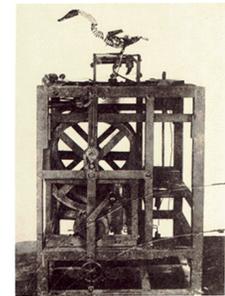


Administrative status report

- I will be out of town Sept 19-28th [inclusive] (thus no office hours in that interval).
- We will have guest lectures. These will be finalized soon.

Robot History [Note: read Ch. 1]

- Automaton: a machine or control mechanism designed to follow automatically a predetermined sequence of operations or respond to encoded instructions.
- The idea of machines becoming to autonomous is recurring and well established. It seems to predate machines themselves! (e.g. ancient Greek myth of Talos).



Modern history of robotics

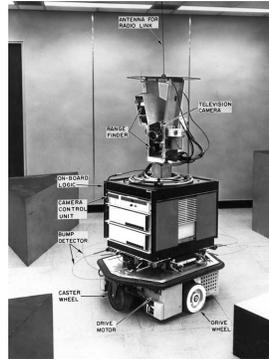
- The *word* robot, from a 1920s play by Czech writer Capek. *Idea* is much older. A human-like machine that replaces human workers.
- Idea in film:
 - Frankenstein ()
 - Metropolis (1926)
 - Forbidden planet (1956)

Industrial history

- 1961
 - George C. Devol obtains the first U.S. robot patent, No. 2,998,237.
 - Joe Engelberger formed Unimation and was the first to market robots
 - First production version Unimate industrial robot is installed in a die-casting machine
- 1962
 - Unimation, Inc. was formed, (Unimation stood for "Universal Automation")

First mobile robot

- **Shakey** (Stanford Research Institute/SRI)
 - the first "autonomous" mobile robot to be operated using AI techniques
- Simple tasks to solve:
 - To recognize an object using vision, given a very restricted world
 - Find its way to the object
 - Perform some action on the object (for example, to push it over)
 - Perform compound actions and basic planning.



Shakey movie



Robot history

- 1969
 - Robot vision, for mobile robot guidance, is demonstrated at the Stanford Research Institute.
 - Unimate robots assemble Chevrolet Vega automobile bodies for General Motors.
- 1970
 - General Motors becomes the first company to use machine vision in an industrial application. The Conisght system is installed at a foundry in St. Catherines, Ontario, Canada.

Stanford Cart



- 1973-1979
 - Stanford Cart developed by Hans Moravec
 - used with stereo vision.
 - Took pictures from several different angles
 - The computer gauged the distance between the cart and obstacles in its path do to basic collision avoidance
 - About 15 min to think about each image, then drives 1 foot or so.

Early History

- 1978
 - The first PUMA (Programmable Universal Machine for Assembly) robot is developed by Unimation for General Motors.
- 1981
 - IBM enters the robotics field with its 7535 and 7565 Manufacturing Systems.
- 1983
 - Westinghouse Electric Corporation bought Unimation, Inc., which became part of its factory automation enterprise. Westinghouse later sold Unimation to Staubli of Switzerland.

Robot vehicle history

- Early 1980's - vehicles unable to drive along road even at low speeds, using general-purpose AI. (DARPA UGV programme)
- Late 1980's - robot vehicle using Kalman filtering drives at highway speed for limited time by tracking white lines (Dickmanns)
- 1990's - autonomous vehicles able to drive long distances over highways (CMU Hands across America)
- 2004 - robot vehicle drives over 100 miles over rough terrain (DARPA grand challenge).

Locomotion

- How to get a vehicle to move.
- Current context: terrestrial (land-based) locomotion.
- Other domains: through the air, in the water.

Vehicle Locomotion

- Objective: convert desire to go someplace into an actual motion.
 - How to arrange effectors.
 - How to relate incremental motion to effector output: kinematics and inverse kinematics
 - How to relate long range motion to local motions: trajectory (path) planning.
- *Kinematics*: prediction of how effector actions alter pose.
- *Inverse Kinematics (inverse-K)*: what action to use for a desired local motion.

First Issue: Effector Arrangement

- Recall:
 - effectors are outputs to the real world.
 - we move in an N-dimensional configuration space C^N
 - We are embedded in the real world R^n
 - "Action space": set of things we can do.
 - Number of degrees of freedom: set of output dimensions in action space, typically number of motors we have (or joints, or muscles).

Design Tradeoffs with Mobility Configurations

1. Maneuverability
2. Controllability
3. Traction
4. Climbing ability
5. Stability
6. Efficiency
7. Maintenance
8. Environmental impact
9. Navigational considerations

Maneuverability

Controllability

Traction

Climbing ability

Stability

Efficiency

- With respect to energy, speed, ...

Maintainability

Environmental impact

Navigational considerations

- Some mechanisms are more accurate and reliable.
- Some are mathematically more easily predicted and controlled.

Differential drive

- 2 wheels
- 2 points of contact
- 2 degrees of freedom

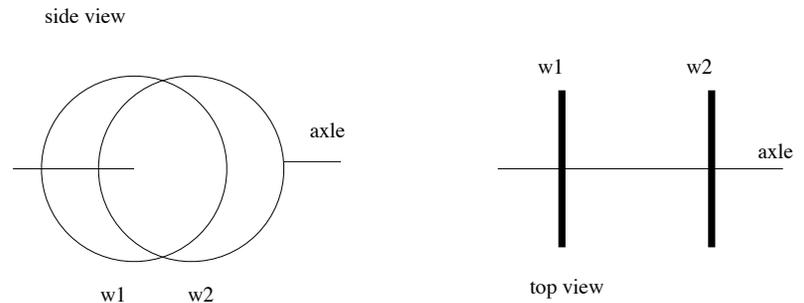
- Translation and rotation are *coupled*
 - You can't do one without the other.
 - Thus, control is a "little bit" complicated.

Differential drive

Basic design:

- 2 circular wheels,
- infinitely thin,
- same diameter,
- mounted along a common axis,
- vehicle body is irrelevant (in theory).

Idealized differential drive



Differential drive intuition

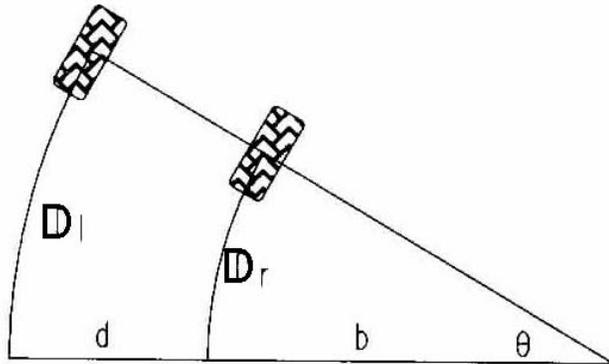
- How do you drive straight ahead?
- How do you turn in place?
- (these are questions of *kinematics*)

Differential drive observations

- Each wheel can turn independently.
- Instantaneous motions depends on the relative rotations speeds of the wheels.
- Vehicle rotation can be described relative to an axis running through the two wheels.

Realistic differential-drive

- Where is the body?
- How is it attached?
- Is there friction, and is it the same for both wheels?
- How is power delivered? Is it the same for both wheels?
- Is there wheel wear?'
- How do you maintain balance?

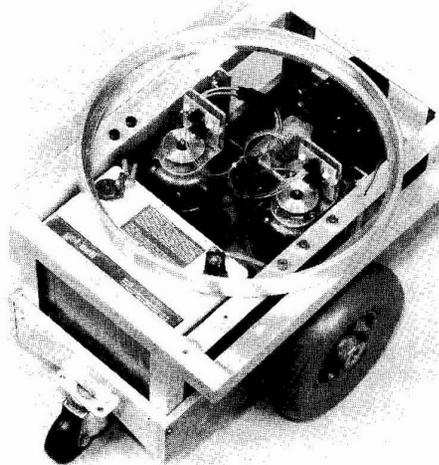


Kinematics of Differential Drive

- Forward kinematics of differential drive
 - How do outputs of left & right wheels relate to rotation and translational components of pose.
 - Wheel rotation by angle ϕ
 - distance of wheel motion $D_i = \phi_i r$

$$D = \frac{D_l + D_r}{2}$$

$$\theta = \frac{D_l - D_r}{d}$$



Instantaneous vs...

- D, θ determine *differential* motion:
 - the tangent and velocity of the vehicle motion.
- From differential estimates, how to we:
 - get the vehicle to go where we want,
 - predict where the vehicle will go?
- Simple strategy: use piecewise straight-line paths.

Differential drive: issues

- Cheap, easy to build
 - Common
- Matching of drive mechanisms
 - tire wear (r is wrong)
 - motors (ϕ is wrong)
 - bearings (ϕ is wrong)
 - friction (rotation ϕr is not motion of ϕr)
 - Net result: motion ϕr is actually wrong
- Balance
 - Castor (caster) wheel