ENPM 809T – Autonomous Robotics: Spring 2022

Master of Engineering Program in Robotics

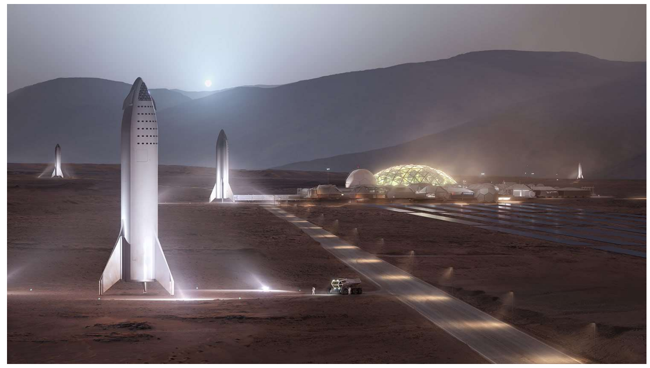


Image credits: Space Exploration Technologies Corp.

On February 6, 2018, SpaceX successfully completed the maiden launch of its Falcon Heavy launch vehicle. The Falcon Heavy carried a Tesla Roadster into trans-Mars injection orbit, demonstrating for the first time Elon Musk's vision of a launch vehicle that could carry payloads into space beyond low Earth orbit.

Recently, SpaceX has publicly stated their goal of sending a cargo mission to Mars as soon as 2022, followed by a second mission with both cargo and crew targeted for 2024. The ships from these initial missions would serve as the beginnings of the first Mars base, eventually leading to a self-sustaining civilization on Mars.

In this spirit of planetary exploration and colonization, the Grand Challenge (GC) for ENPM809T involves the simulated construction of a shelter on Mars. Imagine a robot launched onboard a Falcon Heavy and delivered via parachute onto the surface of Mars. The robot would be programmed with (at best) a crude map of the local terrain. Imagine further that construction materials, here in the form of uniquely colored blocks, have been similarly delivered and are scattered about the landscape. Some have ended up where intended (i.e., in known locations), whereas others have ended up in unknown locations.

Students in ENPM809T will design and implement a ground robot that traverses this new, simulated domain. The robot must collect these blocks and transport them to a predetermined construction zone. All in support of preparing the infrastructure for and reducing the workload required by the first humans to land on Mars.

GC Learning Outcomes

- Apply kinematic models to design and control a mechanical wheeled robot
- Apply control system theory to design and implement a robot control system
- Integrate sensors and actuators into a mechatronic system
- Implement intelligent robotics algorithms, including image processing and motion control and planning

What the GC Involves

- Navigation – traverse autonomously through a cluttered environment in order to find construction blocks and transport them to a specified location. Using known coordinates of landmarks, the robot must use localization techniques to plan the best course to traverse.
- Spatial Awareness – the robot must be aware of its surroundings in order to avoid unwanted situations. It must be able to detect, differentiate, and avoid/interact with objects.
- Efficiency – be able to complete the given task in the most efficient way possible.
- Strategy – employ an effective strategy to optimize speed, task planning, etc.

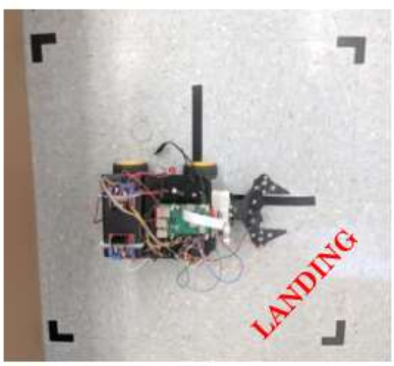
Grand Challenge Rules & Specifications

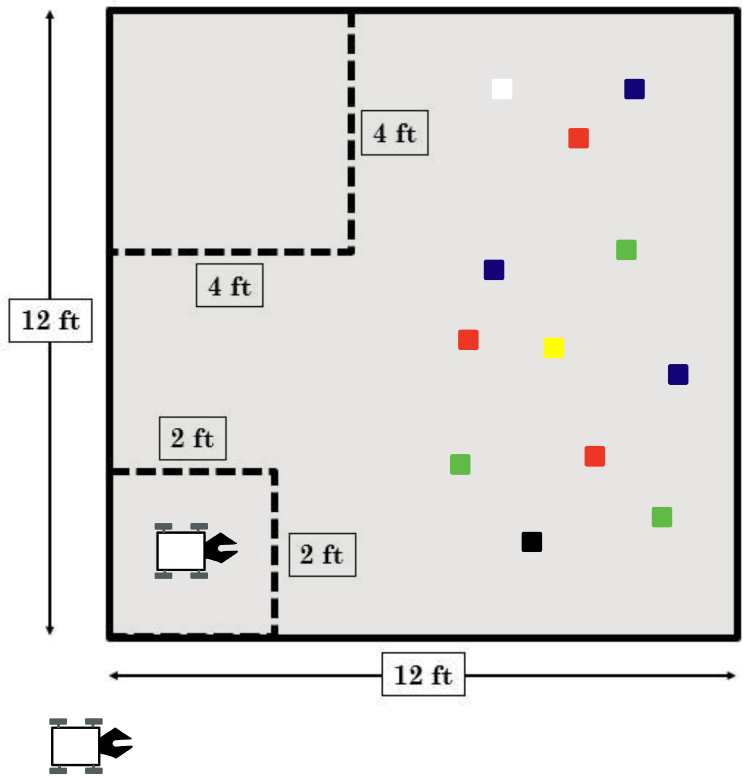
Robot

- The base mobile platform will be the same for each student and is available for purchase from the OAEE office. The mobile platform kit includes the frame, motors, wheels, motor drivers, Raspberry Pi + camera, sonar range sensors, and servo gripper assembly. Students must acquire/install all other required/desired components as well as write code to control the robot.
- Only one robot may perform at a time.
- Each student must construct their own robot.
- Each robot must have a safety shutdown switch.
- Students must communicate with their robot wirelessly. Wi-Fi is the preferred wireless communication method. Participants may set up their own Wi-Fi networks (e.g. cell phone hotspot) or connect through UMD Wi-Fi.

Testing area

- Exact dimensions of the testing area are shown below. To start a run through the Challenge arena, the vehicle will be placed in the center of the landing area, at a heading of the user's choosing:





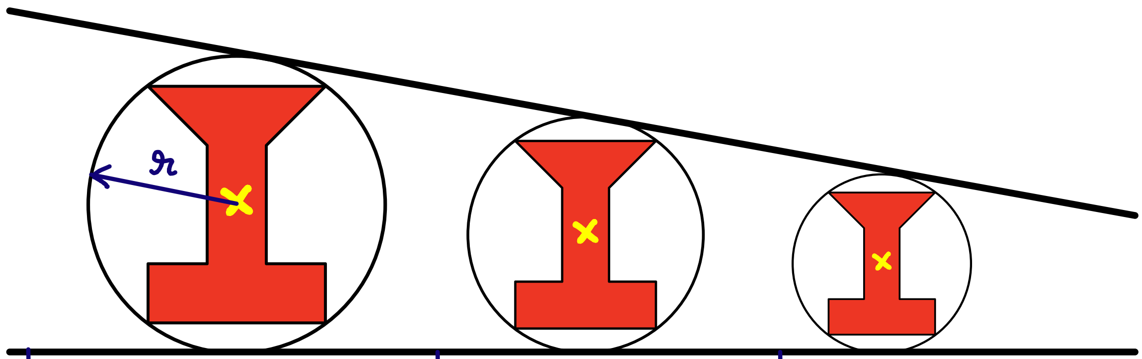
- Walls are made of cardboard or equivalent and colored black.
- All obstacles are fixed and immovable.
- Floor of the testing area is flat and even and colored white/beige (tile).

Building Blocks

- Each block is a basic cubic shape with a vertical gripping arm. Solid model files of the blocks are available under ELMS > Project. The geometry of each block is the same.

Approach The Block

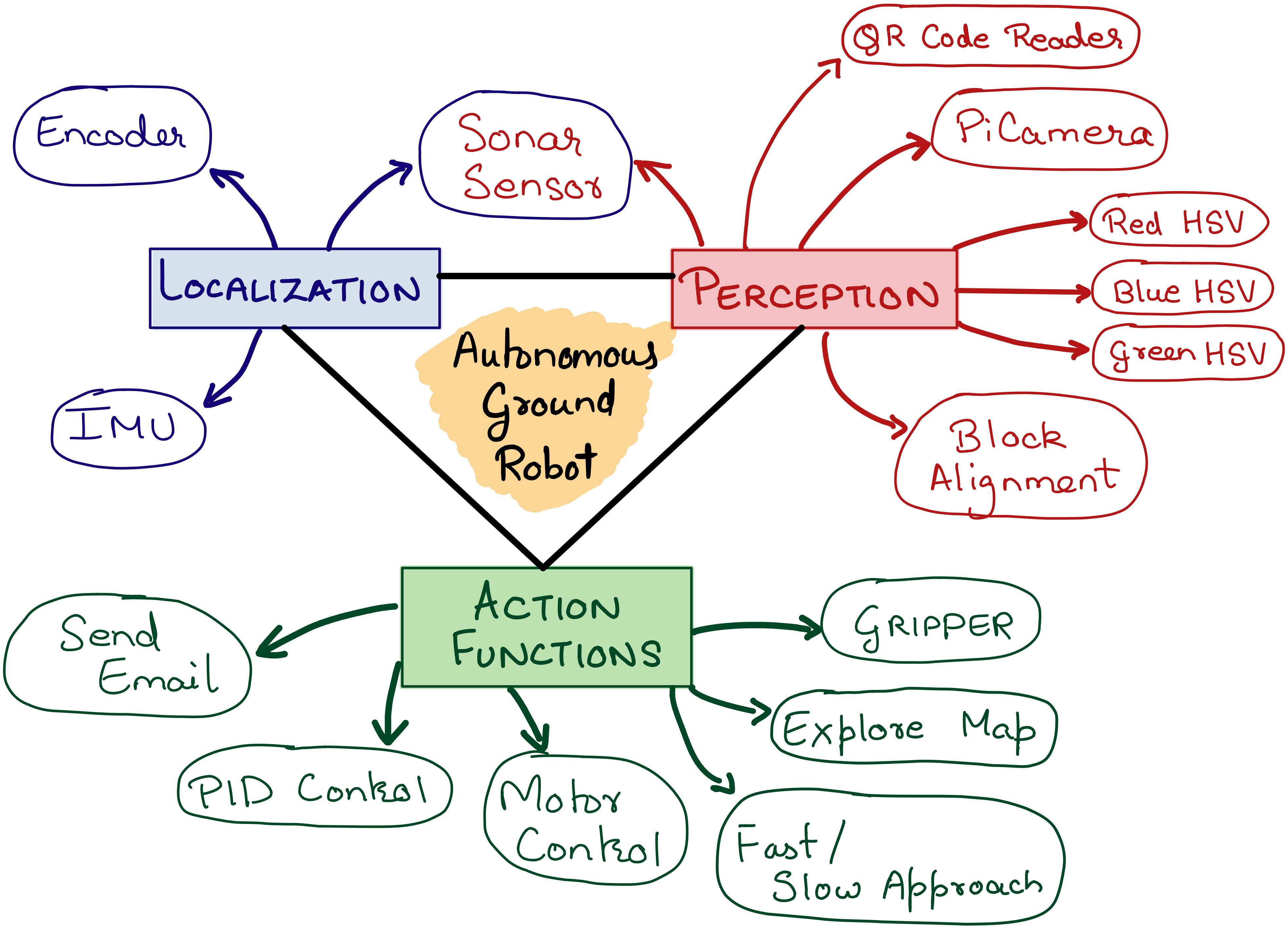
As Radius ↑
Distance to Block ↓



Approach Strategy	GRIP BLOCK	SLOW	FAST
RADIUS RANGE	$r > 120$	$49 < r < 121$	$r < 50$
DISTANCE ESTIMATE	100 mm & Grip	60 mm sprints	$d = 5087(r)^{-0.85}$

ROBOT HARDWARE

→ Chassis
→ DC Motors & Encoders
→ ServoMotor & Gripper
→ PiCamera
→ Sonar Sensor
→ IMU
→ Arduino Nano & RaspBerry Pi


Localization
Encoder
Sonar Sensor
IMU
Perception
QR Code Reader
PiCamera
Red HSV
Blue HSV
Green HSV
Block Alignment
Autonomous Ground Robot
Action Functions
Send Email
PID Control
Motor Control
Gripper
Explore Map
Fast / Slow Approach

Encoder Ticks

$\longrightarrow$ 20 encoder ticks per wheel revolution

$\longrightarrow$ $2\pi(32.5)$ mm per wheel revolution

$\therefore$ # ticks per metre $= \dfrac{20}{2\pi\, 32.5} \times 1000$

$\boxed{98 \text{ ticks per metre}}$

- Each block can be either Red, Green, or Blue, but no combination of more than one color. It is also possible for blocks to be located in the Cluttered Environment of White, Black, or Yellow color.
- Each student will be provided with a single block of either Red, Green, or Blue during the course to use for testing their algorithms in advance of the GC
- Blocks must be delivered by the robot to the predetermined construction zone.

Points

- Students will receive a single point for each Red, Green, or Blue block delivered inside the construction zone. The entirety of the block must be within the construction zone bounds once the block comes to rest.
- Students will be deducted a single point for each White, Black, or Yellow block delivered inside the construction zone, in part or in full.

Procedure

- Students have full access to their robots prior to the beginning of each run, at which point they may only receive data during the run
- Each robot starts the run in the landing zone. Dr. Mitchell will email each student's robot to initiate the run, at which point the clock starts (Dr. Mitchell will keep track of the clock).
- During the run robots must explore the cluttered area, find blocks and deliver them to the construction zone.
- Each run ends if any of the following occurs:
    - robot malfunctions;
    - the student calls to stop the run;
    - all blocks were located, delivered, and assembled;
    - 10 minutes elapsed.
- Students have 2 attempts to complete a run. The run with highest number of blocks transmitted to the construction zone will be used for scoring.
- Students cannot interfere in any way with other students' runs.
- During each run, the student must be in the control room and reference only the data transmitted from the robot (…remember, the robot is on Mars!).
- If a robot breaks through the walls or leaves the testing area during the run, the run ends immediately.
- Students cannot set up any additional external devices (beacons, cameras, etc) to aid the run, outside of those provided.

General

- Students may collaborate during development of their robots, however each student must build their own robot and develop their own codes
- Students are free to acquire additional sensors/actuators to add to their robot throughout the semester

Deliverables

- **Due: Tuesday 5/13/22** via email submission to Dr. Mitchell, NLT **11:59pm** local time. Include in the email:
  - a link to your YouTube video
  - an attached file(s) detailing the codes used during the Grand Challenge

Video Details

A key component of the engineering practice, admittedly often insufficiently addressed in academic curricula, is the link between technical activities and communications/marketing. Often the most successful engineers are those who not only design and deliver cutting edge technologies, but perhaps more importantly effectively communicate technical ideas and relevant financial/societal impacts to a larger audience.

In this spirit, each student is required to create and upload a video to your individual YouTube account and provide the link to it (the video can remain unlisted, which means only people with the link can see it, if you wish). Your video (in its entirety, or a portion) may be showcased in future OAEE publications and presentations. So, spend some time on the video and show off your work! **If nothing else, have fun with the filming process!**

The video must be no less than eight (8) minutes and no longer than ten (10) minutes in length and cover the following:

1. Overall
   a. Minimum eight (8) minutes, maximum ten (10) minutes in length
   b. Visual and audio clarity
   c. Creativity
2. Introduction
   a. Background of the course and the Grand Challenge.
3. Robot Design
   a. Description of robot hardware
   b. Description of robot software

   c. This section should demonstrate your understanding of the fundamentals of autonomous robotics, as applied to your vehicle's hardware/software and the Grand Challenge
   d. Vehicle integration/test/calibration activities
   e. Description of any challenges encountered (e.g. technical, hardware/software obstacles, etc.) and how you overcame those challenges to complete the GC
4. Grand Challenge
   a. Performance of your robot during the GC
   b. Time-lapse of GC performance from robot's perspective
   c. Data/results pertinent to the GC in the context of the course, such as map of block locations

Suggestion: use your phone to record 30-60 second video clips throughout the semester, then stitch them together towards the end of the semester. *General theme of engineering documentation*: take images and video all the time, as you go, then edit as desired later on. **Always better to cut out extra material than to say "I wish I had an image of that…!" at the conclusion of the project**.

Examples of exemplary project student videos from other/related courses:
https://www.youtube.com/watch?v=I1i44fPISbw&list=PLekqOMAzgrTRP6Ms7wI37-2lKjU92tqnL

https://www.youtube.com/watch?v=AiWkhdPCsyo&list=PLekqOMAzgrTQJ5O1nEiZj_Gur7ZQvq-4N

*Please watch immediately: **Vertical Video Syndrome - A PSA**
https://www.youtube.com/watch?v=dechvhb0Meo