Vehicle Design & Locomotion

COMPUTER SCIENCE 417B
Gregory Dudek

References:
  • Dudek & Jenkin, Chapter 2
  • McKerrow p. 53-74
Reprise: Why are we doing this stuff?

• Read Bill Gates article (Sci. Am., Jan 2007).
• He claims robotics is at the same stage the computer industry was at in the 1970s.
  – (Maybe it's a good time to start a company?)
• His claim, which I share, is that the core issue for robotics is software.
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
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.
COMP-417, Dudek, Mobile Robotics
Differential
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 $\varphi$:
    distance of wheel motion $D = \varphi r$

\[
D = \frac{D_l + D_r}{2},
\]

\[
\theta = \frac{D_l - D_r}{d}
\]

COMP-417, Dudek, Mobile Robotics
Differential drive: issues

• Cheap, easy to build
  – Common

• Matching of drive mechanisms
  – tire wear (r is wrong)
  – motors (�� is wrong)
  – bearings (界 is wrong)
  – friction (rotation 寸r is not motion of 寸r)
  – Net result: motion 寸r is actually wrong

• Balance
  – Castor (caster) wheel
Knobbie Tires

- Compliance of tire.
- How many points of contact?
Problem with Differential Drive: Knobbie Tires

Changing diameter makes for uncertainty in dead-reckoning error

COMP-417, Dudek, Mobile Robotics
Usually combined with differential drive
Skid steering
Skid Steering

Advantages:
• Simple drive system

Disadvantages:
• Slippage and poor odometry results
• Requires a large amount of power to turn
Skid Steering: Like Diff'l Drive

• Good outdoors
• Lots of traction
• Lots of skid
  – very inefficient
  – tears up the ground
• You can see it on tanks
  – See any old war movie
Tricycle Drive
Tricycle

Advantages:
• No sliding

Disadvantages:
• Non-holonomic planning required

Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.
Synchro

• 2 DOF
• Decoupling between translation and rotation!
4-wheel syncho
Synchronous (Synchro) Drive

Direction of motion

x

y

Steering pulley

Drive pulley

Wheel

Steering motor

Turret pulley

Steering belt

Drive belt

Rolling axis

Drive motor

Wheel steering axis
Synchro Drive

Advantages:
• Separate motors for translation and rotation makes control easier
• Straight-line motion is guaranteed mechanically

Disadvantages:
• Complex design and implementation
Articulated Drive: Nomad

Advantages:
• Simple to implement except for turning mechanism

Disadvantages:
• Non-holonomic planning is required (to be discussed later)
Wagon (Kingpin) steering

- "Wagon steering": like the old covered wagons of yore.
- Two front wheels on common axle.

- Simple, but inefficient.
  - Small bumps effect steering angle
Ackerman Steering

- Car-like steering
  - "Double pivot"
- Original design: each wheel turns by same amount.
  - Different centers of curvature: leads to slip
    - Energy inefficient, hard to control (physically)
  - Jeantaud modification: slightly different steering angles.
- Front wheels turn by different amounts
- Back wheels do not turn
- ICC
Ackerman Steering

Advantages:
Simple to implement
• Simple 4 bar linkage controls front wheels

Disadvantages:
• Non-holonomic planning required

\[ \cot \theta_i - \cot \theta_o = \frac{d}{l} \]

where:
\( \theta_i \) = relative steering angle of inner wheel
\( \theta_o \) = relative steering angle of outer wheel
\( l \) = longitudinal wheel separation
\( d \) = lateral wheel separation.

Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.
\[ \cot \theta_i - \cot \theta_o = \frac{d}{l} \]

**where:**

- \( \theta_i \) = relative steering angle of inner wheel
- \( \theta_o \) = relative steering angle of outer wheel
- \( l \) = longitudinal wheel separation
- \( d \) = lateral wheel separation.
Geometric constraints

\[
\cot \theta_{SA} = \frac{d}{2l} + \cot \theta_i \quad \text{or alternatively:} \quad \cot \theta_{SA} = \cot \theta_o - \frac{d}{2l}.
\]
Distributed Actuator Arrays: Virtual Vehicle

- Modular Distributed Manipulator System
- Employs use of Omni Wheels
Omni Wheels

Advantages:
• Allows complicated motions

Disadvantages:
• No mechanical constraints to require straight-line motion
• Complicated implementation
Omni wheels (exotic)
Framewalker: Jim2

Advantages:
• Separate actuation of translation and rotation
• Straight-line motion is guaranteed mechanically

Disadvantages:
• Complex design and implementation
• Translation and rotation are exclusive
Snake Robots

Advantages:
• Many applications(?)
• Hyper-redundant

Disadvantages:
• Complex control and planning
• Complex, expensive design
Walking

• Why?
Legged Robots

Advantages:
• Can traverse any terrain a human can

Disadvantages:
• Large number of degrees of freedom
• Maintaining stability is complicated

Are legs better than wheels?

COMP-417, Dudek, Mobile Robotics