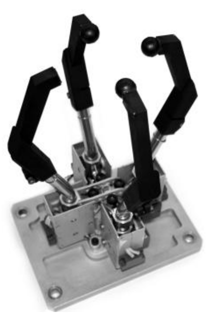
Robot Construction: Effectors and Actuators

Arms, Legs, Wheels, Tracks and What Really Drives Them



https://www.robotshop.com/blog/en/how-do-i-choose-appropriate-actuators-6903

Effectors

- An ***effector**:* any device on a robot that has an effect (impact or influence) on the physical environment.
  - Wheels on a mobile robot
    - Or legs, wings, fins…
  - Whole body might push objects
  - Grippers on an assembly robot
    - Or welding gun, paint sprayer
  - Speaker, light, tracing-pen

http://www.wikiwand.com/en/Robot_end_effector

Replicating fossil paths with toilet roll [Prescott & Ibbotson (1997)]

- A spiral 'foraging' trail generated by the robot trace-maker.
  - Control combines thigmotaxis (stay near previous tracks) & phobotaxis (avoid crossing previous tracks)
    - Thigmotaxis: motion in response to a touch stimulus
    - Phobotaxis: change in the direction of locomotion in response to a given stimulus

Actuators

- Actuator: the mechanism that enables the effector to execute an action or movement.
  - In animals and humans:
    - muscles and tendons are the actuators
    - make the arms and legs and the backs do their jobs.
  - In robots:
    - actuators include electric motors and various other technologies.
    - Connected via transmission:
      - System gears, brakes, valves, locks, springs…

Effectors and Actuators

- terms are often used interchangeably to mean: “whatever makes the robot take an action”
  - but they aren’t the same thing

Effectors and Actuators

- most simple actuators control one degree of freedom
  - i.e., a single motion
  - e.g., up-down; left-right; in-out

Effectors and Actuators

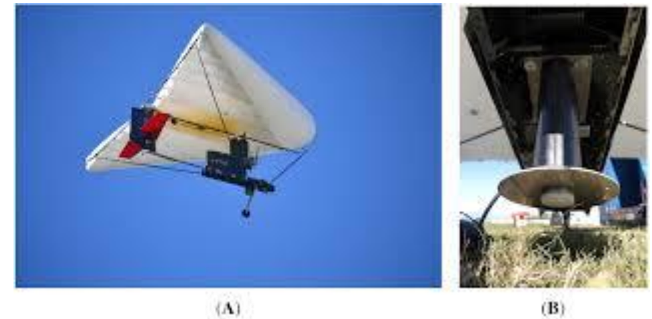
- how many degrees of freedom a robot has is very important in determining how it can affect its world, and therefor how well, if at all, it can accomplish its task
- More on D.O.F. later…

Passive vs. Active Actuation

- The action of actuators and effectors requires some form of energy to provide power.
- Some actuators use *passive actuation*

http://www.mdpi.com/1424-8220/15/11/28287/htm

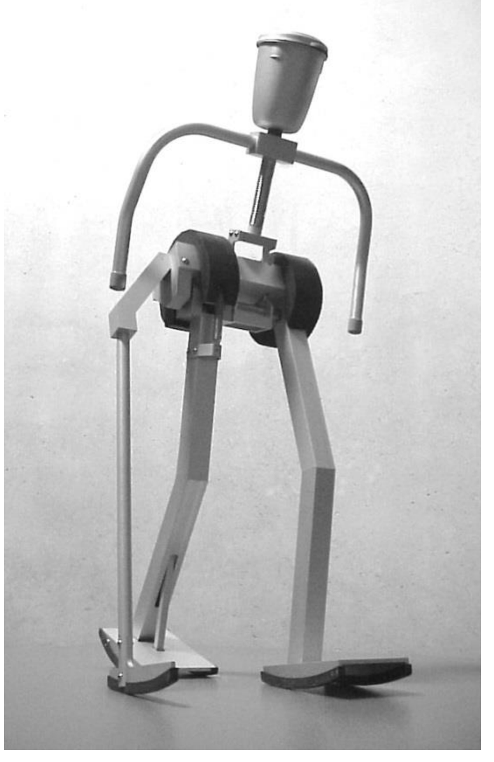
Passive Actuation



- Utilizing potential energy (usually gravity) of the effector and its interaction with the environment
  - Instead of active power consumption.
- A glider is an example of this
- Advantage:
  - No need for extra weight required by energy source (battery, gasoline, etc) and complicated actuators.
- Disadvantage:
  - Dependence on a motivating source that may be transient.
    - For example, weather may affect glider movement

http://www.mdpi.com/1424-8220/15/11/28287/htm

Movement



A passive walker: a robot that uses gravity and clever mechanics to balance and walk without any motors.*

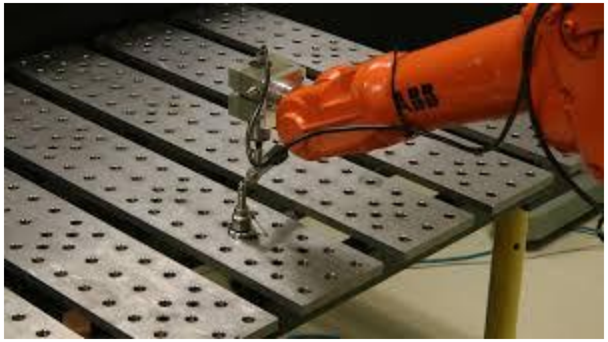
*The robotics primer, Mataric

Types of Actuators

- Electric motors
  - speed proportional to voltage
    - voltage varied (by pulse width modulation)
- Hydraulics
  - Pressurized liquid
- Pneumatics
  - Pressurized air
- Others, including:
  - Photo-reactive materials
  - Chemically reactive materials
  - Thermally reactive materials
  - Piezoelectric materials
    - Crystals create a charge when pushed or pressed.

Variables Affecting Actuators Choice

- Load (e.g. torque to overcome own inertia)
- Speed (fast enough but not too fast)
- Accuracy (will it move to where you want?)
- Resolution (can you specify exactly where?)

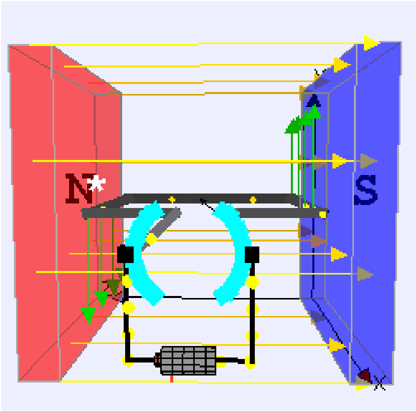
http://www.payper.com/palletizer-robots, https://www.dreamstime.com/stock-illustration-robot-running-high-speed-clipping-path-included-image49547946, , https://www.youtube.com/watch?v=niKo_-EgdJ0

Variables Affecting Actuators Choice

- Repeatability (will it do this every time?)
- Reliability (mean time between failures)
- Power consumption (how to feed it)
- Energy supply & its weight

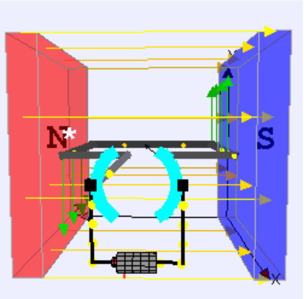
www.photonics.com/a42575/Robotic_Automation_for_Solar_Cell_Manufacturing, https://www.dreamstime.com/stock-images-robot-energy
charge-image22373104

Motors



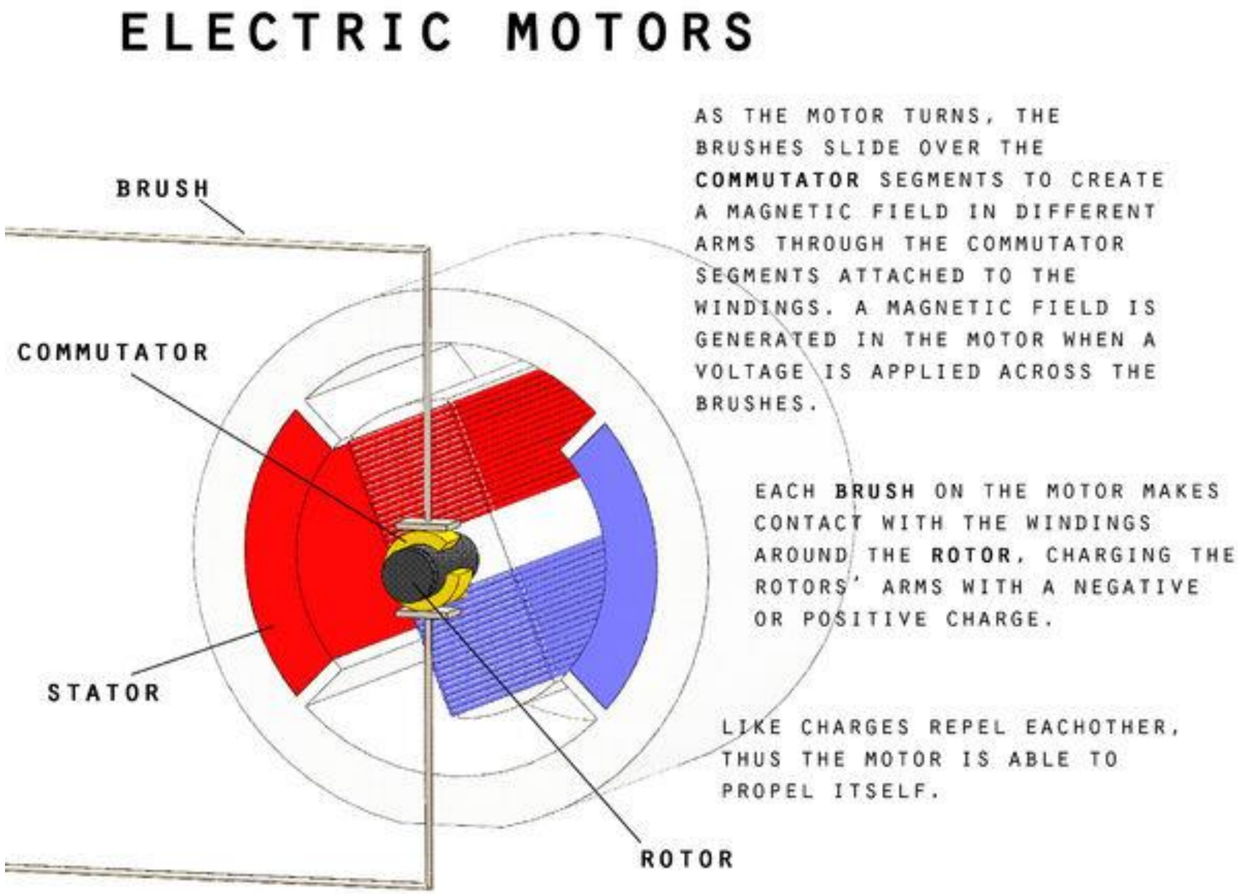
- Compared with all other types of actuators, ***direct current (DC) motors*** are simple, inexpensive, easy to use, and easy to find.
- Motors have a copper wire wound in a way that creates magnetic fields
  - These “push" the rotor inside of the motor around in a circle.

Motors



- To make a motor run, you need to provide it with electrical power in the right voltage range.
  - Low voltage, slower movement.
  - Higher voltage, faster movement
    - but more wear on the motor and can burn out if run fast for too long.
    - Like a lightbulb on a battery. More voltage means a brighter light.

Motors



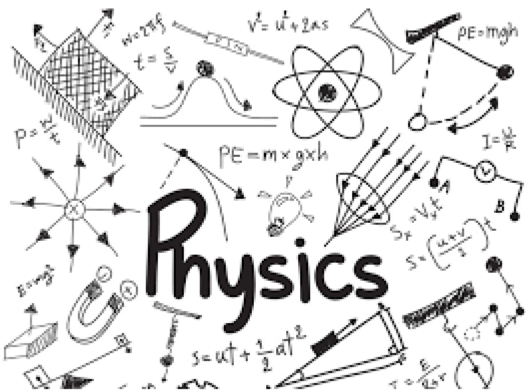
http://makezilla.com/2016/01/21/how-to-motors/

Gearing of motors

- Combining different *gears* is used to change the speed and torque (turning force) of motors.

http://www.jsumo.com/steel-gear-bundle-08-module-6421-reduction

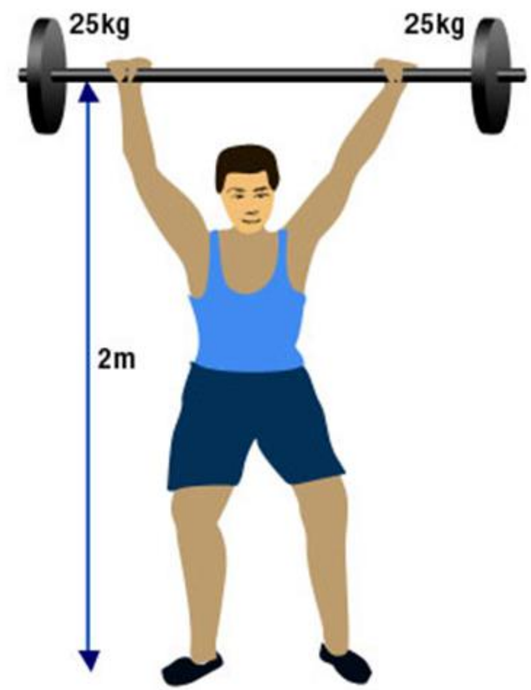
Some Physics



http://theconversation.com/physics-is-taught-badly-because-teachers-struggle-with-basic-concepts-86083

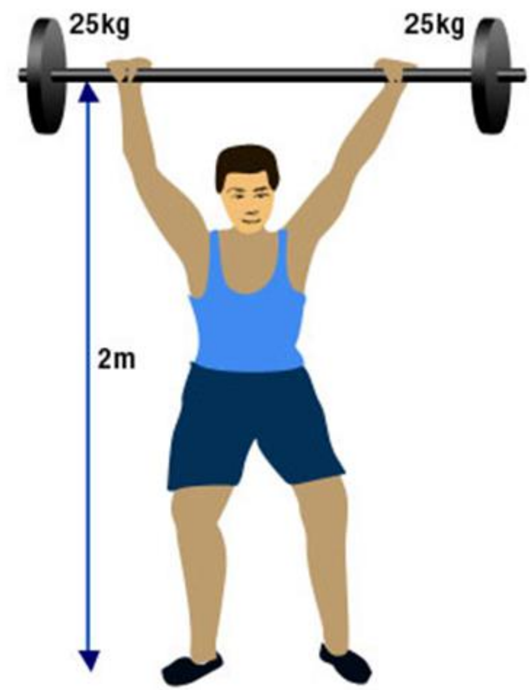
Work, Force and Distance

- Energy is the ability to do work
- Measured in Joules
- Work: The action of a *force* to cause *displacement* of an object
  - Work(J) = Force (N) x distance (m)
    - 1 joule = 1 Newton * 1 meter



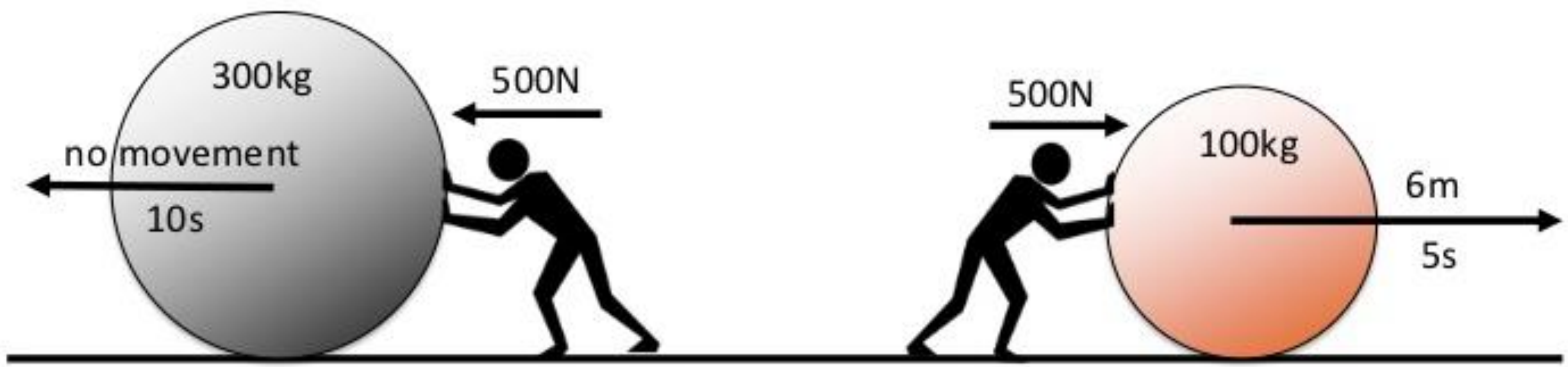
Work, Force and Distance

- Here, in this figure, we can say that, the work done upon the weight against gravity is
- (Mass × acceleration due to gravity) × Displacement
- = (25 x 2 × 9.8) × 2 = 980 J



Work, Force and Distance

- Who has done the most work?
  - Work = Force x Distance



http://www.clker.com/clipart-man-push.html

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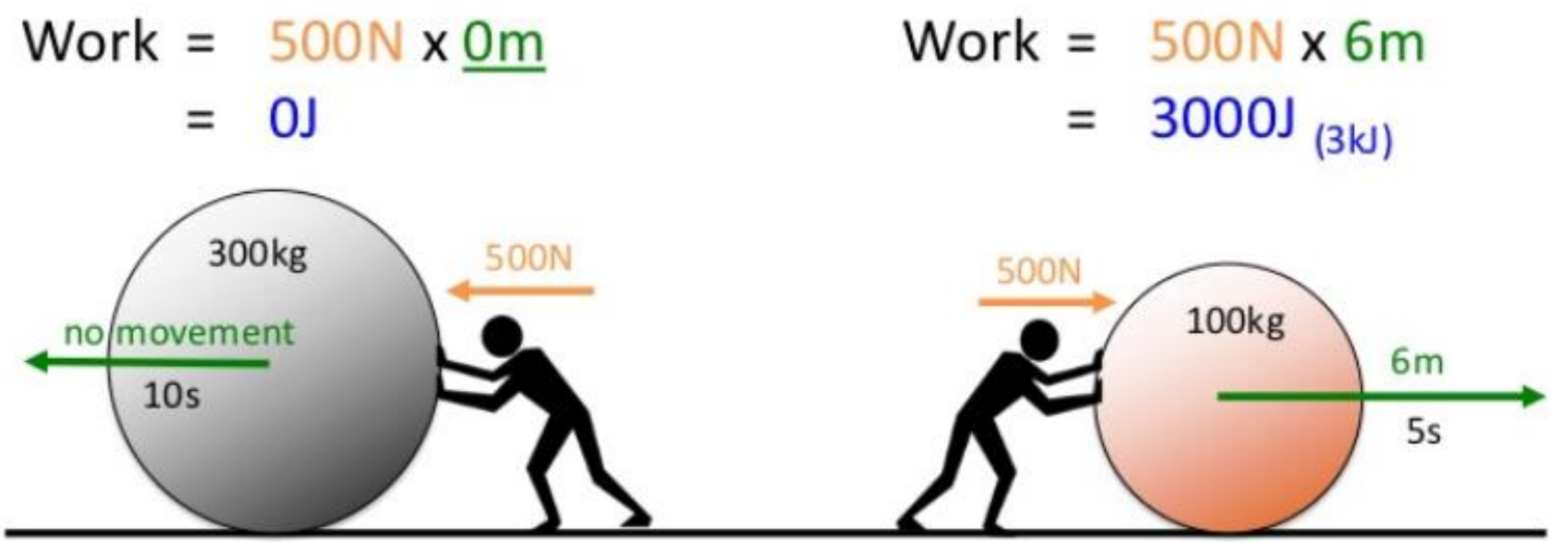


https://www.slideshare.net/gurustip/energy-work-power-10148820

Torque

- Torque is a measure of the force that can cause an object to rotate about an axis.
- TORQUE measures *ROTATIONAL FORCE*
- TORQUE = FORCE x DISTANCE
    - DISTANCE is equivalent to the RADIUS of the rotational circumference.

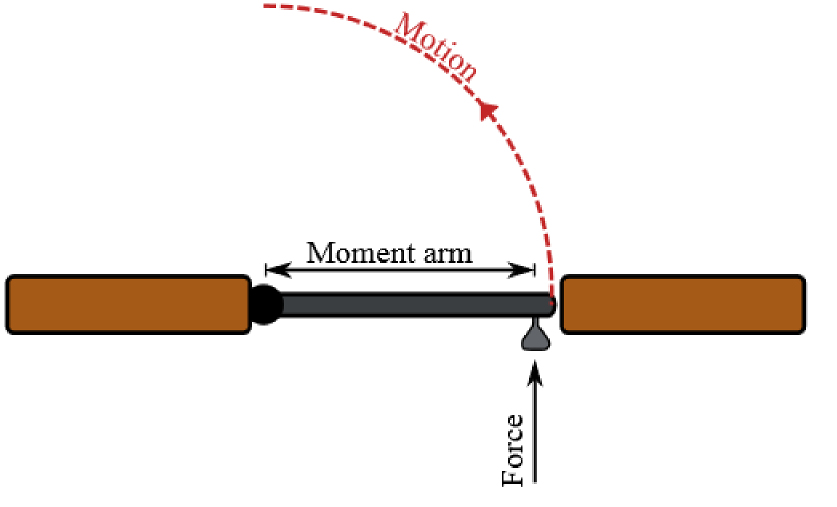
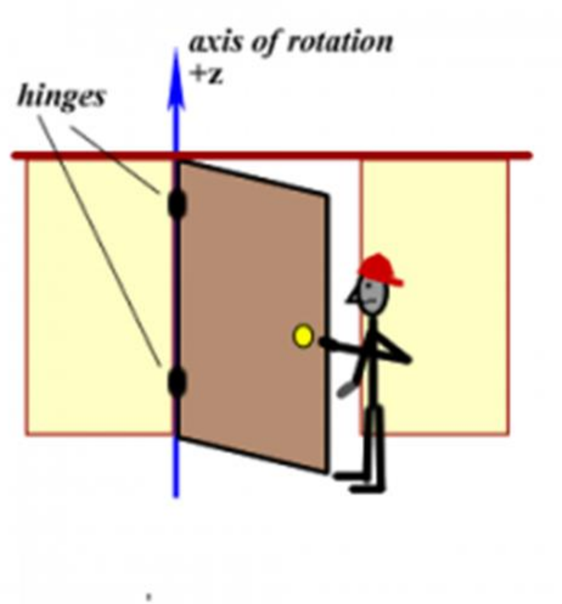


Figure 1: Opening a door with maximum torque.

Torque

- Example: opening a door:
  - Torque is the angular force that the person exerts



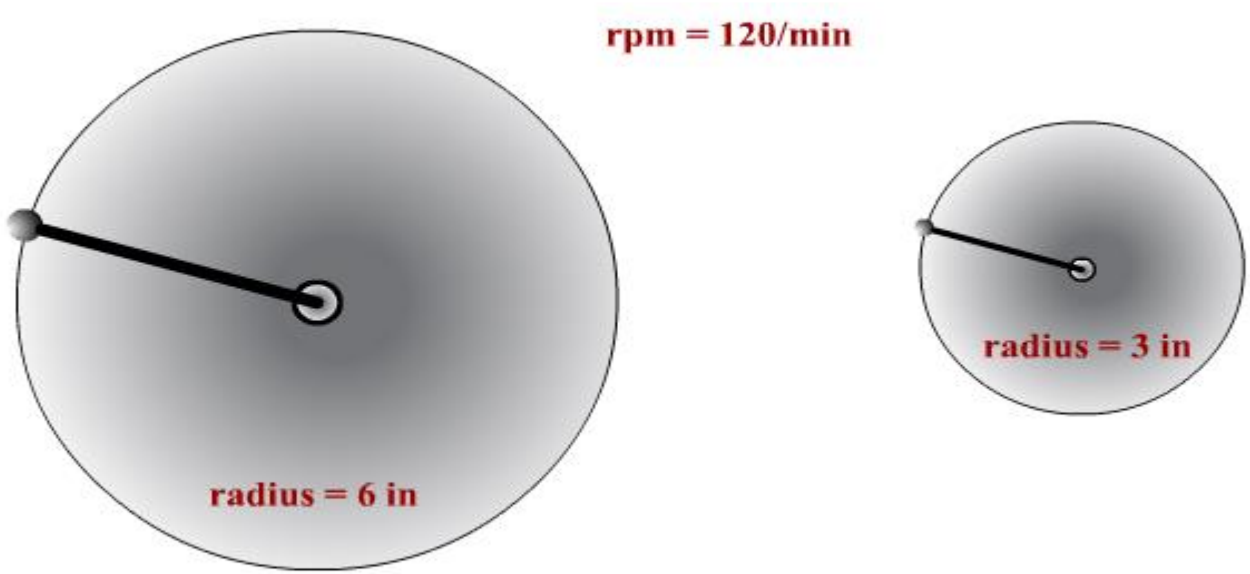
Gearing of motors

- Combining different *gears* is used to change the speed and torque (turning force) of motors.
- Work, as defined in physics, is the product of force and distance.
  - Work = force × distance
  - Distance moved in the direction of the force
- Gears rotate around their axis in a certain velocity
  - Rotational Velocity is specified in Rotations Per Minute.

Gearing of Motors

- Torque provided by motor is typically constant
- For a wheel on the ground, torque needed to turn wheel equals to overcome friction
  - $Torque = F_f * Distance$
    - Distance = wheel radius
- For a larger wheel, smaller rotational force will be provided by same engine
  - Harder to turn larger wheels
    - Think of a truck vs. car, who has the bigger engine?

Rotational and Linear Velocity



- Both wheels touch the ground and rotate at 120rpm
- Which wheel will travel further?
  - Larger wheel will travel further!
    - Can we calculate its linear velocity?

- <u>Note:</u>
  - <u>Rotational Velocity</u> is specified in Rotations Per Minute.
  - <u>Linear Velocity</u> is usually specified in Feet Per Minute.

Rotational and Linear Velocity

- To convert from Rotational Velocity (RV) to Linear Velocity (LV) first find the Circumference (C) of the circles:
  - $C \quad = 2 \times \pi \times r$ inches (where r is the radius)

    $C_1 = 2 \times \pi \times 6 = 37.70\, inches$

    $C_2 = 2 \times \pi \times 3 = 18.85\, inches$

- Linear Velocity = C x Rotational Velocity (120 rpm both)
  - $V_l = 37.70 \ast 120 = 4524\, inches/min$
  - $V_2 = 18.85 \ast 120 = 2262\, inches/min$

http://domarcompanies.com/velocity-business-systems/

Gears

Gears

- Gears are wheels with teeth. Gears mesh together and make things turn.
- Gears are used to transfer motion or power from one moving part to another.
- Both the input gear (driven gear) and the output gear each have a set number of teeth
- The ratio between these two gears can be used to find the torque and speed of the output gear
  - if the input torque/speed to the driven gear is known.

Gears

- **Output Speed** = (*Input gear / Output gear*) * *Input Speed*
- **Output Torque** = (*Output gear / Input gear*) * *Input Torque*

Gears - example

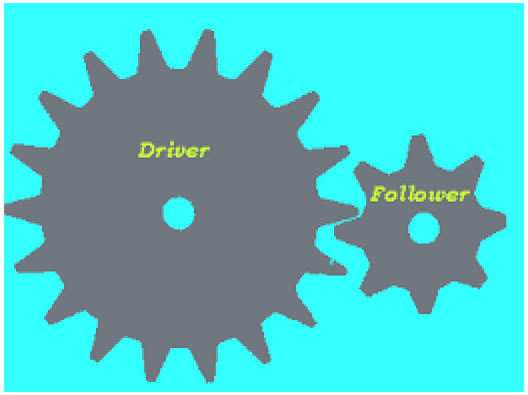
- A motor is attached to a 10 tooth spur gear
  – Gear spins at 100 rpm (rotations per minute)
  – Gear has a torque of 1 joule and 3 in radius
- 20 tooth gear attached to the 10 tooth gear
- What are the output speed and torque?
  – Output speed = (10 /20) * 100 = 50 rpm
  – Output torque = (20 / 10) * 1 = 2 joules

Gears – The Purpose

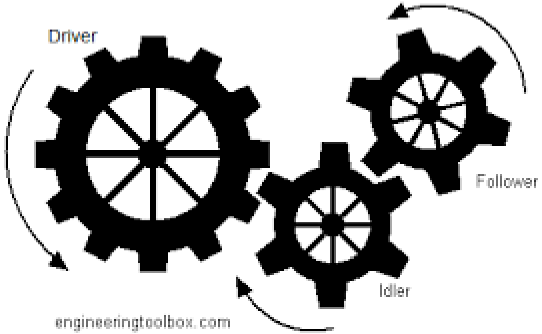
Gears are generally used for one of four different reasons:

- To reverse the direction of rotation
- To increase or decrease the speed of rotation
- To move rotational motion to a different axis
- To keep the rotation of two axis synchronized

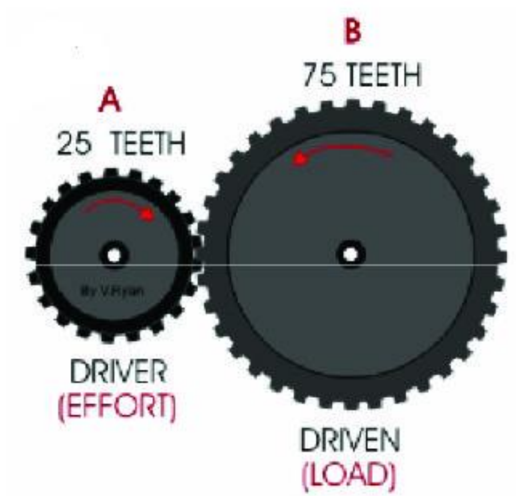
Gear System



- Compound Gears



Gear Ratio



$$\frac{\textbf{Driven}}{\textbf{Driving}} = \frac{75}{25} = \frac{3}{1} \longrightarrow \mathbf{3:1}$$

Locomotion and Manipulations

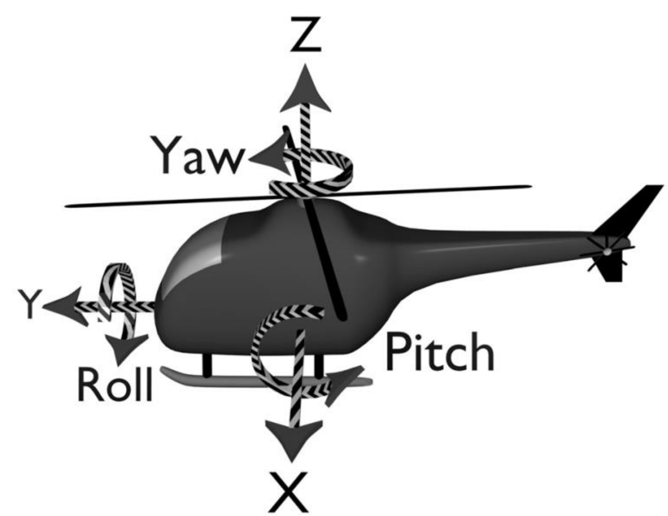
- Choice of effectors and actuators sets the limits on what the robot can do
- Usually categorized as locomotion or manipulation
  – Locomotion: vehicle moving itself
  – Manipulation: An arm moving things
- In both cases can consider the *degrees of freedom* in the design

Degrees of freedom (D.O.F.)

- Definition: How many independent factors needed to specify the motion of the system?
  - The specific number of axes that a rigid body is able to freely move in three-dimensional space
  - For robots: directions of independent motions

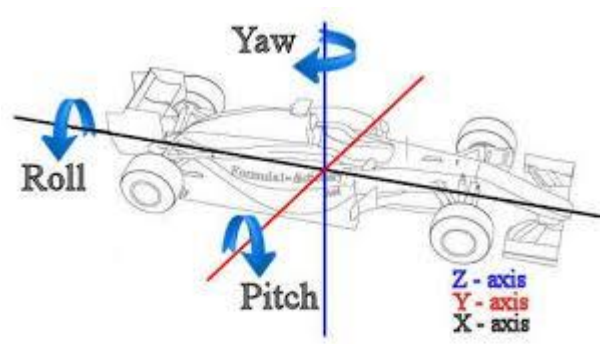
Degrees of freedom (D.O.F.)

- For an object in space have:
  - The body can move in three dimensions, on the X, Y and Z axes
  - Also, it can change orientation between those axes though rotation usually called pitch, yaw and roll
  - Total of 6 degrees of freedom



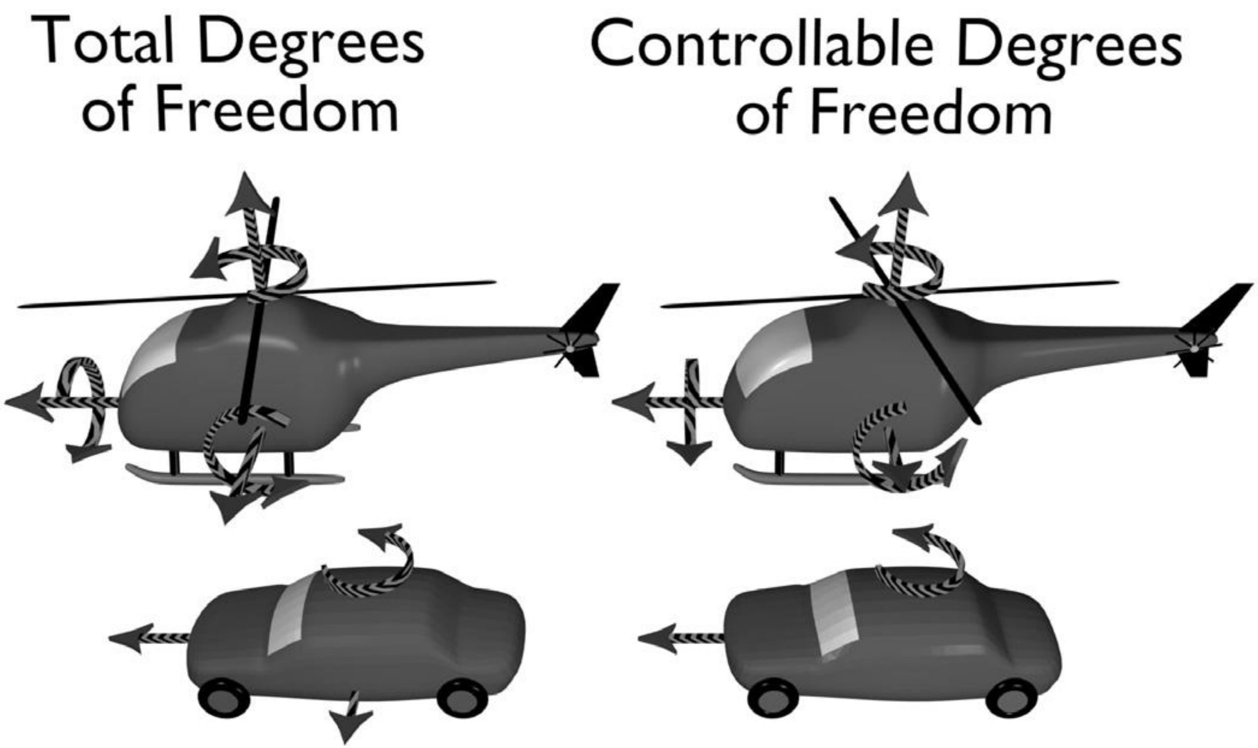
Degrees of freedom (D.O.F.)

- How many D.O.F. to specify movement of a vehicle on a flat surface?
  - Three: X,Y and yaw (turn in x-y dimension)
- How many Controllable D.O.F.'s?
  - In which direction can driver drive the car?
  - X and yaw

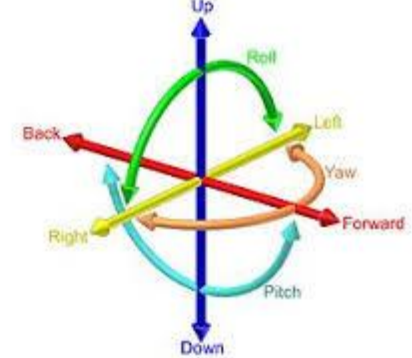


http://www.f6tech.com/our-solution/, http://www.formula1-dictionary.net/motions_of_f1_car.html

Degrees of freedom (D.O.F.)

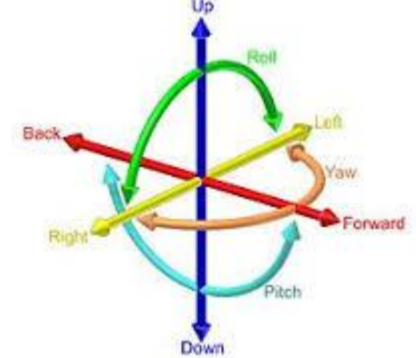


Robot’s Variables Affecting D.O.F.



- Number of joints/articulations/moving parts
  - If parts are linked, fewer parameters needed to specify them.
- Number of Individually controlled moving part
  - Need parameters for each to define configuration
  - Often described as ‘controllable degrees of freedom’
  - But some may be *redundent*
    - Two movements may be in the same axis

Robot's Variables Affecting D.O.F



- How many parameters to describe the position of the whole robot or its end effector?
  - Fixed robot: D.O.F. of end-effector determined by D.O.F. of robot
    - max six D.O.F.
  - Mobile robot on a plane:
    - Can reach positions described by 3 D.O.F. (similar to a car)
    - But robot may have fewer D.O.F. by design, than it is non-holonomic

Lab time!

- Let’s work with our robots!