Unit B

Construction

Exploring Robotics
Spring, 2013

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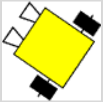


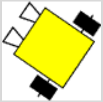
Effectors

An effector is a device on a robot whose *intended purpose* is to

- have an effect on the environment.
- directly interact with the environment.
- perform some kind of work.

Examples

- wheels
- tracks
- legs
- grippers



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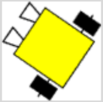
Actuators

An actuator is a mechanism on a robot that

- enables an effector to execute an action or movement.
- transforms energy and transfers it to an effector.

Examples

- electric motors
- internal combustion engines
- hydraulics
- pneumatics



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"Passive Actuation"

Examples

- Gliders
- Passive walkers

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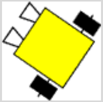
Degrees of Freedom - Rigid Objects

A degree of freedom is a coordinate or parameter needed to completely specify the location, orientation, and configuration of a rigid object in three-dimensional space.
A free body in 3-D space has 6 degrees of freedom

- 3 for position (x, y, z)
- 3 for orientation (roll, pitch, yaw)
  - Roll is tilt side-to-side
  - Pitch is tilt front-to-back
  - Yaw is facing direction

Reference: http://en.wikipedia.org/wiki/Degrees_of_freedom_(mechanics)



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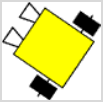
Controllable Degrees of Freedom

Holonomicity

A robot is said to be holonomic if every degree of freedom is controllable

- Holonomic: CDOF = TDOF
- Non-holonomic: CDOF < TDOF



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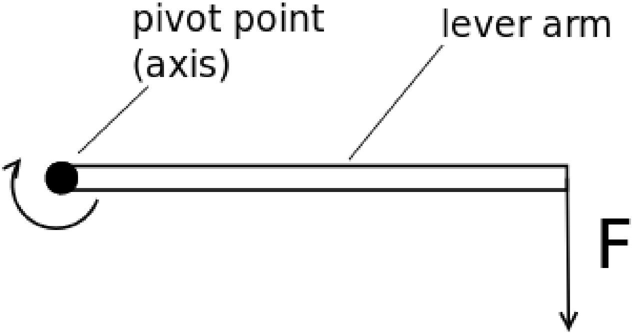
Degrees of Freedom - Redundancy

Joints introduce additional degrees of freedom.

- A *kinematic* degree of freedom is the specific sequence of actions used to accomplish a goal.
- In problems involving motor control of jointed systems (think in terms of animals/humans as well as machines), there are often many possible sequences of trajectories, velocities and accelerations that will achieve the same ultimate result. This is referred to as *redundancy*.
- This is sometimes described as having more controllable degrees of freedom than total degrees of freedom, i.e.:
  CDOF > TDOF

Torque

Torque is the tendency of a force to cause an object to rotate about an axis.



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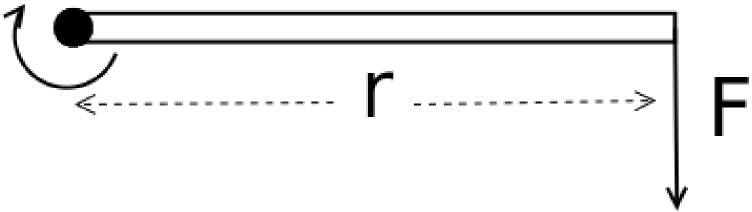
Calculating Torque

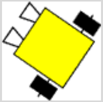
$$\tau = F \times r$$



Actually, the magnitude of a torque depends on 3 quantities

- the magnitude of the force
- the length of the lever arm
- the angle between the direction of the force and the lever arm

but we will be dealing exclusively with force *perpendicular* to the lever arm. This allows us to disregard the angle in our calculations.



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Calculating Torque

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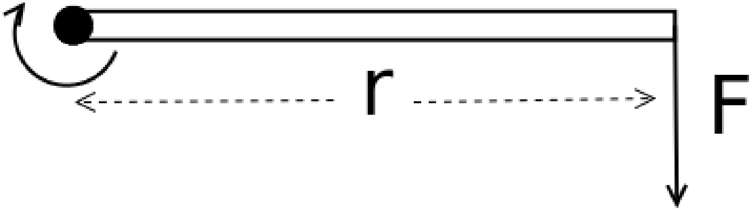


τ is the magnitude of the torque

F is the magnitude of the force

r (radius) is the distance from the point of application of the force to the axis

Note:

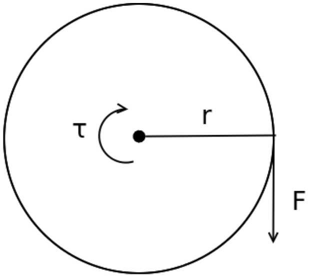
The perpendicular distance from point of application of the force to the axis is called the *moment arm*.

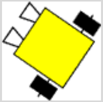
Torque on Circular Objects

The same principle applies to circular objects such as wheels and gears.

- the wheel is attached to an axle (axis) at its centerpoint
- a force is applied along a tangent to the wheel
- the radius of the circle acts as the moment arm
- a torque is generated about the axis

$$\tau = F \times r$$





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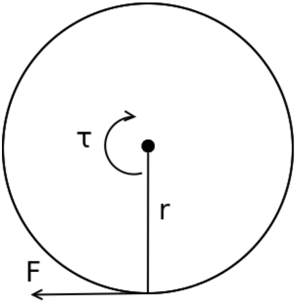
Calculating Force from Torque

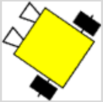
The same principle works in reverse. Given the torque and the radius, we can calculate the force.



$$F = \tau / r$$

So ...

knowing the amount of torque applied by a motor to spin a wheel allows us to calculate the force applied at the floor, propelling the vehicle forward.



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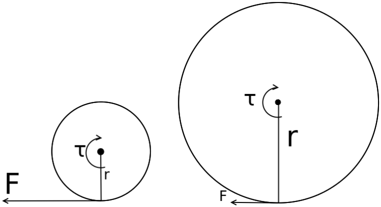
Force and Wheel Size

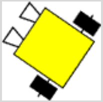
$$F = \frac{\tau}{r}$$

For any given amount of torque about the axis (e.g., the torque supplied by a particular motor), the greater the radius, the smaller the force at the circumference of the wheel.



Notice ...

attach a bigger wheel to the same motor and there will be less force applied at the floor.



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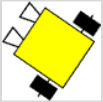
Force and Movement

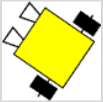
- Moving the robot requires a *net* force pushing it in the desired direction.
- The primary forces opposing the robot's motion are friction and (if moving uphill) gravity. Friction occurs wherever two objects rub against each other, so there is friction at every axle in the drivetrain and also at the axles of any *non-drive* wheels, and where any part of the robot slides along the floor.
- Ultimately, if the robot is to move, it must produce enough force to overcome the friction in the drivetrain, and still deliver enough force to the floor to overcome friction in non-drive wheels, etc., and gravity.



Moving with gears ...

- We have seen that smaller wheels deliver more force to the floor. However, other design considerations may favor larger wheels.
- It's also not always desirable to mount the wheels directly on the motor shafts.

Fortunately, gears can help to solve both of these problems ...



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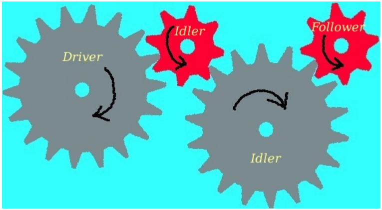
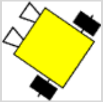
Gear Trains

A system of gears working together (intermeshed) is called a *gear train*.



Gear trains can

- transfer power from one place to another
- change the direction of rotation
- increase or decrease rotational speed
- increase or decrease torque

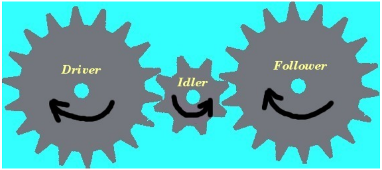


Gear Terminology

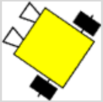
A gear that is connected to a power source (e.g. a motor) is called a *driver* or *input* gear.

A gear that is connected to a wheel or other effector is called a *follower*, *output*, or *driven* gear.

A gear that that is located between two other gears, meshed with both of them and transferring power from one to the other, is called an *idler* gear.



⇒ Adjacent gears rotate in opposite directions.



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Gear Ratio

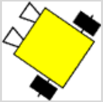
gear ratio *(gr)* is the ratio of the number of teeth on the *follower* to the number of teeth on the *driver*, thus
gr = (output teeth) : (input teeth)
or expressed as a fraction,

$$gr = \frac{\text{(output teeth)}}{\text{(input teeth)}}$$

The number of teeth is proportional to the size of the gear, therefore:

$$gr = \frac{\text{(follower radius)}}{\text{(driver radius)}}$$

⇒ Idler gears do not affect the overall gear ratio.



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Gear Ratio and Torque

If we know the input torque and the gear ratio, we can calculate the torque at the axle of the follower gear:

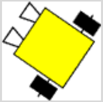
$$\tau_{out} = \tau_{in} \times gr$$

Example

Calculate the output torque, given that motor torque = 0.5 Newton-meter, follower teeth = 40, and driver teeth = 16.

Solution:

$$\tau_{out} = 0.5 \times \frac{40}{16} = 1.25 \text{ Newton-meter}$$



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Gear Ratio and Speed

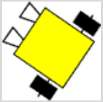
If we know the rotational velocity (*angular velocity*) of the driver and the gear ratio, we can calculate the rotational velocity of the follower gear:

$$\omega_{out} = \omega_{in} \div gr$$

Example

Calculate the output speed, given that motor speed = 100 RPM, follower teeth = 40, and driver teeth = 16.
Solution:

$$\omega_{out} = 100 \div \frac{40}{16} = 100 \times \frac{16}{40} = 40 \text{ RPM}$$



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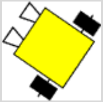
Gearing Up and Down

When gears are meshed together, the smallest gear turns fastest.

- Using gears to *increase* rotational speed is called gearing up. Gearing up occurs when the gear ratio is **less than** 1.00 [i.e., $(\text{output teeth}) < (\text{input teeth})$]
- Using gears to *decrease* rotational speed is called gearing down. Gearing down occurs when the gear ratio is **greater than** 1.00 [i.e., $(\text{output teeth}) > (\text{input teeth})$]



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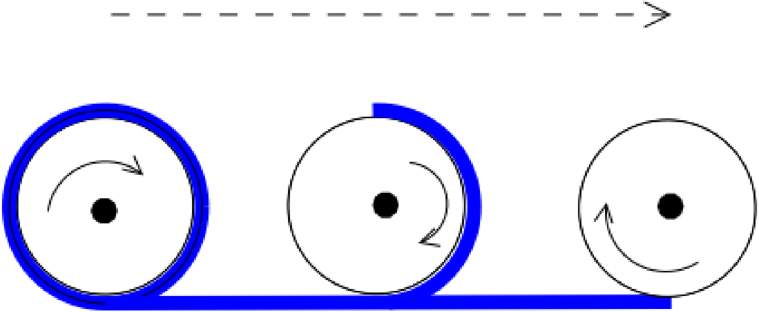
Wheel Size and Speed

The distance travelled by a wheel during one revolution is equal to the wheel's circumference.



Calculating Linear Velocity

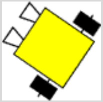
The wheel's circumference $C = 2\pi r$. Therefore, if we know the radius r and the rotational velocity ω, we can calculate the linear velocity v (speed).

$$v = 2\pi r \times \omega$$

Example

Calculate the linear velocity (speed) of a robot *in meters/second*, given that the radius of its wheel is 2 cm and the wheel's rotational velocity is 60 RPM.
Solution: 2 cm = 0.02 meter and 60 RPM = 60 $\div$ 60 = 1 revolution/second, and using $\pi \sim 3.14$,

$$v = 2 \times \pi \times 0.02 \times 1 = 0.04\pi \sim 0.1256 \text{ m/sec}$$



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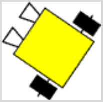
Designing for Reliability

Redundancy

Multiple components or subsystems with duplicate or overlapping functions

- one component can supplement or take over the function of another in case of failure
- increases the reliability of a system
- enhances ability to continue to perform mission despite partial breakdown



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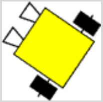
Design Compromises

Robot design often requires compromises among conflicting factors in order to achieve the desired results. For example,

- a larger wheel can yield an increase in linear velocity, but results in *less* force pushing the robot forward.
- “gearing down” produces an increase in torque but also causes a decrease in rotational speed.
- “gearing up” produces an increase in rotational speed but also causes a decrease in torque.



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