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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June 30, 2012

Updates: Shankar Sastry and Koushil Sreenath
Aug 25, 2022

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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."

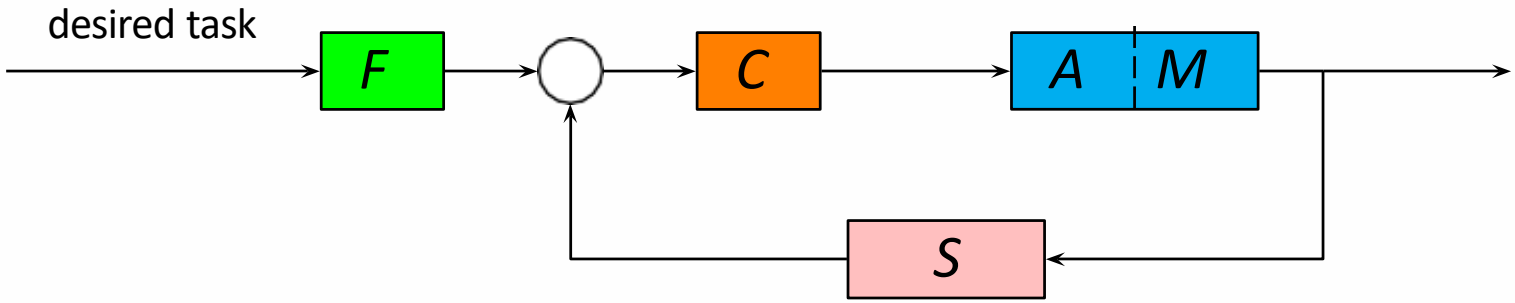
American Heritage Dictionary

Definition: Robotics

Science and technology of robots.

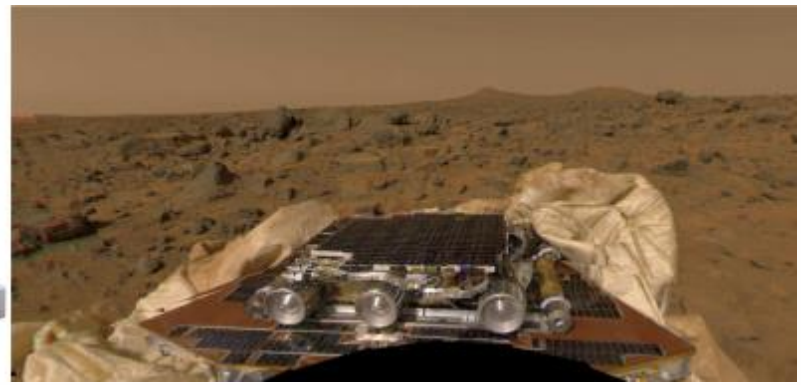
Robots and Robotics

◊ 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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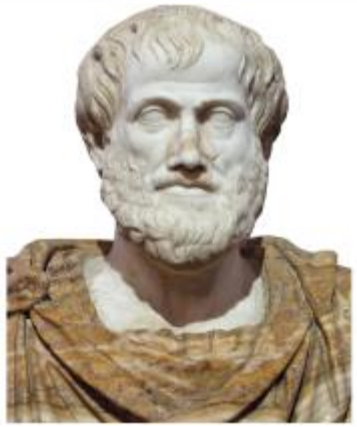
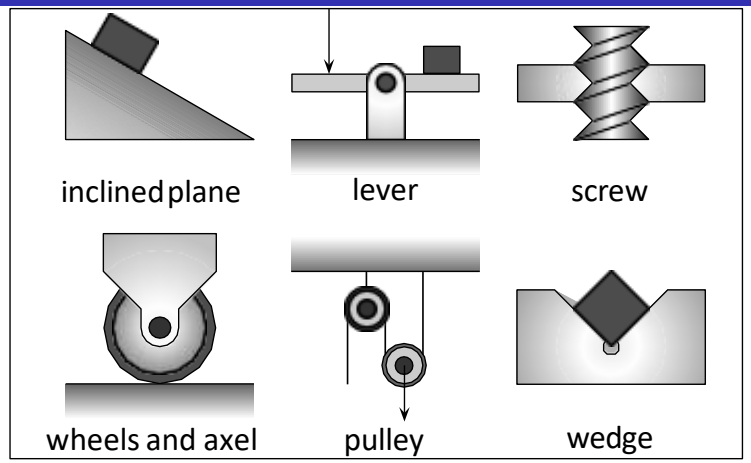




"If every tool, when ordered, or even of its own accord, could do the work that befits it... then there would be no need either of apprentices for the master workers or of slaves for the lords."

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

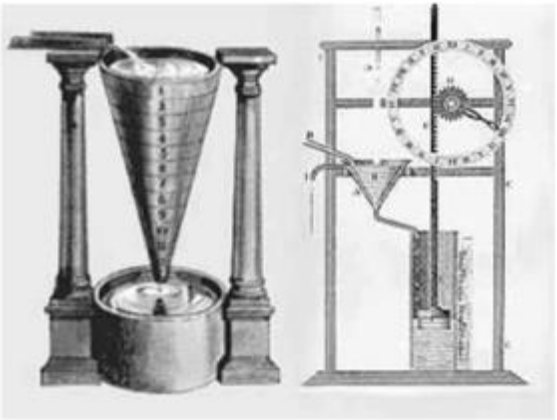
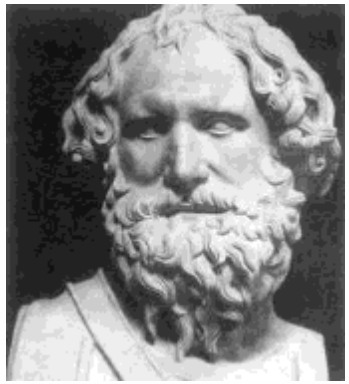


Figure 1.3: Ctesibius (Greek engineer, 270 B.C.): Water clock



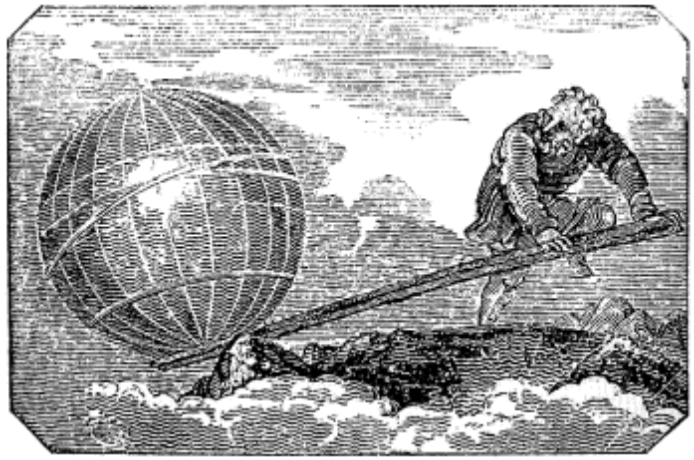


Figure 1.4: Archimedes (287 - 212 B.C.): Using six machine elements for machine design

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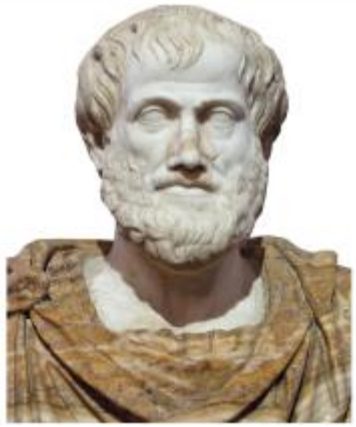

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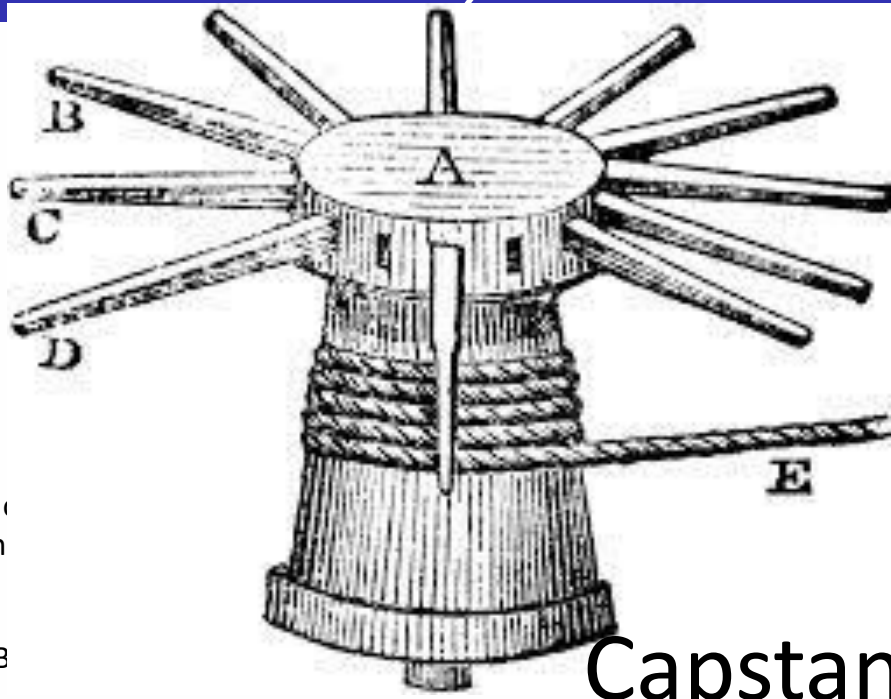
Figure 1.2: Aristotle (384-322 B robot



Capstan

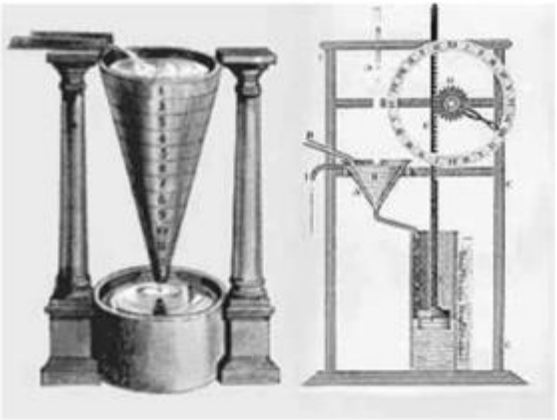
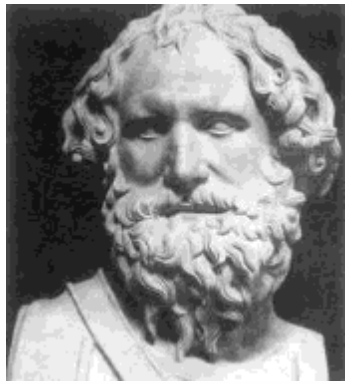


Figure 1.3: Ctesibius (Greek engineer, 270 B.C.): Water clock



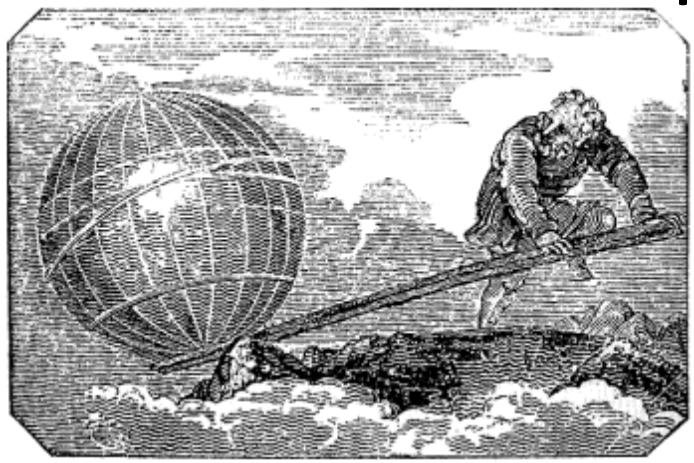


Figure 1.4: Archimedes (287 - 212 B.C.): Using six machine elements for machine design

Ancient History (3000 B.C.-1450 A.D.)

Figure 1.5: Heron of Alexandria (85 A.D.): Automatic theater and a steam engine

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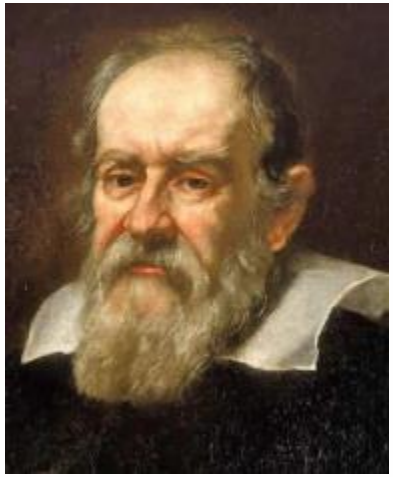
Figure 1.9: P. Ambroise (Paris 1564): Design of a mechan- ical hand.



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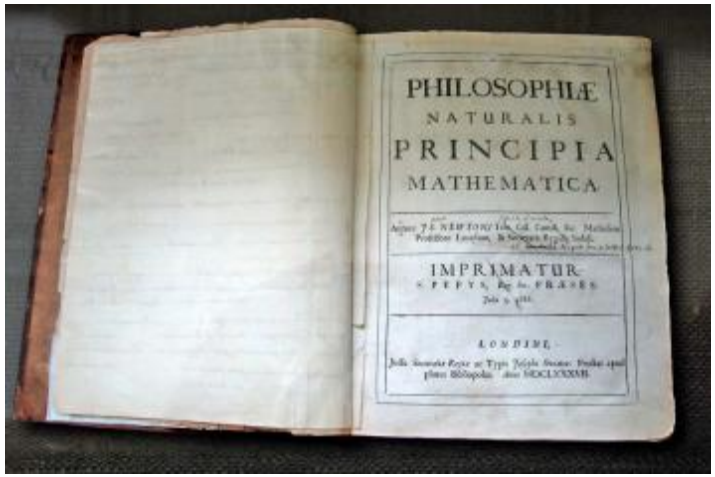

Figure 1.11: Isaac Newton (1642-1727): Calculus and Laws of Motion

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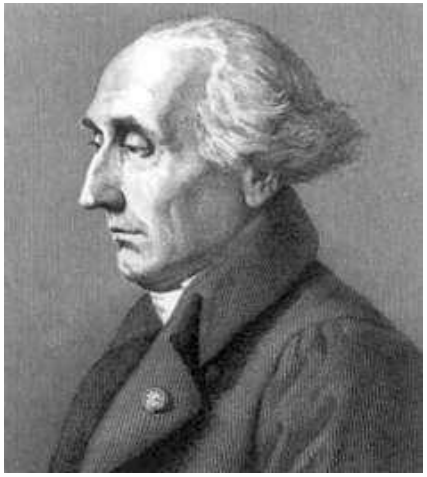
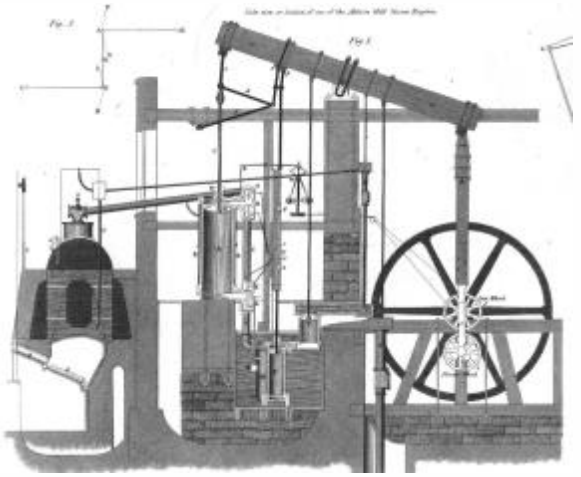


Figure 1.13: J. Lagrange (1736-1813): Calculus of variation and Principles of least action.



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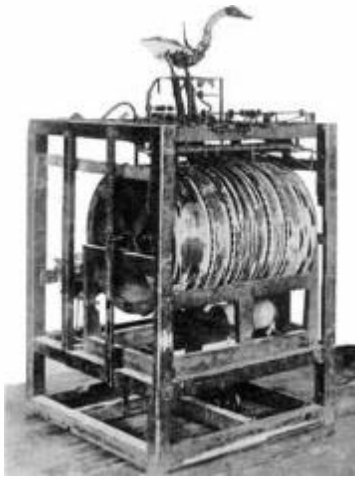

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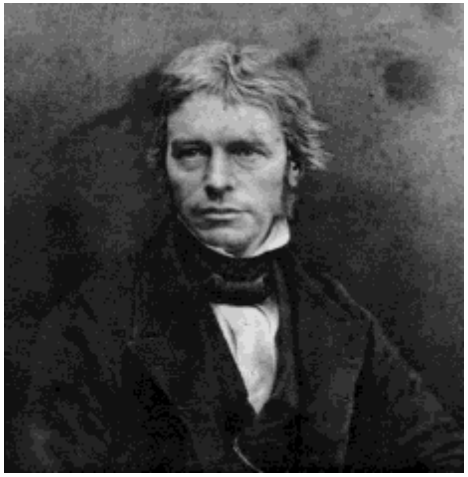
Figure 1.20: G. Boole (1815-1864): Theory of binary logic.



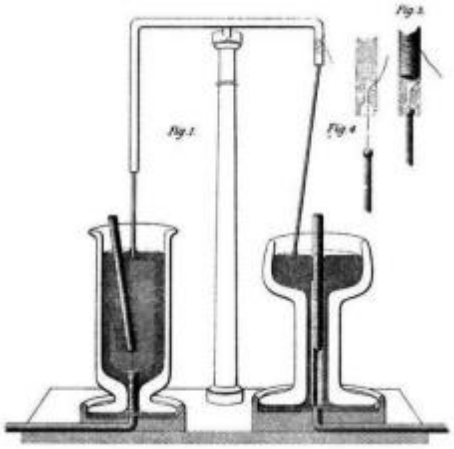


Figure 1.21: M. Farady (1821): electromagnetic rotation and motors.

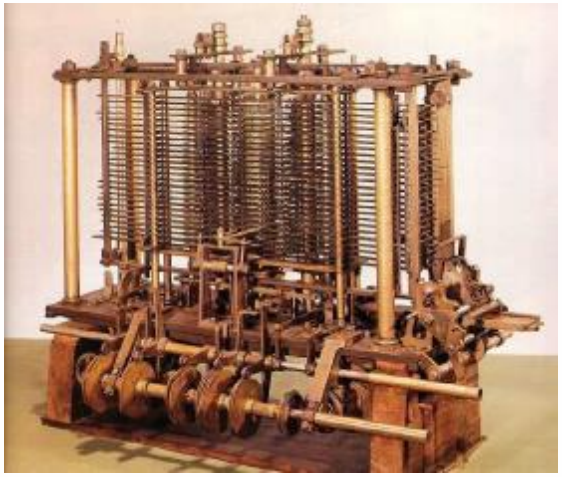


Figure 1.22: C. Babbage (1822): Difference and analytic engines.

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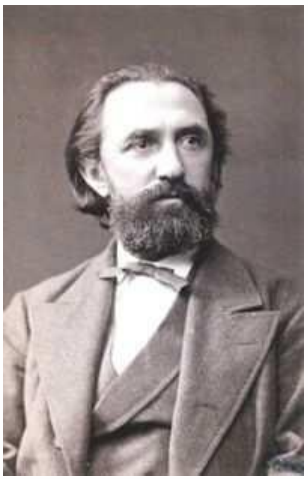

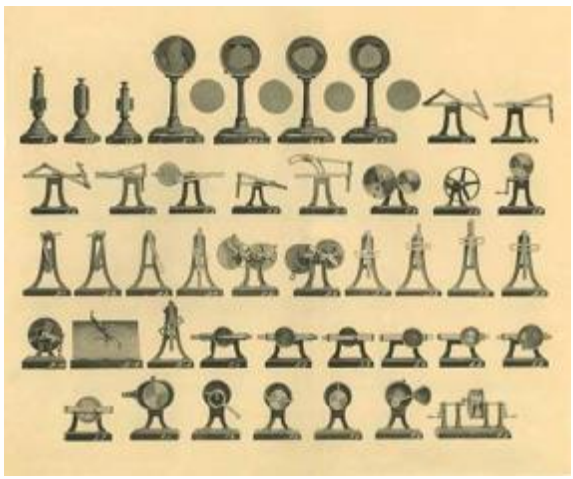

Figure 1.23: F. Reuleaux (1829-1905): Lower pairs and modern kinematics.

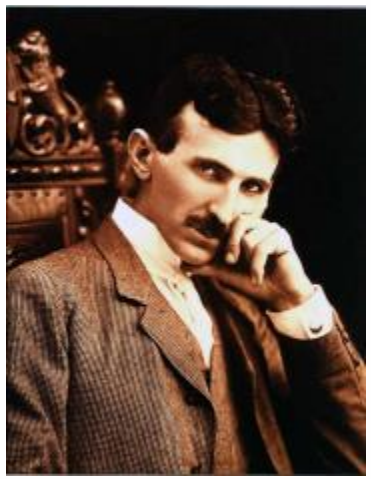

Figure 1.24: Nikola Tesla (1898): Remote controlled robot boat.

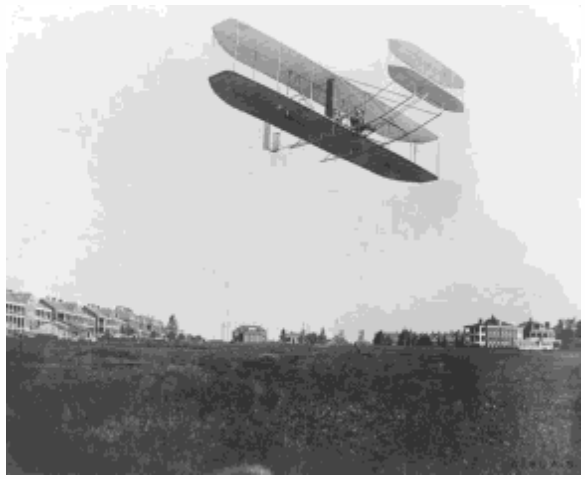

Figure 1.25: O. Wright (1908): First poweredflight.

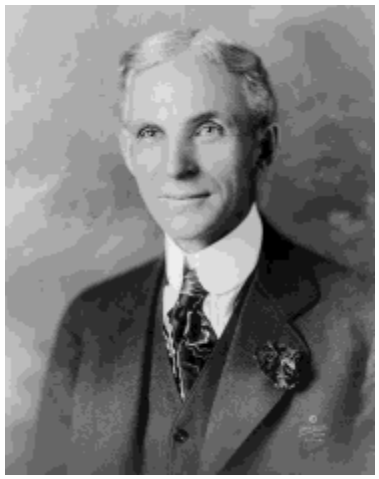

Figure 1.26: Henry Ford (1903): Assembly-line method of automated production.

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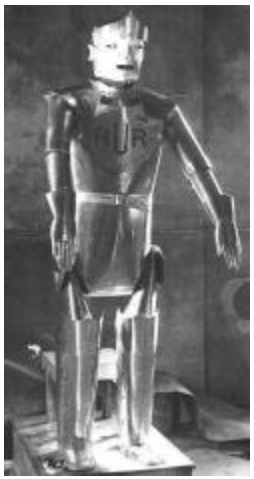

Figure 1.27: Karel Capek (1921): Coined the word "ROBOT"in a play called "RUR"(Rossum's Universal Robots)

Figure 1.28: V. Bush (1927): Analog computer.

Figure 1.29: Nyquist and Bode (1932, 1938): Classic control.

Figure 1.30: A. Turing (1936): Machine Intelligence

Bomb Drops

Norden Bombsight

Early History (1451 A.D.-1960)

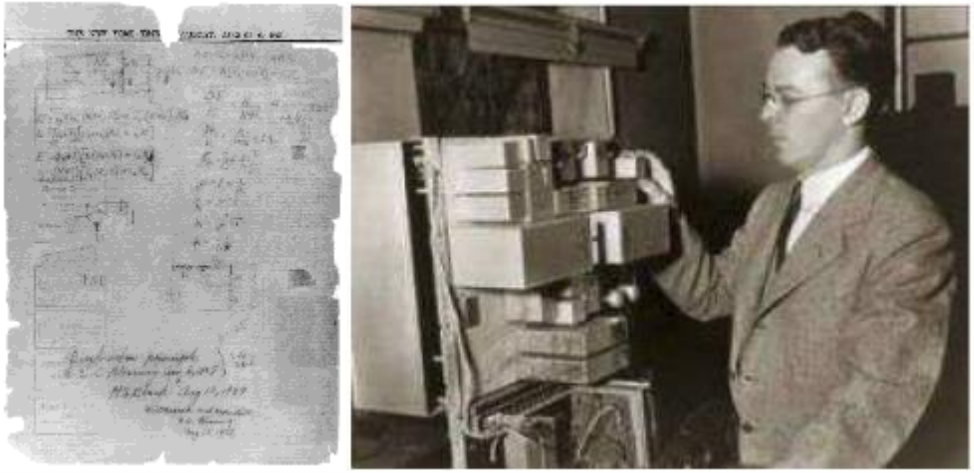

Figure 1.31: H. black (1898-1983): Negative feedback

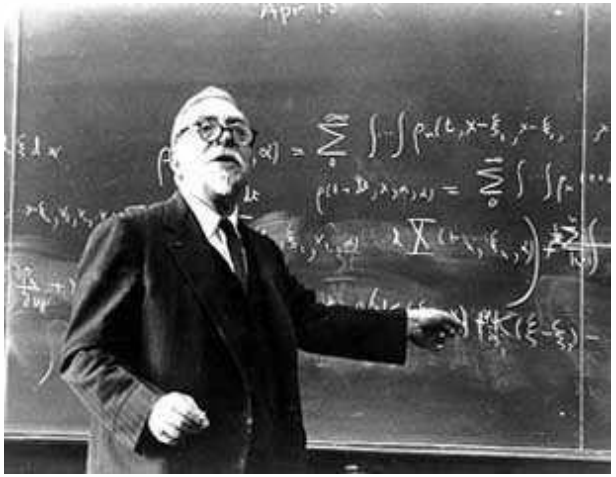

Figure 1.32: N. Wiener (1894-1964): Cybernetics

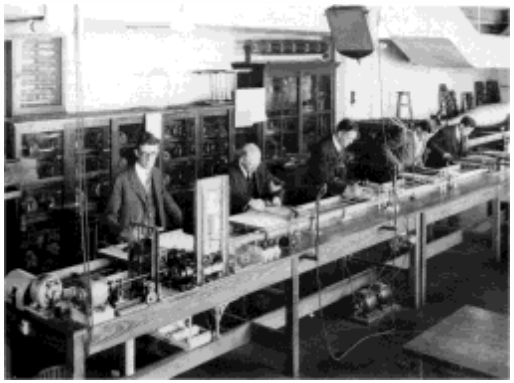

Figure 1.33: Hazen (1934): Theory of servomechanism.

Figure 1.34: R. Kalman (1930-): Modern control and Kalman filter

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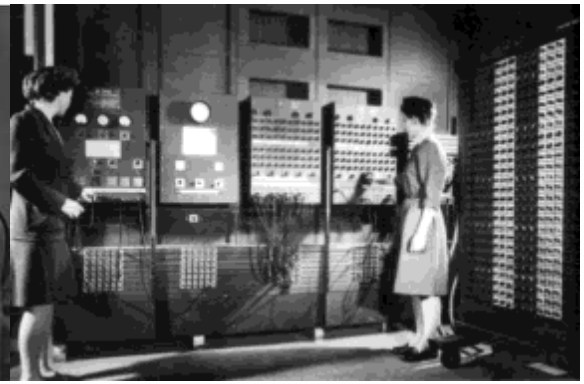
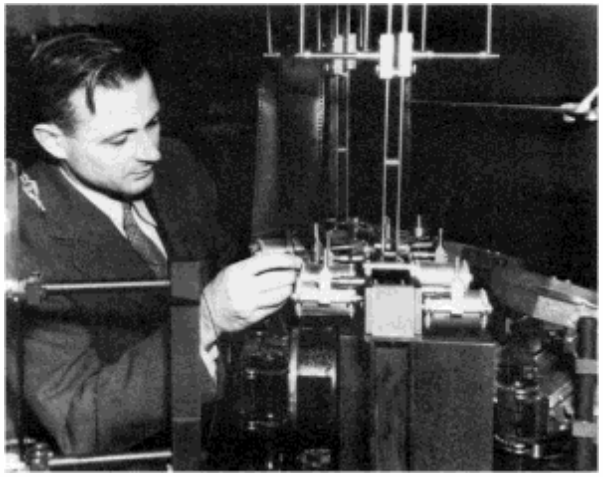
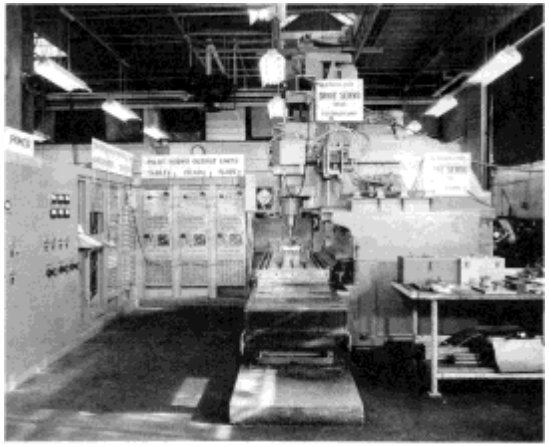


Figure 1.35: J. Eckert and J. Mauchley (1946): developed ENIAC, electronic digital computer

Figure 1.36: J. Von Neumann (1903-1957): Game theory and Von Neumann architecture.

Figure 1.37: Goertz at Argonne & Oakridge National Lab (1948): Telemanipulator.





The MIT numerically controlled milling machine

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

Early History (1451 A.D.-1960)

"

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

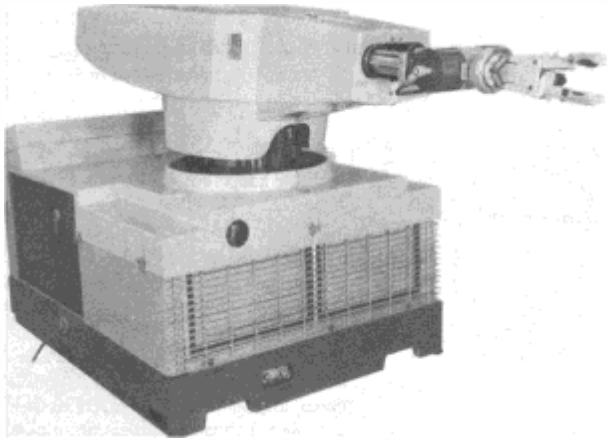


Figure 1.40: George Devol filed first robot patent (1954).

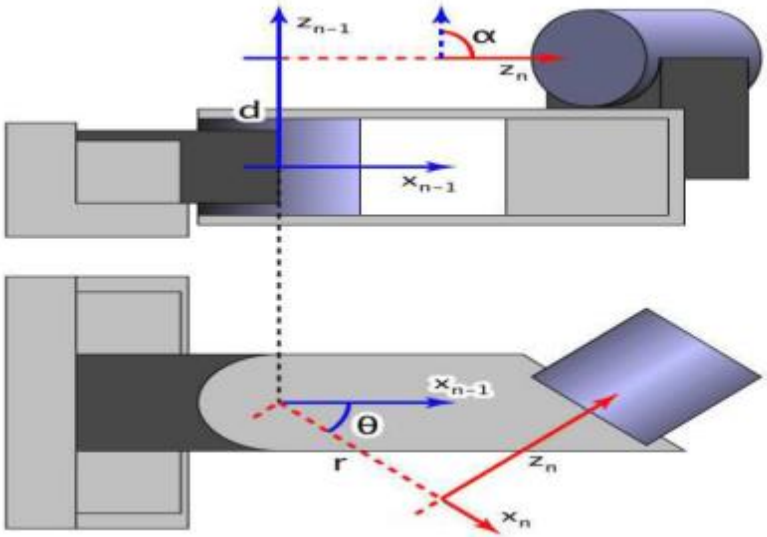


Figure 1.41: J. Denavit and R.S. Hartenberg (1956): Homogeneous transformations for Lower-pair mechanisms.

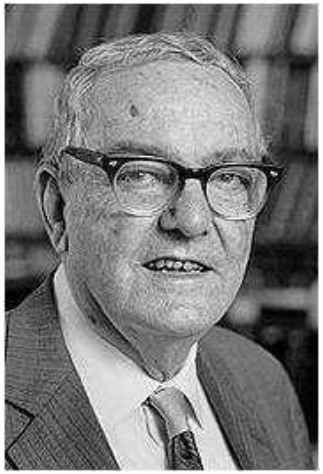


Figure 1.42: A. Newell and H. Simon (1956): Expert system

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Figure 1.43: Marvin Minsky and John McCarthy (1956): AI lab at MIT

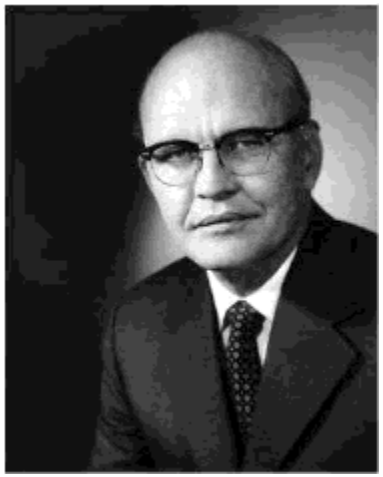

Figure 1.44: J. Kilby and R. Noyce (1958-1959): Integrated circuit

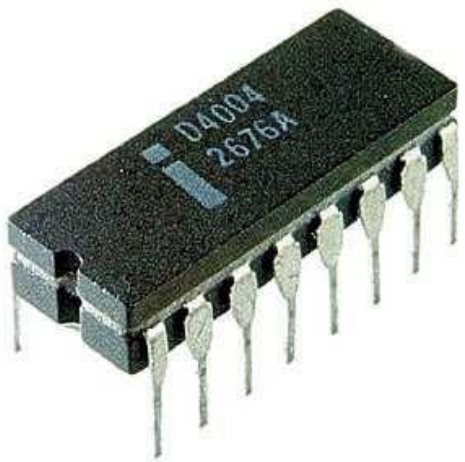

Figure 1.45: F. Faggin, T. Hoff and S. Mazor (1971): First microprocessor

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Modern History (1961-)

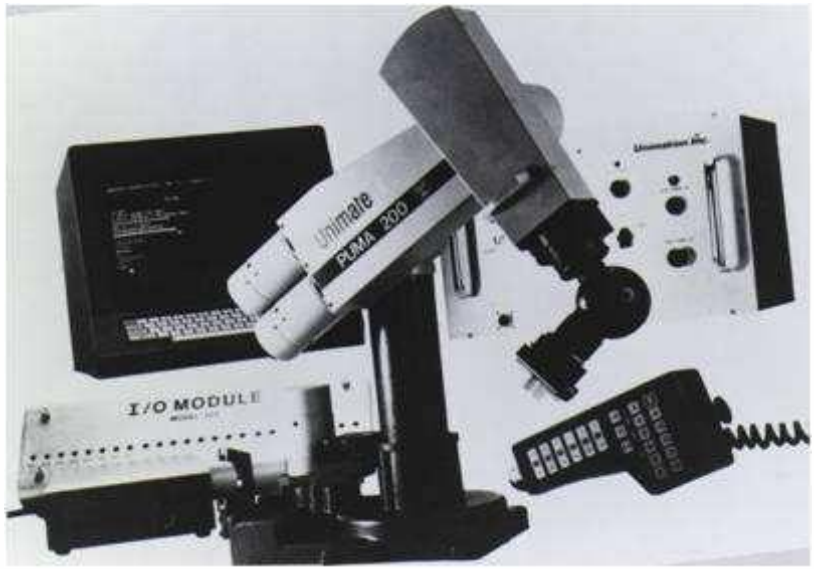

Figure 1.46: George Devol and Joseph Engelberger founded Unimation (1961), which installed the first industry robot at a GM plant in Trenton, New Jersy.

Figure 1.47: American Machine Foundry (AMF 1960) markets Versatran, a cylindrical robot.

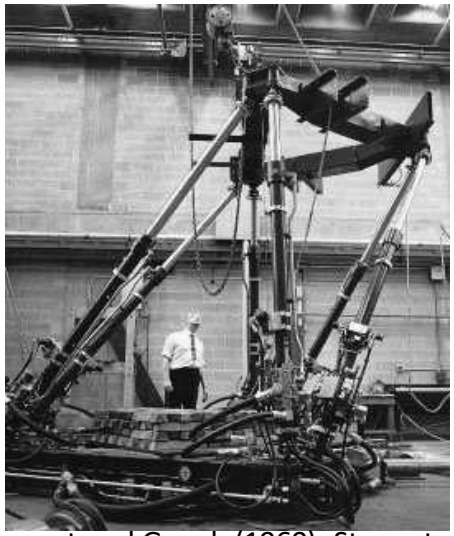

Figure 1.48: Stewart and Gough (1960): Stewart platform

Modern History (1961-)

Figure 1.49: H. A. Ernst (MIT 1961): Computer control of mechanical arms using touch sensor.

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

1.51: Research on robot kinematics and design initiated by B. Roth (1964), D. Pieper (1968), K. J. Waldron (1972), etc.

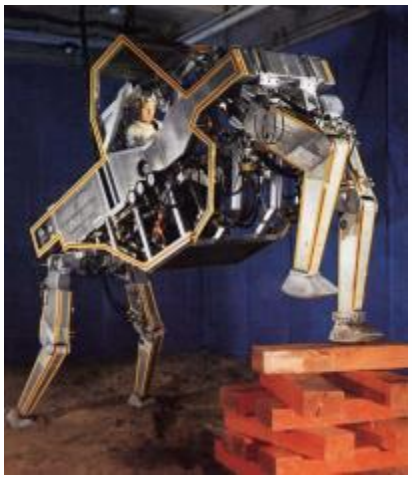

Figure 1.52: R. Mosher at General Electric (1968): quadrupled walking machine (11 ft tall, 3000lb)

Modern History (1961-)

Figure 1.53: Kawasaki robots in Japan with a patent from Unimation (1968)

Figure 1.54: V. Scheinman (1969): The Stanford arm

Figure 1.55: Draper Lab (1970) (RCC Device), SCARA robots by H. Makino, Japan (1978), Adept Robotics (1982)

Figure 1.56: Yaskawa engineers coined the term "Mechatronics" (1971)

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Figure 1.57: Waseda University develops Wabot-1 (1973) and Wabot-2 (1980)

Figure 1.58: Cincinnati Milacron (1974): (T3 Robots) Payload (100lb)

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

Figure 1.60: Viking 1 and 2 space probes, equipped with robot arms (1976)

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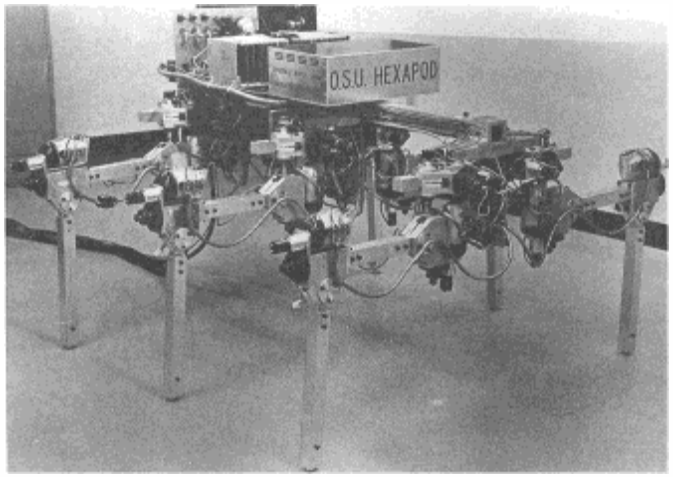


Figure 1.61: OSU Hexapod (1977)

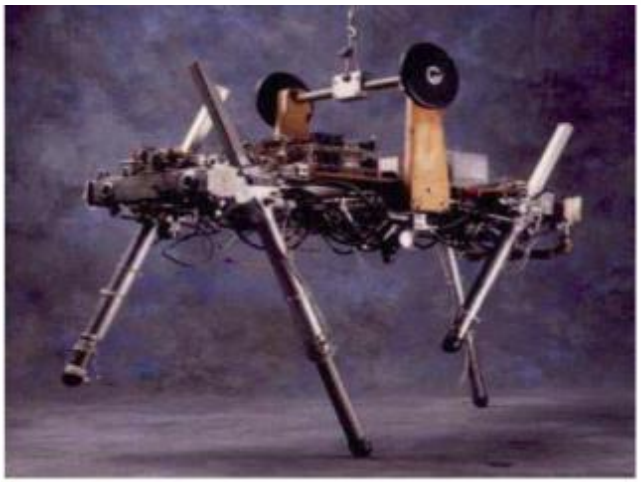
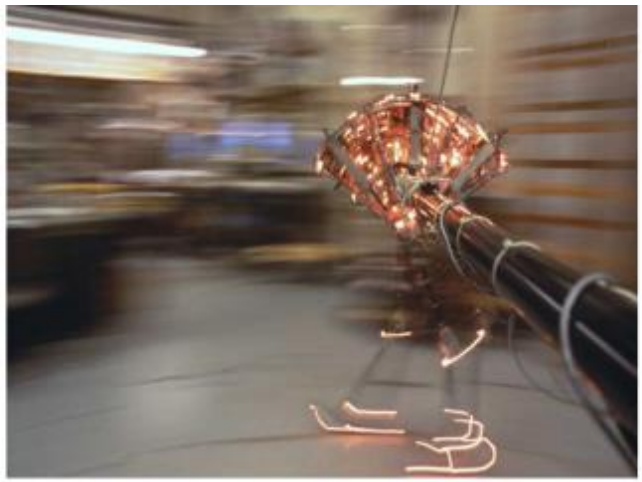
Figure 1.62: Star Wars (1977): R2-D2 and C-3PO

THE ROBOTICS INSTITUTE

Figure 1.63: Robotics Institute at CMU is established (1979), leading to first PhD program in Robotics.

1.64: Research on robot control initiated by J. Luh, M.W. Walker, R. Paul (1980), S. Arimoto (1984), D.E. Whit- ney (1977), J. Salisbury (1980), M. Raibert and J. Craig (1981), N. Hogan (1985), M. Mason (1981), O. Khatib (1987), etc.

Modern History (1961-)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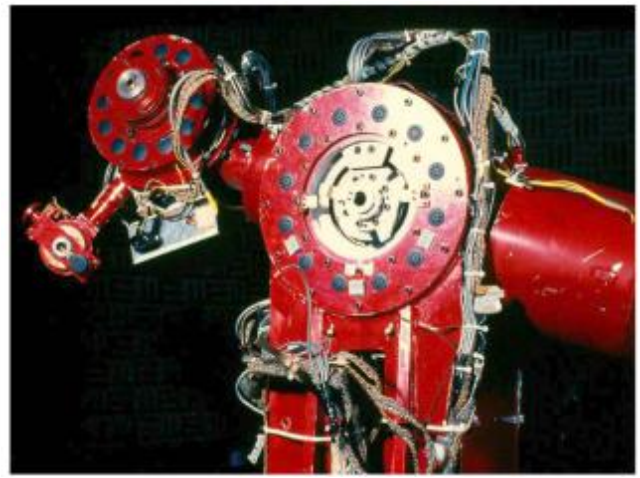
1.66: Research on robot dynamics initiated by J. Luh (1980), T. Kane (1983), R. Featherstone (1983), etc.



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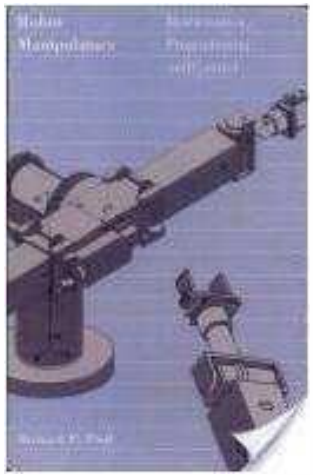

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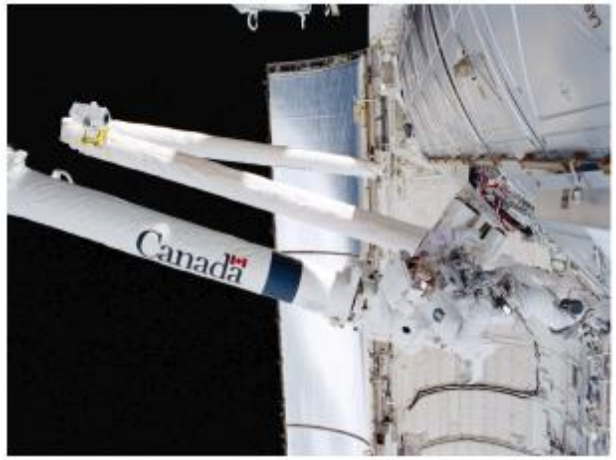

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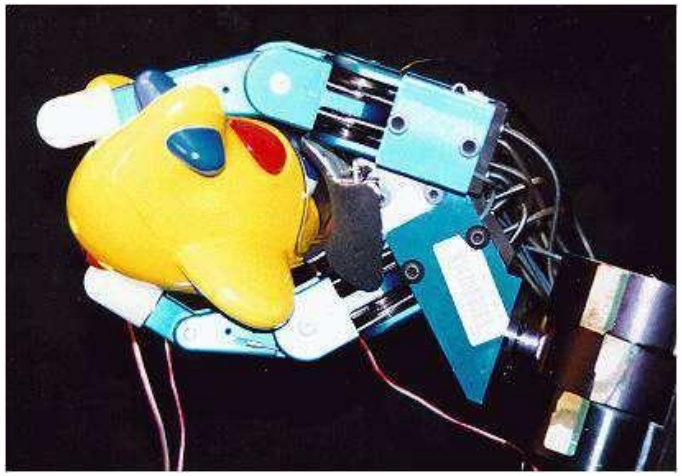

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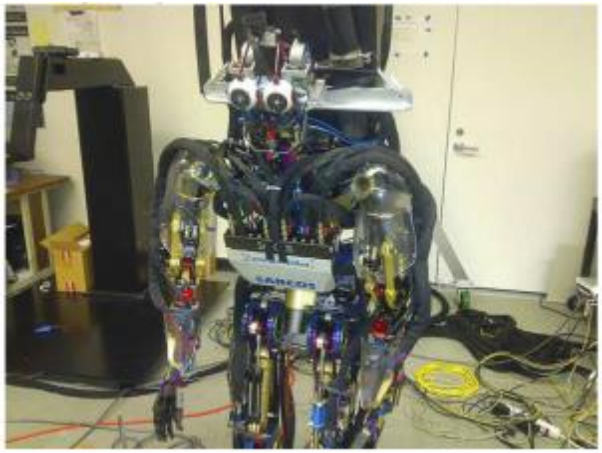
1.73: R. Brockett (1983): Product of exponential formula for robot kinematics, and D. Montana (1986): Kinematics of contact.



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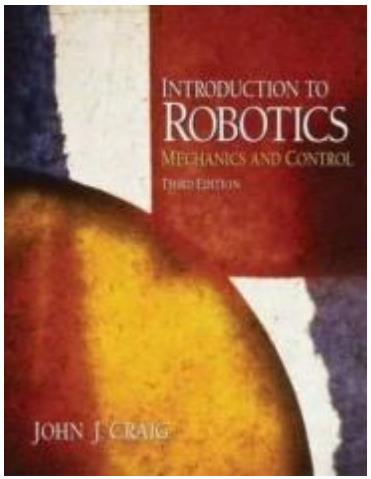

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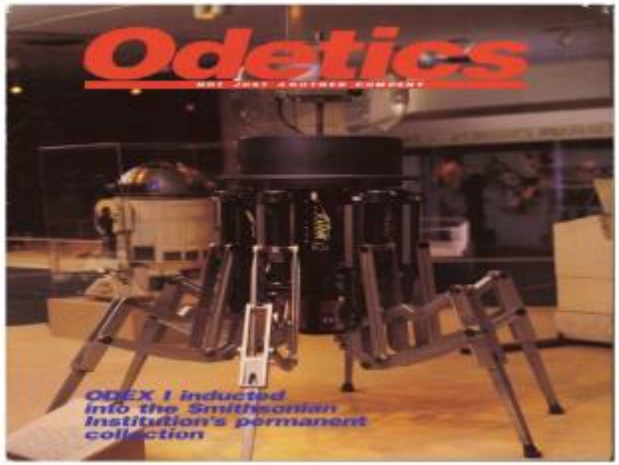

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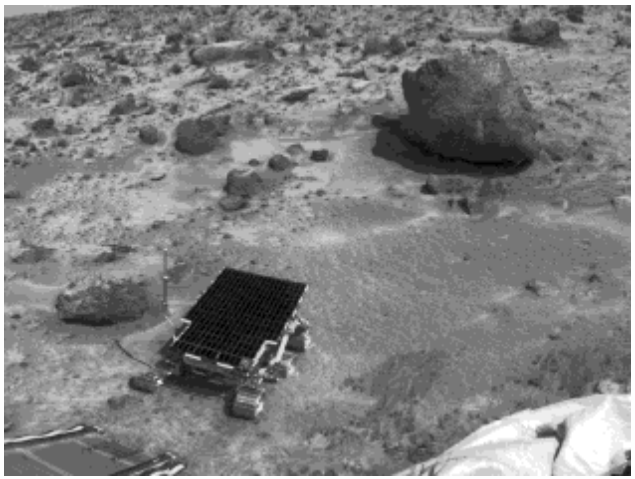

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QURIO

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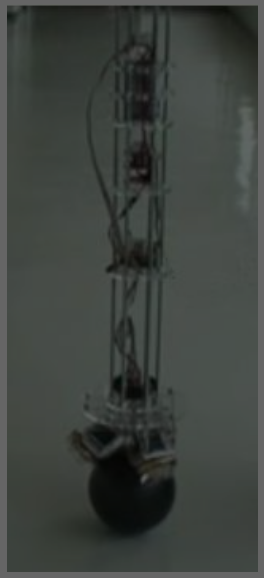
ASIMO (1989-2000)

Segway

Ball Bot

Gyrover

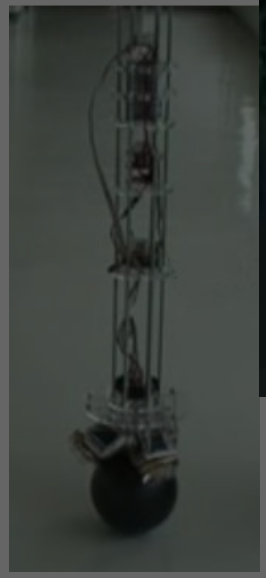
Segway



Ball Bot

Gyrover

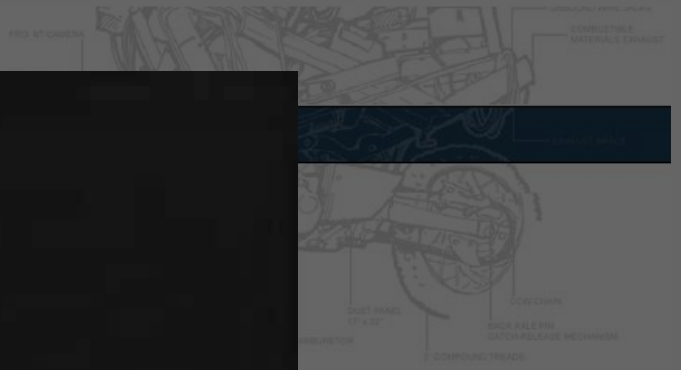
Segway



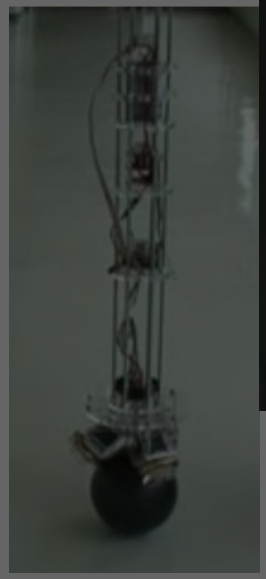
Ball Bot

Gyrover

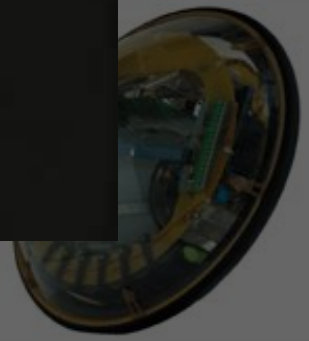
Segway



m Blue



Ball Bot



Gyrover

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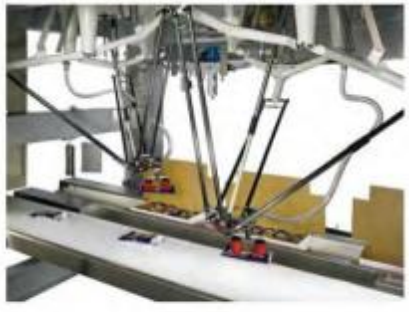

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KUKA LBR iiwa

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 – Aug. 21, 2021

https://youtu.be/FqEqSs-TBG0

New Vistas 3: Aerial Robotics

Austria attacks Venice, 1849

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

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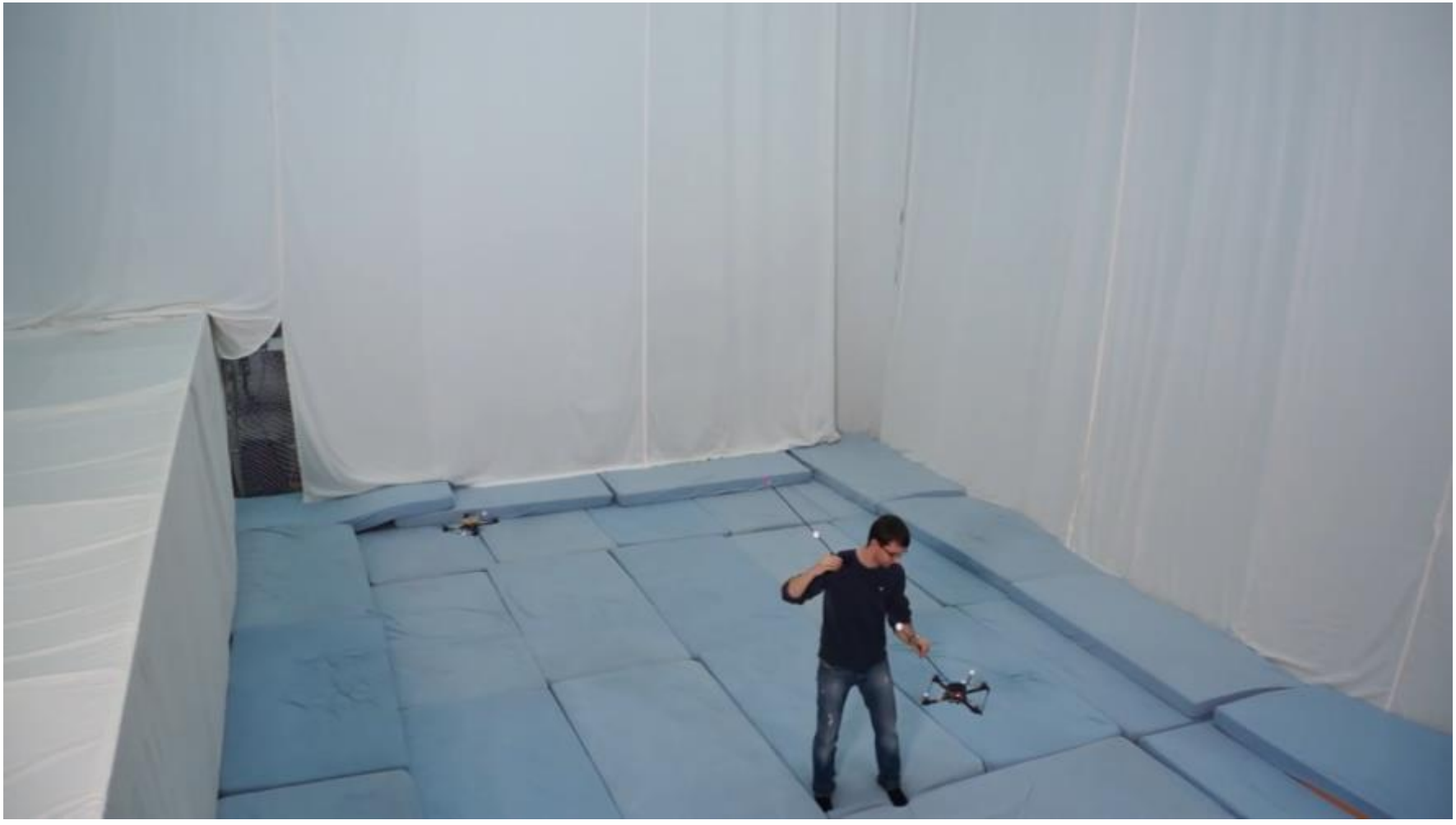

Cirque du Soleil, ETH Zurich and Verity Studios

https://youtu.be/6C8OJsHfmpI

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Play/Pause Stop

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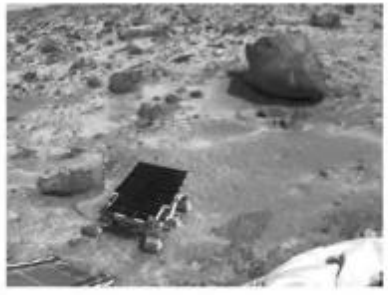

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Play/Pause Stop

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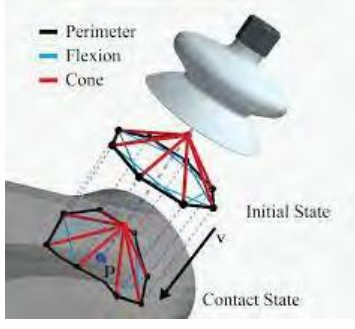
"Jamming" robot manipulator



Dex-Net 2.0, UCB Goldberg Lab

Google Robotics "arm farm"

OpenAI – Solving the Rubic's Cube Single-Handed

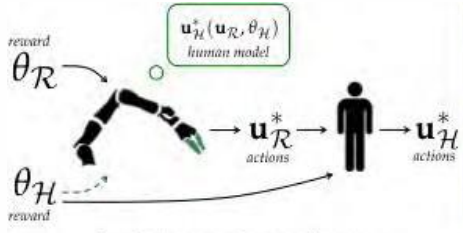
https://youtu.be/kVmp0uGtShk

New Vistas 6: Human-Robot Interaction (HRI)

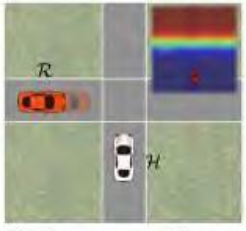
"1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey any orders given to it by human beings, except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict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

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

BCI, University of Pittsburgh, 2008



Formulation as an underactuated system



R backs up to encourage H to cross

R hands over the object s.t. H's likely grasps work at H's goal

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

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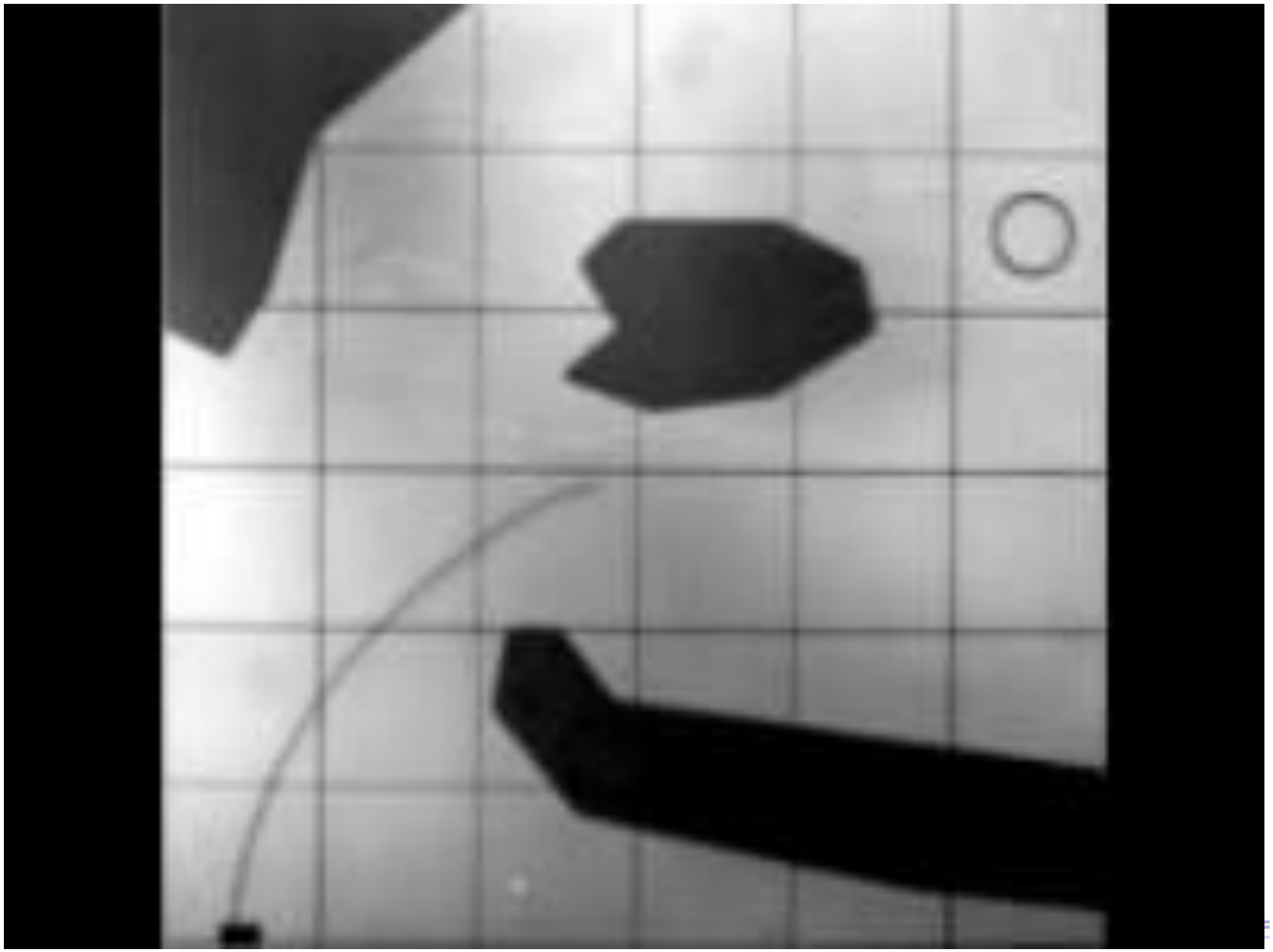
Steerable Needles



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Play/Pause Stop

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Octobot, Harvard
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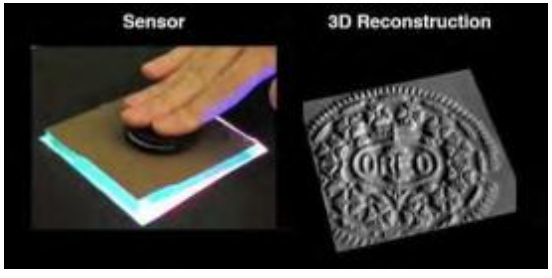
Okamura Lab

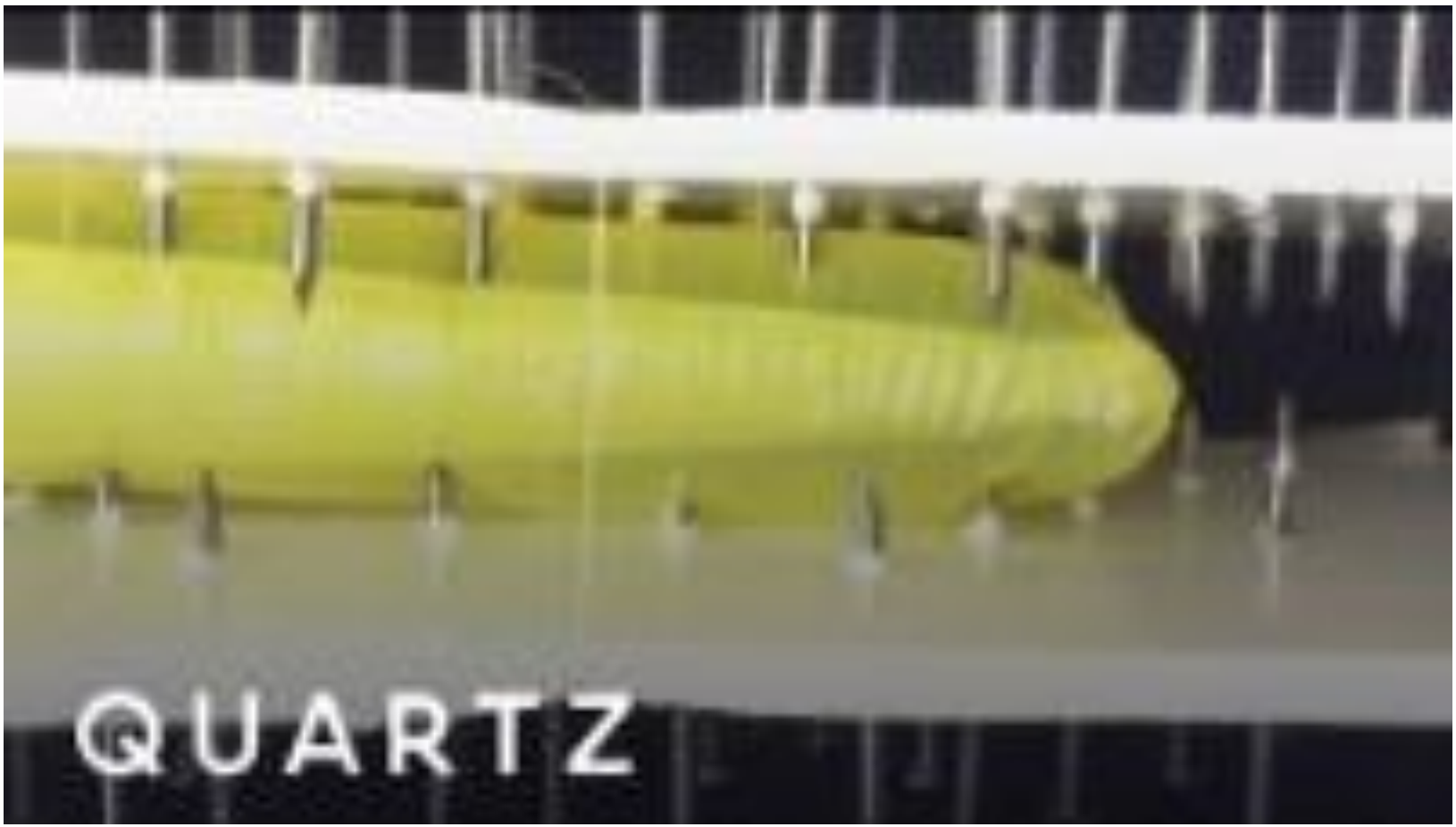


GelSight sensor, MIT

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

Reference

1J.T. Schwartz, M. Sharir, A survey of motion planning and related geometric algorithms. Artificial Intelligence Journal, 37, pp.157-169, 1988.

2T. Lozano-Perez, Spatial Planning: A configuration space approach. IEEE Transactions on Computers, 32(2), pp.108-120, 1983.

3 J. Canny, The Complexity of Robot Motion Planning. MIT Press, Cambridge, 1988.

4O. Khatib, Real-time obstacle avoidance for manipulators and mobile robots. International Journal of Robotics Research, 5(1), pp.90 - 98, 1986.

5 O. Bottema, B. Roth Theoretical Kinematics. North-Holland, New York, 1979.

6 K. Waldron, A method of studying joint geometry. Mechanism and Machine Theory, 7, pp.347-353, 1972.

7T. Kane, D. Levinson, The Use of Kane's Dynamical Equations in Robotics. International Journal of Robotics Research, 2(3), pp.3-21, 1983.

8 R. Featherstone, The Calculation of Robot Dynamics using Articulated-Body Inertias. International Journal of Robotics Research, 2(1), pp.13-30, 1983.

9J. Luh, M. Walker,R. Paul, On-Line Computational Scheme for Mechanical Manipulators. ASME Journal of Dynamic Systems, Measurement and Control, 102(2), pp.69-76, 1980.

10 S. Arimoto, F. Miyazaki, Stability and robustness of PID feedback control for robot manipulators of sensory capability. In Robotics Research, ed. by M. Brady, R. Paul (MIT Press, Cambridge) pp.783-799,1984.

11D. Whitney, Force feedback control of manipulator fine motions. ASME Journal of Dynamic Systems, Measurement and Control, 99, pp.91-97, 1977.

12J. Salisbury, Active stiffness control of a manipulator in Cartesian coordinates,19th IEEE Conference on Decision and Control, Albuquerque, pp.95-100, 1980.

13 M. Raibert, J. Craig, Hybrid position/force control of manipulators. ASME Journal of Dynamic Systems, Measurement and Control, 103, pp.126-133, 1981.

14R. Brockett, Robotic Manipulators and the Product of Exponentials Formula. Lecture Notes in Control and Information Sciences , pp. 120-129,1984.

15 D. Montana, The kinematics of contact and grasp. International Journal of Robotics Research, 7(3),17-32, 1988.