Chapter 1 Robotics History

Lecture Notes for A Geometrical Introduction to Robotics and Manipulation

Richard Murray and Zexiang Li and Shankar S. Sastry CRC Press

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Updates: Shankar Sastry, Koushil Sreenath and Roberto Horowitz
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Robots and Robotics

Definition: Robot

"A *mechanical device* that sometimes resembles a human and is capable of performing a variety of often complex human tasks on command or being programmed in advance."

"A *machine* or *device* that operates automatically or by remote control."

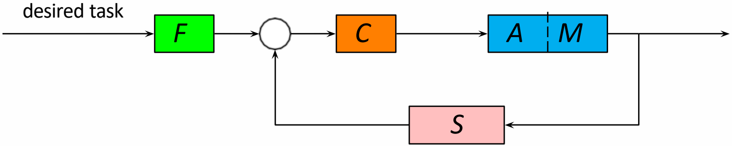
American Heritage Dictionary

Definition: Robotics

Science and technology of robots.

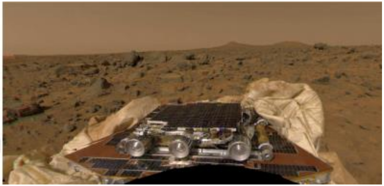
Robots and Robotics

◊ Function block description:



C: Control (Kinematics, dynamics, control)
A: Actuators (Motors, drives, servos, and transmissions)
M: Mechanisms (Synthesis and design)
S: Sensors (Signal processing, estimation, data fusion)
F: Feedforward (Motion planning and generation)





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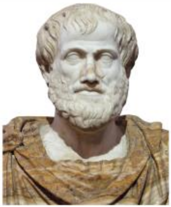
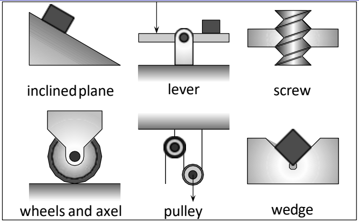
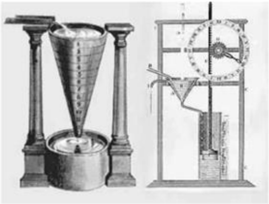




“If every tool, when ordered, or even of its own accord, could do the work that befits it... then there would be no need either of apprentices for the master workers or of slaves for the lords.”

Figure 1.2: Aristotle (384-322 B.C.): Six basic machine elements and description of a robot



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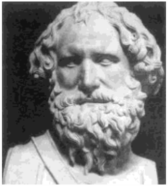

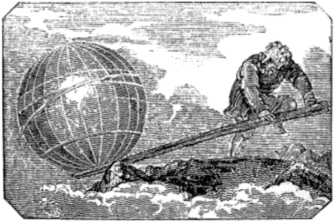

Figure 1.4: Archimedes (287 - 212 B.C.): Using six machine elements for machine design

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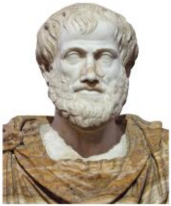

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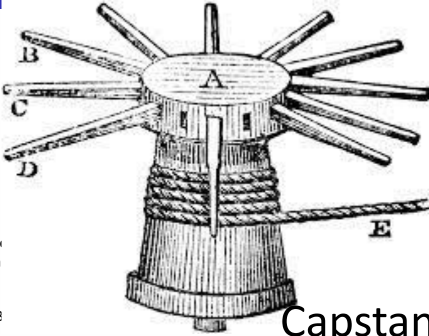
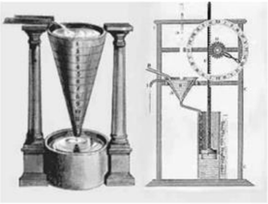
Figure 1.2: Aristotle (384-322 B
robot



Capstan



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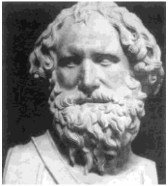

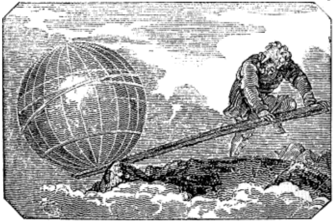

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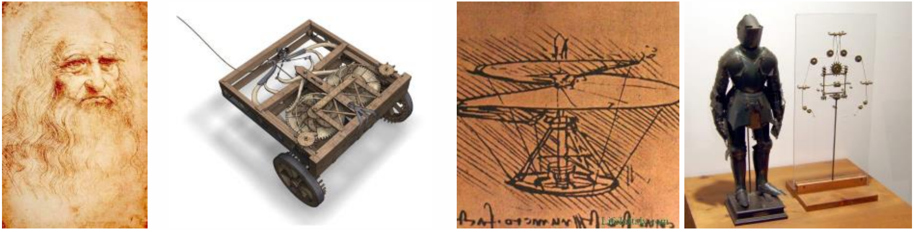

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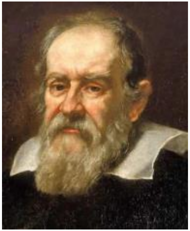

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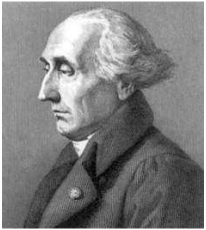

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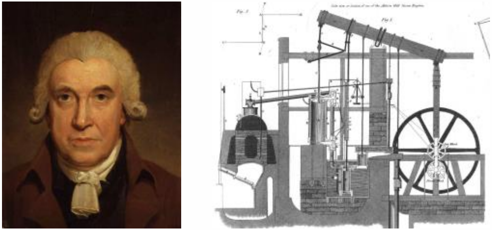

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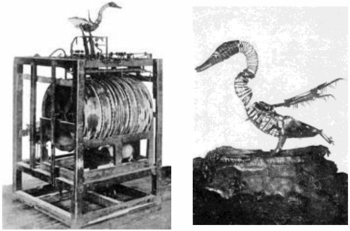

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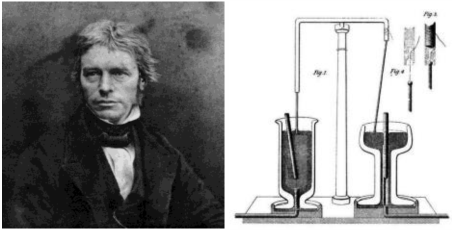
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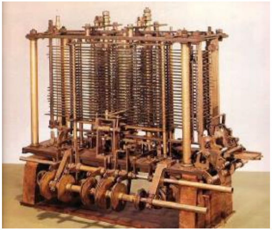
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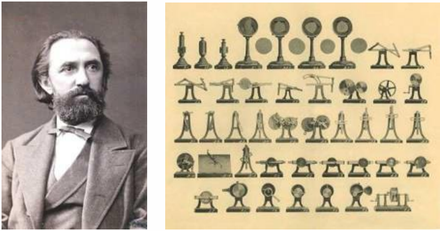

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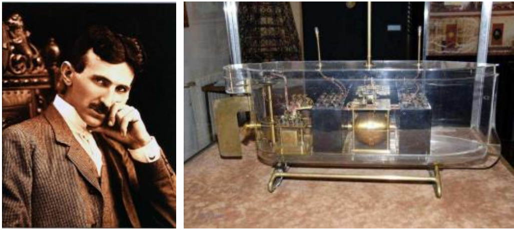

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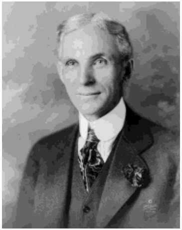

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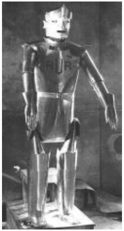

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Bomb Drops

Norden Bombsight

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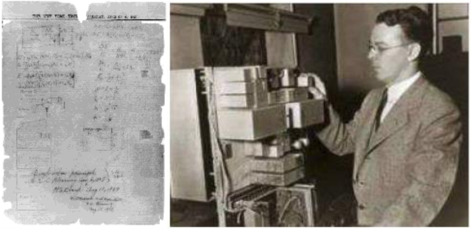

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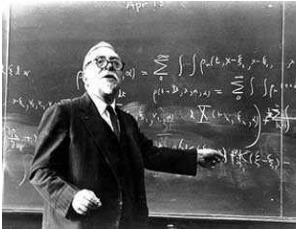

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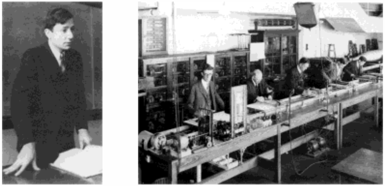

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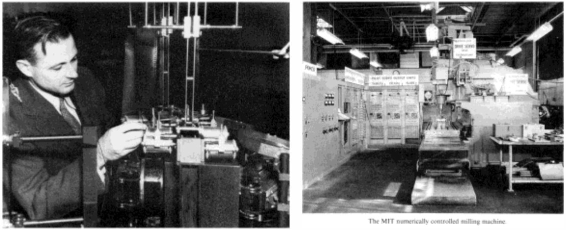

Figure 1.38: G. Brown (1952): First CNC machine and APT

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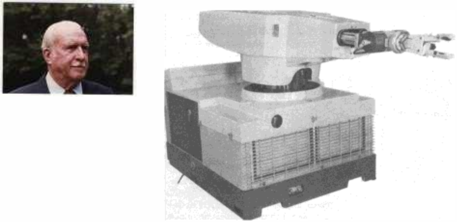
> 1.A robot may not injure a human being or, through inaction, allow a human being to come to harm.
> 2. A robot must obey any orders given to it by human beings, except where such orders would conflict with the First Law.
> 3.A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

Figure 1.39: I. Asimov (1950): Three Laws of arobot



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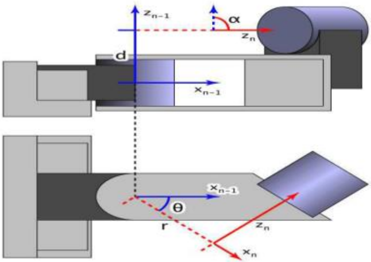

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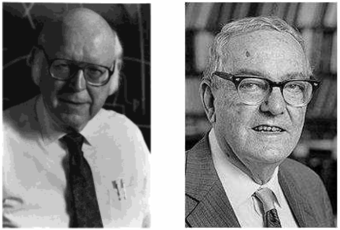

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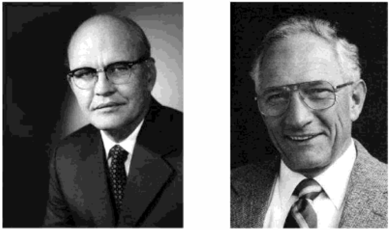

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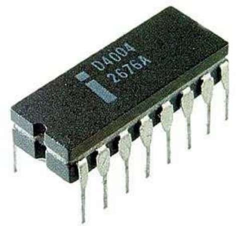

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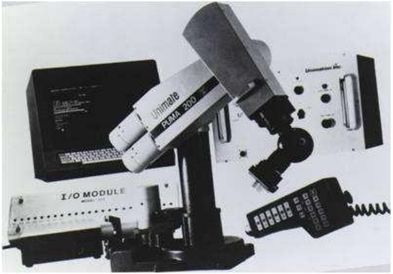

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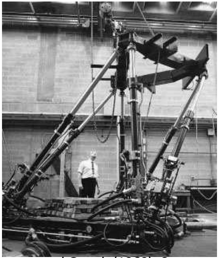

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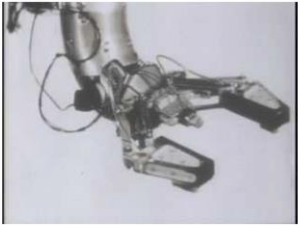

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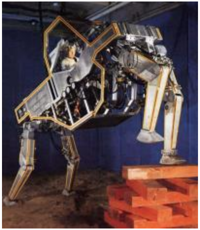

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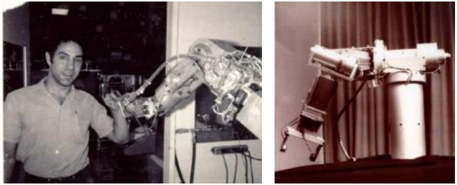

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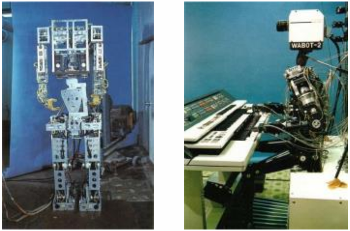

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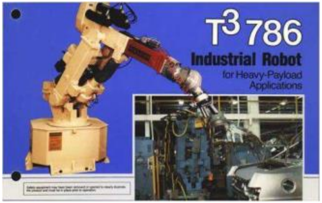

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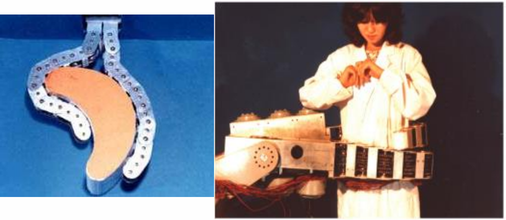

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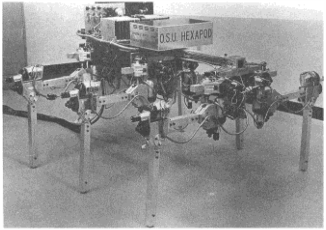

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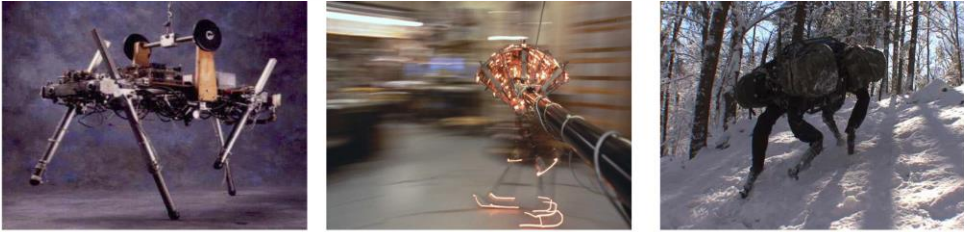

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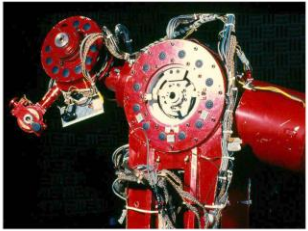

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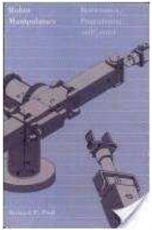
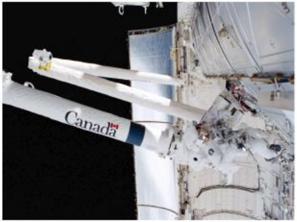


Figure 1.68: R. Paul (1981): Robot Manipulators: Mathematics, Programming, and Control. MIT Press.



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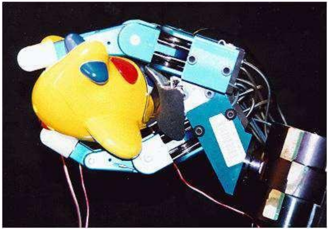

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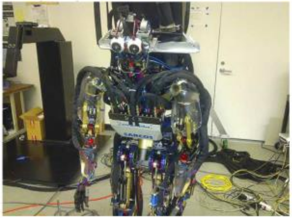

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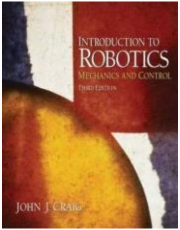

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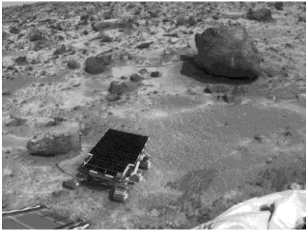

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QURIO

Figure 1.87: EPFL (1999): High Mobility Wheeled Rover, SHRIMP

Modern History (1961-)

Figure 1.88: Honda (2000):Humanoid Robot, ASIMO

ASIMO (1989-2000)

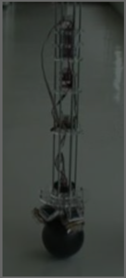

Segway


Ball Bot


Gyrover

Segway

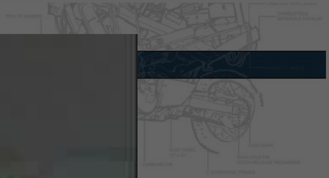
am Blue



Ball Bot

Gyrover

Segway



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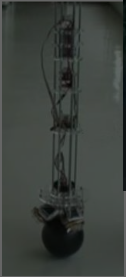
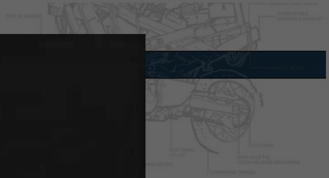


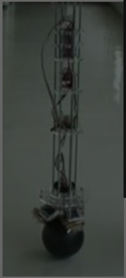
Ball Bot

Gyrover

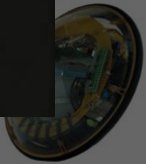
Segway



m Blue



Ball Bot



Gyrover

Modern History (1961-)

Figure 1.89: Defense Advanced Research Projects Agency (DARPA, 2004-): DARPA Grand Challenge

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Figure 1.91: DARPA Grand Challenge: Team Blue

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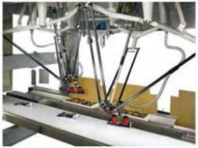
Figure 1.50: Stanford University(1963): Rancho Arm, the first artificial robotic arm to be controlled by a computer.



Play/Pause Stop

Figure 1.82: R. Clavel (1991): Delta robot

KUKA LBR iiwa

Amazon/Kiva

Kiva Systems

https://youtu.be/3UxZDJ1HiPE?t=5

New Vistas 2: Autonomous Driving

Play/Pause Stop

Figure 1.89: Defense Advanced Research Projects Agency (DARPA, 2004-): DARPA Grand/Urban Challenge

WAYMO

cruise

TOYOTA RESEARCH INSTITUTE

TESLA

VOLVO

IntelliSafe

UBER ATG

nuTonomy

lyft

Tesla FSD Beta

https://youtu.be/FqEqSs-TBG0

New Vistas 3: Aerial Robotics

Austria attacks Venice, 1849

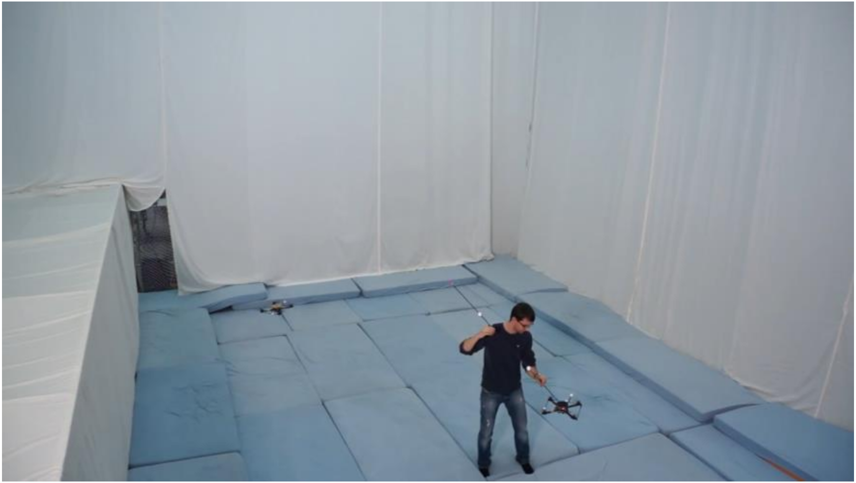
A.M. Low's "Aerial Target," 1916

DJI Phantom

Crazyflie

Berkeley Aerobots Sastry 2003

ETH Zurich – Raf D’Andrea



Cirque du Soleil, ETH Zurich and Verity Studios

https://youtu.be/6C8OJsHfmpI

New Vistas 4: Extreme Locomotion

Play/Pause Stop　　Play/Pause Stop　　Play/Pause Stop

Figure 1.65: M. Raibert (1980) (RI, CMU & AI lab, MIT): Hopping, Robots, Monoped, biped and Quadpeds. Dynamically stable quadruped robot BigDog created by Boston Dynamics (founded by M. Raibert in 1992) with the NASA Jet Propulsion Laboratory, Caltech (2005).

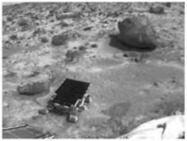


Figure 1.84: NASA (1996): Sojourner, NASA (First Manned Robot to land on Martian Surface)

ATLAS, Boston Dynamics

Snake robots, CMU Choset Lab

Salto, UCB Fearing Lab

Berkeley Humanoid, Sreenath's Lab UCB

New Vistas 5: Manipulation

Figure 1.9: P. Ambroise (Paris 1564): Design of a mechanical hand.

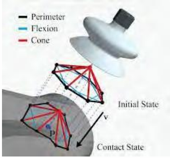
Play/Pause Stop

Figure 1.78: Utah/MIT (1989): Utah/MIT hand

Play/Pause Stop

Figure 1.85: DLR Hand (1998)

"Jamming" robot manipulator



Dex-Net 2.0, UCB Goldberg Lab

Google Robotics "arm farm"

OpenAI – Solving the Rubic’s Cube Single-Handed

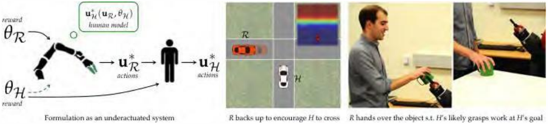
https://youtu.be/kVmp0uGtShk

New Vistas 6: Human-Robot Interaction (HRI)

“
1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey any orders given to it by human beings, except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.
”

Figure 1.39: I. Asimov (1950): Three Laws of a robot

BCI, University of Pittsburgh, 2008



Human intent inference, UCB Sastry / Dragan Lab

BiOM prosthesis, MIT Herr Lab

Kinova Jaco arm

APEX exoskeleton, UCB Bajcsy Lab

Robot-Aided Surgery

Play/Pause Stop

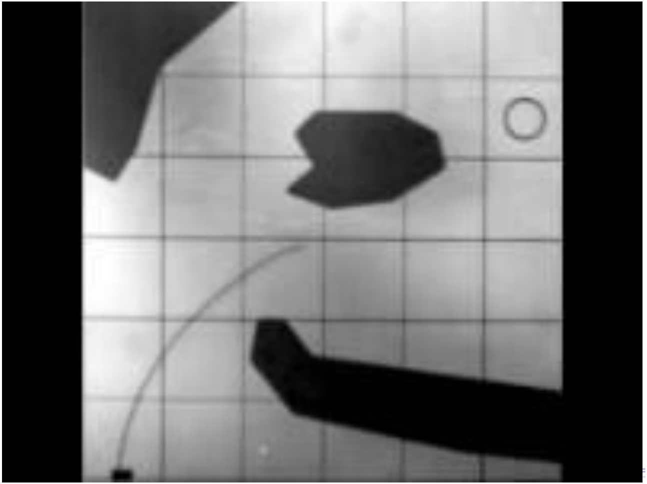
Figure 1.83: Da Vinci robot by Intuitive surgical (1995)

Telesurgery Workstation 1999
Sastry

Phantom haptic device

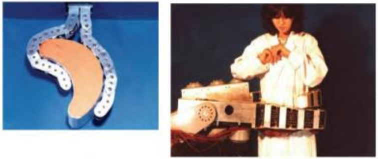
Robot cutting and suturing, UCB Goldberg/Abbeel Lab

Steerable Needles



https://youtu.be/C66GySBmNHw

New Vistas 7: Soft Robotics



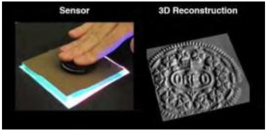
Play/Pause Stop

Figure 1.59: S. Hirose (1976): The soft gripper

G. Pratt (1995): Series elastic actuator (SEA)

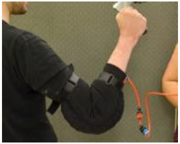
Okamura Lab

Octobot, Harvard
Lewis Lab



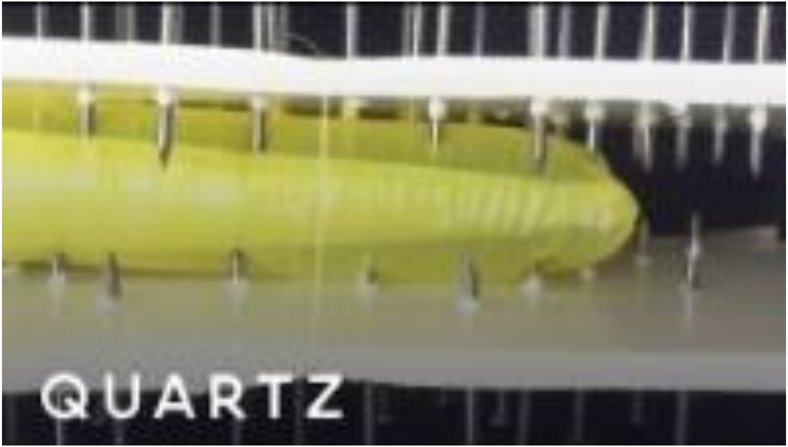
GelSight sensor, MIT

Soft optical sensor/actuator, UCB
Bajcsy/Fearing/Goldberg Lab



Soft exoskeleton,
UCB Bajcsy Lab

Vine Robots



https://youtu.be/jXWfThyEIc4

New Vistas 8: Space Robotics

SpaceX Grasshopper

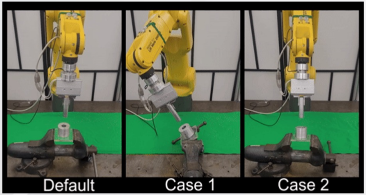
SpaceX Starship

NASA Perseverance

NASA Ingenuity

New Vistas 9: Machine Learning

Horowitz' Lab UCB
Contact-rich Robot Manipulation Task Learning Leveraging Group Invariance and Equivariance



- A differential geometric control approach to increase transferability in learning robot manipulation tasks that involve contact-rich interaction with the environment.
- A control law and a learning representation framework that remains invariant under arbitrary SE(3) transformations of the manipulation task definition.
- Based on utilizing a recently presented geometric impedance control (GIC), the gain scheduling policy is trained in a supervised learning fashion from expert demonstrations.
- A hardware implementation on a peg-in-hole task is conducted to validate the learning transferability and feasibility of the proposed approach.

Video demos from UC Berkeley

SE(3) Special Euclidean Group – the set of all rigid body rotations and translations

https://sites.google.com/berkeley.edu/equivariant-task-learning/home

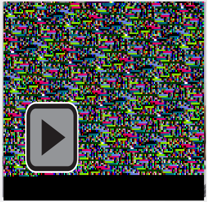
New Vistas 9: Machine Learning

Horowitz' Lab:
Diffusion-EDFs: Bi-equivariant Denoising Generative Modeling for Visual Robotic Manipulation

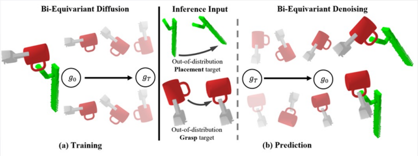
- We are working on Diffusion Equivariant Descriptor Fields (Diffusion-EDFs), a novel approach that incorporates spatial roto-translation equivariance, i.e., SE(3)-equivariance to diffusion generative learning models.
- By integrating SE(3)-equivariance into our model architectures, we demonstrate that our proposed method exhibits remarkable data efficiency, requiring only 5 to 10 task demonstrations for effective end-to-end training.
- Our approach showcases superior generalizability compared to previous diffusion-based vision manipulation methods.

Video demos from Prof. J. Choi's laboratory in Yonsei University, Seoul, Korea

Training



Executing training



https://sites.google.com/view/diffusion-edfs

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