WESTERN NEW ENGLAND UNIVERSITY
SPRINGFIELD, MASSACHUSETTS

DEPARTMENT OF MECHANICAL ENGINEERING

ME 455-41 APPLIED MECHATRONIC SYSTEMS
ME 656-41 ADVANCED MECHATRONICS SYSTEMS

Instructor: Dr. Vedang Chauhan

Sizing of Drive Motors for Wheeled Mobile Robots, Selection of Sensors, and Robot Assembly

Objective: The objective of this activity is to learn motor torque and speed calculations for wheeled mobile robots, sensor selection guidelines, and assembly of a mobile robot.

Figure 1 Smart Mobile Robot (image course: *ELEGOO UNO R3 Smart Robot Car Kit* Amazon.com)

Applications

Mobile robots play a crucial role in various applications, including material transport in automated industries, supply transport in hospitals and elderly care homes, space exploration (as seen with the Mars Rover), military surveillance, household cleaning and monitoring, STEM education, and warehouse operations.

Main Components

Mobile robots typically consist of several main components that work together to enable their movement, sensing, and decision-making capabilities. Some of the key components you might find in a typical mobile robot, refer to Figure 1, are:

1. **Chassis**: The chassis is the physical structure of the robot that houses all the other components. It provides the framework for mounting other components and determines the robot's size, shape, and mobility.
2. **Wheels or Tracks**: These are how the robot moves. Depending on the type of terrain the robot is designed to navigate, it may have wheels, tracks, or other locomotion mechanisms.
3. **Motors**: Motors are used to drive the wheels or tracks of the robot, enabling it to move around. These motors are usually controlled by a motor controller to regulate speed and direction.
4. **Sensors**: Sensors are essential for a mobile robot to perceive its environment. Common sensors include:
   - **Ultrasonic Sensors**: for proximity detection.
   - **Infrared Sensors**: for line following or obstacle avoidance.
   - **LIDAR** (Light Detection and Ranging): for mapping and localization.
   - **Cameras**: for visual recognition and navigation.
   - **IMU** (Inertial Measurement Unit): for measuring acceleration, rotation, and orientation.
5. **Microcontroller or Processor**: This is the brain of the robot that processes sensor data and controls the robot's movements. Common microcontrollers used in mobile robots include Arduino, Raspberry Pi, or specialized microcontrollers like STM32.
6. **Power Supply**: Mobile robots require a power source to operate. This can be a battery or a combination of batteries that provide enough power to run the motors, sensors, and other electronics onboard. Robots can also utilize renewable energy to power or recharge batteries.

7. **Control System**: The control system of a mobile robot includes the algorithms and software that govern its behavior. This may involve path planning, obstacle avoidance, localization, and other decision-making processes.
8. **Communication Module**: Some mobile robots are equipped with communication modules like Wi-Fi, Bluetooth, or RF modules to enable wireless communication for remote control or data transfer.
9. **Manipulators (Optional)**: Some mobile robots are equipped with manipulators or robotic arms to interact with objects in their environment.

These components work together to enable a mobile robot to navigate its environment, avoid obstacles, perform tasks, and communicate with other systems or operators.

Table 1 lists some examples of robot's sensors, actuators, controllers, software, and power supplies. The links to purchase these components are provided at the bottom of the table.

Popular Robot Electro-Mechanical Components Suppliers

- https://www.robotshop.com/
- https://www.adafruit.com/
- https://www.digikey.com/
- https://www.sparkfun.com/
- https://www.mouser.com/
- https://www.amazon.com/
- https://www.automationdirect.com/adc/home/home
- https://www.mcmaster.com/ (Mechanical components)

From Conceptualization to Prototyping

The first step in the robot design is to understand the application requirements and constraints. Understand the purpose, functionality, size, weight, mobility, and any other specifications needed for the robot. Using Computer-Aided Design (CAD) for robot synthesis involves leveraging specialized software to design, analyze, and optimize the physical structure and components of a robot. Choose a CAD software suitable for robotics design, such as, SolidWorks, AutoCAD, Fusion 360, or others that offer tools for mechanical design, motion simulation, and rendering.

The second step is to create 3D models of the robot components including the chassis, actuators, sensors, wheels, and any other parts. Ensure the design is precise and considers factors like tolerances and assembly requirements. This step requires the drive motor sizing for wheeled mobile robots. The sizing calculations are explained in the following section.

The third step involves assembly of the individual components into the complete robot structure within the CAD software. Check for interferences, clearances, and ensure proper alignment of parts.

The fourth step tests motion, stress analysis, and any other relevant simulations to optimize the design and ensure it meets performance criteria.

Design as an iterative process. Therefore, in the fifth step make necessary adjustments based on simulation results and feedback. Iterate on the design to improve functionality, efficiency, and overall performance of the robot.

The Sixth step: Once the CAD model is finalized, it can be used to create physical prototypes through various manufacturing methods such as 3D printing, CNC machining, or traditional manufacturing techniques.

The final step is to program the robot for a given application, test it in the work environment, and update/modify the robot software/hardware until it matches the required performance criteria.

Drive Motor Sizing and Power Requirements for Wheeled Mobile Robots [9]

Drive Motor Sizing for Wheeled Mobile Robots" refers to the process of determining the appropriate specifications and characteristics of the motors used to propel wheeled mobile robots. This crucial aspect of robot design involves selecting motors that can efficiently provide the required torque and speed to move the robot effectively while considering various factors such as payload, terrain, energy efficiency, and control system requirements.

Key considerations in drive motor sizing for wheeled mobile robots include:

1. Payload Capacity: The weight of the robot and any additional payload it needs to carry significantly impacts the motor selection. Motors must be capable of providing sufficient torque to move the robot and its payload. Torque is also needed to overcome surface imperfections, wheel friction, and motor friction. Horizontal movement requires minimal torque (Forward, Backwards, Left and Right). Moving up an incline needs more torque to counteract gravity.
2. Speed Requirements: The desired speed at which the robot needs to move influences the selection of motors with appropriate speed ratings. Motors should be able to achieve the required velocity for the robot's intended applications.
3. Terrain and Environment: The type of terrain the robot will navigate, such as smooth floors, rough outdoor terrain, or inclines, affects motor selection. Motors with adequate power and torque are necessary for handling different surfaces and gradients.
4. Efficiency and Power Consumption: Selecting motors with optimal efficiency is crucial for conserving energy and extending the robot's operating time. Efficient motors help reduce power consumption and increase the robot's overall performance.
5. Control System Compatibility: Motors must be compatible with the robot's control system, including motor controllers and feedback mechanisms. Ensuring seamless integration between the motors and control electronics is essential for precise motion control.
6. Overload and Stall Conditions: Motors should be sized to handle peak loads and prevent stalling under maximum load conditions. Ensuring that motors have a sufficient safety margin helps prevent overheating and damage during operation.

For the following calculations, assume that the robot is moving up an incline with angle θ as shown in Figure 2.

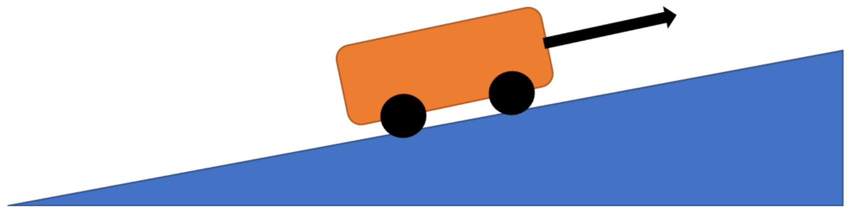


Figure 2 A robot moving up the incline

First, draw a Free Body Diagram (FBD) and kinematic diagram (Figure 3) for the robot moving up the incline. Refer Figure 3.

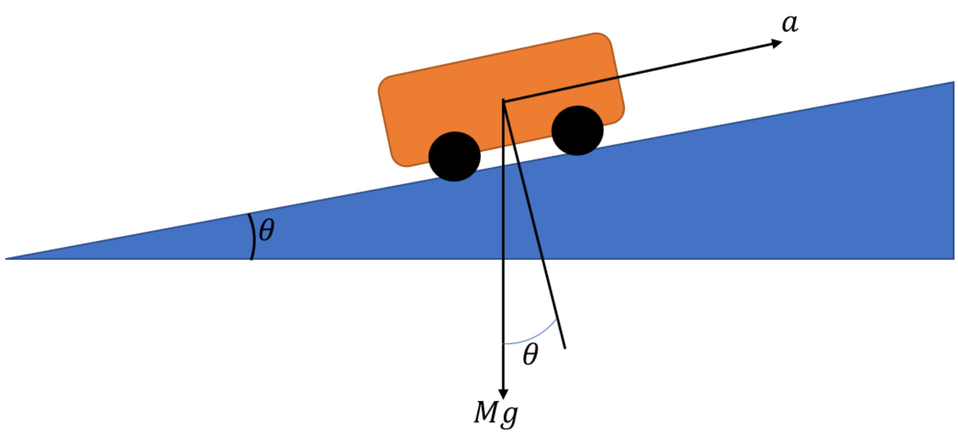


Figure 3 A robot moving up the incline

Assuming,

- Traction force between the wheels and the surface is F that includes any friction present.
- X-axis of the coordinate system is parallel to the incline and positive moving up the incline.
- Y-axis of the coordinate system is perpendicular to X-axis and positive away from the incline.
- Calculate torque for the "worst-case scenario": robot accelerating up an incline.
- Total torque required is divided by the number of drive wheels.

Redrawing the FBD only for one wheel of the robot. Refer Figure 4.

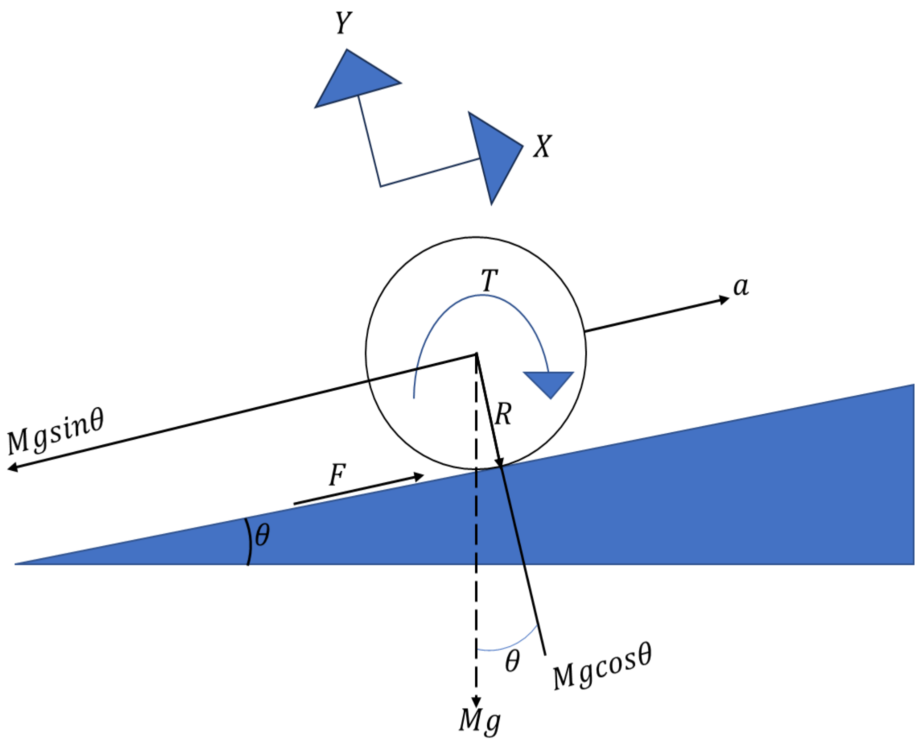


Figure 4 The robot wheel and forces FBD

Applying Equation of Equilibrium (EOE) along X-axis

$$\sum F_x = M * a$$

$$F - (M * g * sin\theta) = M * a \tag{1}$$

where,
$F = Traction\ force$, N
$M =$ Mass of the robot including payload, kg
$a =$ Acceleration of the robot, m/s^2

Total required torque depends on the traction force F and radius of the wheel.

$$T = F * R \tag{2}$$

where,
$T = Total\ required\ torue\ to\ accelerate\ the\ robot\ up\ an\ incline, Nm$
$R =$ Radius of the wheel, m

Substituting F from equation (2) into equation (1),

$$\frac{T}{R} - (M * g * sin\theta) = M * a$$

$$T = M * R * (a + g * sin\theta) \tag{3}$$

The torque value from equation (3) shows how much force is needed to move the robot uphill. Divide this value by the number of drive wheels (N) to find the torque required for each drive motor. Passive wheels, which only add weight, do not affect the torque needed for movement.

Often motors are connected to the wheels via gears. Therefore, consider the efficiency of motor, gearing system, and wheel slip, into calculating the torque needed.

Torque needed for each drive motor,

$$T_m = \frac{M * R * (a + g * sin\theta)}{N} * \frac{100}{e} \tag{4}$$

where,
$N = number\ of\ drive\ wheels$
$T_m = Motor\ torque, Nm$
$e = Overall\ efficiency\ of\ the\ motor, gearing\ system$
$including\ loss\ due\ to\ slipping$, %

Total power per motor,

$$P = T_m * \omega \tag{5}$$

where,
$\omega = Angular\ velocity\ of\ the\ motor, rad/s$

Motors need electrical power as input. The power required to climb the incline,

$$P = I_{max} * V \tag{6}$$

where,
$I_{max} = max\ current\ consumed\ by\ the\ motor, Ampere(A)$

$V = Voltage\ required\ by\ the\ motor, V$

From equation (5) and equation (6),

$$I_{max} = \frac{T_m * \omega}{V} \tag{7}$$

Finally, the capacity (c) of the battery pack required can be estimated using the equation:

$$c = I_{max} * t * N \tag{8}$$

where,
$c = battery\ pack\ capacity, Ampere - hours\ (Ah)$
$t = robot\ operational\ time\ between\ charing, hours$

Select a battery pack with a higher capacity than calculated from equation (8). The reason is that battery pack ratings in terms of amp hours may not accurately reflect the maximum current output over extended durations. Moreover, battery packs often do not retain their full charge over time. By considering this, you can ensure that the chosen battery pack can supply the required current for your motors, considering the necessary duration and accounting for inherent inefficiencies in recharging them. Equation (8) provides the rough estimate for the battery pack. Refer to [10] for the detailed calculation on battery pack selection.

Example: Motor Sizing and Power Calculations for a Pharmaceutical Lab Robot

For a mobile robot used in a pharmaceutical lab with a total mass of 1 kg (including payload), a required velocity of 2 m/s, and a desired acceleration of 0.2 m/s^2, the robot has two drive wheels with a wheel radius of 30 mm. The motors require 12V to operate, and the robot primarily moves on a flat surface but encounters a 20-degree incline at times. The robot should operate for 1 hour between charges, with an overall electro-mechanical system efficiency of 65%.

Utilizing motor sizing and power calculations, determine the angular speed of each motor, its RPM, and the required torque. Calculate the electrical power needed by each motor and the maximum current consumed by the motor. Finally, ascertain the total battery pack capacity needed for the robot, considering the power requirements of all motors.

Answers:

For each motor

$\omega = 66.7\ rad/s$

$n = 637\ rpm$

$T_m = 0.082\ Nm$

$P = 5.47\ W$

$I_{max} = 0.46\ A$

For the robot

$c = 0.91\ Ah$

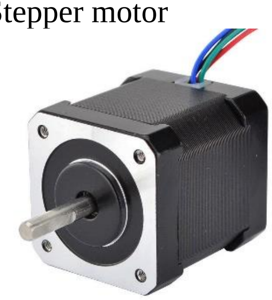
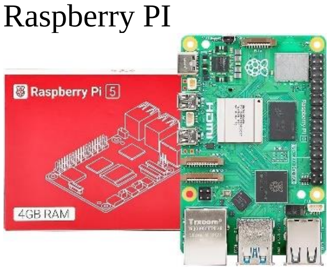
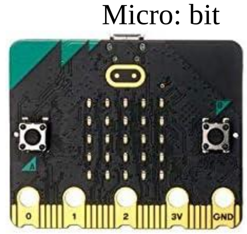
References

1. https://www.robotshop.com/
2. https://www.adafruit.com/
3. https://www.digikey.com/
4. https://www.sparkfun.com/
5. https://www.mouser.com/
6. https://www.amazon.com/
7. https://www.automationdirect.com/adc/home/home
8. https://www.mcmaster.com/ (Mechanical components)
9. https://community.robotshop.com/tutorials/show/drive-motor-sizing-tutorial
10. https://husarion.com/blog/batteries-for-mobile-robots/

Assembly

- Assemble your mobile robot before the next session.

Table 1 Robot Components Examples

Sensors		
Limit switch 	Infrared sensors 	Ultrasonic sensors 
LiDAR sensors 	Cameras 	Infrared sensors 
Actuators		
DC Motor 	Stepper motor 	Brushless motor 
Controller		
Raspberry PI 	Arduino	Micro: bit  

		
Software		
Arduino 2.3.2/C++	ROS	Python 3.0+
Power supplies		
18650 batteries 	Lithium-ion Battery back 	Li-Po Batteries 

***