Robot building
Basic physical criteria for your robot

• Your robot should not fall apart due to forces experienced in normal operation
• Your robot should not fall over
• Your robot should generate enough force to achieve its desired actions
• Your robot should not be massively inefficient in its use of available power
Task 1:

• Build a ~20cm square frame from Lego that does not break when dropped on the floor
Some physics issues in robotics: (1) Strength

• A robot that falls apart due to forces experienced in normal operation is no use (and certainly not autonomous!)
• The strength of a structure is the load required to break it: depends on load distribution and the material of the parts
  • Strength of material is the stress required to break it
  • Stress $\sigma$ is force per unit area
  • Strain $\varepsilon$ is % deformation under stress

• Stress/strain ($E$) defines elasticity:
  – Note a material or structure can be stiff and strong (steel), stiff and weak (biscuit), flexible and strong (rubber) or flexible and weak (jelly)

• Area under curve is ‘strain energy’: resilience (toughness) is amount of
Some physics issues in robotics: (1) Strength

- Strength of a structure is depends on whether any point (or joint) is under sufficient stress to break
  - The distribution of stress depends on the geometry of the structure and distribution of load
    - E.g. stress at the tip of a crack of length $L$ and tip radius $r$
      \[ s(1 + 2\sqrt{\frac{L}{r}}) \]
  - Also the direction of forces may lead to a lack of stability
    - E.g. if outside ‘middle third’
Some physics issues in robotics: (1) Strength

- Try to have smooth force lines, e.g. straight compression or tension, and appropriate balance
- Use short path/small number of components to transmit forces
- Top tip for Lego: use bracing
Task 2:

- Build a ~20cm wheel-base for a mobile robot
Some physics issues in robotics: (2) Stability

• Usually want structure as a whole to be statically stable, i.e. no net torque due to gravity
• Depends on centre of mass: force of gravity through centre of mass to ground must fall within base of support.
  – Minimum three points for base support
  – Wider base of support and lower centre of mass will reduce potential tipping due to inertia
• Rotating around the centre of mass
Some physics issues in robotics: (3) Friction

- Robot efficiency will depend on how much energy is dissipated through inefficient mechanisms and friction
- E.g. using differential drive and third sliding contact point
  - Force to reach threshold of motion = $\mu N$
    where $\mu$ is co-efficient of friction, $N$ normal force
  - Force transferred to ground via wheel is also proportional to $\mu_{wheel}N$
  - $N = \text{mass} \times \text{gravity}$ → so should reduce mass resting on the sliding contact and increase mass resting on drive wheels
  - $\mu$ depends on surfaces → should make sliding contact smooth, tire rough
Some physics issues in robotics: (3) Friction

- Want to minimise friction of rotation
  - Avoid any direct contact of gear or wheel to frame
  - Minimise the bend in the axle beams
    - Bend is proportional to $dP/I$, where $I$ is beam inertia, depending on shape and material of beam
    - Reduce mass
    - Reduce distance
    - Add supports (opposing forces)
Some physics issues in robotics: (4) Power

- Have fixed amount of power, i.e. rate of work or force x distance/second
- Hence fundamental tradeoff between speed and force (torque) of your robot
- Primarily determined by the gear ratio \( r_p/r_f \) where \( r_p \) is radius of the powered gear, and \( r_f \) the radius of the follower gear
- Gears act like levers:
  - distance/speed changes by \( r_p/r_f \)
  - Force/torque changes by \( r_f/r_p \)
- Same ratio can be calculated by counting teeth on each gear
Task 3

- Build a 1:15 gear system (i.e. rotating one wheel will make another wheel turn at 1/15th the speed)
Gearing example

- Both ends of axle supported
- Gear/wheel not touching surface, well aligned

Motor → 8:40 → 8:24 → 8:40 → Wheel

1:5 × 1:3 × 1:5 = 1:75

Lower ratio (e.g. 1:25) increases velocity but decreases acceleration.
Additional criteria

• Modularity
• Easy to change battery
• Easy to pick up
• Tidy routing for wires