Department of Robotics & Mechatronics Engineering
University of Dhaka

Course code : RME 4111
Course name : Advanced Robotics Lab

Experiment no : 07
Experiment name : Gear ratio of a mobile robot based on motor current, efficiency and system performance.

Group no : 02
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Objective:

- Investigate the relationship between gear ratio and motor current
- Assess the impact of gear ratio on system efficiency
- Optimize system performance through gear ratio selection

Theory:

The design of the gear ratio will vary depending on the specific application requirements. For instance, in a robot's movement, whether it is on a horizontal surface, a slope, or needs to follow a specific velocity profile or climb a wall with its own weight, the gear ratio will need to be adjusted accordingly.

In industrial robots, each joint may have different requirements. Some joints may need to bear vertical loads, while others may only require horizontal movement. Similarly, in a two-legged humanoid robot, the knee joint may require fast movement, while the hip pitch joint may need to handle heavier loads.

When designing the gear ratio for a particular application, it is important to consider various factors. While it is not feasible to cover all possible approaches, specific cases can be illustrated. For example, if the robot needs to follow a velocity profile while moving on an inclined plane, it is a prudent approach as terrain cannot always be assumed to be horizontal. Fig. 1 provides a schematic representation of such a system, where the motor is designed for high-speed operation.

The robot does not need to move that fast, but it needs to provide high torque at the drive wheels. Therefore, we need a reduction gear to drive the robot. The discussion starts with the overall torque required on the drive wheel to move the robot. It is assumed that the proposed gear ratio is Ng and the drive wheel radius is Rw.

$$\tau_w = (f_a + f_b + f_g)R_w$$

$$\tau_w = (M\,a + B\,v + Mg\sin\alpha)R_w$$

Then, the torque to be developed by the motor is given by

$$t_m = \frac{(M\,a + B\,v + Mg\sin a\,)R_w}{N_g}$$

Some assumptions made regarding the motor parameters are as follows:

Supply voltage = Vs
Armature resistance = ra
Torque constant (Nm/A) = Kt
Back EMF constant (Vs/rad) = Kb
Motor speed (rps) = nm
Armature current (amp) = ia

From the basic knowledge of the DC machine theory, the torque developed by the motor will be

$$\tau_m = \frac{V_s - K_b 2\mathrm{p}\, n_m}{r_a} K_t$$

$$\tau_m = \frac{V_s K_t}{r_a} - \frac{K_b K_t 2\mathrm{p}\, n_m}{r_a}$$

For any ground speed of v, the drive wheel speed and motor speed can be obtained as

$$n_w = \frac{v}{2\mathrm{p}\, R_w}$$

$$n_m = \frac{vN_g}{2\mathrm{p}\, R_w}$$

The torque developed by the motor at any ground speed v can be obtained as

$$t_m = \frac{V_s K_t}{r_a} - \frac{K_b K_t 2p}{r_a} \frac{v N_g}{2p R_w}$$

$$t_m = \frac{V_s K_t}{r_a} - \frac{K_b K_t v N_g}{r_a R_w}$$

The robot has to move with an acceleration of a and reach a velocity of v.Combining Equations-3 and Equation-9, we can write:

$$\frac{V_s K_t}{r_a} - \frac{K_b K_t v N_g}{r_a R_w} \geq \frac{\left(Ma + Bv + Mg \sin a\right) R_w}{N_g}$$

At the limits, it becomes:

$$\frac{K_b K_t v N_g^2}{r_a R_w} - \frac{V_s K_t N_g}{r_a} + \left(Ma + Bv + Mg \sin a\right) R_w = 0$$

The above equation is quadratic in Ng, the solution of which yields two values Ng1 and Ng2.

For the above two gear ratios obtained, the current drawn ia1 and per-unit power efficiency η1 can be calculated by ignoring iron and frictional losses of the DC motor as given below:

$$i_{a1} = \left[V_s - \frac{K_b v N_{g1}}{R_w} \right] \frac{1}{r_a} \qquad i_{a2} = \left[V_s - \frac{K_b v N_{g2}}{R_w} \right] \frac{1}{r_a}$$

$$i_{a1} = \left[V_s - \frac{K_b v N_{g1}}{R_w} \right] \frac{1}{r_a} \qquad \mathrm{h}_2 = \frac{V_s i_{a2} - i_{a2}^2 r_a}{V_s i_{a2}}$$

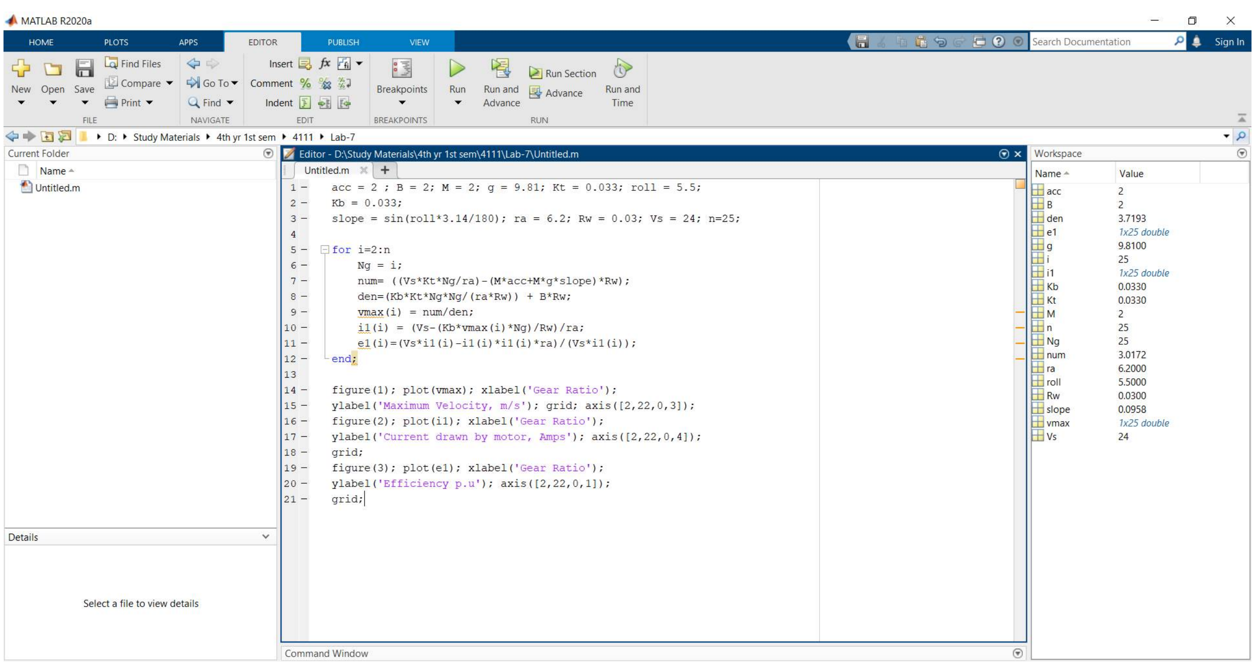
Equipment:

- MATLAB Software

Procedure:

- At first, we need to open Matlab
- Write the script based on the theory of our experiment
- Changing the theta value to according to our roll number.
- Execute the code

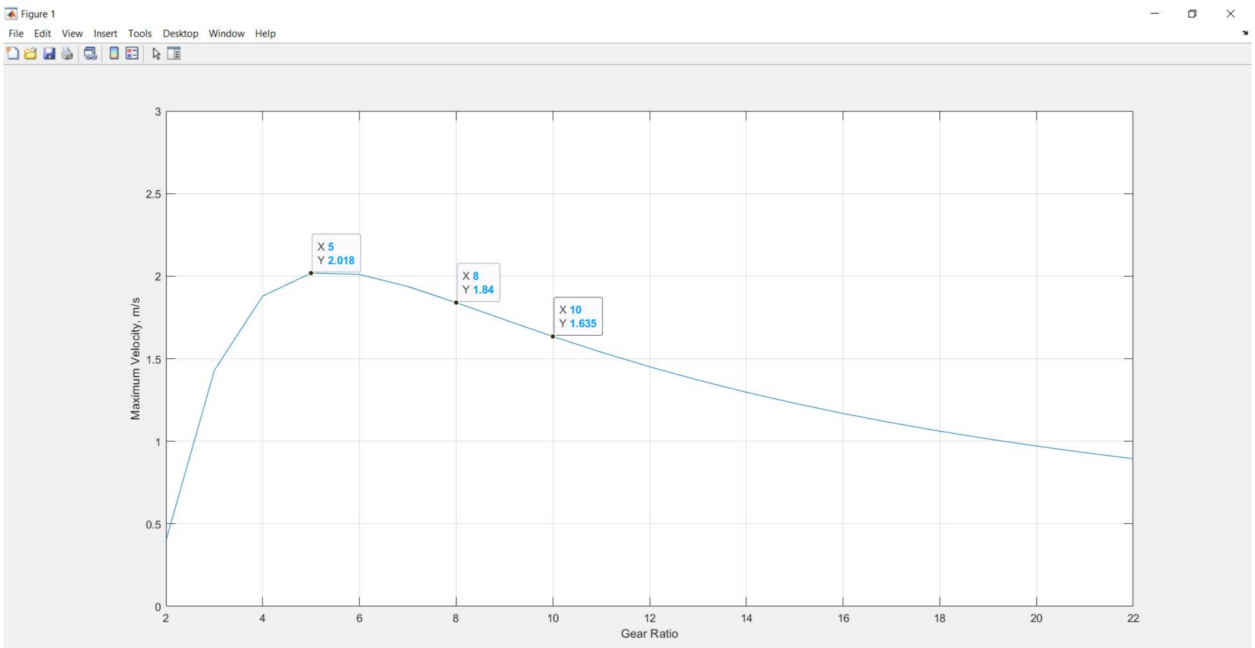
Code:



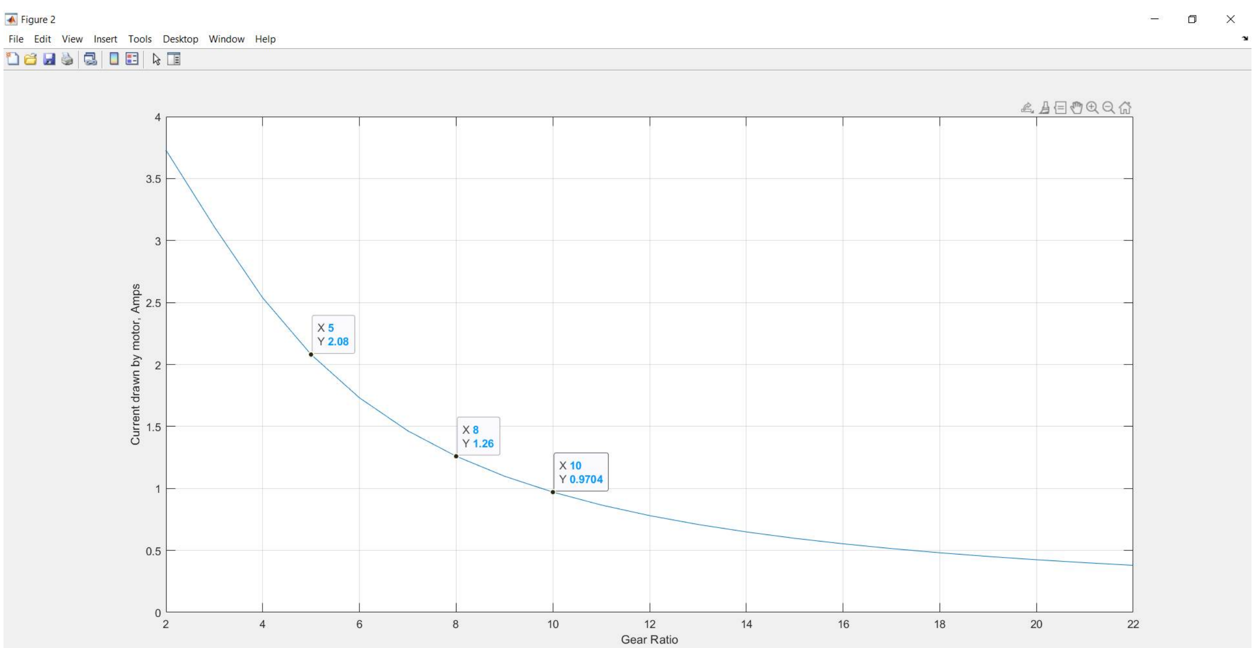
```
acc = 2 ; B = 2; M = 2; g = 9.81; Kt = 0.033; roll = 5.5;
Kb = 0.033;
slope = sin(roll*3.14/180); ra = 6.2; Rw = 0.03; Vs = 24; n=25;

for i=2:n
    Ng = i;
    num= ((Vs*Kt*Ng/ra)-(M*acc+M*g*slope)*Rw);
    den=(Kb*Kt*Ng*Ng/(ra*Rw)) + B*Rw;
    vmax(i) = num/den;
    i1(i) = (Vs-(Kb*vmax(i)*Ng)/Rw)/ra;
    e1(i)=(Vs*i1(i)-i1(i)*i1(i)*ra)/(Vs*i1(i));
end;

figure(1); plot(vmax); xlabel('Gear Ratio');
ylabel('Maximum Velocity, m/s'); grid; axis([2,22,0,3]);
figure(2); plot(i1); xlabel('Gear Ratio');
ylabel('Current drawn by motor, Amps'); axis([2,22,0,4]);
grid;
figure(3); plot(e1); xlabel('Gear Ratio');
ylabel('Efficiency p.u'); axis([2,22,0,1]);
grid;
```

Result:

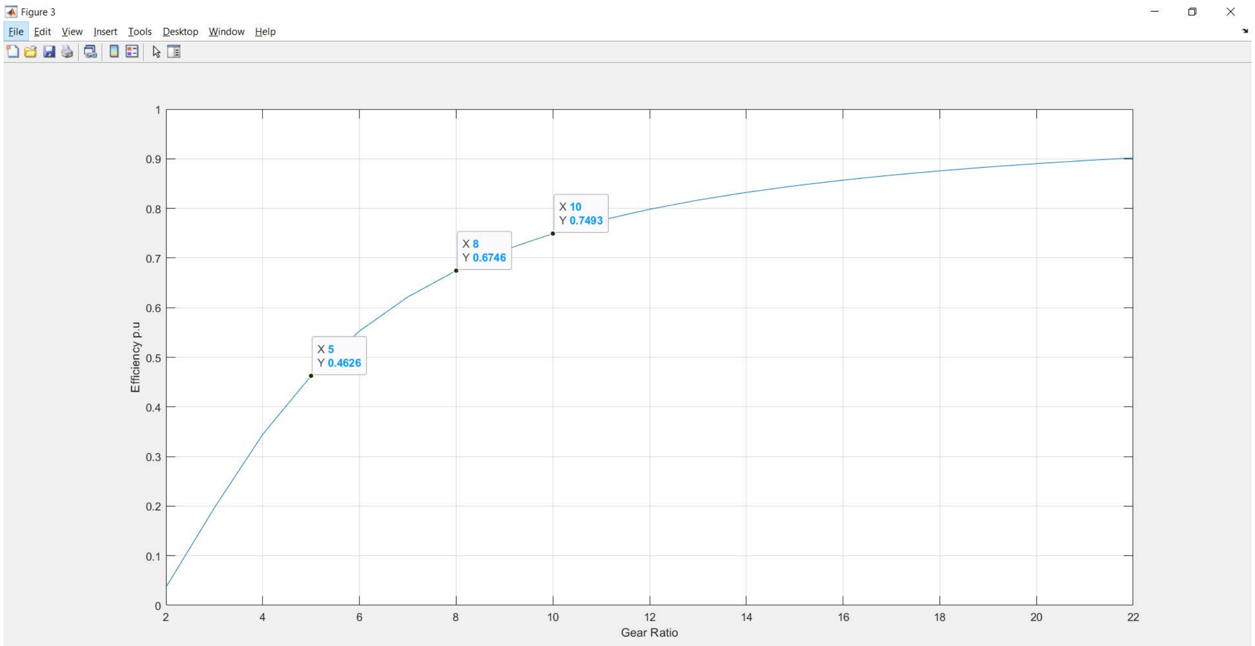
Graph of Maximum Velocity VS Gear Ratio:



Graph of Current Drawn by Motor VS Gear Ratio:



Graph of Efficiency VS Gear Ratio:



For gear ratio = 5,

- Maximum velocity = 2.01 m/s
- Current drawn = 2.07 Amps
- Efficiency = 46.26%

For gear ratio = 10,

- Maximum velocity = 1.63 m/s
- Current drawn = 0.97 Amps
- Efficiency = 74.93%

For maximum velocity that we can get for gear ratio = 5, current drawn is high and efficiency is low, which will produce a lot of heat as loss. But for gear ratio 0, even though the maximum velocity decreases by a small amount, current drawn and efficiency increases by a substantial amount. So we choose gear ratio= 10.

Discussion:

It is typical to use a greater gear ratio when choosing a gear ratio for a certain application. However, it is imperative to consider elements like the motor's current draw and the system's efficiency. These factors must be taken into account in order to select a gear ratio that is ideal for the given application.

We may evaluate the power needs and electrical load on the system by taking into account the current that the motor draws. A gear ratio that causes an extremely high current draw could stress the motor and cause inefficiencies, which could have an impact on the system's overall performance and durability.

The choice of gear ratio also heavily depends on the system's effectiveness. Although a larger gear ratio can offer more torque or speed, it could also result in more energy losses and less overall system efficiency. Therefore, choosing the right gear ratio requires striking a compromise between obtaining the desired performance and retaining maximum efficiency.

A more thorough assessment of a gear ratio's suitability for a particular application is possible when both the current drawn and efficiency are taken into consideration. We can choose a gear ratio that assures adequate application functionality while maximizing system performance and efficiency by taking into account these aspects along with the desired performance attributes.

Experiment no : 07

Name of the experiment : Gear ratio design of a mobile robot based on motor current, efficiency and system performance.

Group no-

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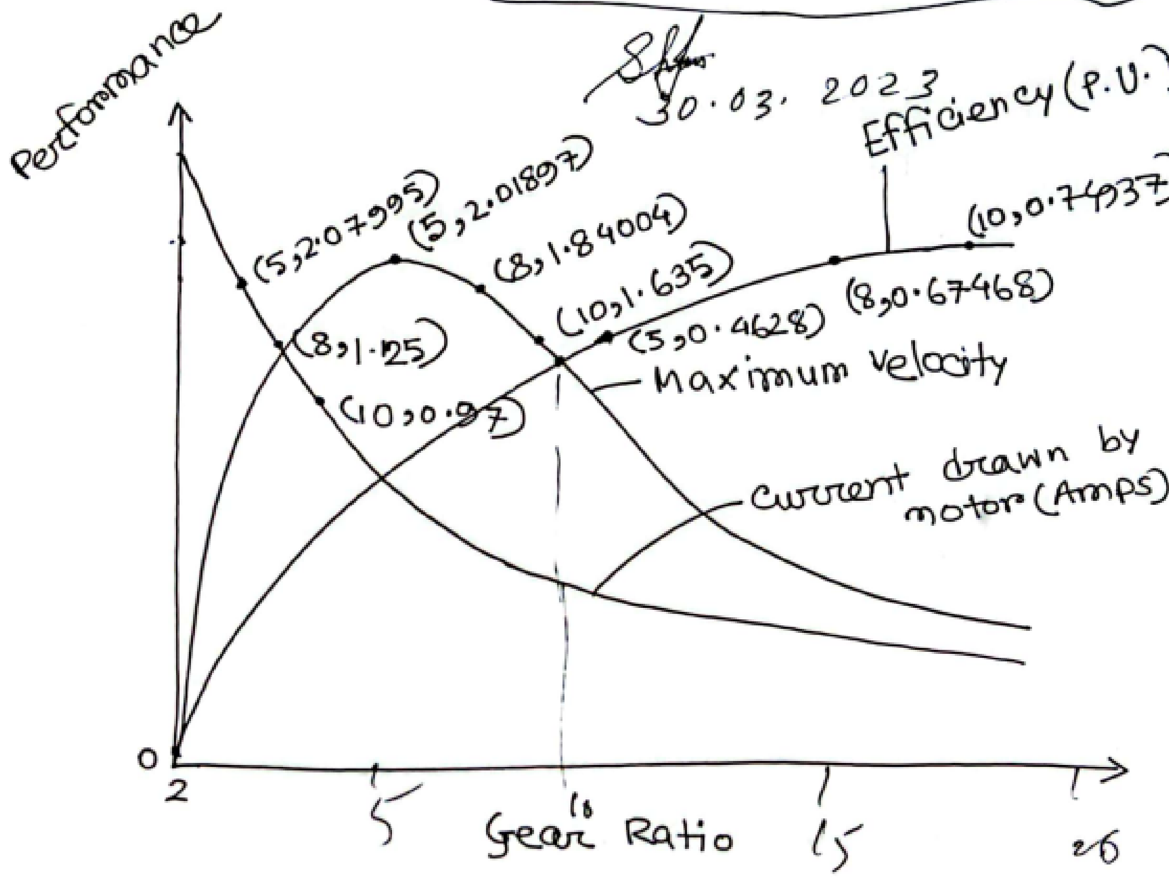
30.03.2023



For gear ratio = 5

Maximum velocity = 2.01897 m/s

Current drawn = 2.07995 Amps

Efficiency = 0.46268 = 46.268%

For gear ratio = 10

Maximum velocity = 1.635 m/s

Current drawn = 0.970163 Amps

Efficiency = 0.749375 = 74.9375%

For maximum velocity that we can get for gear ratio = 5, current drawn is high and efficiency is low, which will produce a lot of heat as loss.

But for gear ratio 10, even though the maximum velocity decreases by a small amount, current drawn and efficiency increases by a substantial amount. So we choose gear ratio = 10.