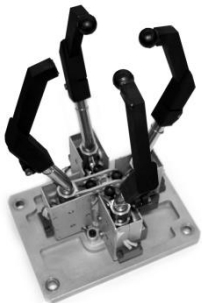


Robot Construction: Effectors and Actuators

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



ACTUATORS



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

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) & phototaxis (avoid crossing previous tracks)
 - Thigmotaxis: motion in response to a touch stimulus
 - Phototaxis: 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

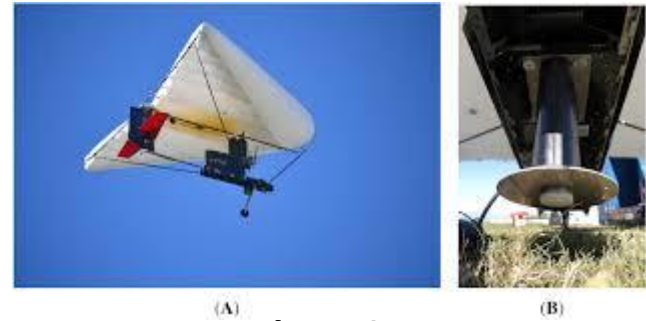
- how many degrees of freedom a robot has is very important in determining how it can affect its world, and therefor how well, if at all, it can accomplish its task
- More on D.O.F. later...

Passive vs. Active Actuation



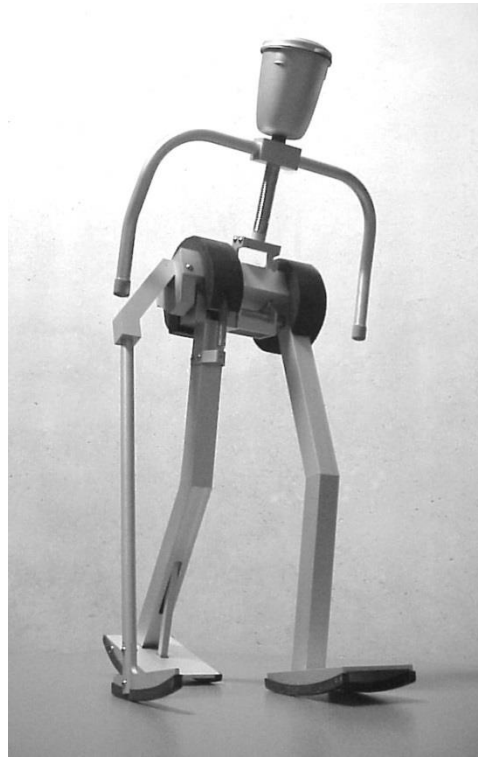
- The action of actuators and effectors requires some form of energy to provide power.
- Some actuators use *passive actuation*

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

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?)

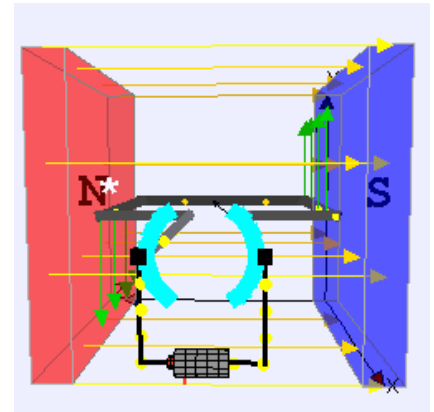


Variables Affecting Actuators Choice

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

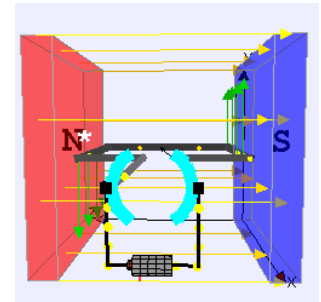


Motors



- 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.

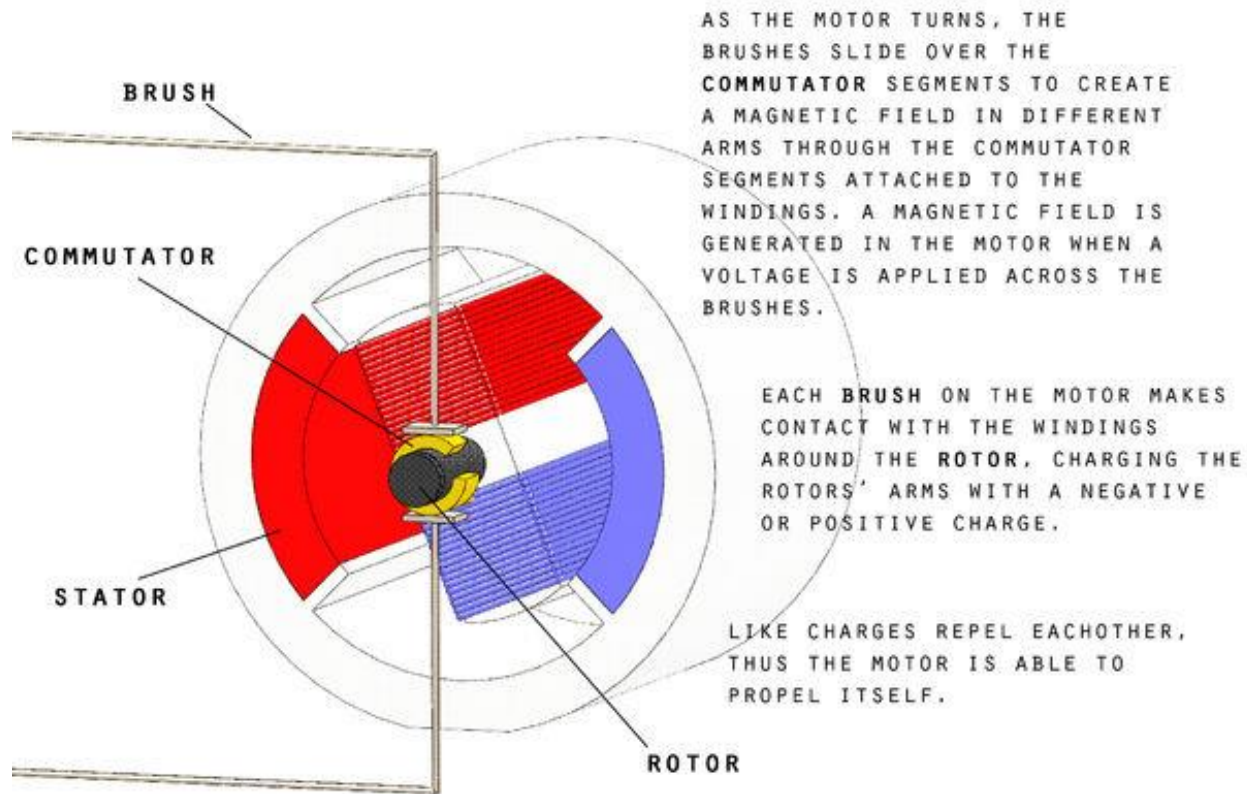
Motors



- 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

ELECTRIC MOTORS

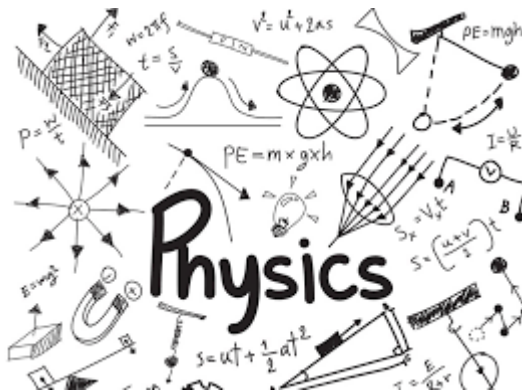


Gearing of motors



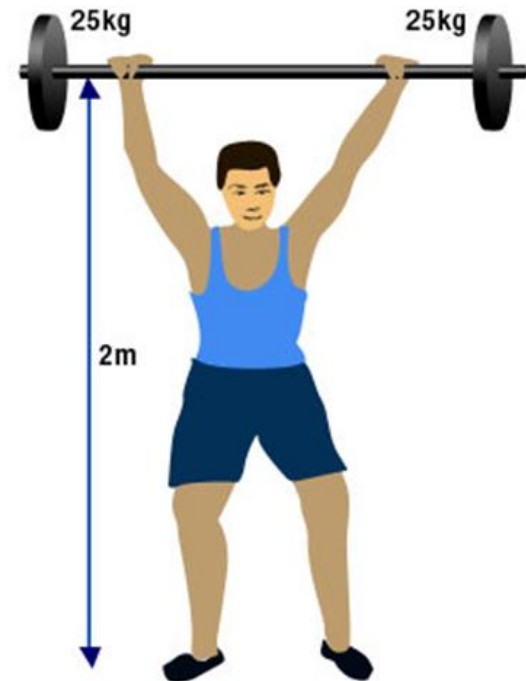
- Combining different *gears* is used to change the speed and torque (turning force) of motors.

Some Physics



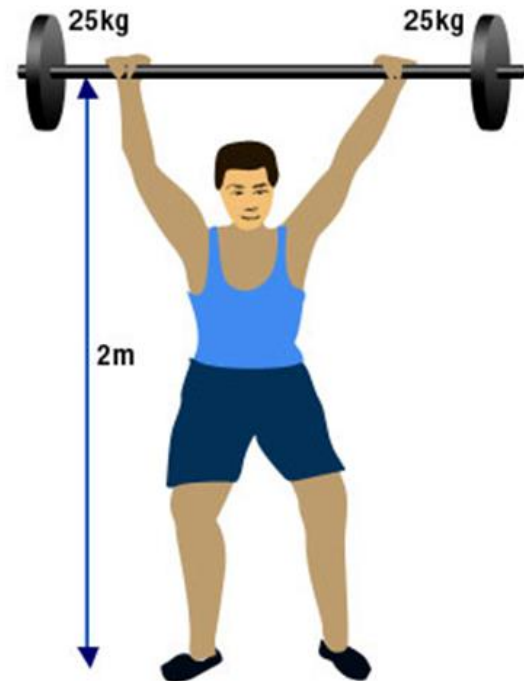
Work, Force and Distance

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



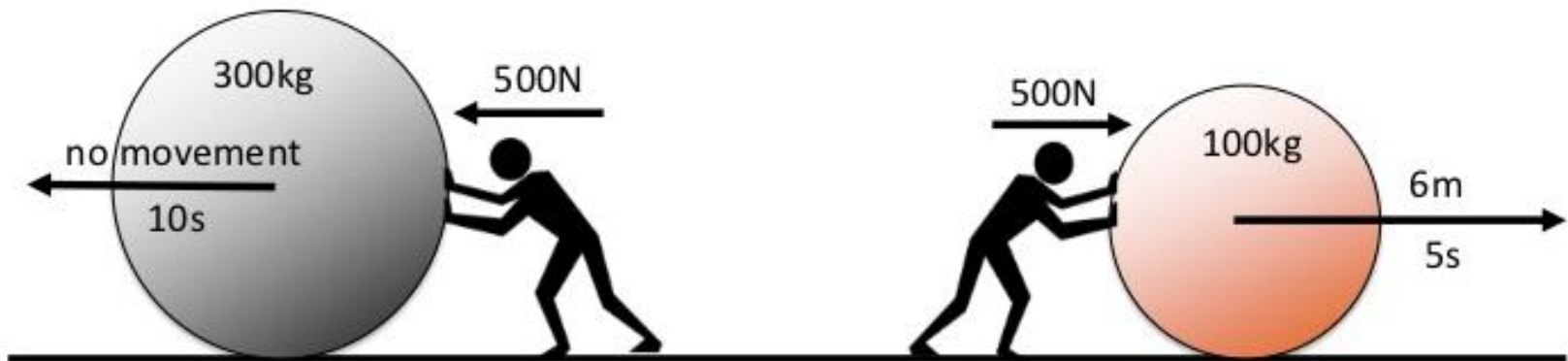
Work, Force and Distance

- Here, in this figure, we can say that, the work done upon the weight against gravity is
- $(\text{Mass} \times \text{acceleration due to gravity}) \times \text{Displacement}$
- $= (25 \times 2 \times 9.8) \times 2 = 980 \text{ J}$



Work, Force and Distance

- Who has done the most work?
 - $\text{Work} = \text{Force} \times \text{Distance}$

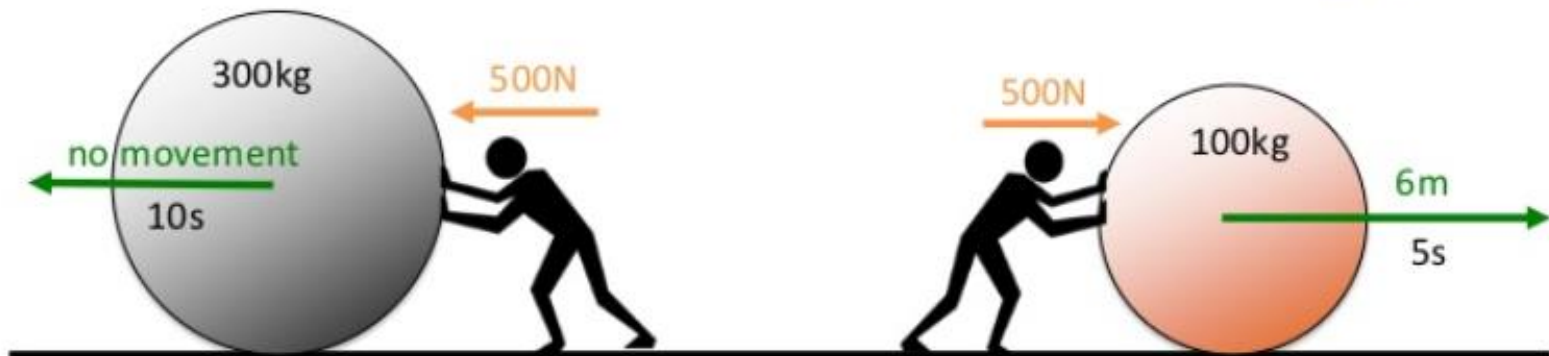


Work, Force and Distance

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

$$\begin{aligned}\text{Work} &= 500\text{N} \times \underline{0\text{m}} \\ &= 0\text{J}\end{aligned}$$

$$\begin{aligned}\text{Work} &= 500\text{N} \times 6\text{m} \\ &= 3000\text{J} \text{ (3kJ)}\end{aligned}$$



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.

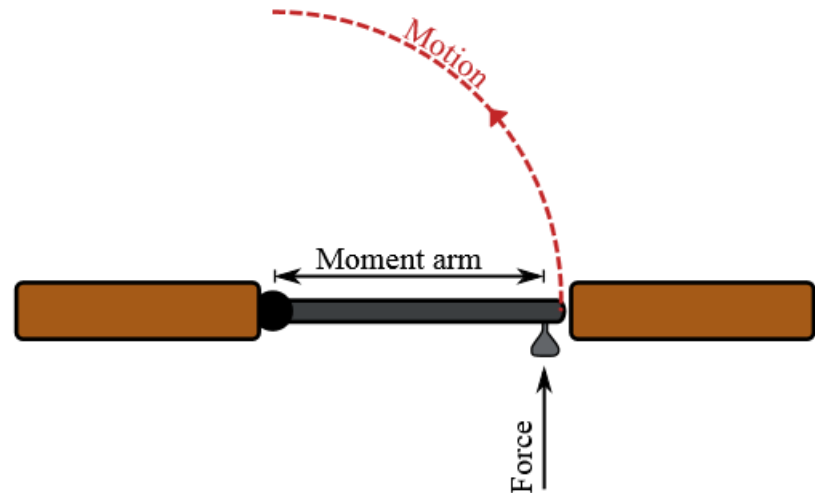
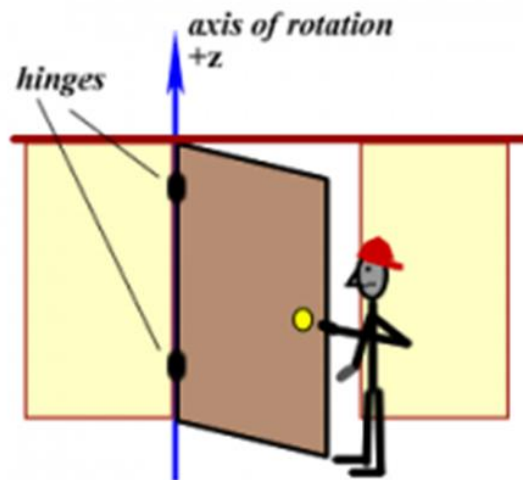


Figure 1: Opening a door with maximum torque.

Torque

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



Gearing of motors



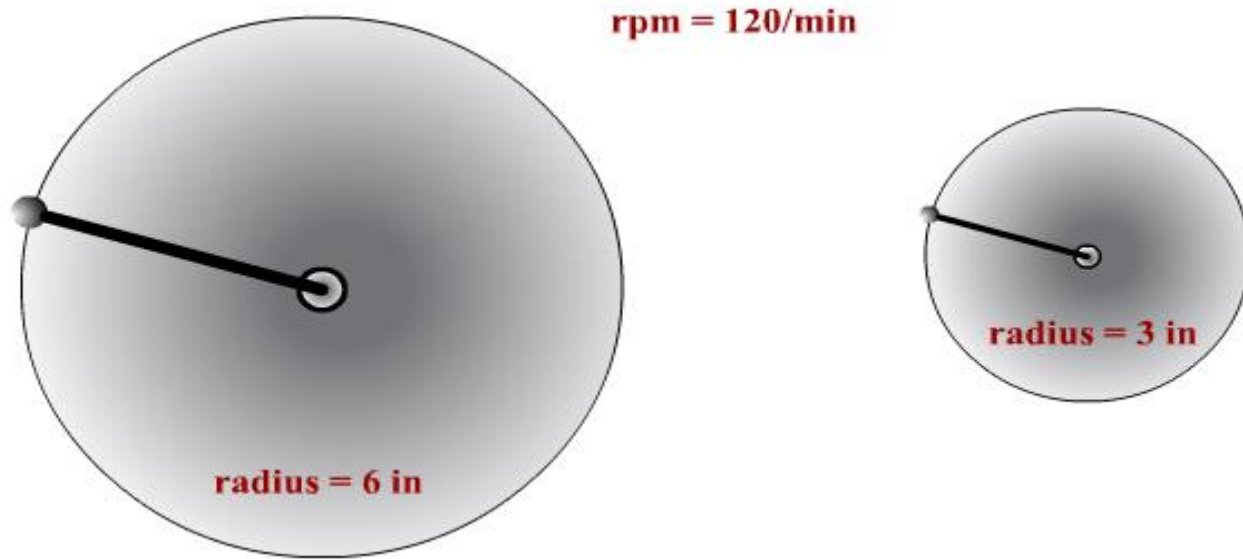
- Combining different *gears* is used to change the speed and torque (turning force) of motors.
- Work, as defined in physics, is the product of force and distance.
 - $\text{Work} = \text{force} \times \text{distance}$
 - Distance moved in the direction of the force
- Gears rotate around their axis 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?
- Note:
 - Rotational Velocity is specified in Rotations Per Minute.
 - Linear Velocity is usually specified in Feet Per Minute.

Rotational and Linear Velocity

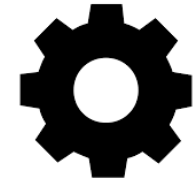


- To convert from Rotational Velocity (RV) to Linear Velocity (LV) first find the Circumference (C) of the circles:
 - $C = 2 \times \pi \times r$ inches (where r is the radius)
 - $C_1 = 2 \times \pi \times 6 = 37.70 \text{ inches}$
 - $C_2 = 2 \times \pi \times 3 = 18.85 \text{ inches}$
- Linear Velocity = C x Rotational Velocity (120 rpm both)
 - $V_1 = 37.70 * 120 = 4524 \text{ inches/min}$
 - $V_2 = 18.85 * 120 = 2262 \text{ inches/min}$

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



Academy Artworks

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

Gears - example



Academy Artworks

- 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

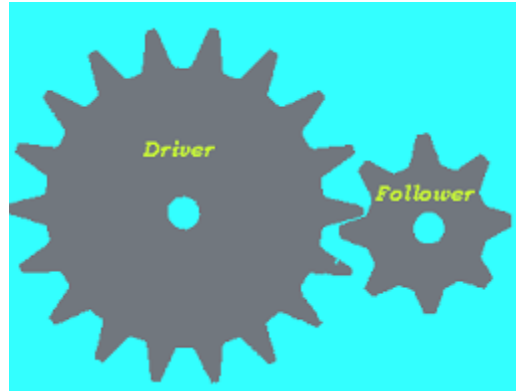


Academy Artworks

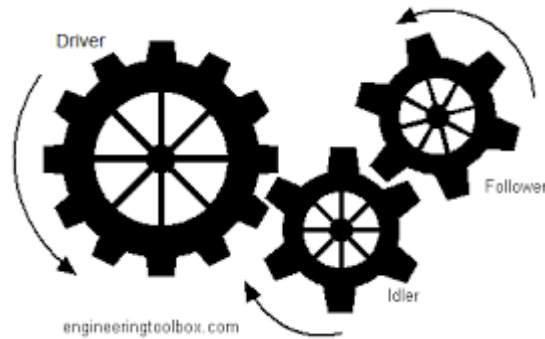
Gears are generally used for one of four different reasons:

- 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

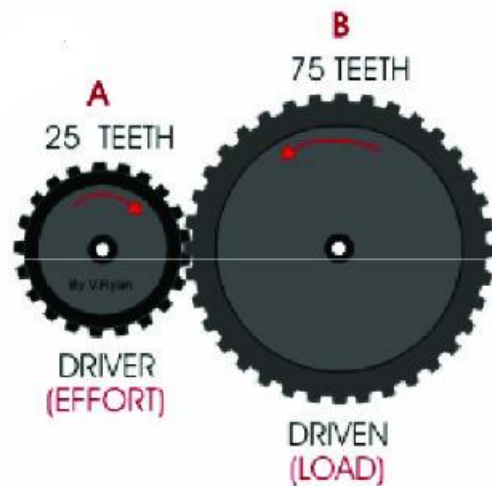
Gear System



- Compound Gears



Gear Ratio



$$\frac{\text{Driven}}{\text{Driving}} = \frac{75}{25} = \frac{3}{1} \rightarrow \mathbf{3:1}$$



Locomotion and Manipulations

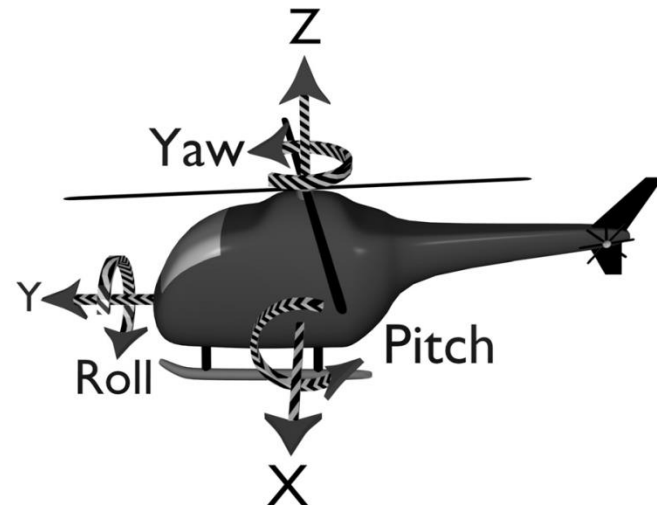
- Choice of effectors and actuators sets the limits on what the robot can do
- Usually categorized as locomotion or manipulation
 - Locomotion: vehicle moving itself
 - Manipulation: An arm moving things
- In both cases can consider the *degrees of freedom* in the design

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

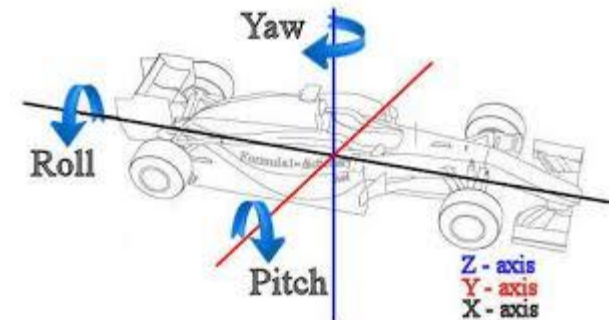
Degrees of freedom (D.O.F.)

- For an object in space have:
 - The body can move straight 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



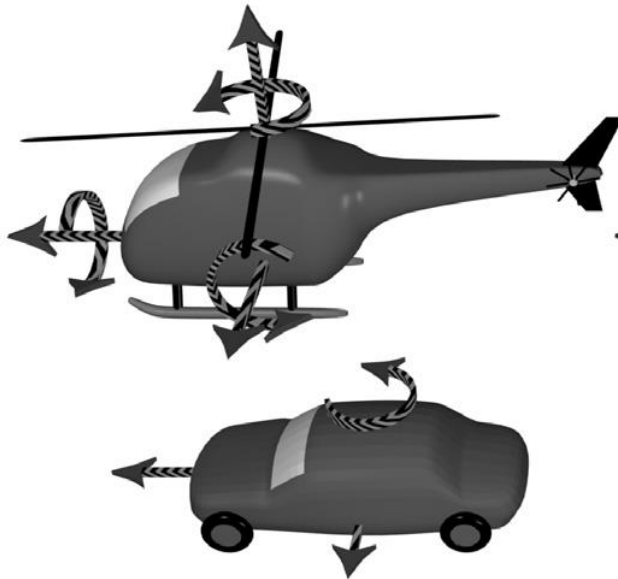
Degrees of freedom (D.O.F.)

- 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

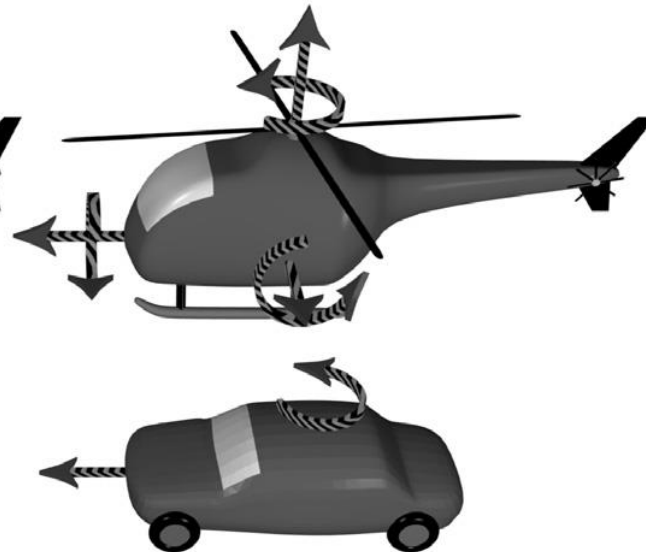


Degrees of freedom (D.O.F.)

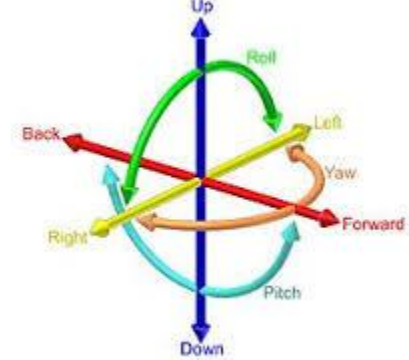
Total Degrees
of Freedom



Controllable Degrees
of Freedom

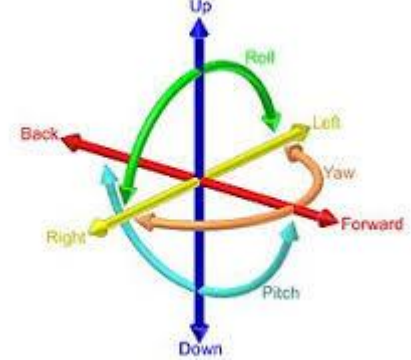


Robot's Variables Affecting D.O.F.



- 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 *redundant*
 - 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!

