UCSB HYPERLOOP

Final Presentation

Spring 2017

SENSORS & CONTROLS

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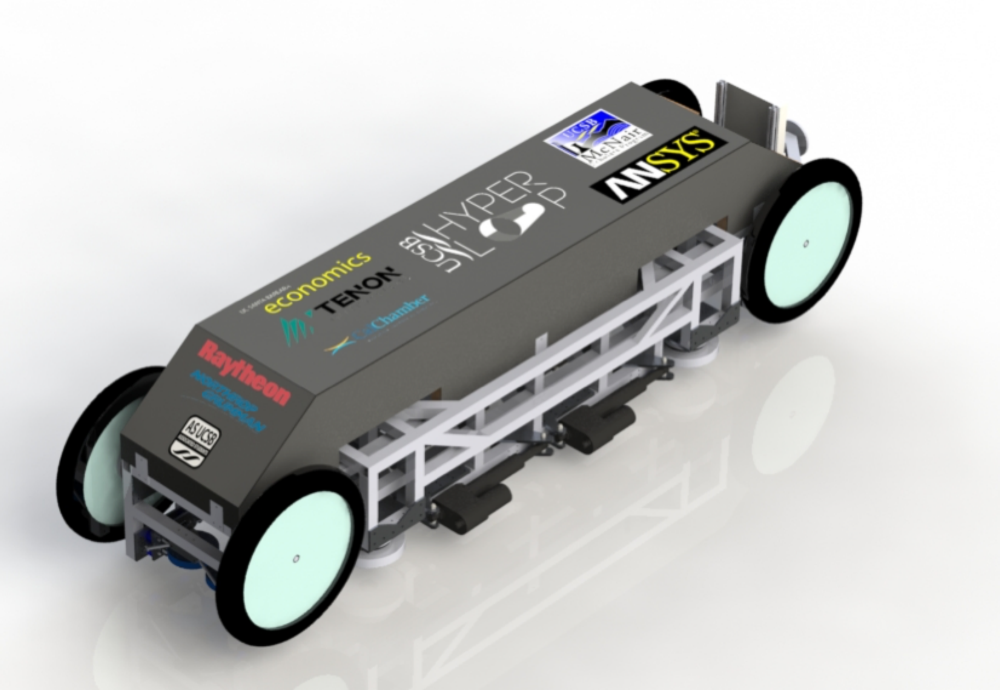
Team
Overview
Structure
Stabilization
Levitation
Braking
Electronics
Power
Thermal
Logistics

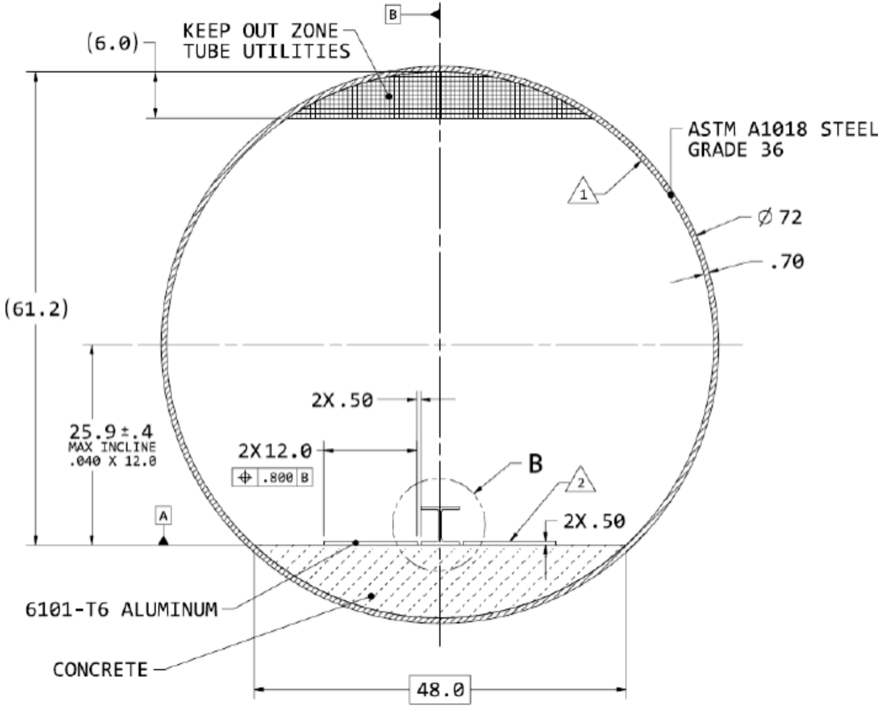
CONTENTS

- Overview
- Hardware
- Maglev
- Actuators
- Navigation
- Power
- Control Systems
- Pod Run
- Testing
- Conclusion



SPACEX COMPETITION

- SpaceX has constructed a mile long test track to develop technology through open competition
- Task: Design a Hyperloop Pod
- Main criteria of success: top pod speed
  - Our pod's max theoretical speed is 205mph



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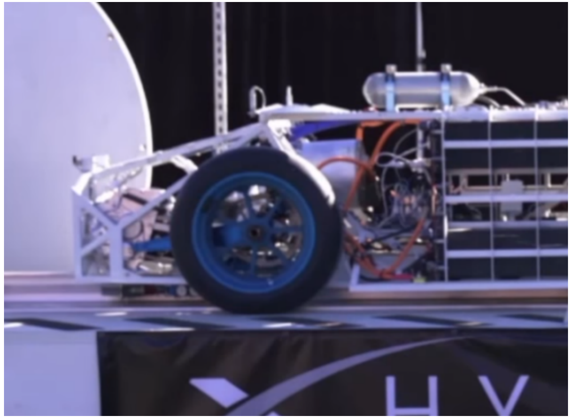
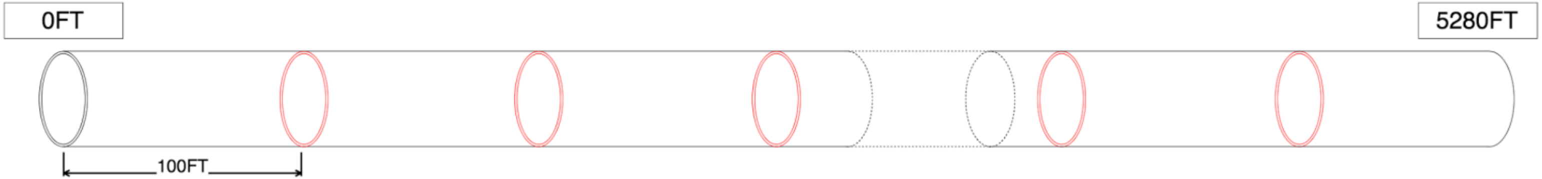
SPACEX COMPETITION

Reducing project complexity

- Photo-reflective tape strips every 100 ft for navigation
- Pod pusher for propulsion
- I-Beam for stabilization
- Network Access Panel for communications





DESIGN SUMMARY

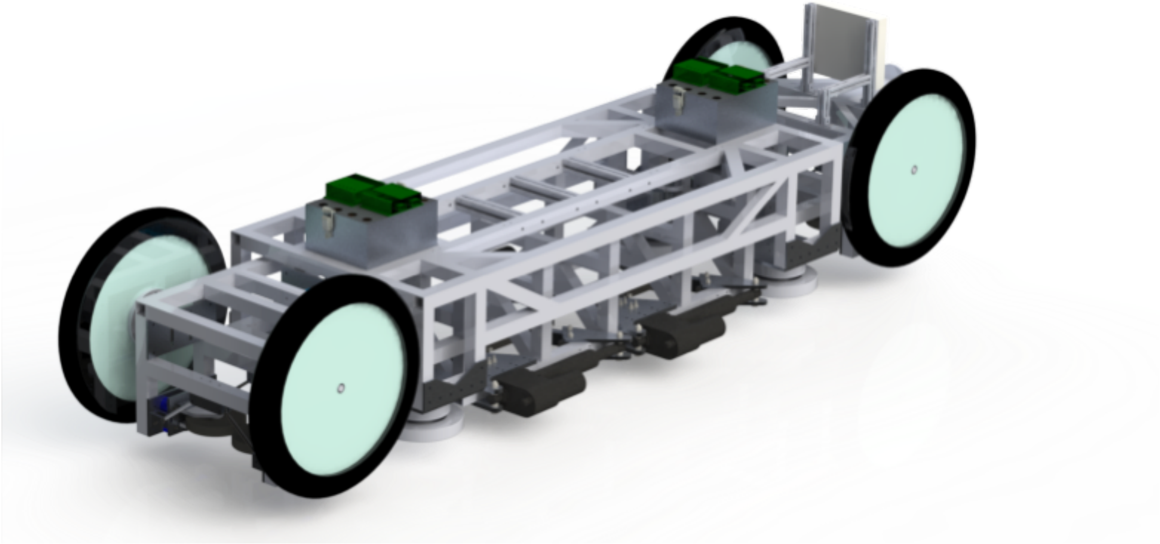


Figure: UCSB Hyperloop proposed design

USA
32
EAGLE
WELD

FRAME

- Made of Al-6061 Tubes
- Cart chassis (**green**)
  - Rides on drag wheels
  - Supports stabilization and braking
- Payload chassis (**blue**)
  - Levitates on maglev motors
  - Floats on linear bearings (**red**)
  - Supports the payload.

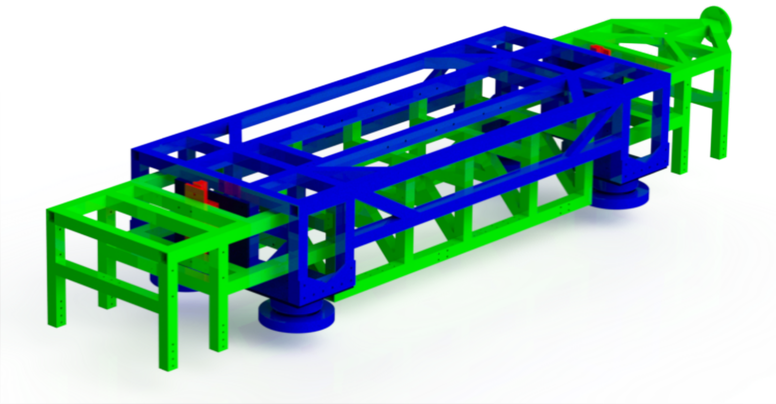


Figure: Pod Chassis

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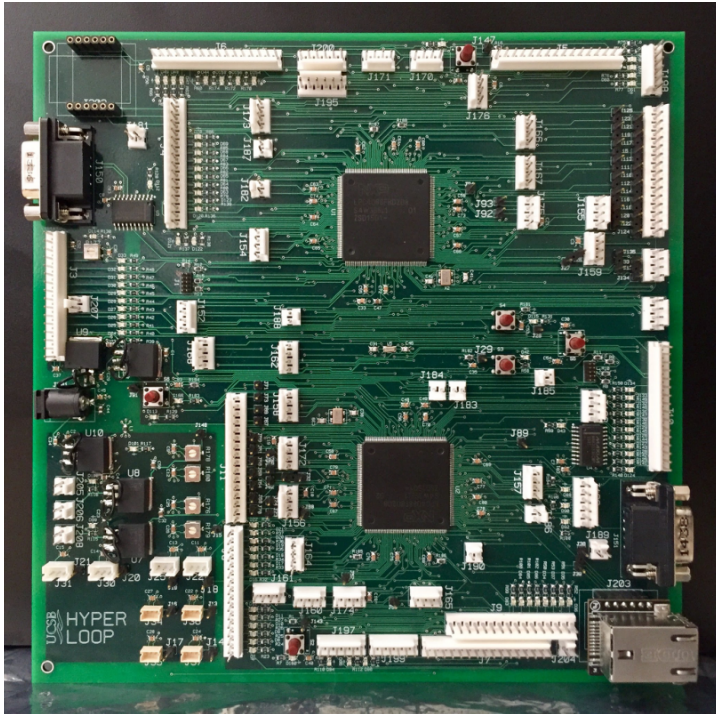
HARDWARE

Pod Control Board (PCB)

- Designed by the 2015-2016 team
- Two (2) LPC4088 chips
- Three (3) I2C ports
- Two (2) SPI ports
- Lots of GPIO + ADCs
- Ethernet module



PCB Code

- Pod control system
- Actuation & data collection
- Communication & telemetry w/ web app

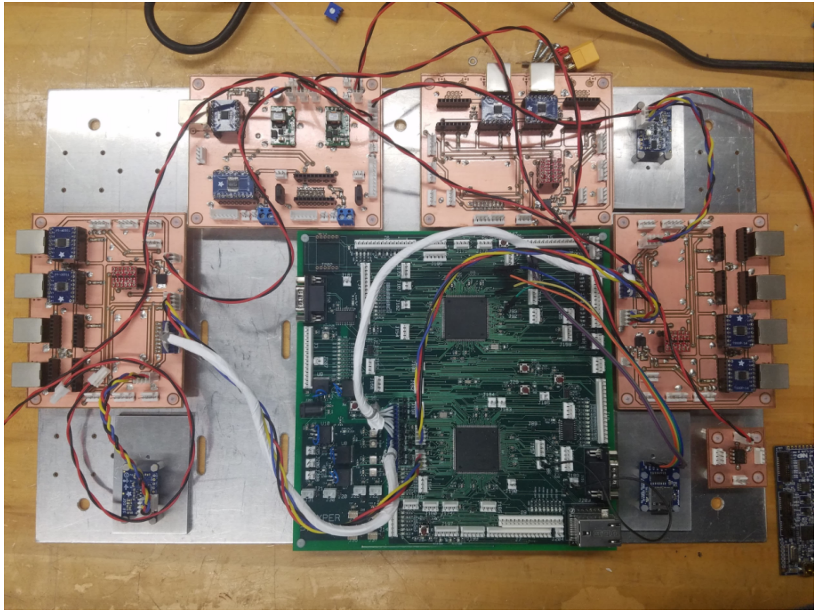
HARDWARE

Electronics Mounting

- PCB
- dI2C hubs
- Power distribution board
- SD card breakout
- Accelerometers

Peripheral Boards (dI2C)

- Types
  - Motor control
  - Actuator control
  - Battery management



PAYLOAD LEVITATION

- Arx Pax HE3.0 Hover Engines lift payload
  - Brushless DC motor spins permanent magnet Halbach Array
- Hyperloop v2 team using four engines
  - Motor current does not exceed 50 A (continuous rating of motor controllers)
- Mounted to payload frame
  - Wheels serve as backup if levitation fails

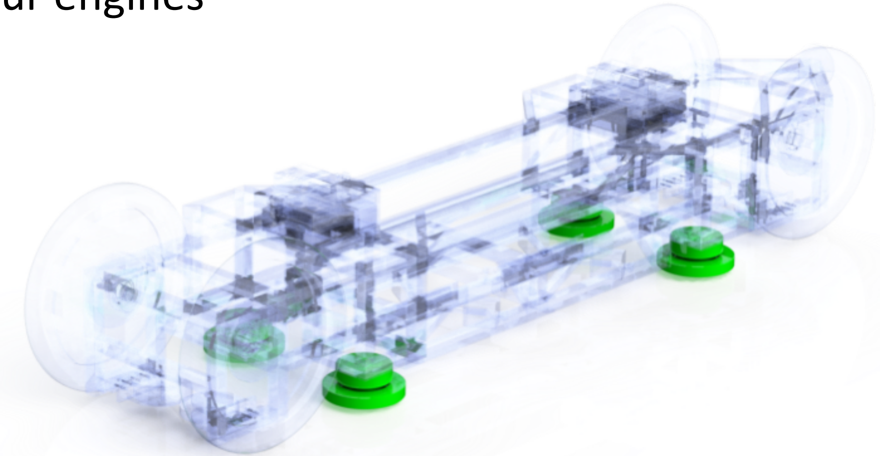


Figure: Position of hover engines on pod

PAYLOAD LEVITATION

- Motor Control
  - Analog throttle signal provided to control motor speed
- Motor Sensors
  - Tachometers implemented to read RPM (0-2800 RPM)
  - Current and temperature sensors implemented as well
- dI2C Motor Boards

Figure: Arx Pax HE3.0 Hover Engine

BRAKING

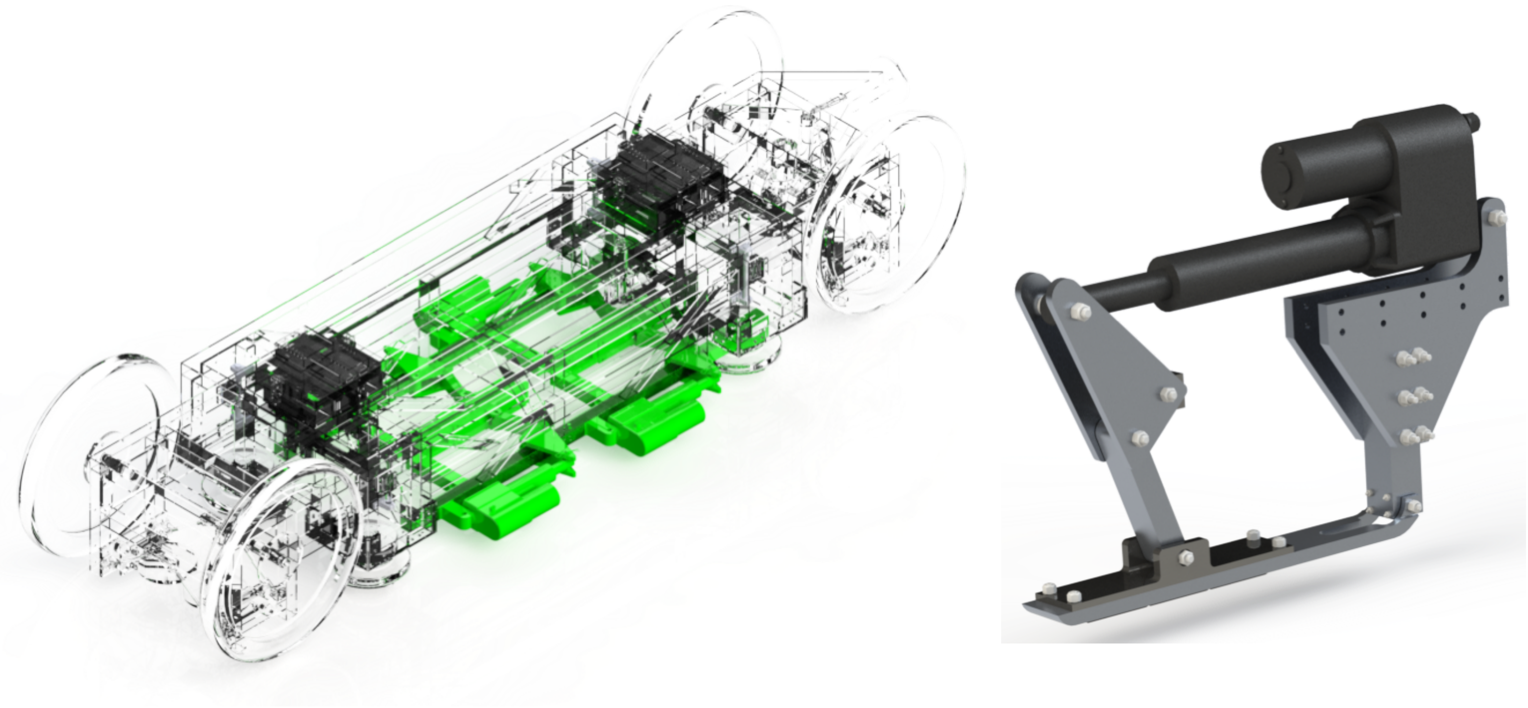


Figure: Brakes subsystem and placement on pod chassis

BRAKING SPECIFICATIONS

- Friction Brakes - Two Pairs
  - Located at the front and rear
  - Equal distance from center of mass
    - Reduces moment on I-beam
- Brake Controls & Feedback
  - PWM speed control and direction signal
  - Position feedback through I2C ADC

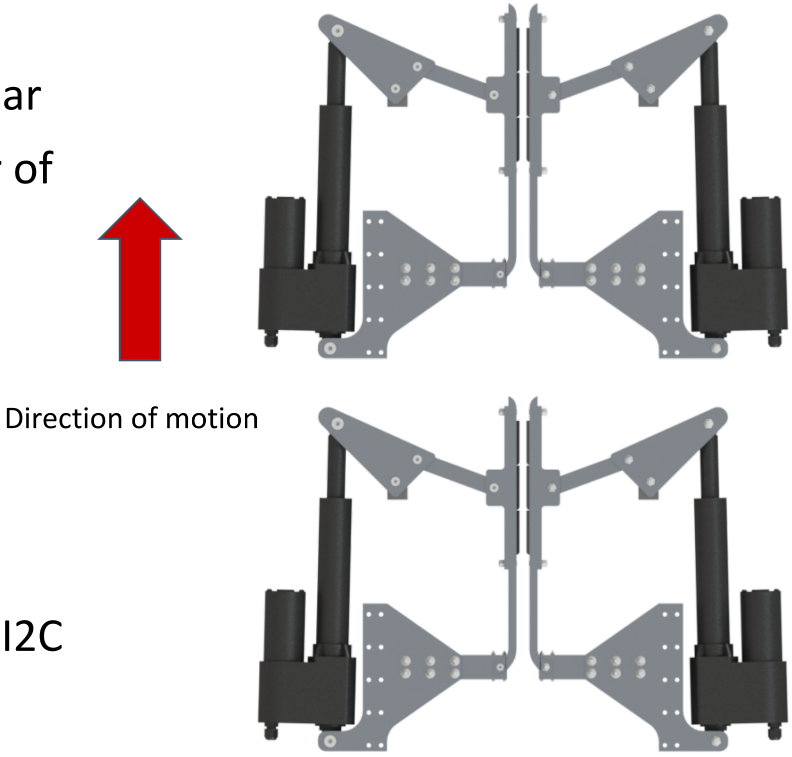


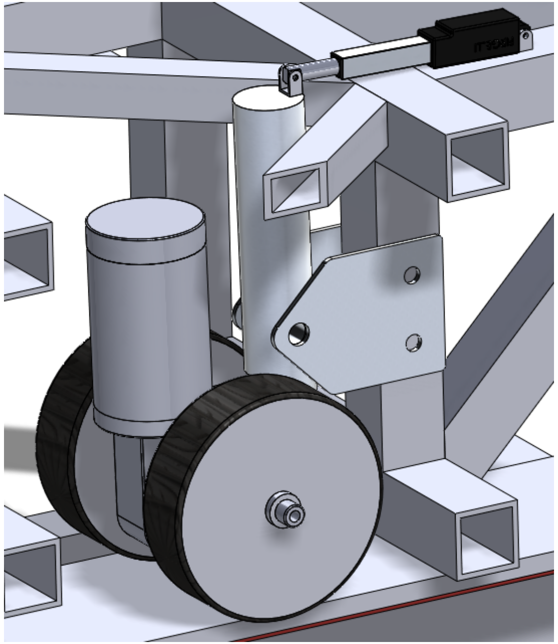
Figure: Top view of system

CONTACT SENSOR

- Pod Pusher Interface
- Optical Contact Sensor
  - Photo-reflective contact sensor indicates when pusher is mated with pod
  - 3-inch detection range

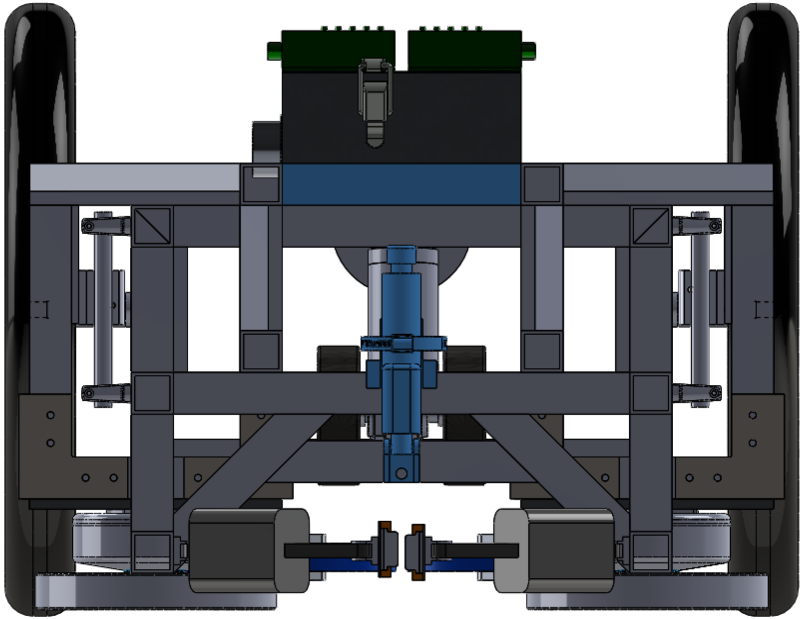
SERVICE PROPULSION

- Post-Braking
  - Service propulsion drive for low speed service travel powered internally
  - Used after successful braking when the pod is fully stopped



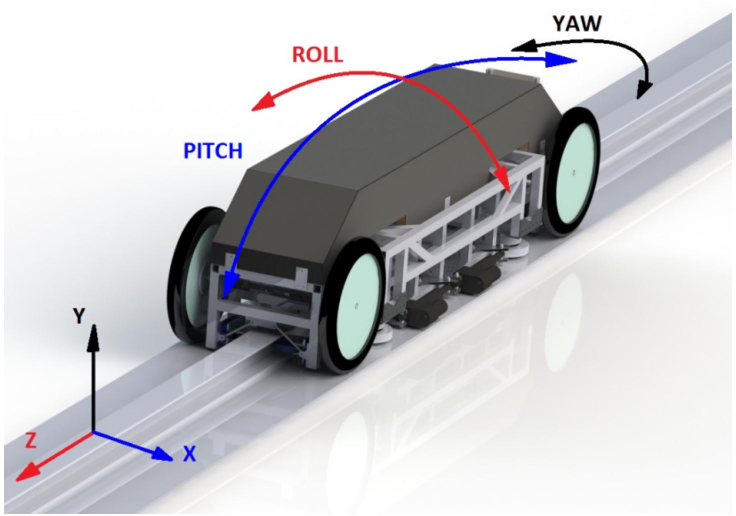
PAYLOAD ACTUATORS

- Vertical Service Lifter
  - Located opposite ends of pod
  - Raises payload to reduce magnetic drag for service propulsion
  - Uses linear actuators that push against the payload chassis



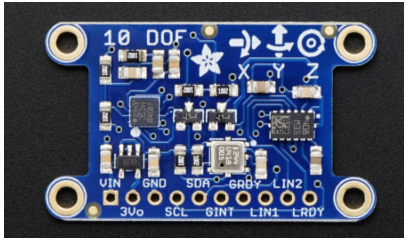
NAVIGATION

Direction	Sensor System
X	I-Beam Short-Ranging
Y	Downward Short-Ranging
Z	Photoelectric Sensors Cart Wheel Tachometers Accelerometers
Roll	Downward Short-Ranging
Pitch	Downward Short-Ranging
Yaw	I-Beam Short-Ranging



Z-AXIS MOVEMENT

- Acceleration is measured directly with two accelerometers
- Distance is measured with photoelectric sensors that detect reflective strips placed 100 ft apart
- Velocity and distance are measured with tachometers placed on each of the four wheels



SHORT-RANGING

Downward facing (4)

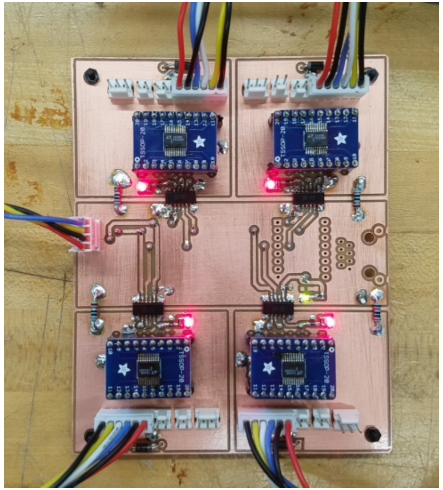
- Measures the pod's vertical offset from the track
- Y-Position, Roll, and Pitch

I-beam facing (2)

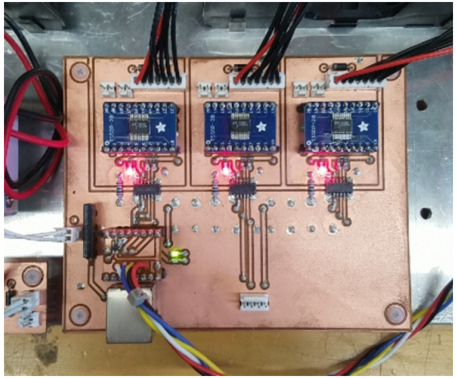
- Measures the pod's lateral offset from the I-Beam
- X-direction and Yaw

BATTERY MANAGEMENT

- Custom designed and fabricated battery management boards for each subsystem
- Monitor battery voltage, cell voltages, current, battery temperature



5 Cell Battery BMS board



6 Cell Battery Maglev BMS board

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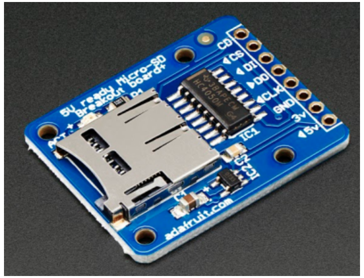
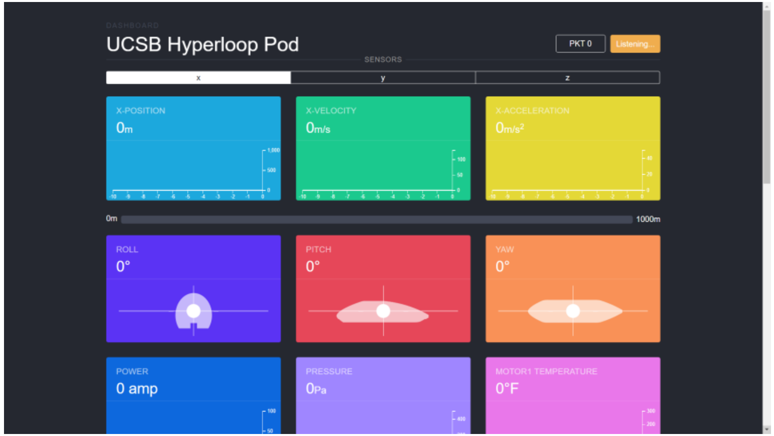
DATA & TELEMETRY

- Telemetry
  - All sensor data automatically sent to web app and logged on SD card
  - Sensor data transmitted in real time at 10 Hz
- Control Signals
  - Sent from web app
  - Initialization
  - Start
  - Emergency braking





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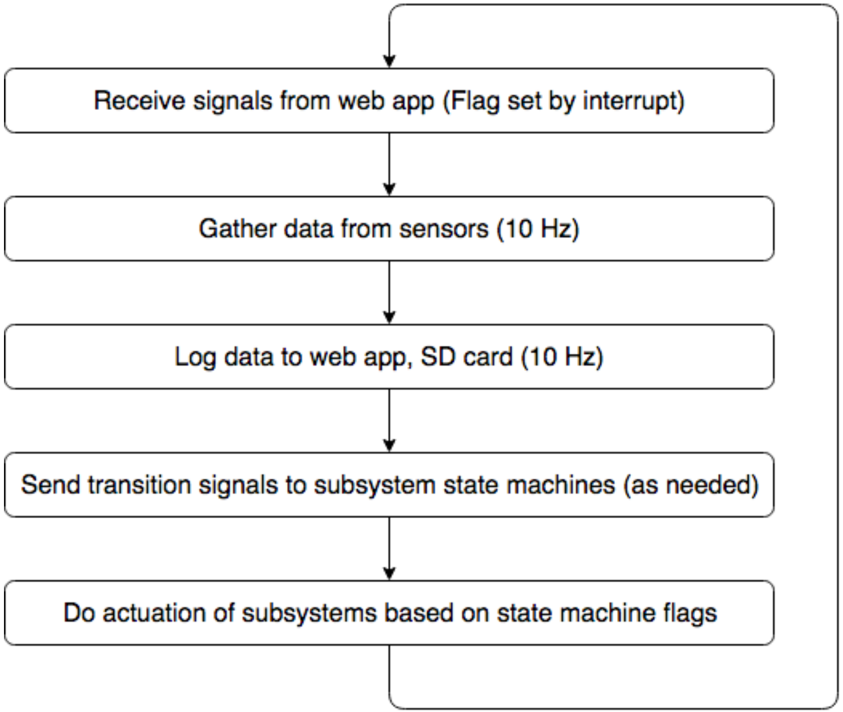
SOFTWARE ARCHITECTURE



Special Routines:

- Braking feedback / control (high frequency TBD)
  - Only during braking phase (with feedback)
  - Braking force adjusted dynamically
- Photoelectric strip detected
  - Triggers interrupt
  - Navigation processes immediately

STATE MACHINES

State machines guard actuation of subsystems

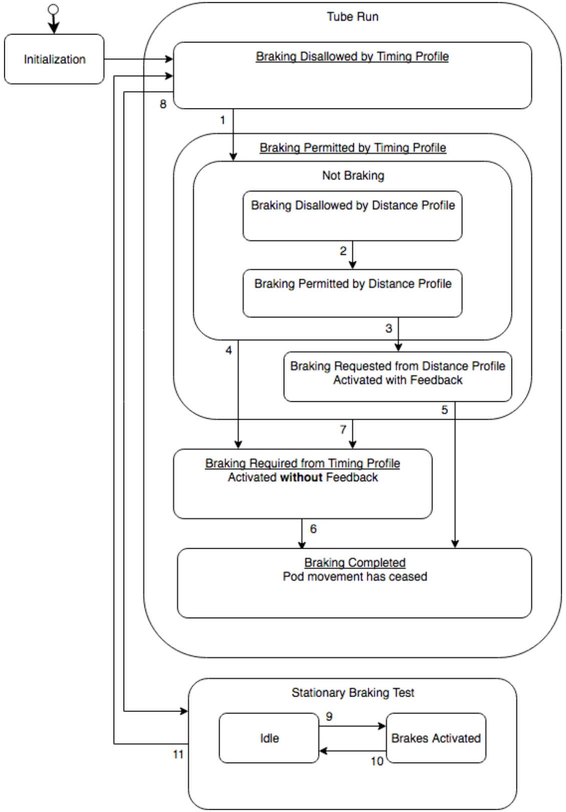
- States represent conditions of pod / system
- Signals issued based on sensor data
    - Ensure proper conditions are met
- Built on the QPnano framework

Subsystems with state machines

- Braking (see diagram)
- Magnetic levitation motors
- Payload actuators
- Service propulsion system

Subsystems without direct actuation don't need state machines

- Navigation
- Power



Braking Subsystem State Machine

POD RUN @ SPACEX

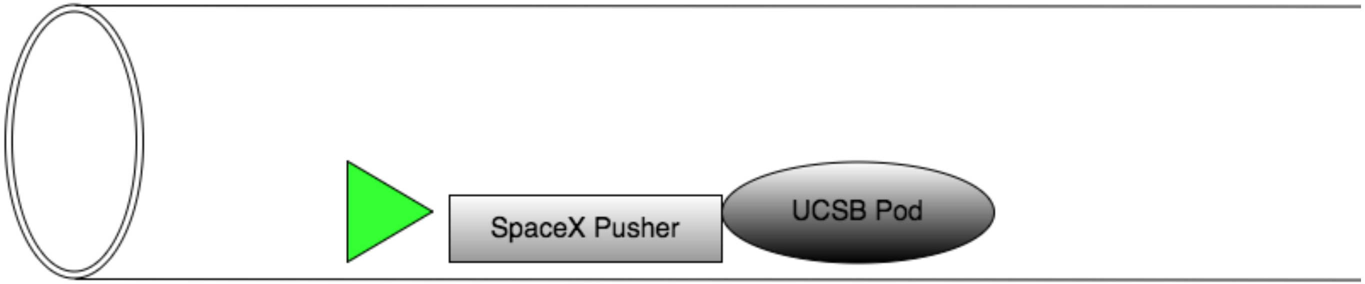
PRE-RUN PHASE

Phase lasts from pod entering tube to beginning of acceleration

Pre-Run Setup & Checks

- Establish web app connection
- Begin data monitoring / logging
- Calibrate sensors
- Run subsystem checks
- Engage maglev engines

ACCELERATION PHASE



Phase lasts from pusher beginning movement until decoupling Pod

Navigation sensor data processed into unified measurement

- Photoelectric sensors (2) - highest accuracy
- Wheel tachometers (4) - highest precision
  - Combined tach value coerced to 100 ft. interval upon strip detection if within 15ft. window
- Accelerometers, pusher sensor provide additional checks

COASTING PHASE

Phase lasts from pusher decoupling to start of braking

Pod must determine when to brake

- Timing profile required by SpaceX provides allowable window
  - Start - estimated time when coasting begins
  - End - last time to safely brake before end of tube
- Navigation determines distance within timing profile window
  - Braking begins at window end even if distance not reached

BRAKING PHASE

Phase lasts from when braking starts until pod is stopped

- Distance Needed to Stop Pod

  = ½ (Pod Mass) x (Pod Velocity)^2 / (Braking Force)

Braking Force Application

- Ideal actuation - dynamic adjustment of braking actuator force
- Timing profile end or emergency signal trigger full force braking

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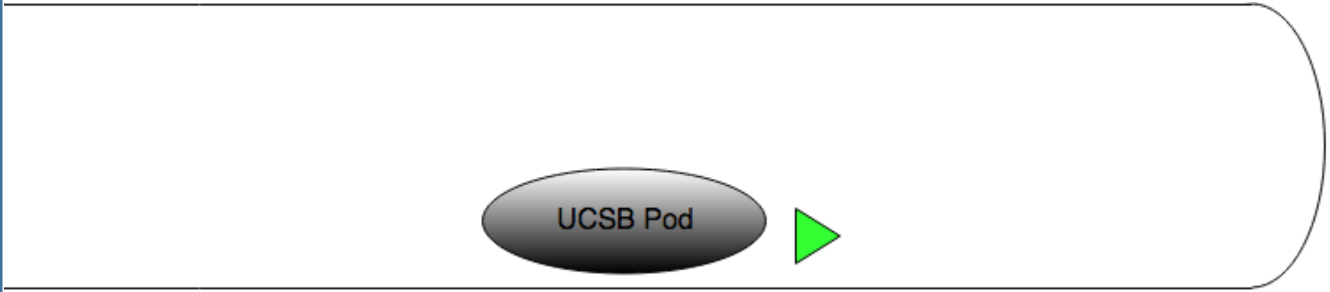
SERVICE PROPULSION PHASE



Phase lasts from pod stopping until end of tube is reached

- Maglev engines disabled and payload raised to lower drag
- Service propulsion assembly actuator lowered
- Service motor propels pod slowly to end of tube

Test run is then complete!

EMERGENCY SITUATIONS

Conditions monitored

- Over-temperature in systems or power supply
- Over-current condition in systems
- Abnormal voltage conditions (cell imbalance, etc.)
- Imbalance in maglev motor speeds
- Imbalance in braking actuator force/position

Mitigation actions performed

- Affected system disabled
- Battery isolation by disconnecting relays

PROTOTYPE TESTING

- Four engine hovering prototype
- Was used for testing and code development
- Systems/phenomenon tested:
  - Vibrational environment
  - Subtrack and electronics heating
  - Telemetry sensors
  - Tachometers

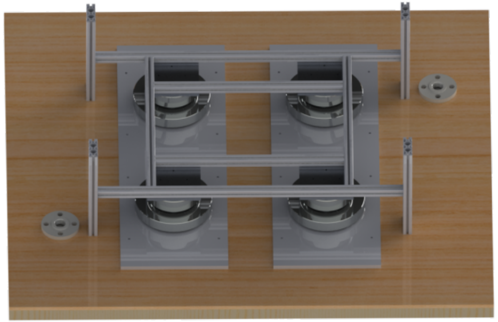


Figure: CAD Rendering of 4-Motor Prototype

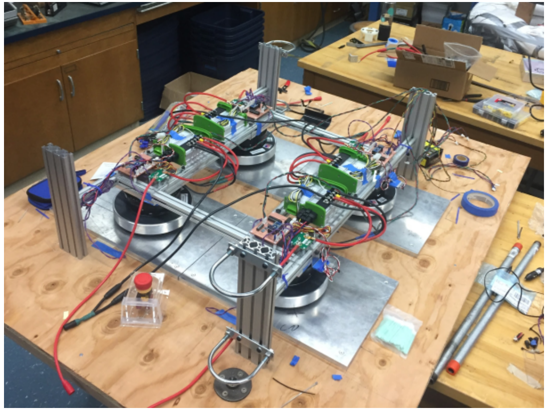


Figure: Working Prototype

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VACUUM TESTING

- SpaceX Tube reaches 0.15 psi
- 20” inner diameter bell jar vacuum chamber
- Low pressure performance tests:
  - Maglev engines
  - Motor controllers
  - LIPO batteries
  - PCB & peripheral boards
  - Sensors
  - Actuators

Figure: Bell vacuum chamber for testing

CONCLUSION

SpaceX Testing Week and Hyperloop Competition II scheduled for Late August 2017

- Systems integration testing and preparation ongoing
- Our interns will continue system testing up to the competition date
- Opportunity for full scale on-site tests a week before the competition

ADVISORS

Thank you to Professor Johnson and Celeste for all of your help and guidance!

SPONSORS

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