Today's Topics

- Art of Lego Design
  - Notes from Jason Geist, Carnegie Mellon University
- Differential Drive
  - Notes from Zachary Dodd, Harvey-Mudd College

Know your Materials

- Quick facts:
  - Plastic bricks since 1949 (wooden blocks prior)
  - On average, 2100 different parts each year
  - Manufacturing tolerance: 1/1000 of an inch
  - Number of ways of combining six 8-stud bricks: 102,981,500
  - Widely used by scientists and engineers as a rapid prototyping tool

Geometry

- Three plates = 1 brick in height
- 1-stud brick dimensions: exactly 5/16" x 5/16" x 3/8" (excluding stud height 1/16"),
- This is the base geometry components for all LEGO
Structure

- Common pitfall when trying to increase mechanical robustness:

Mindstorms 2.5

![Image of LEGO model]

Structure

- The right way:

Mindstorms 2.6

![Image of LEGO model]

Structure

- The right way:

Mindstorms 2.7

![Image of LEGO model]

Connector pegs

- Black pegs are tight-fitting for locking bricks together.
- Grey pegs turn smoothly in bricks for making a pivot

Mindstorms 2.8

![Image of LEGO connector pegs]
**Structure**

- LEGO bricks are finicky:
  - They *HATE* duct tape.
  - They *HATE* hot glue.
  - They *HATE* super glue.
  - They *HATE* epoxy.

- You should never need adhesives to build reliable LEGO structures

**Worm Gears**

- Pull one tooth per revolution

- Result is a 24:1 gearbox
- Not back driveable!

**Drivetrain**

- LEGO Gears
  - 8T
  - 16T
  - 24T
  - 24T Crown
  - 1T Worm
  - Bevel

**Motors**

- 9V Gear Motor
- ~ 150 mA
- 300 RPM (no load)
Mounting Motors

- Add a gear:

Build for good control

- Slow vs. fast?
- Gear backlash
- Stability
- Skidding
**Design Strategy**

- Incremental
  - Test components parts as you build them
    - Drivetrain
    - Sensors, sensor mounting
    - Structure
- Don’t be afraid to redesign
- KISS

**Testing**

- Don’t wait until you have a final robot to test
  - Interaction of systems
  - Work division (work concurrently)
- Develop test methods
- Repeatability

**Design Strategy**

- Drivetrain driven
- Chassis/structure driven
- Modular?

**Philosophy**

- Have fun
- Be creative, unique
- Strive for cool solutions, that work!
- Aesthetics: it’s fun to make beautiful robots!
Differential drive

Most common kinematic choice
All of the miniature robots…Khepera, Braitenberg

- difference in wheels’ speeds determines its turning angle

1) Specify system measurements
- consider possible coordinate systems
2) Determine the point (the radius) around which the robot is turning.
   - each wheel must be traveling at the same angular velocity around the ICC
3) Determine the robot’s speed around the ICC and then linear velocity
   \[
   \omega(R+d) = V_L \\
   \omega(R-d) = V_R
   \]
   \[
   \omega = \frac{(V_R - V_L)}{l} \\
   R = \frac{l(V_R + V_L)}{(V_R - V_L)}
   \]
   Thus, \( \omega = \frac{(V_R - V_L)}{l} \)
   \( R = \frac{l(V_R + V_L)}{(V_R - V_L)} \)
   So, the robot’s velocity is \( V = \omega R = \frac{(V_R + V_L)}{2} \)

4) Integrate to obtain position
   \[
   x(t) = \int V(t) \cos(\theta(t)) \, dt \\
   y(t) = \int V(t) \sin(\theta(t)) \, dt \\
   \theta(t) = \int \omega(t) \, dt
   \]
   Thus, \( x(t) = \int V(t) \cos(\theta(t)) \, dt \\
   y(t) = \int V(t) \sin(\theta(t)) \, dt \\
   \theta(t) = \int \omega(t) \, dt \)

Questions (forward kinematics)
Given the wheel’s velocities or positions, what is the robot’s velocity/position?
Are there any inherent system constraints?
1) Specify system measurements
2) Determine the point (the radius) around which the robot is turning.
3) Determine the speed at which the robot is turning to obtain the robot velocity.
4) Integrate to find position.