

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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# Chapter 1 Robotics History

## 1 Robots and Robotics

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

## 3 Early History (1451 A.D.-1960)

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# 1.1 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."*

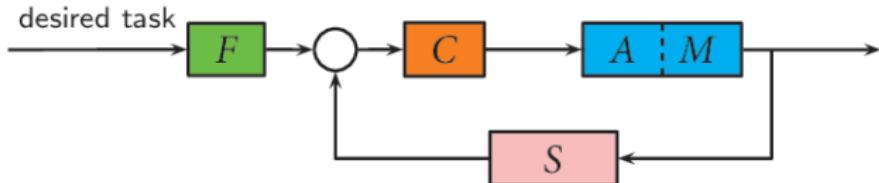
American Heritage Dictionary

## Definition: Robotics

Science and technology of robots.

# 1.1 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)



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

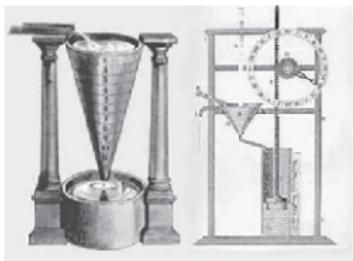


Figure 1.1: Egyptian statues (3000 B.C.)



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

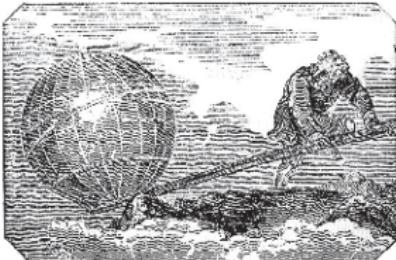
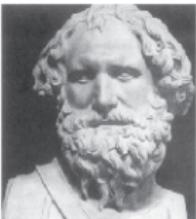


Figure 1.4: Archimedes (287 - 212 B.C.): Using six machine elements for machine design

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



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



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Figure 1.6: Zhang Heng (100 A.D.): South-pointing Chariot (non-magnetic differential mechanism)



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Figure 1.7: Al-Jazari (1200 A.D.): Automata and first use of crank

# 1.3 Early History (1451 A.D.-1960)



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Figure 1.8: Leonardo da Vinci (1452-1519): Numerous machine designs recorded in Codex Atlanticus, Manuscript B and Codex Madrid (watch the da Vinci movie).

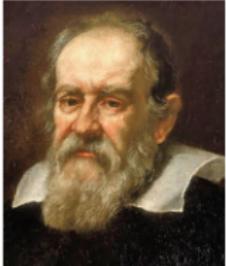


Figure 1.9: P. Ambroise (Paris 1564): Design of a mechanical hand.

Figure 1.10: Galileo Galilei (1564-1642): Mechanics of motion

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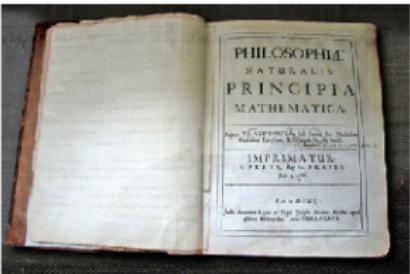


Figure 1.11: Isaac Newton (1642-1727): Calculus and Laws of Motion

Figure 1.12: L. Euler(1707-1783): Rigid dynamics and Euler's equations

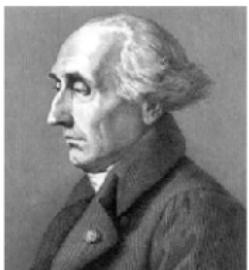
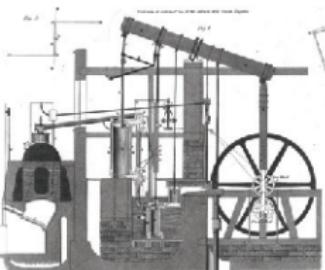


Figure 1.13: J. Lagrange (1736-1813): Calculus of variation and Principles of least action.

Figure 1.14: J. Watt(1736-1819): Sun and planet gear, centrifugal governor, parallel motion linkage, and double acting engine.



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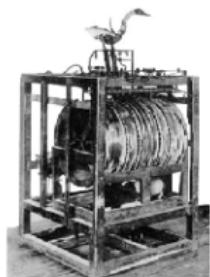


Figure 1.15: J. Vaucanson (French 1738): Automata and the duck.



Figure 1.16: P. Jaquet-Droz (1770): The writer and piano player.



Figure 1.17: A.M. Ampere (1775-1836): Kinematics.



Figure 1.18: J. Jacquard (1801): Automated loom controlled by punched cards.

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Figure 1.19: F. Kaufmann (1810): Mechanical Trumpeter.



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

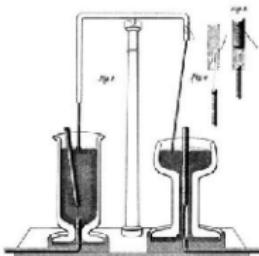


Figure 1.21: M. Faraday (1821): electromagnetic rotation and motors.

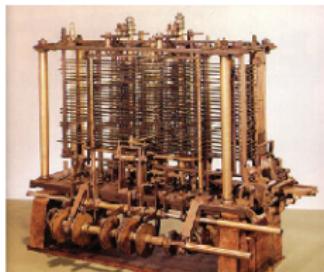


Figure 1.22: C. Babbage (1822): Difference and analytic engines.

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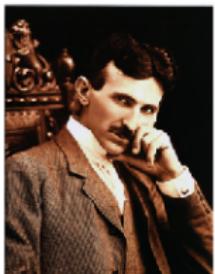
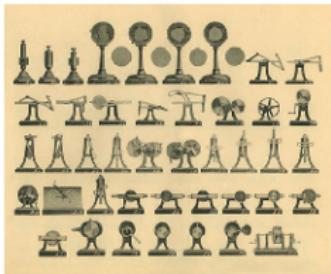


Figure 1.23: F. Reuleaux (1829-1905): Lower pairs and modern kinematics.

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



Figure 1.25: O. Wright (1908): First powered flight.



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

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Figure 1.27: Karel Čapek (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

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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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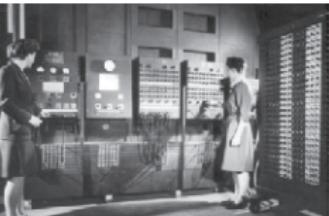


Figure 1.35: J. Eckert and J. Mauchley (1946): developed ENIAC, electronic digital computer



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.

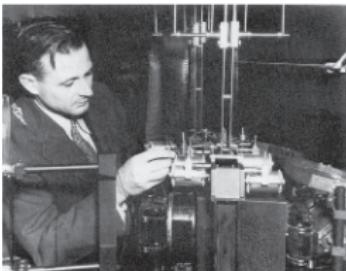
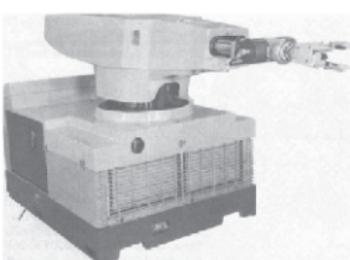


Figure 1.38: G. Brown (1952): First CNC machine and APT

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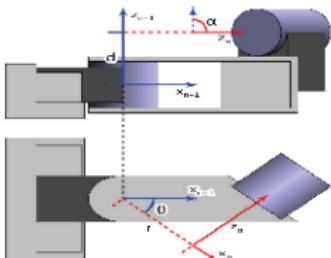
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1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey any orders given to it by human beings, except where such orders would conflict with the First Law.
3. A robot must protect its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



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

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



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

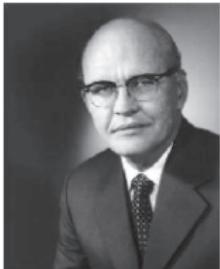


Figure 1.44: J. Kilby and R. Noyce (1958-1959): Integrated circuit

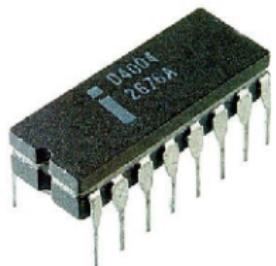
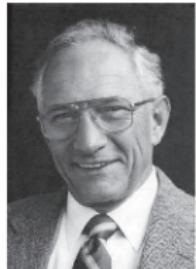


Figure 1.45: F. Faggin, T. Hoff and S. Mazor (1971): First microprocessor

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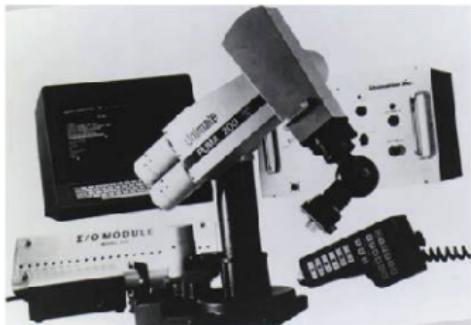


Figure 1.46: George Devol and Joseph Engelberger founded Unimation (1961), which installed the first industry robot at a GM plant in Trenton, New Jersey.



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

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

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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.



B. Roth

K.J. Waldron

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): quadruped walking machine (11 ft tall, 3000lb)

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

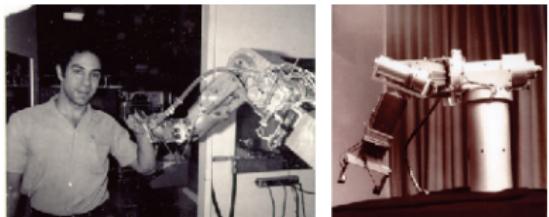


Figure 1.54: V. Scheinman (1969): The Stanford arm



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)

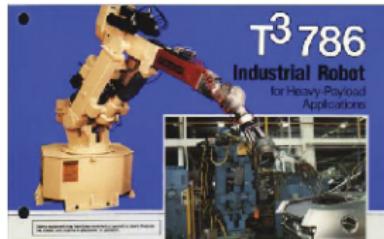


Figure 1.58: Cincinnati Milacron (1974): (T3 Robots) Payload (100lb)



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



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

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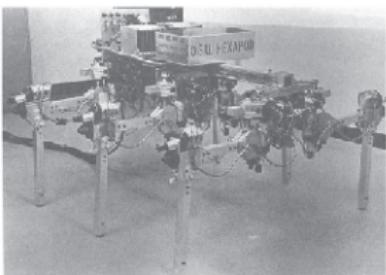


Figure 1.61: OSU Hexapod (1977)



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



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. Whitney (1977), J. Salisbury (1980), M. Raibert and J. Craig (1981), N. Hogan (1985), M. Mason (1981), O. Khatib (1987), etc.



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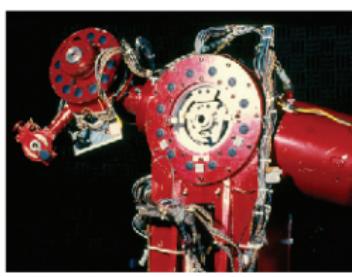


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Figure 1.65: M. Raibert (1980) (RI, CMU & AI lab, MIT): Hopping, Robots, Monoped, biped and Quadpeds. Dynamically stable quadruped robot BigDog created by Boston Dynamics (founded by M. Raibert in 1992) with the NASA Jet Propulsion Laboratory, Caltech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



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

Figure 1.67: H. Asada and T. Kanade at CMU (1981): Direct drive robots

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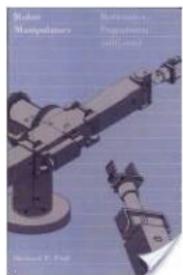


Figure 1.68: R. Paul (1981): **Robot Manipulators: Mathematics, Programming, and Control.** MIT Press.



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Figure 1.69: NASA (1981): Canadarm

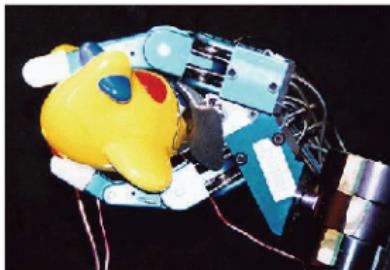


Figure 1.70: K. Salisbury (1981): Salisbury Hand



Figure 1.71: Fanuc of Japan and General Motors form a joint Venture (1982): Fanuc Robotics America

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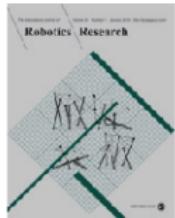
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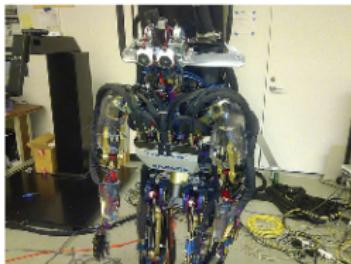
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1.72: International Journal of Robotics Research (1982), IEEE International Conference on Robotics and Automation (ICRA , 1985), and IEEE Journal of Robotics and Automation (1985)



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Figure 1.74: Sarcos, Utah (1983): Entertainment robot.



Roger Brockett

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



Jacob (Jack) Schwartz

1.75: Motion planning research initiated by J. Schwartz and M. Sharir (1983), Lozano-Perez (1983), Canny (1988), and O. Khatib (1986).

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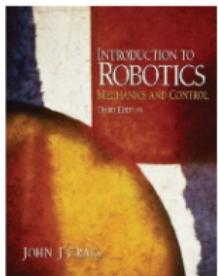
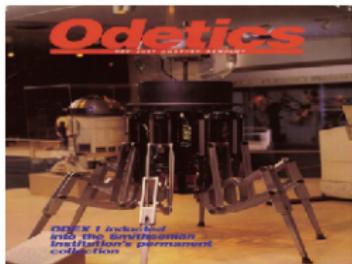


Figure 1.76: J. Craig (1986): **Introduction to Robotics: Mechanics and Control.** Addison-Wesley.



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Figure 1.77: Odetics Walking robots (1988)



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

1.79: R. Brooks and A.M. Flynn (MIT, 1989):  
**"Fast, cheap and Out of Control: A Robot Invasion  
of the Solar System"**

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Figure 1.80: ABB of Switzerland acquires Cincinnati Milacron, creator of PUMA (1990)



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Figure 1.81: iRobot was founded in 1990 by Rodney Brooks, Colin Angle and Helen Greiner after working in MIT's Artificial Intelligence Lab (1990)



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



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

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



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Figure 1.85: DLR Hand (1998)



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Figure 1.86: Sony (1999): AIBO robots



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

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



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

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# New Vistas 0: Industrial Robotics

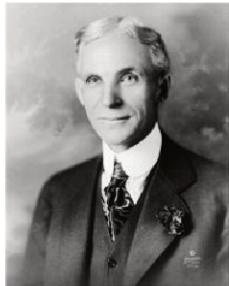


Figure 1.26: Henry Ford (1903): Assembly-line method of automated production.



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



Figure 1.80: ABB of Switzerland acquires Cincinnati Milacron, creator of PUMA (1990)



Figure 1.82: R. Clavel (1991): Delta robot  
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Amazon/Kiva

# New Vistas 2: Autonomous Driving



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



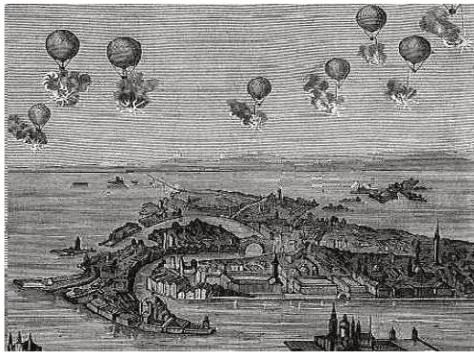
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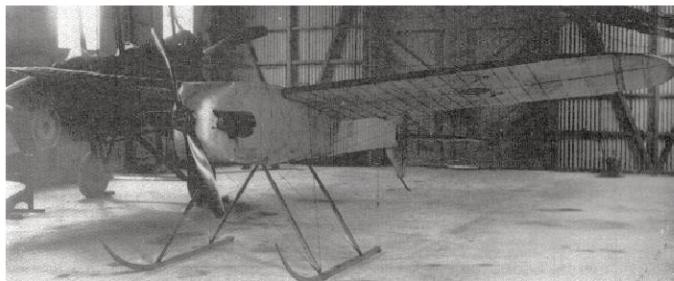
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# New Vistas 3: Aerial Robotics



Austria attacks Venice, 1849



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

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DJI Phantom

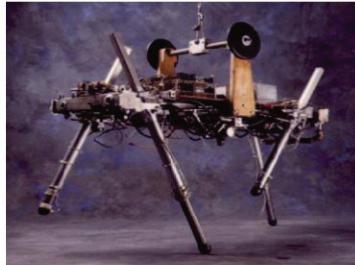


Berkeley Aerobots Sastry  
2003

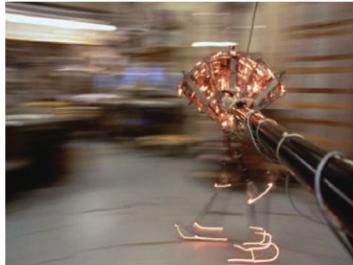


Crazyflie

# New Vistas 4: Extreme Locomotion



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Play/Pause Stop



Play/Pause Stop

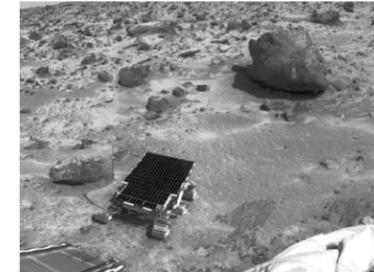
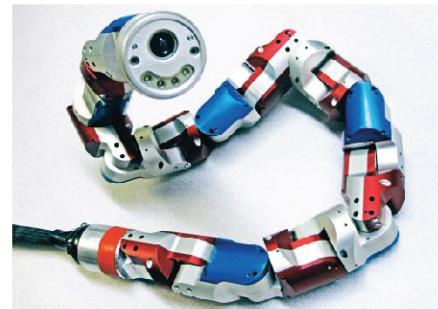


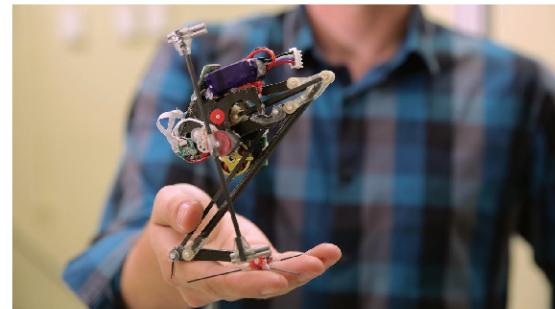
Figure 1.84: NASA (1996): Sojourner, NASA (First Manned Robot to land on Martian Surface)



ATLAS, Boston Dynamics



Snake robots, CMU Choset Lab



Salto, UCB Fearing Lab

# New Vistas 5: Manipulation



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



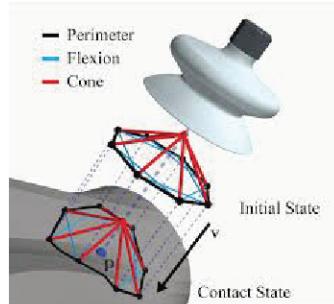
Play/Pause Stop  
Figure 1.78: Utah/MIT (1989): Utah/MIT hand



Play/Pause Stop  
Figure 1.85: DLR Hand (1998)



“Jamming” robot manipulator



Dex-Net 2.0, UCB Goldberg Lab



Google Robotics “arm farm”

# 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.

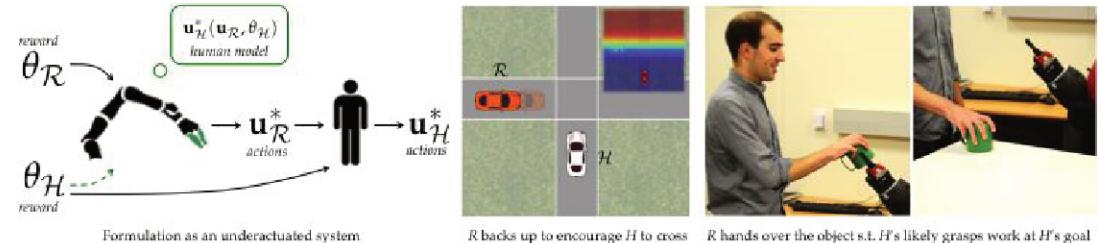
”

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



BCI, University of Pittsburgh, 2008

“



Human intent inference, UCB Sastry / Dragan Lab

”



Kinova Jaco arm



BiOM  
prosthesis,  
MIT Herr Lab



APEX exoskeleton, UCB Bajcsy Lab

# Frontier 6: Robot-Aided Surgery

Telesurgery Workstation 1999  
Sastry



Play/Pause Stop

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



Phantom haptic device



Robot cutting and suturing,  
UCB Goldberg/Abbeel Lab

# New Vistas 7: Soft Robotics



Play/Pause Stop

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

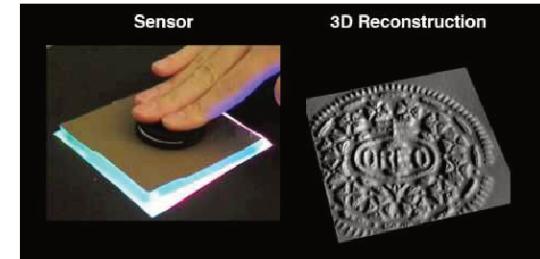


G. Pratt (1995): Series elastic actuator (SEA)

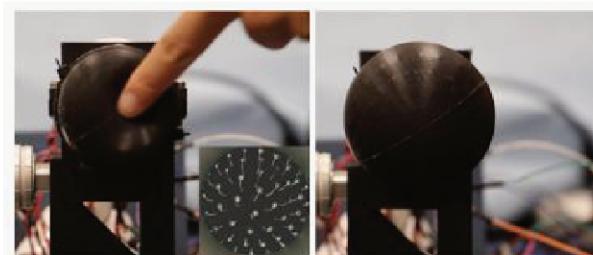
Vine robots, Stanford  
Okamura Lab



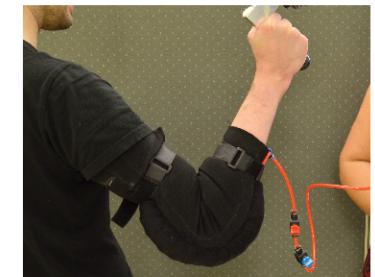
Octobot, Harvard  
Lewis Lab



GelSight sensor, MIT



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



Soft exoskeleton,  
UCB Bajcsy Lab

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