How reaction Wheels actually Work

[How Reaction Wheels Actually Work]

- Wires interfere with determining the correct balancing point
    - Additional weight changes the center of gravity
    - Disconnect all wires (use bluetooth instead)
    - Do not have wires that go to motors/CPU
    - Can only work when nothing interferes
- When testing the reaction wheel
    - Do not hold the reaction wheel - just push it
        - Controller is not getting feedback so it goes full force
    - Let go when the wheels start working
- Determine the balancing point
    - Do everything only via bluetooth
    - Send c+ via serial monitor
        - Will start calibration procedure
        - C- will complete calibration procedure
    - Message that the angles is wrong if the stick is not vertical
        - Send c+
    - Place the stick vertically
        - Where it doesn't fall over to any side
        - Keep still
        - Send c-
            - Will begin to balance
        - Offsets values will be written to the EEPROM
- Check if everything is connected correctly
- When motors start turn to left/ right
    - Note which way motor is turning and which motor
- Use a battery/ cables are a bad idea
- Why voltage/ current are needed

Understanding Reaction wheels

[Understanding reaction wheels]

- Integral part of any satellite/ spacecraft
- Secures 3 axis attitude control without the need of external sources of torque
- Reaction wheels aka momentum wheels:
    - Flywheels that enable repositioning of space vehicles
        - Flywheel: device that contains rotational energy (conserves angular momentum)
    - Used to control position and attitude of a satellite
- Benefits:
    - Reduction in payload fraction needed for fuel
    - Extremely accurate
    - Enable precise repositioning
    - Benefits over thrusters:

        - Saves space
        - Light weight
        - Easier to manage
        - More precise
        - EX:
            - Earth Observation satellites could not perform at top standards w/out reaction wheel assembly
        - Thrusters are dependant on fuel
        - Saves costs
        - Avoid propellant issues
- How it works:
    - The object feels a force, and the reaction wheel triggers a counter rotation that is opposite to that force through the conservation of angular momentum
    - Only occurs in torque
    - Cannot move the spacecraft/ satellite
- To have complete control
    - Object needs 3 rws

Kepler Mission Operations Response to Wheel Anomalies

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- Mission goal:
    - Search for earth-sized planets in the habitable zone
    - Has identified 3.500 planets
- How it completed its goal:
    - Steady pointing of the aircraft
        - 4 reaction wheels, a set of fine guidance sensors, w/ science CCDs
- Reaction Wheel failure
    - Wheel 2 failed
    - Design only required 3 wheels for pointing accuracy
- Overview of mitigations and operations changes
    - Needed to preserve the reaction wheel health
    - Relied on those wheels

Introduction to Reaction Wheels

Introduction to Reaction Wheels – Space Steps

- Reaction wheel: wheel attached to a motor (motorized wheel)
    - If the object is spun one way, the wheel changes its spinning speed and moves in the opposite direction
        - Not as fast as the movement of the object itself
    - Makes spacecraft turn around objects center of mass
    - You need 3+ reaction wheels to turn the object in all directions
        - All have to be pointing in different directions
    - Used to make a spacecraft point in a certain direction
- Why reaction wheels are used:

- You want to point at things
- Want to stop your spacecraft from tumbling
  - Tumbles caused by magnetic fields, atmospheric drag, micrometeoroid, solar wind, oblateness of earth, gravity, and more
- Wheels are used to combat the twisting
- Mass of reaction wheel < mass spacecraft
  - Wheel has to change its speed a lot to twist spacecraft
  - Wheels on medium to large systems have 2k rev/min
- Angular momentum: how fast the wheel is turning
  - It's the wheel's change in speed the matters not how fast the wheel is spinning

Example of a single-axis reaction wheel
Single-Axis Reaction Wheel Self-Balancing System

Reaction Wheel Attitude Control
Charles' Labs - Reaction Wheel Attitude Control
- Physics behind reaction wheels is based on conservation of angular momentum
  - I(fly) * w(fly) + I(sat) * w(sat) = k
  - Change in w(sat) = - I(fly)/I(sat) * change in w(fly)
  - W = angular speed
  - I = moment of inertia -> opposition that the body exhibits
  - I = triple integral p(x,y,y)||r||^2dV
  - I for a cylinder:
    - I = .5mR^2
- Electronics:
  - You need something that can:
    - measure the current angular speed
    - Drive the stepper motor
    - Reun the control algorithms
    - LiPo battery
    - If the MPU and arduino are different volts you need a bi-directional level converter board
- Control Algorithms
  - Needs to control angular momentum
  - Control theory:
    - Stepper motor affects the rotation speed of the model. Measured by the gyroscope which gives feedback

PID Explained
PID Controller Explained • PID Explained
- Proportional Integral Derivative controller
  - Works by controlling an output to bring a process value to a certain point
- Key terms
  - Set point: a user entered value

- Process value: value that is being controlled
    - Output: the controlled value of a PID controller
    - Error: error value used to determine how to manipulate the output to bring the process value to the set point
        - Error = setpoint - process value
- Explanation
    - The PID continuously monitors the error value
        - Calculates proportional, integral, and derivative values
        - Adds above values together to create the output
- Gain: multiplication factor
    - User can control how much effect the PID has on output
- P or Proportional
    - Calculated by multiplying P-Gain by the error
    - Used to have a large immediate reaction on the output
    - Error is smaller, influence of proportional value on output is less
    - Math:
        - kP = proportional gain, SP = set point, PV = process value, Err = Error, P = proportional
        - Err = SP - PV
        - P = kP x Err
- I or integral:
    - Calc by multiplying the I-gain by error then by cycle time of controller
        - Cycle time: how often controller performs PID calculation
        - Accumulates the value as total integral
    - Doesn't have as much immediate influence on output as proportional
    - Continuously accumulating
        - Takes longer for process value to reach set point
            - More effect integral will have on output
    - Math:
        - I = Integral, kI = Integral Gain, dt = cycle time of the controller, It = integral total
        - I = kI x Err x dt
        - It = It + I
- D or derivative
    - Calc by multiplying D gain by ramp rate of the process values
    - Used to predict where the process value is going
    - Bias the output in the opposite direction of proportional and integral
    - Prevents controller from overshooting set point
    - Math:
        - D = derivative, kD = derivative gain, dt = cycle time of controller, pErr = previous Error
        - D = kD x (Err - pErr) / dt
- Output
    - Calc by adding P I and D

- Determines how much effect PID have on output
- Math:
    - Output: P + It + D