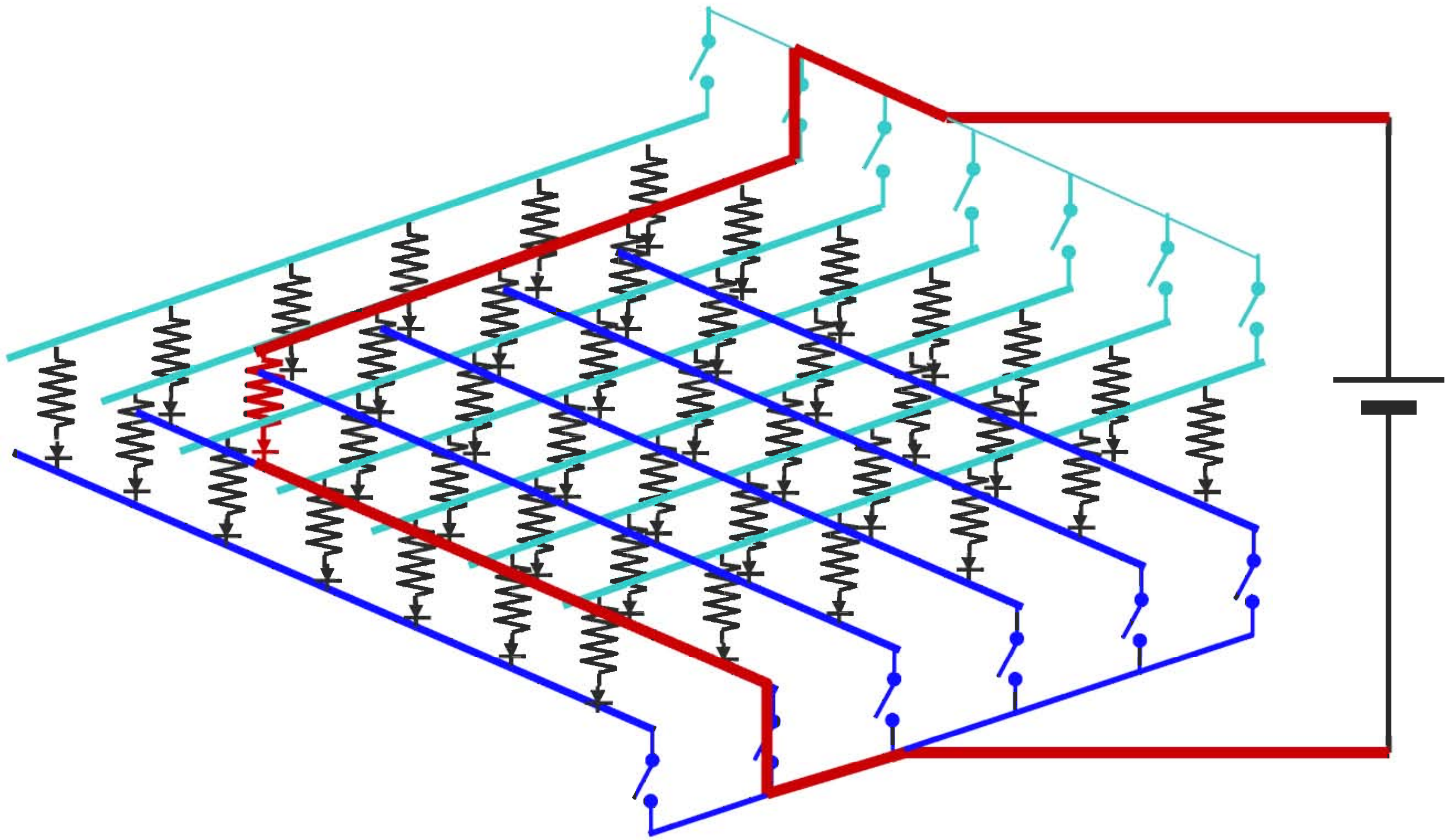
- How to process the 2-D data of pressure distribution
- How to reduce wires

A tactile sensor = Measuring 2-D pressure distribution

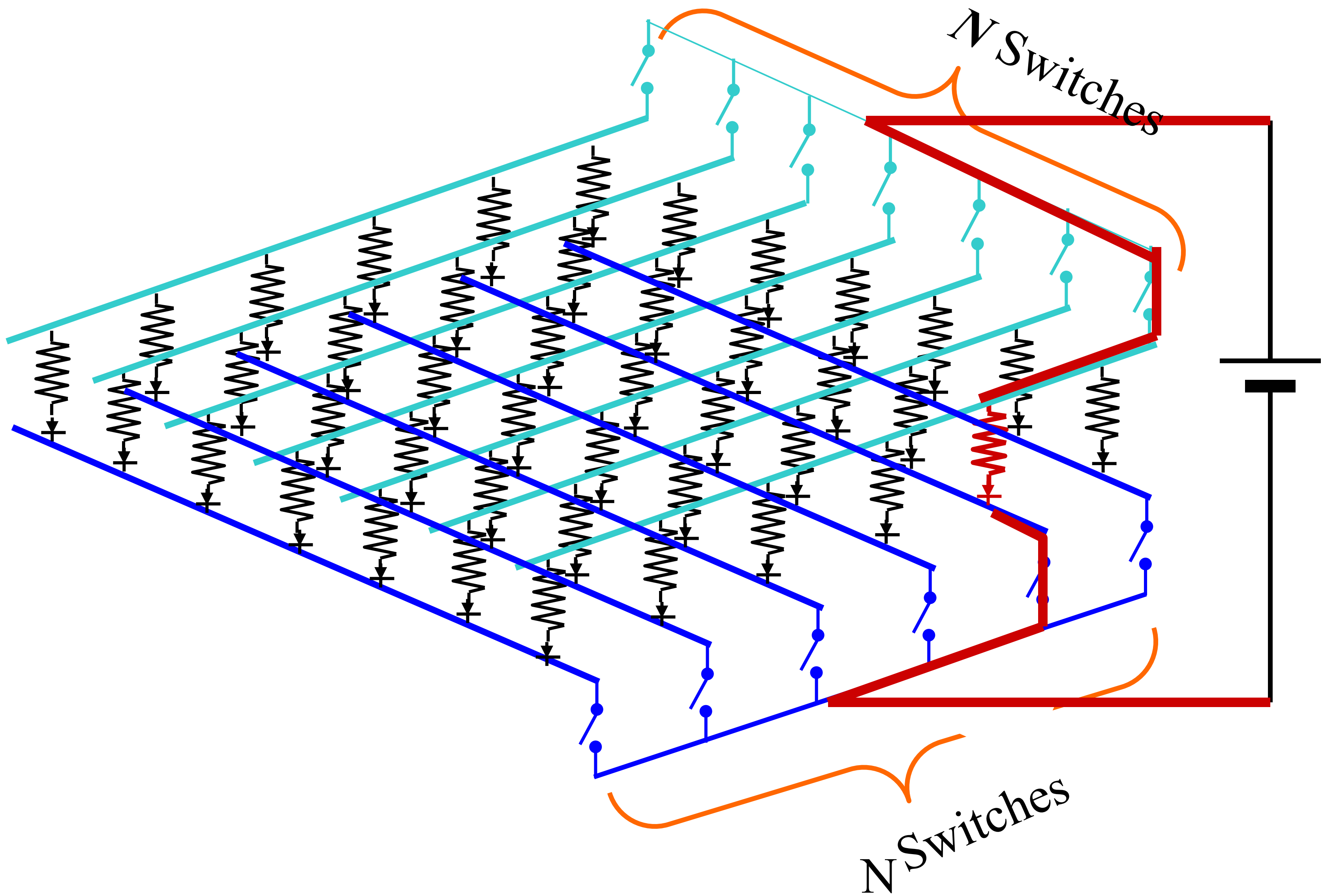
A *Matrix* Wiring Structure for Reducing Cables

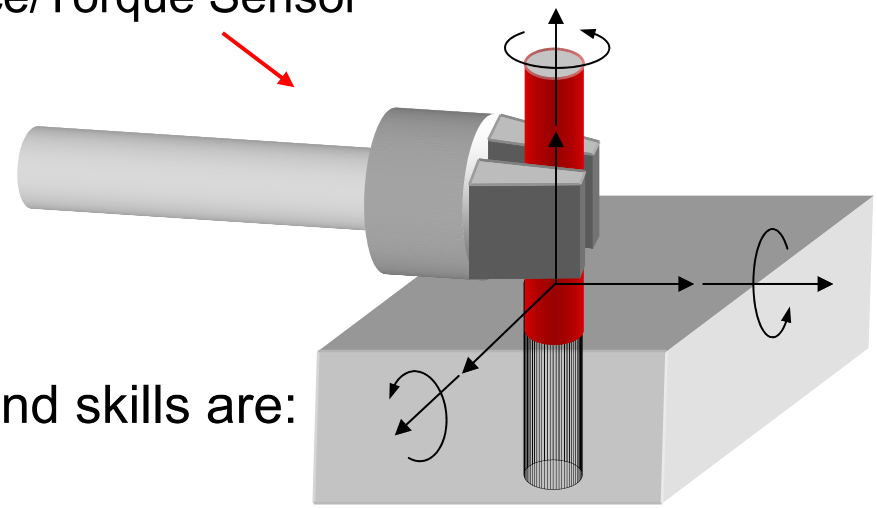






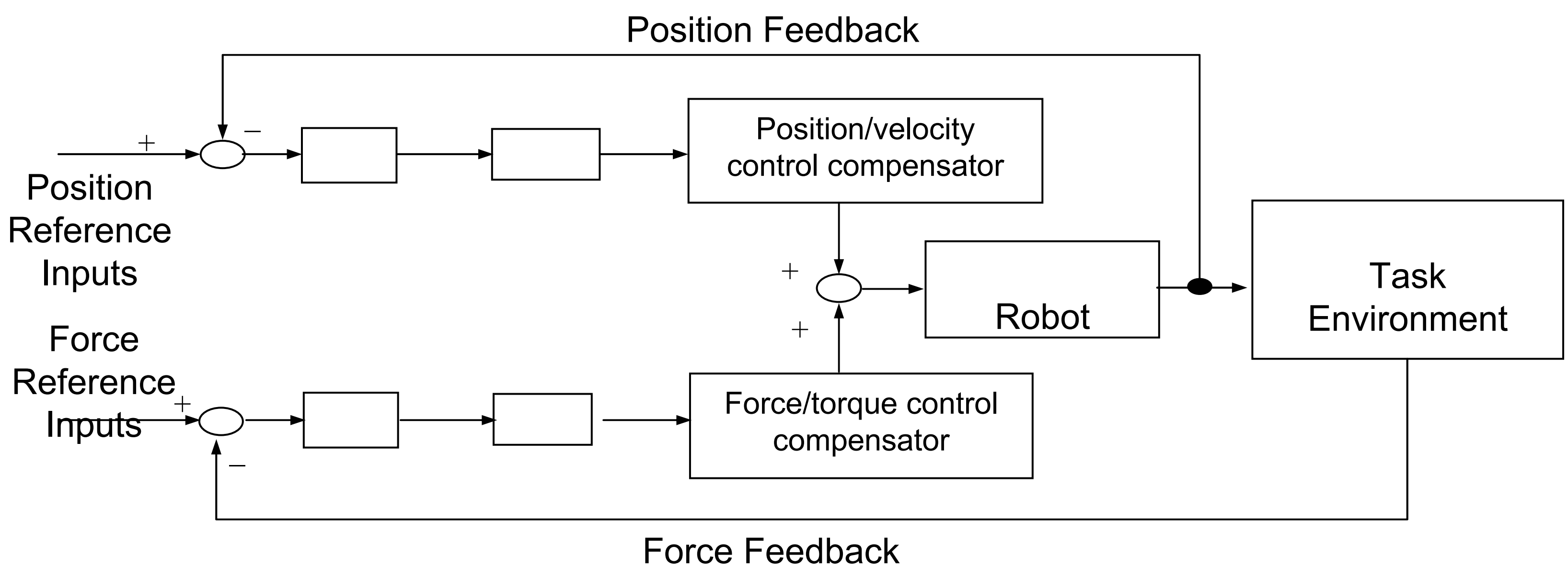
Reading N^2 Points of pressure with $2N$ Switches



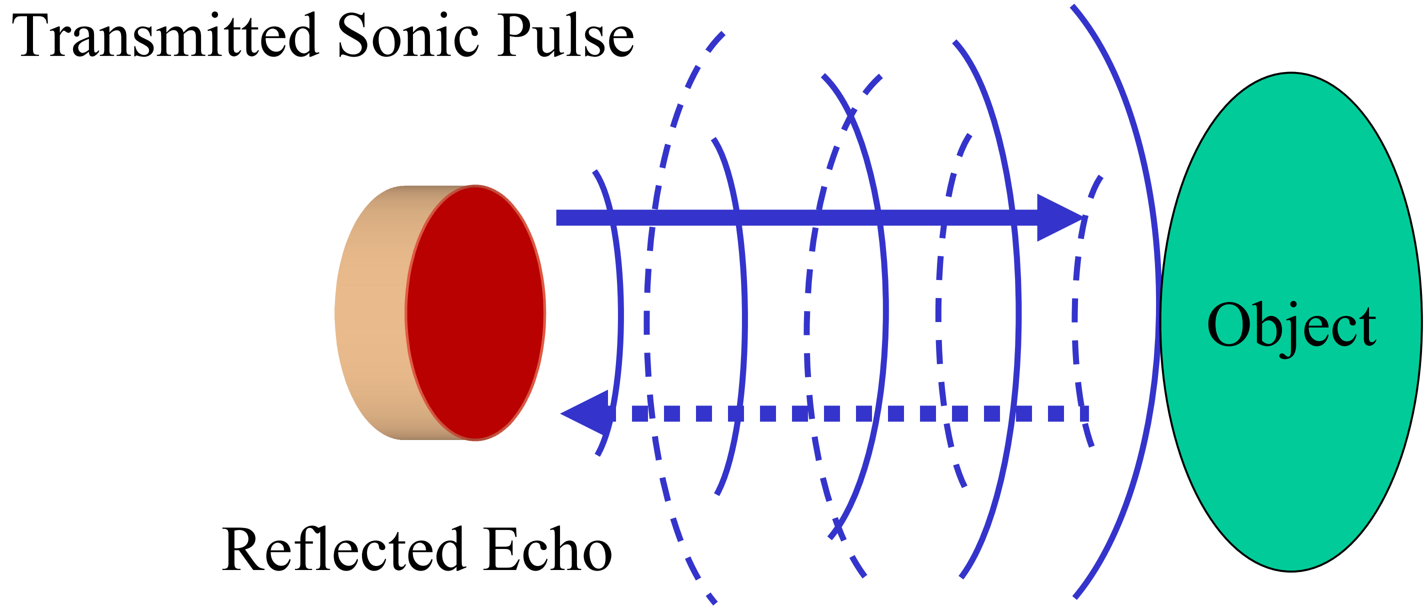


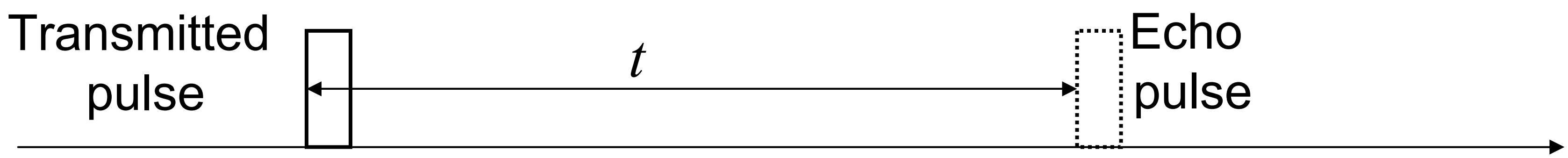
We do not know what are dexterity and skills are:
Subconscious knowledge

Hybrid Position/Force Control



Ultrasonic Sensors





Measuring the distance ***d*** to an object by the time interval between the transmitted and reflected sonic pulses.

$$2\,\mathbf{d} = v\,t$$

v = speed of sound, t= time interval

Optical Sensors

CCD (Charge Coupled Device)

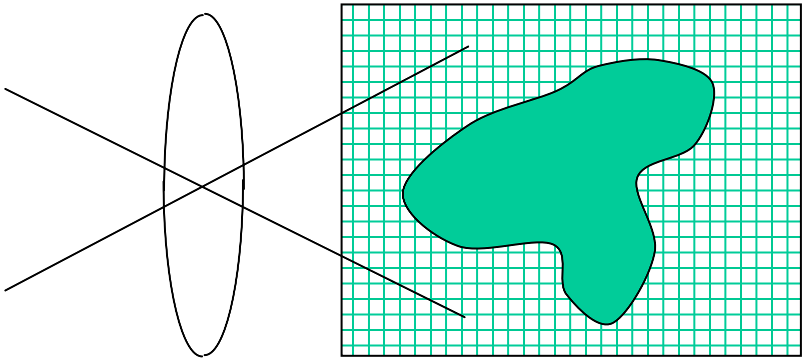


Photo Sensitive Array
Scanned pixel by pixel

Light beam

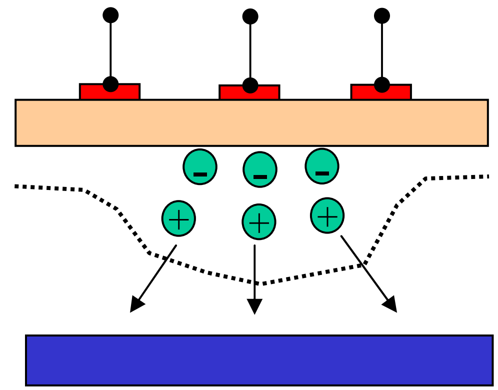
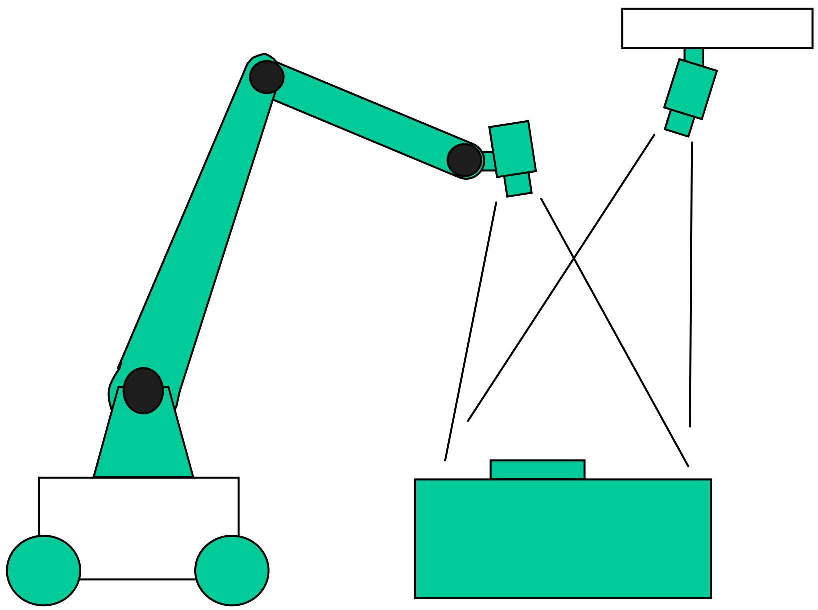


Image Processing

A. Two-dimensional Images



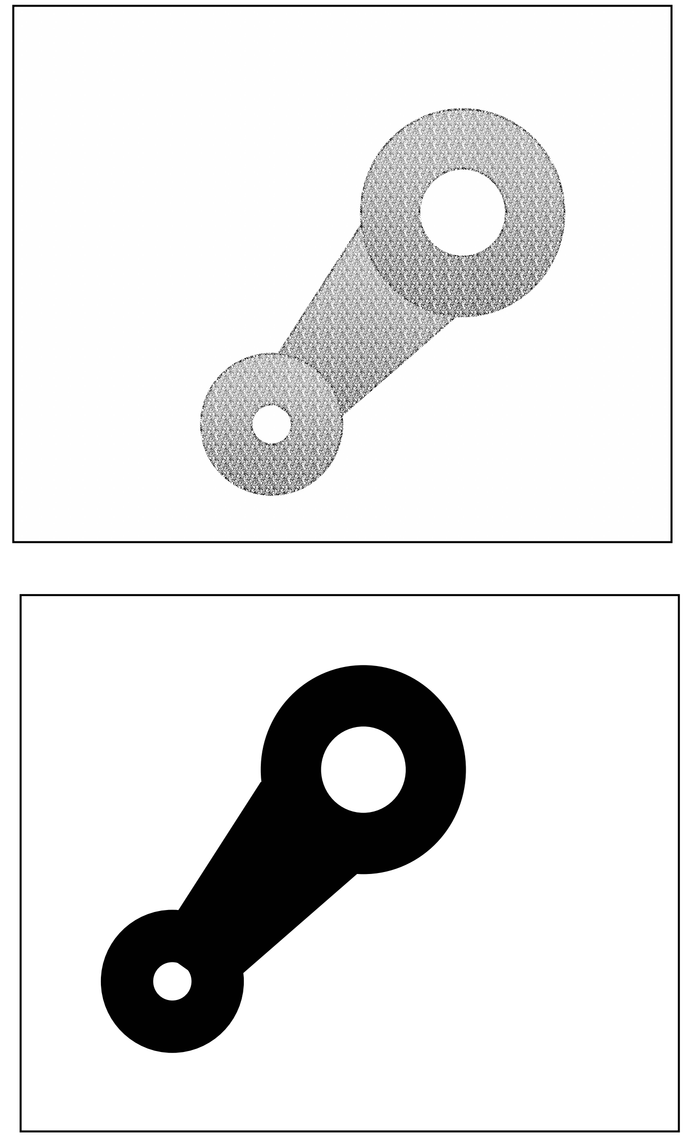
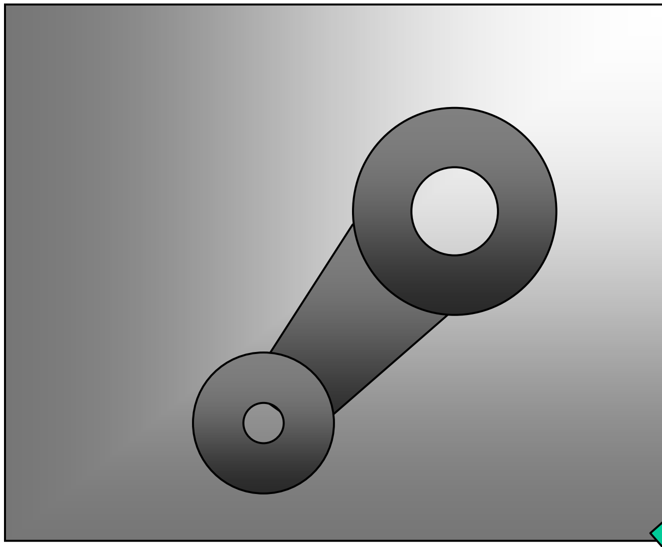
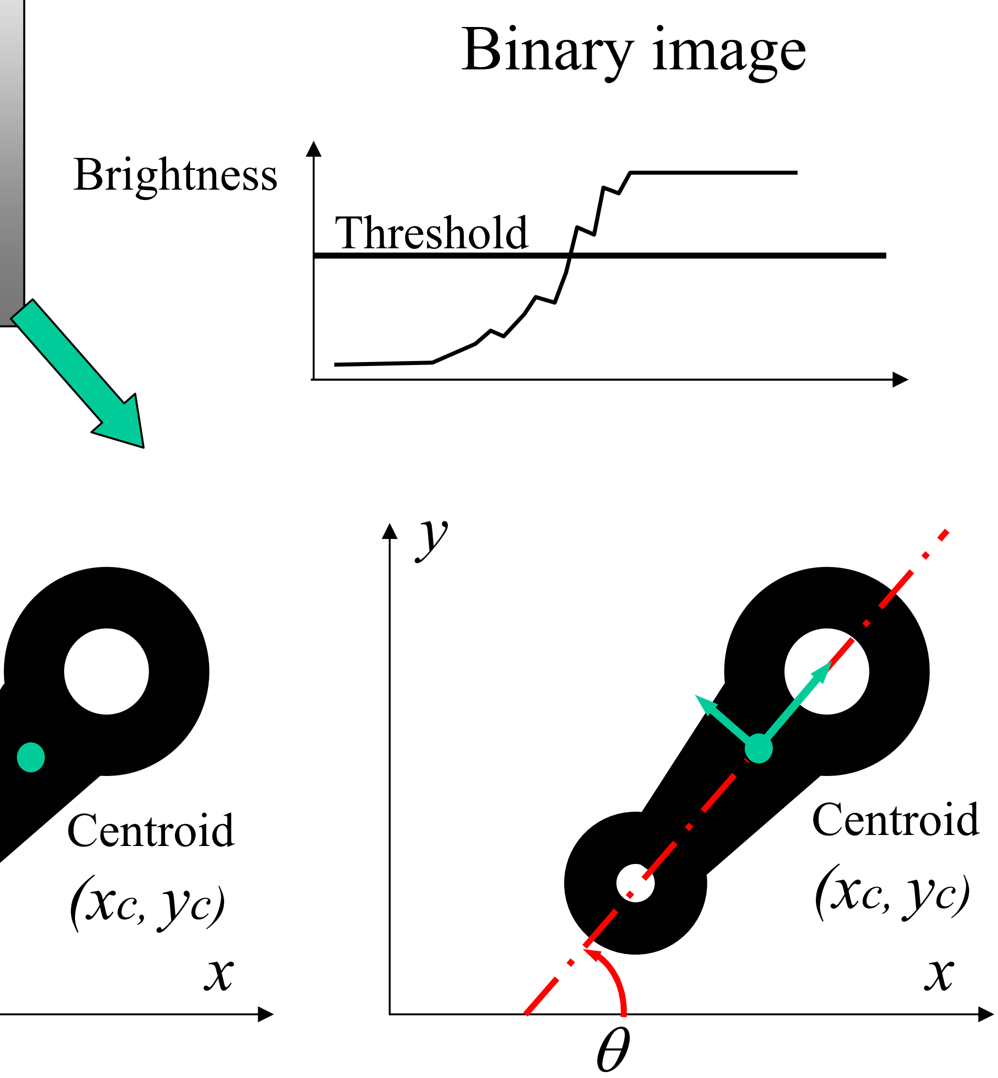
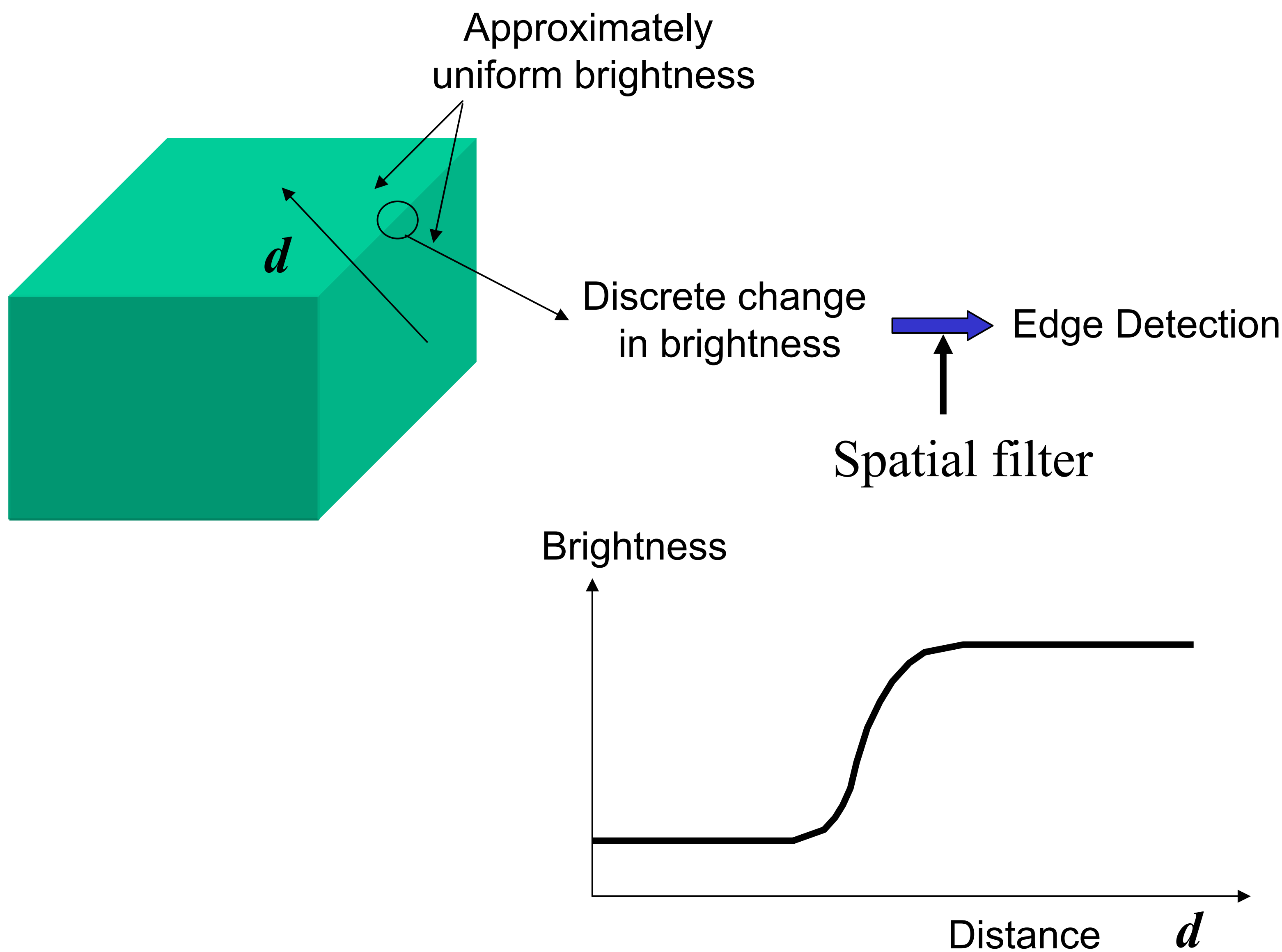


Image Processing





3-D Grey-level Images



Discrete 2-D Edge Detection Filter

Brightness of pixel *i,j* and its neighboring pixels

$E_{i-1,j+1}$	$E_{i,j+1}$	$E_{i+1,j+1}$
$E_{i-1,j}$	$E_{i,j}$	$E_{i+1,j}$
$E_{i-1,j-1}$	$E_{i,j-1}$	$E_{i+1,j-1}$

ε

$$\frac{\partial^2 E}{\partial x^2} = \frac{1}{\varepsilon}\left[\frac{E_{i+1,j} - E_{i,j}}{\varepsilon} - \frac{E_{i,j} - E_{i-1,j}}{\varepsilon}\right]$$

$$= \frac{1}{\varepsilon^2}(E_{i+1,j} - 2E_{i,j} + E_{i-1,j})$$

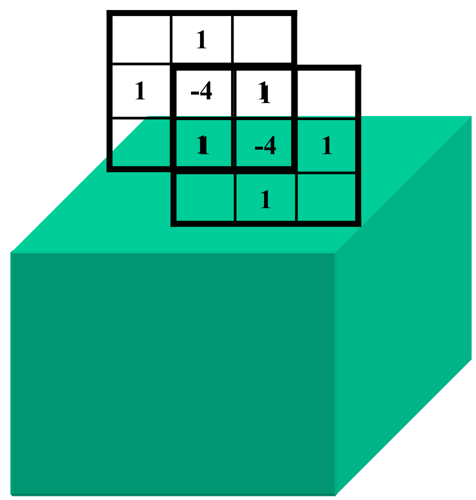
$$\frac{\partial^2 E}{\partial y^2} = \frac{1}{\varepsilon^2}(E_{i,j+1} - 2E_{i,j} + E_{i,j-1})$$

$$\frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} = \frac{1}{\varepsilon^2}(E_{i-1,j} + E_{i,j-1} + E_{i,j+1} + E_{i+1,j} - 4E_{i,j})$$

Discrete filter gains

Stencil $\frac{1}{2\varepsilon^2}$

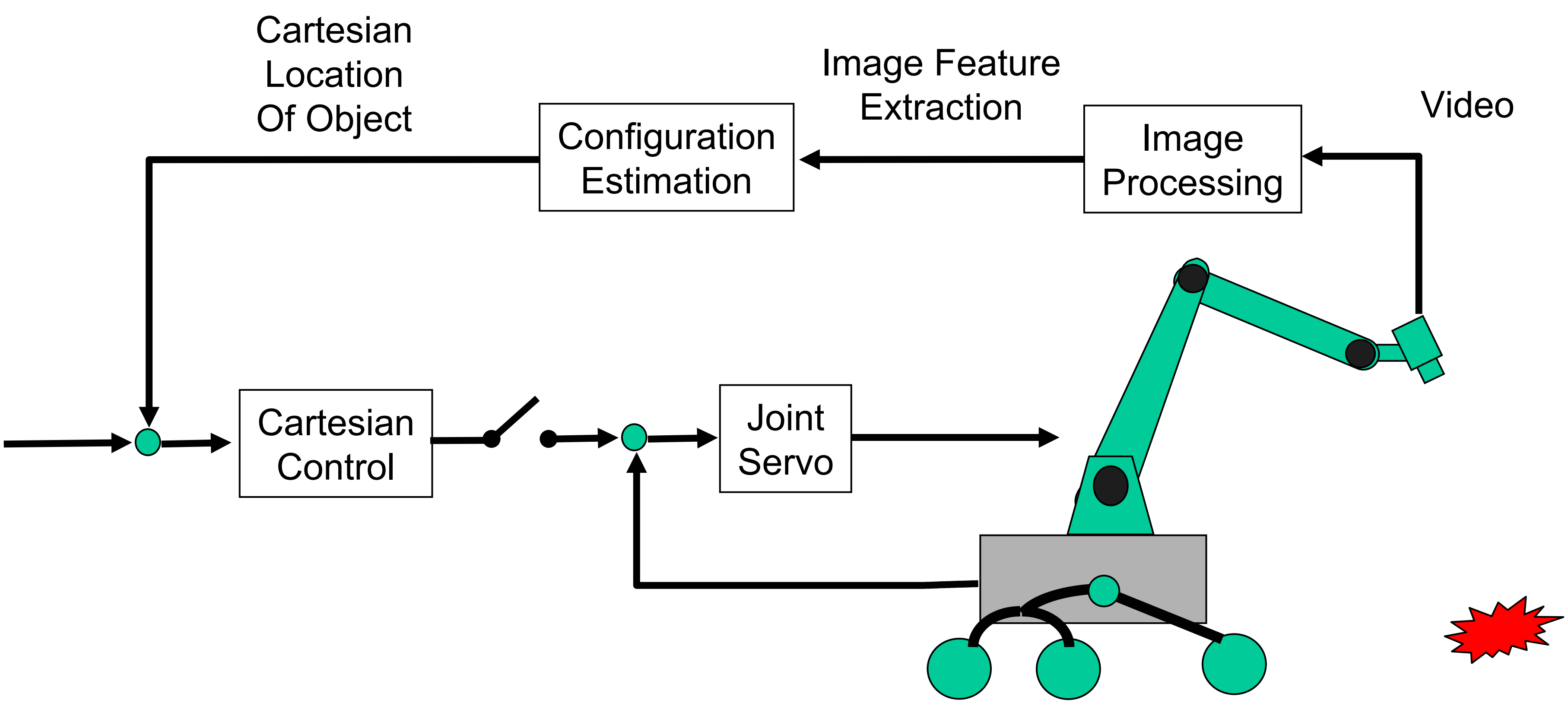
	1	
1	-4	1
	1	



$\frac{1}{6\varepsilon^2}$

1	4	1
4	-20	4
1	4	1

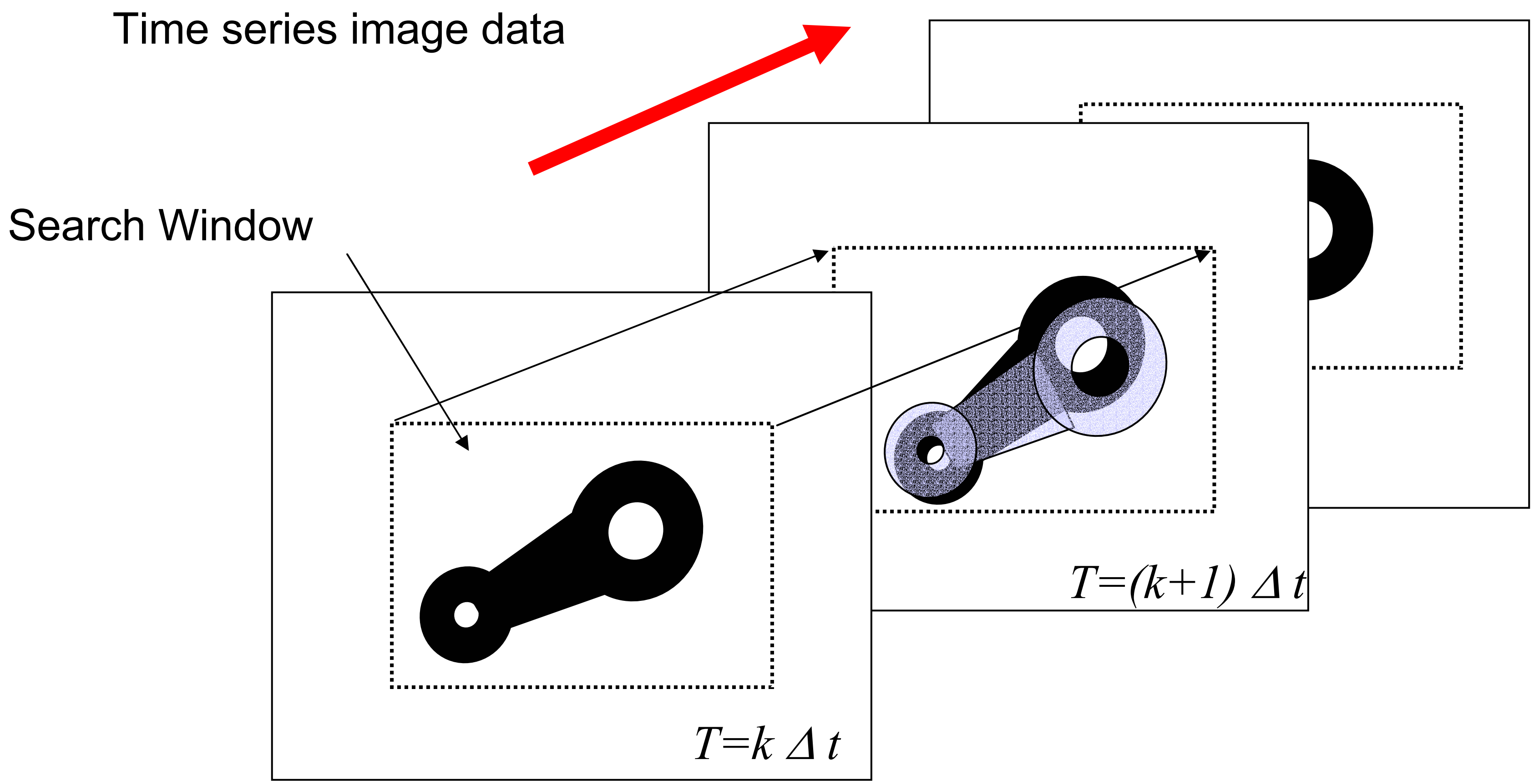
Visual Feedback



Issue:

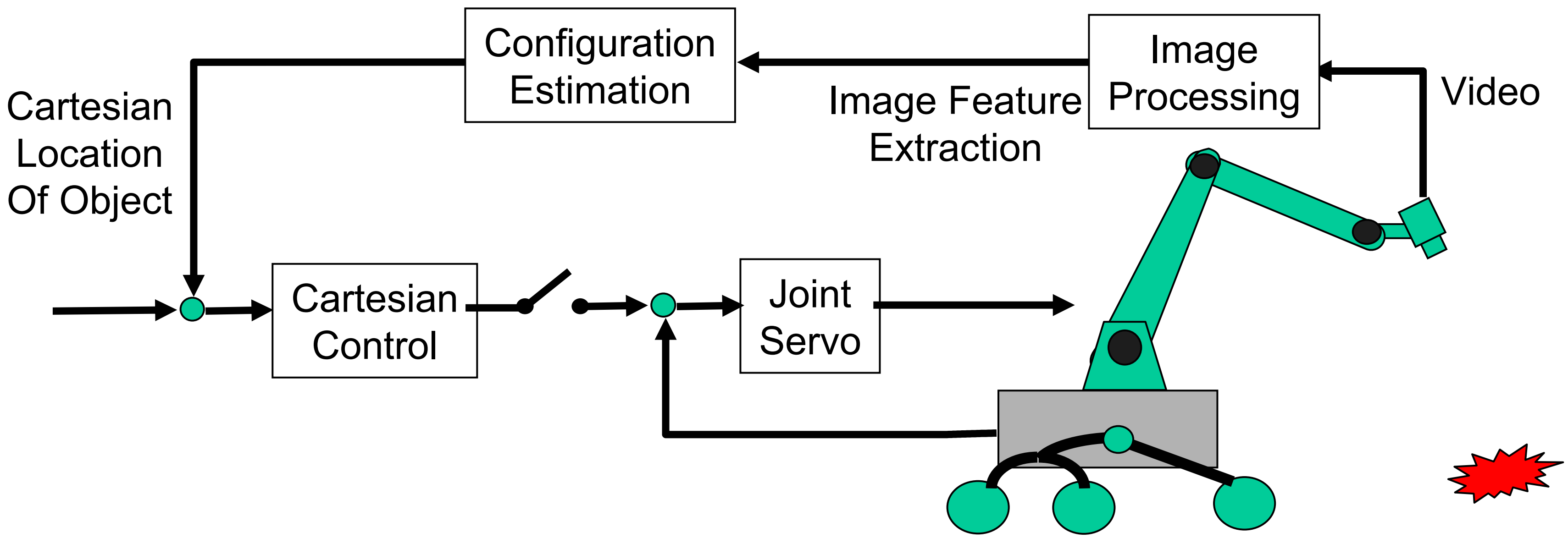
Real-time control
Fast image processing

Real-Time Image Processing and Feedback Control



Based the previous location of the target object, the location of the object in the subsequent image frame can be localized or estimated.

Predictor: $s(k+1) = s(k) + \mathbf{J}_s \dot{\mathbf{q}}(k) \cdot \Delta T$


Configuration Estimation
Image Processing
Video
Image Feature Extraction
Cartesian Location Of Object
Cartesian Control
Joint Servo

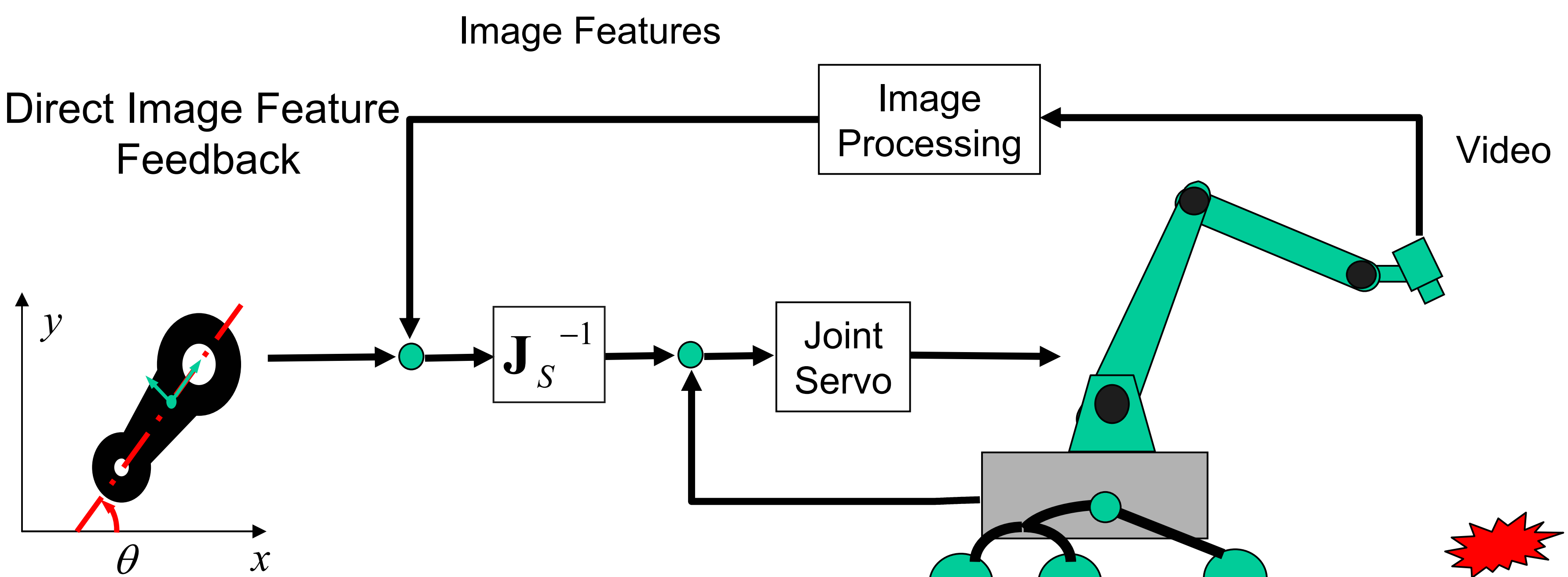


Image Features
Direct Image Feature Feedback
Image Processing
Video
$\mathbf{J}_S^{-1}$
Joint Servo
y
x
θ

Service Robots: Automatically Guided Vehicles

Transition Technology Inc., Joe Engelberger

Photo removed for copyright reasons.

Meal delivery robot
Hospitals and nursing homes

Supporting Scientific Research

Planet Exploration Robotics

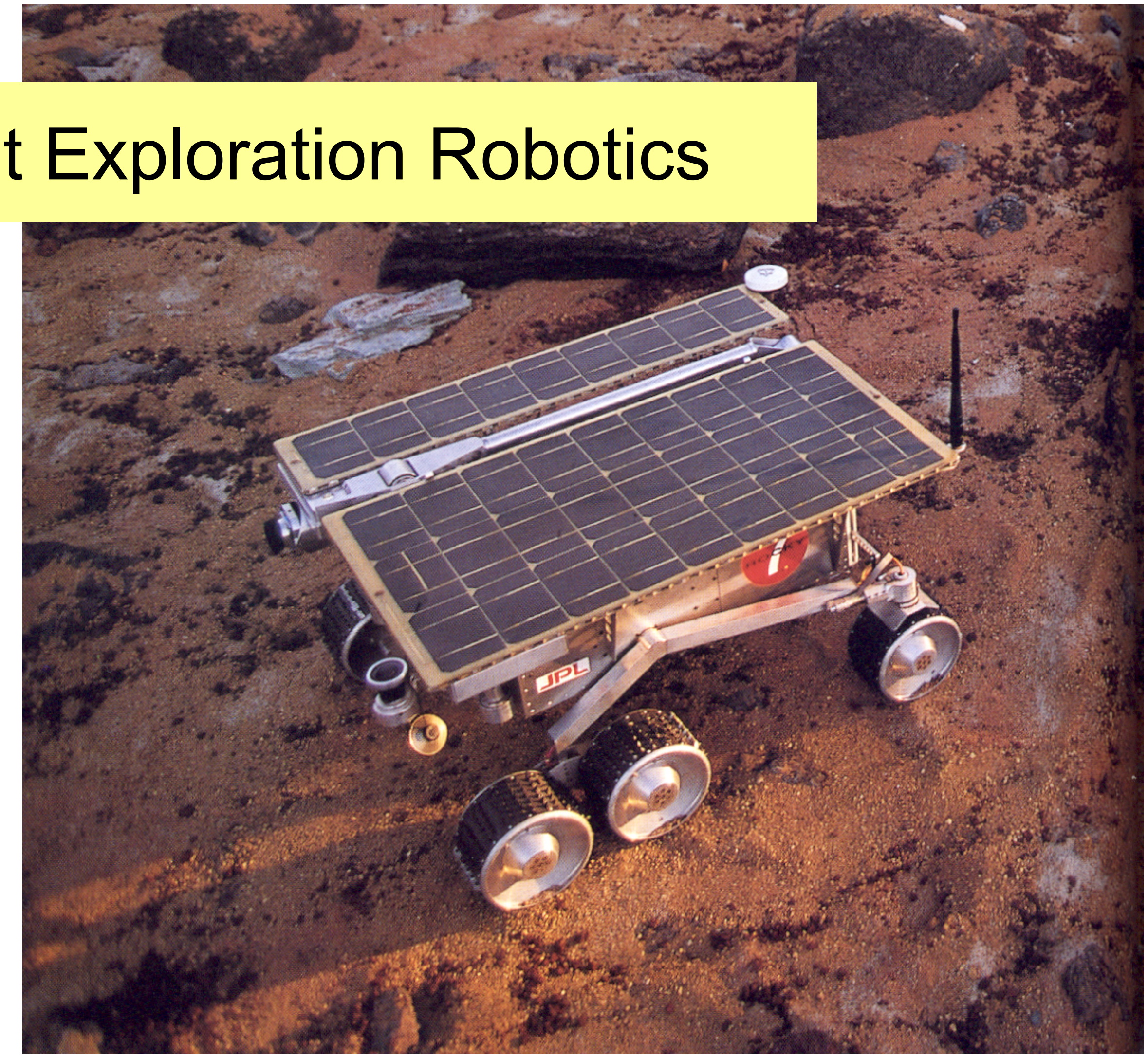
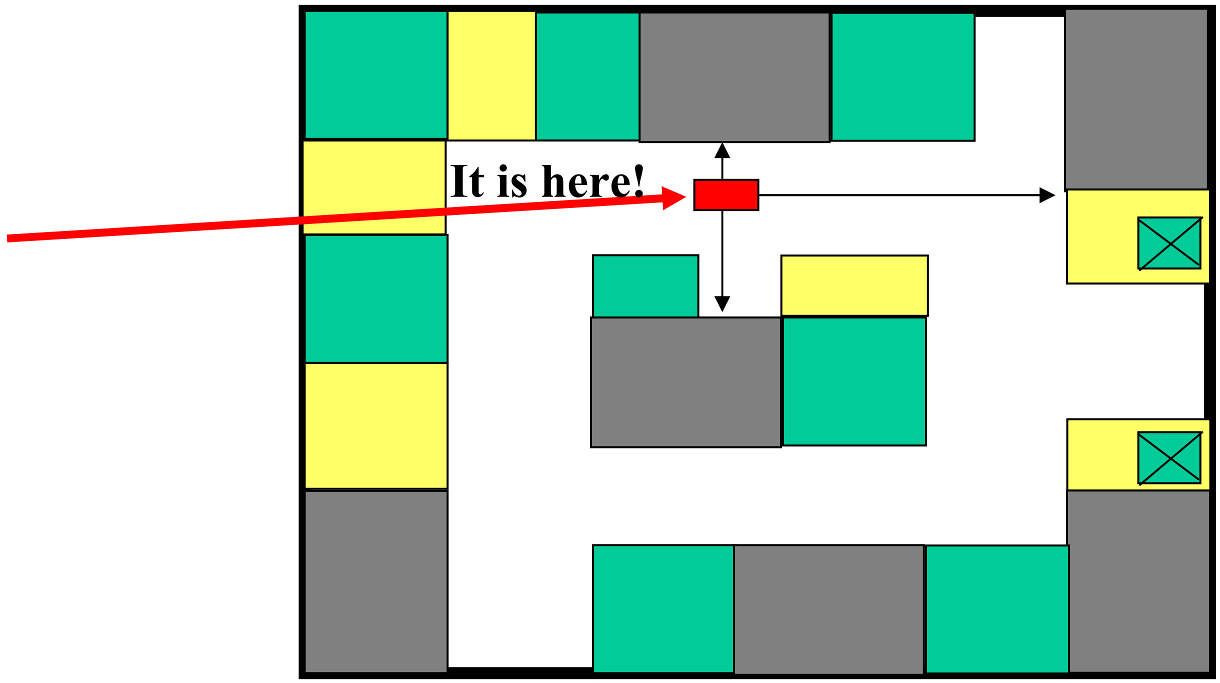


Image courtesy of JPL.

Map-Based Navigation
of Automatically Guided Vehicles

Map and real-time
sensor data matching

Meal delivery robot
Hospitals and nursing homes



Floor Plan

Simultaneous Location And Mapping (SLAM)

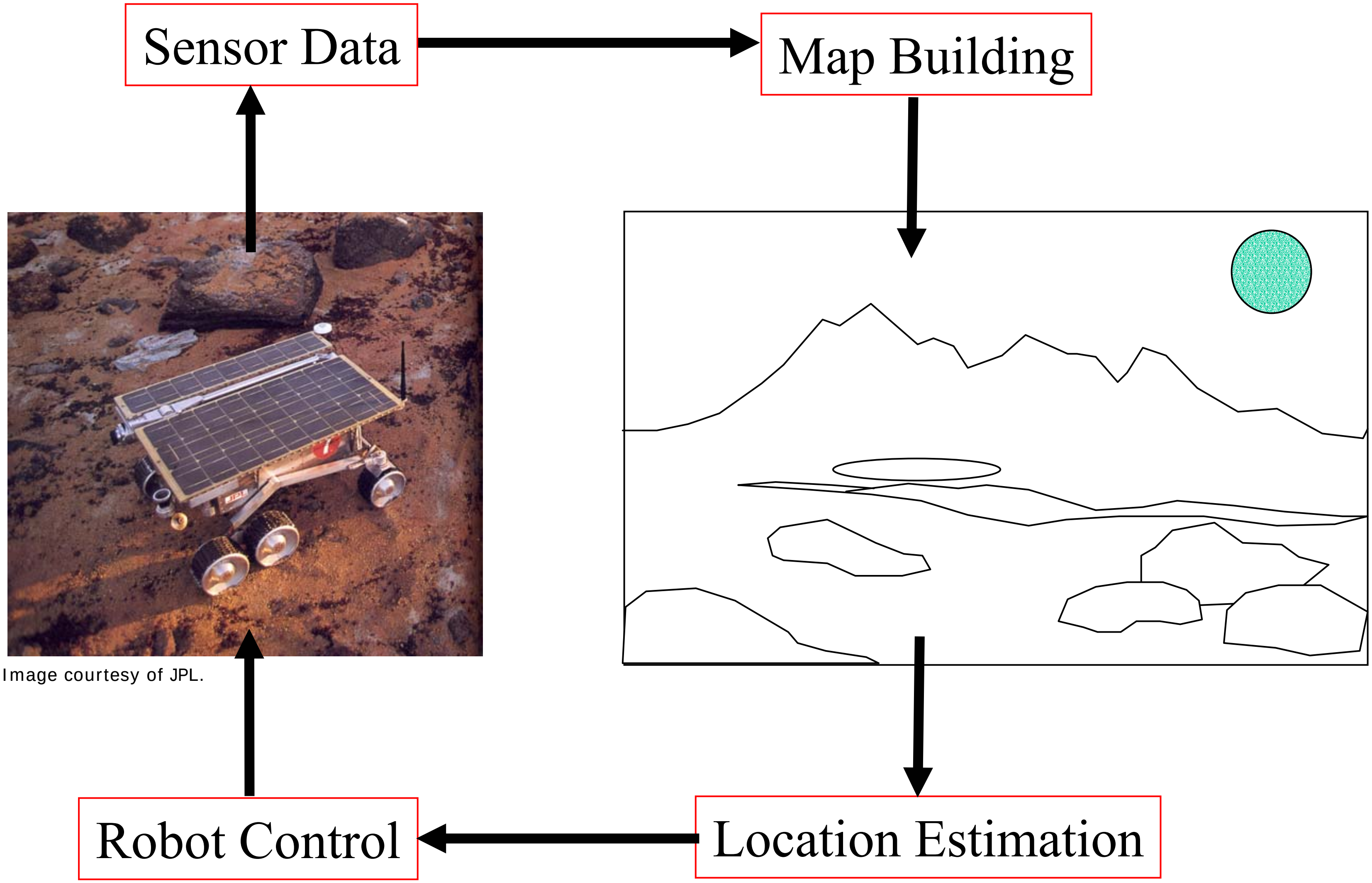
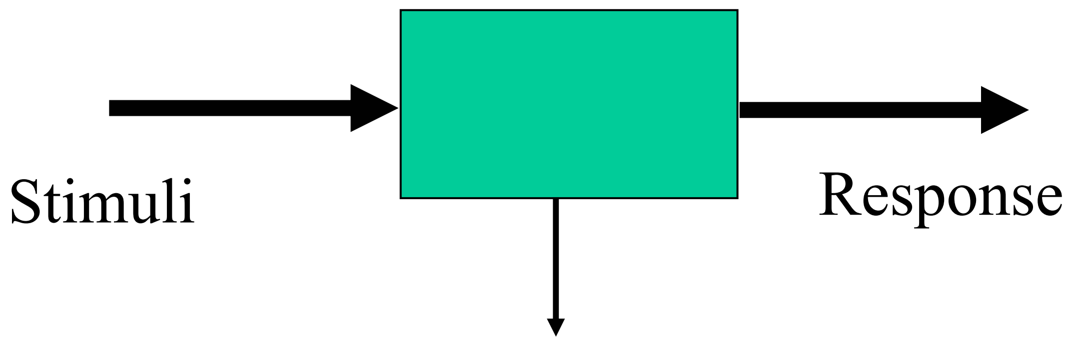


Image courtesy of JPL.

Planet Exploration Robotics

Behavior-Based Control

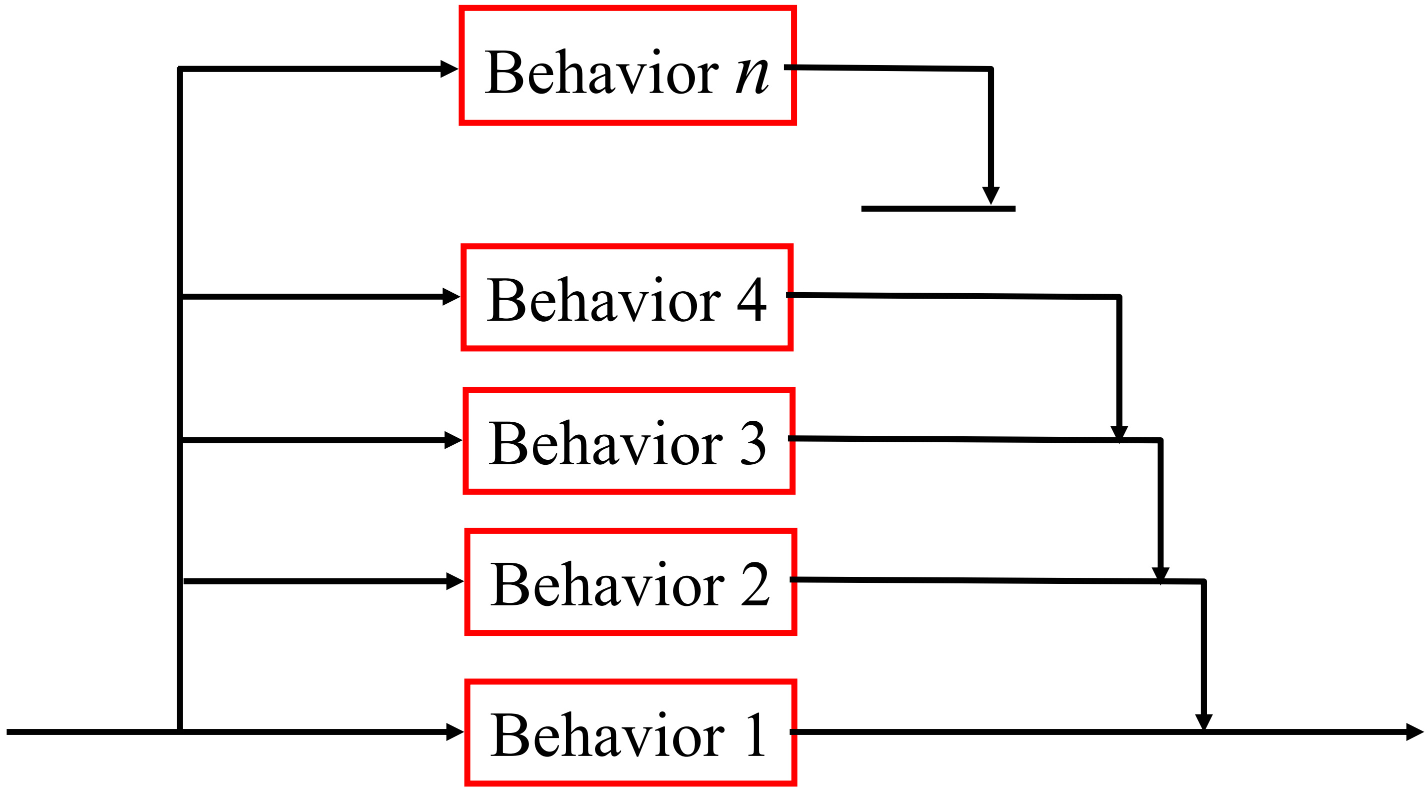
Behavior = Response to stimuli



No memory,
No abstract reasoning,
No symbolic knowledge,
No internal state,
No internal model

Subsumption Architecture

A higher level behavior subsumes all the lower level behaviors



Coordination based on Priority

Subsumption Architecture

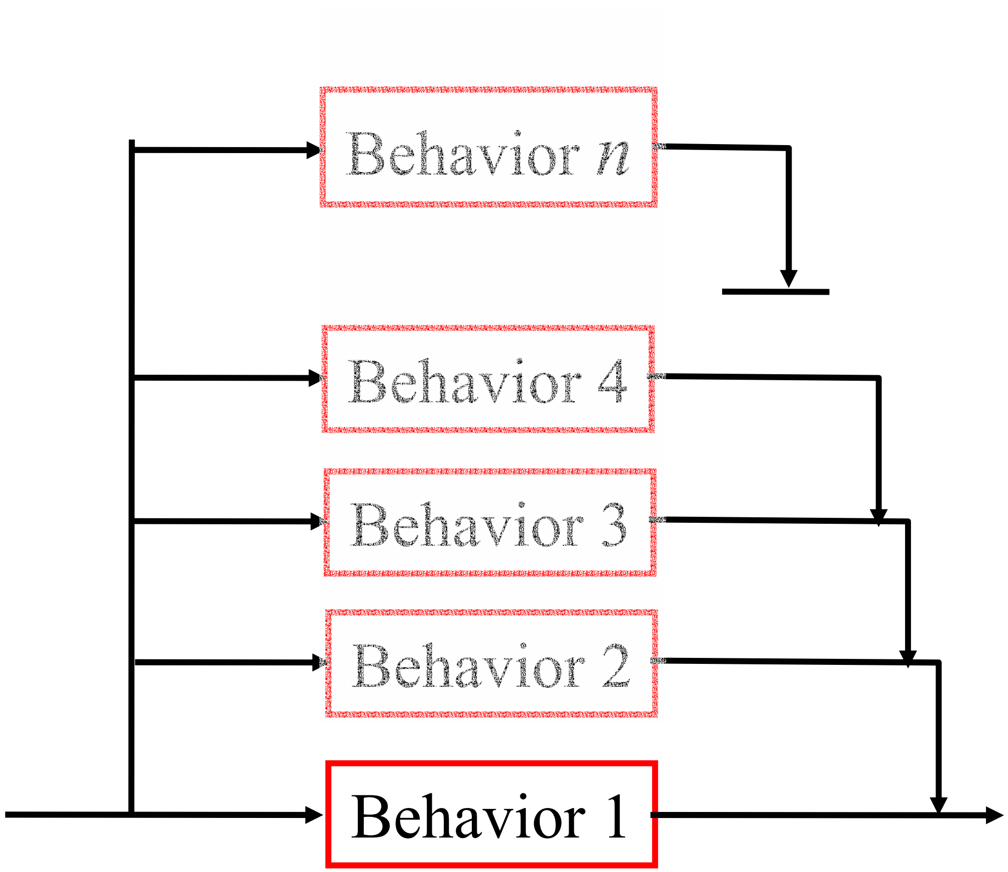


Photo of Sony Aibo™ robot (dog) removed for copyright reasons.

Walk

Subsumption Architecture

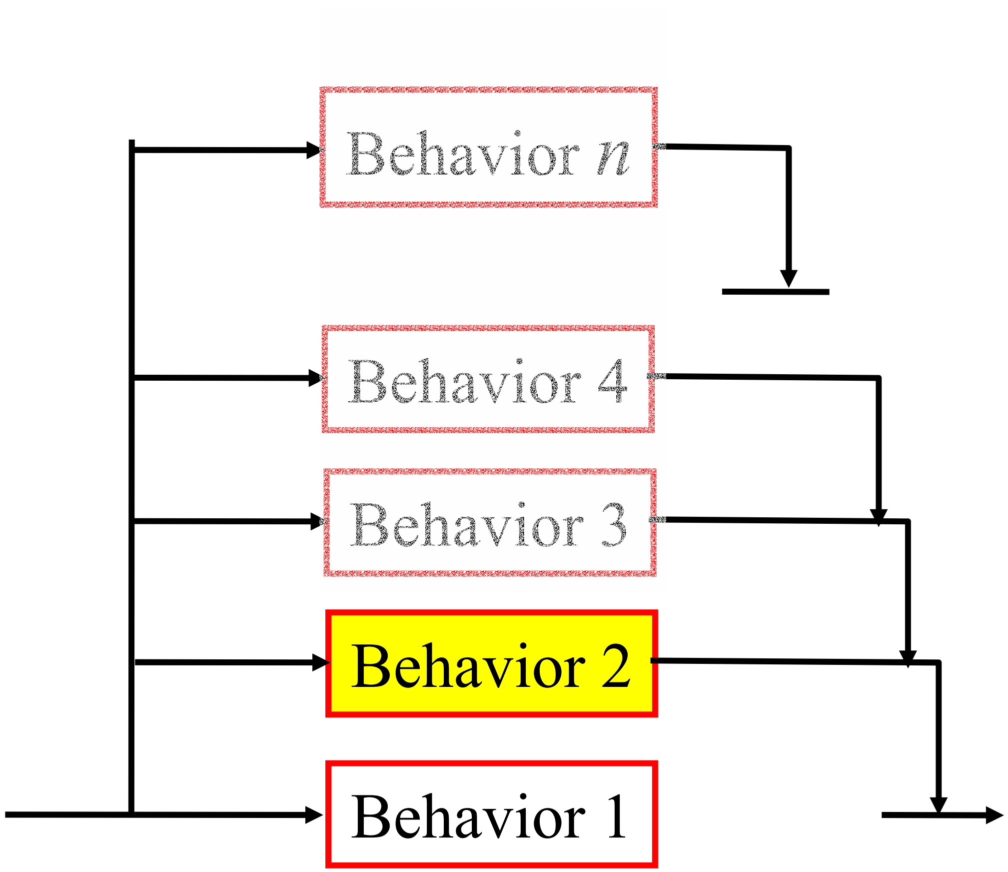


Photo of Sony Aibo™ robot (dog) removed for copyright reasons.

Chase

Subsumption Architecture

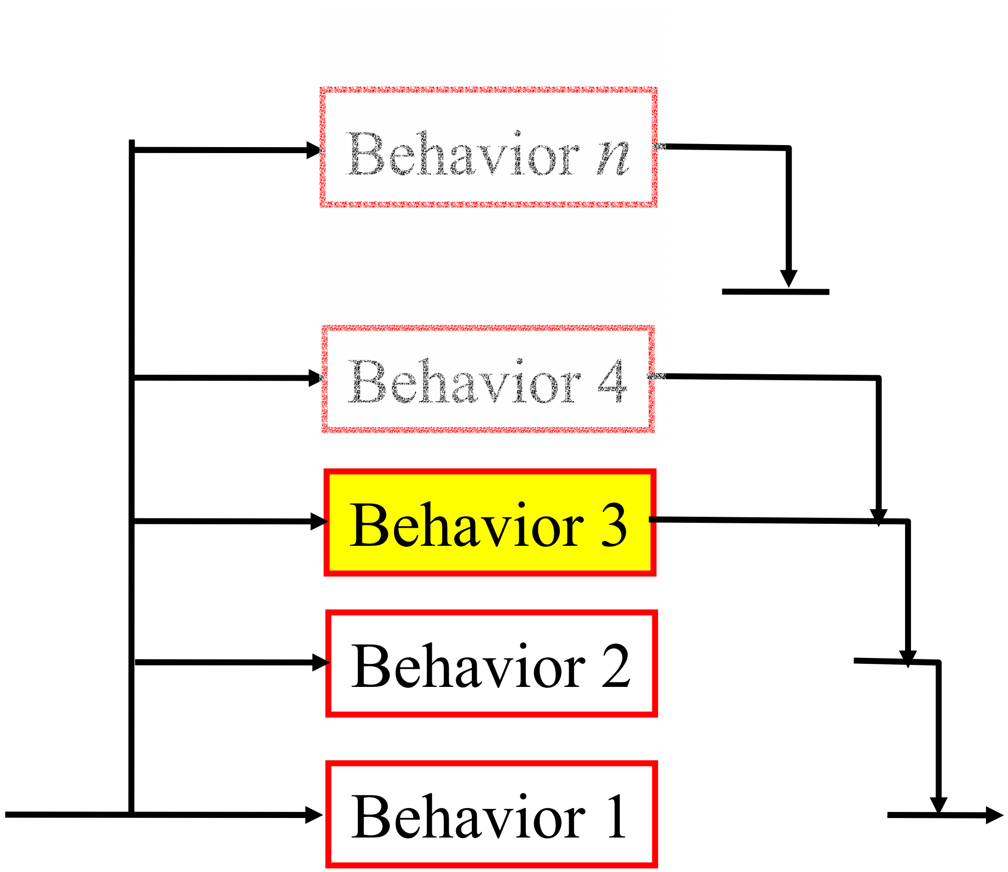
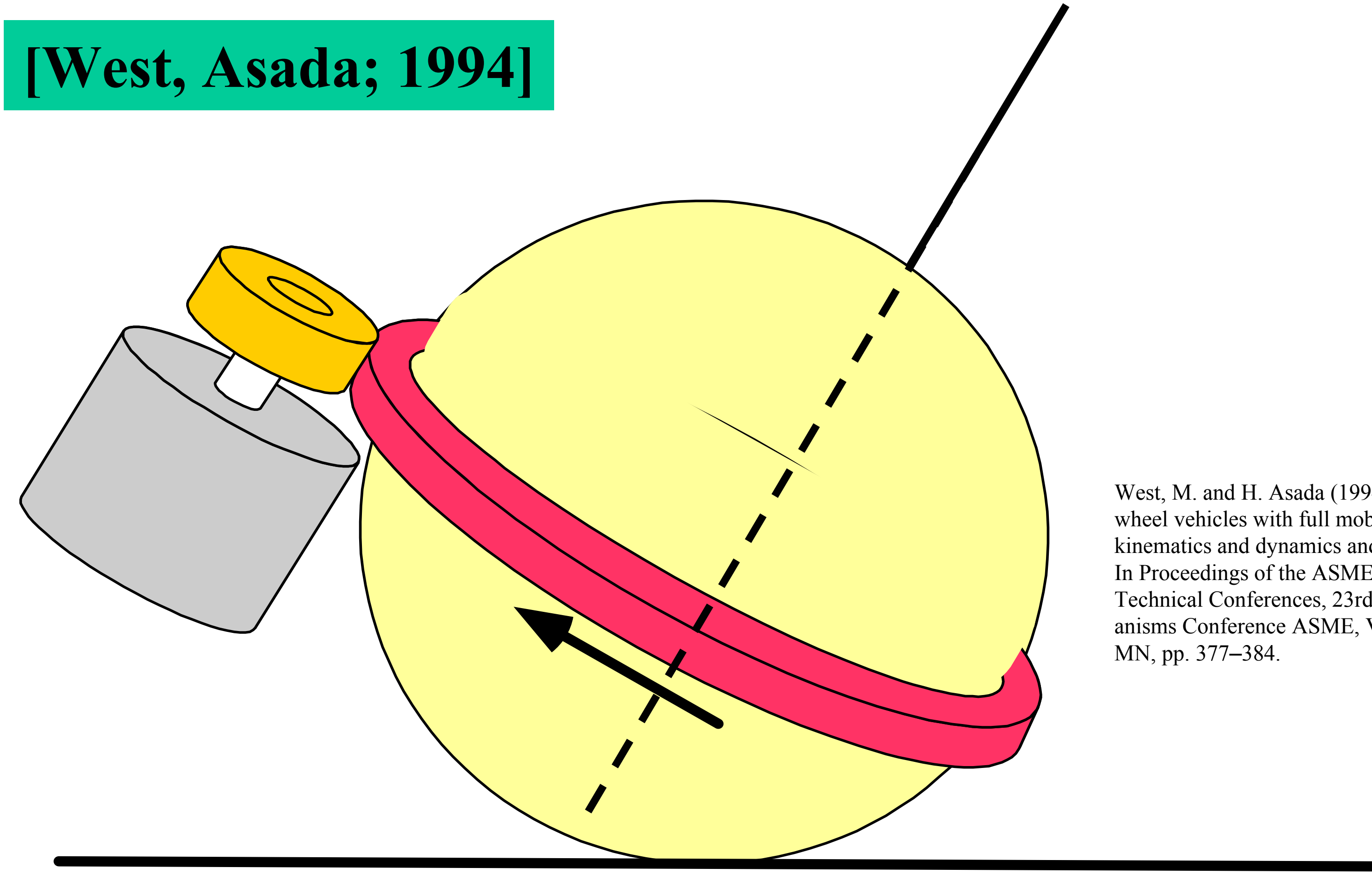


Photo of Sony Aibo™ robot (dog) removed for copyright reasons.

Bark

Ball Wheel Mechanism:
Onmi-Directional, Holonomic, and Configuration-Invariant Kinematics

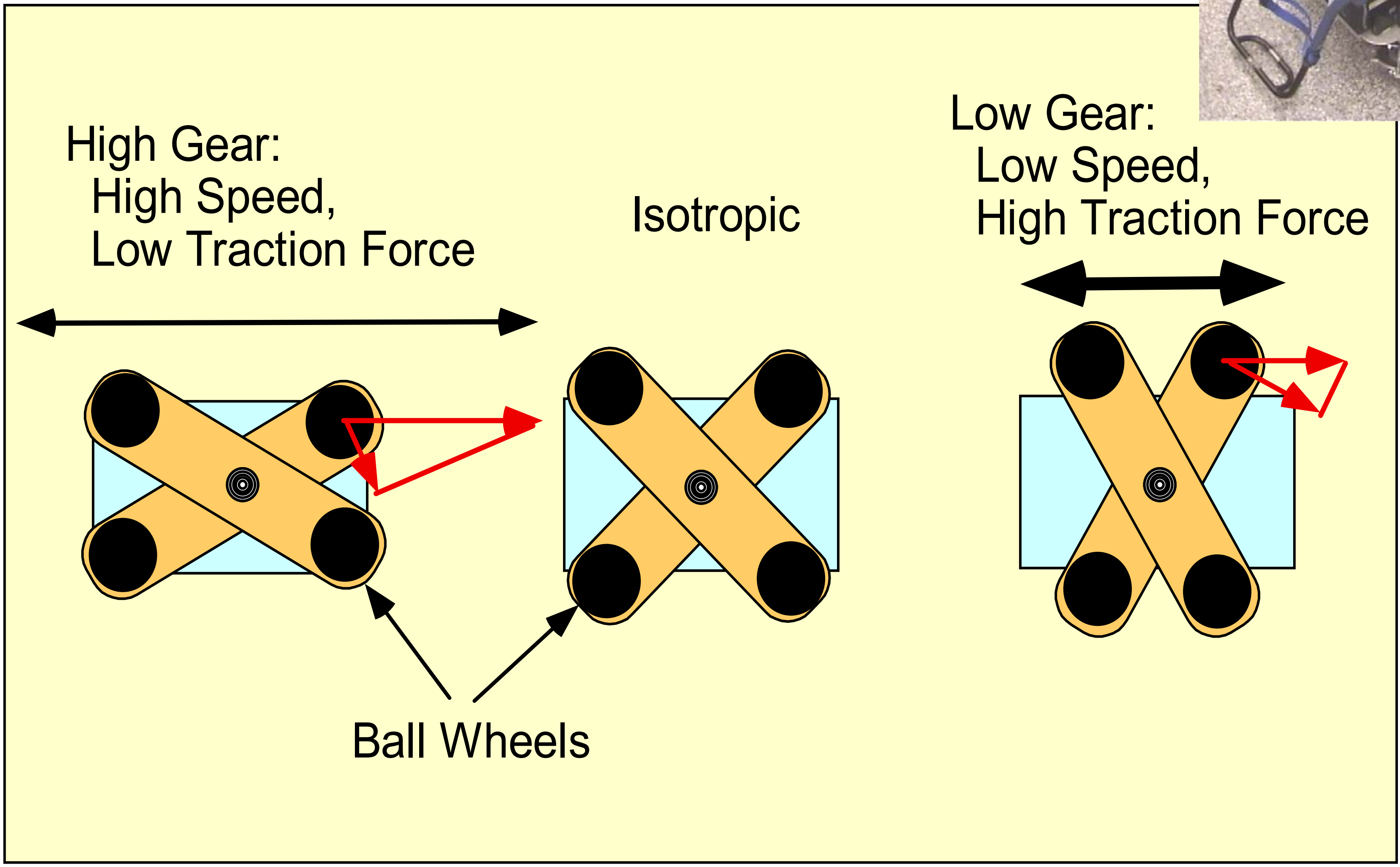
[West, Asada; 1994]



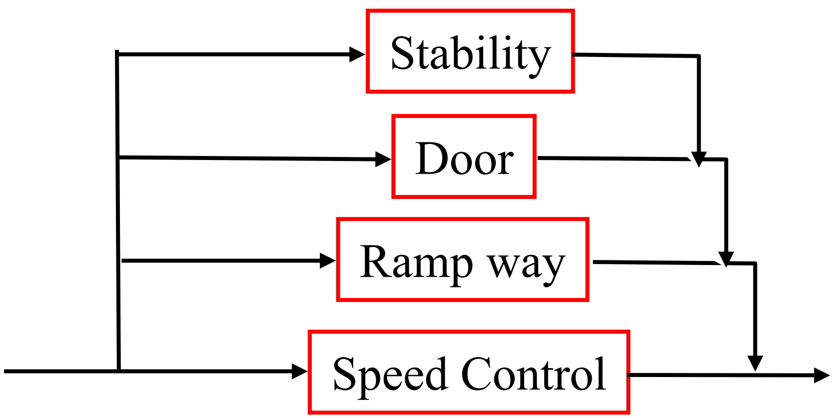
West, M. and H. Asada (1994). “Design of ball wheel vehicles with full mobility, invariant kinematics and dynamics and anti-slip control.” In Proceedings of the ASME Design Technical Conferences, 23rd Biennial Mechanisms Conference ASME, Volume 72, Minneapolis, MN, pp. 377–384.

The Cross Link Mechanism As a CVT

- Continuously Variable Transmission -



Subsumption Architecture for the Ball-wheel Chair



Coordination based on Priority

Medical Robotics

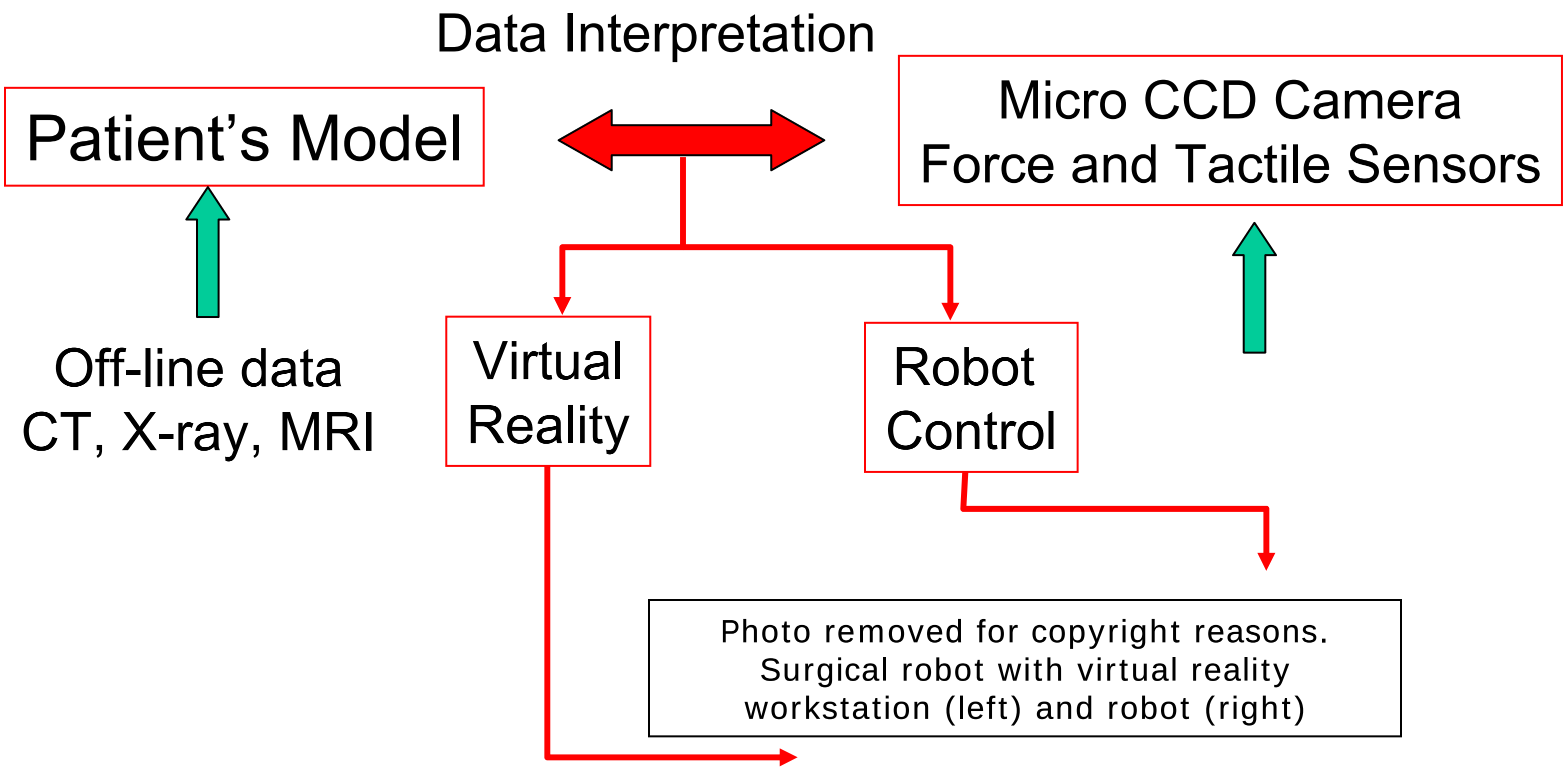
Photo removed for copyright reasons.

1994 Proposal of robotic hip replacement surgery
by Russell Taylor
1998 Minimally invasive surgery

Minimally-Invasive Surgery

Photo removed for copyright reasons.
Surgical robot with virtual reality
workstation (left) and robot (right)

Model-Sensor Data Matching



Surgical Robot System

Biologically-Inspired Actuators

Ball-Wheel Holonomic Wheelchair

RHOMBUS Hybrid Bed/Wheelchair

Fingernail Sensors

Repositioning Active Bed Sheet

Bio Robotics Research

H. Asada, MIT d'Arbeloff Lab

Surface Wave Actuators

Digital Human

Wearable Goniometry

Wearable Health Monitoring

Ring Sensor

Driver Monitoring

Fitness Monitoring

Health Chair

Cable-Free Smart Vest

Data Glove

Measurement of hand posture and touch force

Fingernail Sensors:

Measurement of Fingertip Touch Force and Posture through Nail Color Change

Photos removed for copyright reasons.

Free-Fingered Glove