Robotics Laboratory 3

ACTUATORS, DRIVES, AND CONTROL COMPONENTS

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***Abstract*—This experiment explores how to control and test different types of motors (DC motor, servo motor, and stepper motor) using an Arduino. The motors were tested both in the real world and in a Webots simulation to observe how changes in speed and control affect the tractor's movement. The DC motor's speed was adjusted from 50% to 100%, and the servo motor's angle was changed from 0 to 180 degrees. The Webots simulation included a speed limit of 30 km/h to prevent instability and maintain control. Observations showed that at lower speeds, the tractor was easy to control, but as speed increased, it became harder to manage, and the sensors struggled to keep up. This experiment helps students understand how actuators work in robotics and how different speeds affect control and stability.**

I. Rationale

This experiment is important because it helps students understand how actuators work and how they are controlled in robotics. Actuators, like DC motors, servo motors, and stepper motors, are key parts of any robot—they make the robot move and interact with the world. To control these actuators, we use microcontrollers like the Arduino, along with control signals such as PWM (Pulse Width Modulation) (Bolton, 2015).

Many students learn about these components in theory, but they don't always get a chance to apply that knowledge in real situations. This experiment fills that gap by allowing students to connect and control real actuators, adjust their speed and direction, and see how changes in signals affect movement (Siciliano & Khatib, 2016). It also includes simulation in Webots, helping students test their understanding in a virtual environment.

Learning how to control actuators is essential for anyone working in robotics or automation. It's a skill used in everything from industrial machines to everyday technology like drones or smart appliances. This lab gives students the hands-on experience they need to design and build better robotic systems in the future (Craig, 2005).

II. Objectives

A. Interface and control at least three actuators (DC motor, servo motor, and stepper motor) using the Arduino

This objective focuses to connect and program different types of motors with the Arduino to control their movement properly, including speed and direction.

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B. Use PWM signals to control the speed of a DC motor and observe the change in motor speed across a range from 50% to 100%

Understanding the changing of PWM values within the range of 50% to 100% that affects the motor's speed and practice adjusting it within a specific range.

C. Simulate the movement of motors in Webots with a success rate of 95% for correct motor movement and speed

Test the motor control code in a virtual environment to make sure the motors respond correctly and move as expected.

III. Materials and Software

- Materials:
  - Arduino Uno R3
  - DC Motor
  - Servo Motor
  - Stepper Motor
  - L298N Dual H-Bridge Motor Driver Module
  - Breadboard and Jumper Wires
  - 3x 3.7V Li-ion Battery
- Software:
  - Arduino IDE
  - Webots Simulator

IV. Procedures

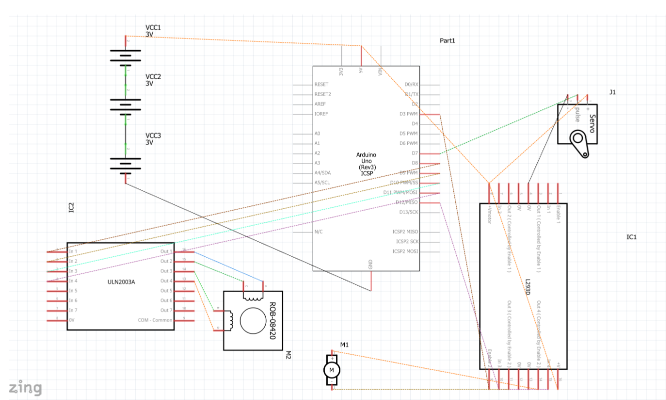

Fig. 1. Schematic Diagram for the component connections

- Motor Driver Setup

TABLE I
MOTOR DRIVERS/ULTRASONIC SENSOR/SERVO MOTOR TO ARDUINO UNO CONNECTIONS

Components Pin Connections	
Motor Drivers/Ultrasonic Sensor/Servo Motor Pins	***Arduino UNO Pins***
All VCC	5V
All GND	GND
IN2 & IN1	D12
ENB	D3
DATA Pin(Servo Motor)	D7
IN1	D8
IN2	D9
IN3	D10
IN4	D11

- For the supply, connect VCC and GND to 5V and GND respectively, of Arduino Uno. Connect IN2 and IN1 to Pin 13 for the logic direction. And also the ENA pin to D11 to vary the speed of the motor.

- Servo Motor Setup:
  - Connect the servo motor to the PWM-capable pin (D4) on the Arduino Uno.
- Stepper Motor:
  - Connect IN1, IN2, IN3, IN4 of the ULN2003 driver board to D8, D9, D10, D11 of Arduino Uno to control the direction, speed, and torque of Stepper motor.
- Webots Simulation
  - Simulate and observe the behavior of the tractor based on the adjustments of its speed.

V. OBSERVATIONS AND DATA COLLECTION

Motors Observation

As observed during the actual test process, in every 2 seconds, the DC motor changes its speed from 50% to 100% sequentially in a clockwise(forward) direction. The servo motor was also controlled by changing the angle from 0 degree to 180 degree and the stepper motor cycled in 1 revolution. Each motors run sequentially (DC motor - Servo Motor - Stepper Motor).

Webots Simulation

A maximum speed of 30 kilometers per hour is set for the vehicle(tractor) in the code provided for the Webots simulation. A condition that determines whether the requested speed is greater than 30 is used to implement this limit inside the set_speed() function. In the event that it is, the speed is automatically reset to 30 to prevent the car from going over this restriction. In the simulation, this serves as a safety cap to keep the tractor from moving too quickly, which could lead to unusual behavior or even instability. While the keyboard controls let you use the UP arrow key to raise the speed, you can only do so in tiny increments (1 km/h per push), and no matter how many times you press the key, the speed stops advancing once it hits 30 km/h. This improves control and predictability in the simulation, which is particularly helpful for evaluating steering, navigation, or sensor reactions.

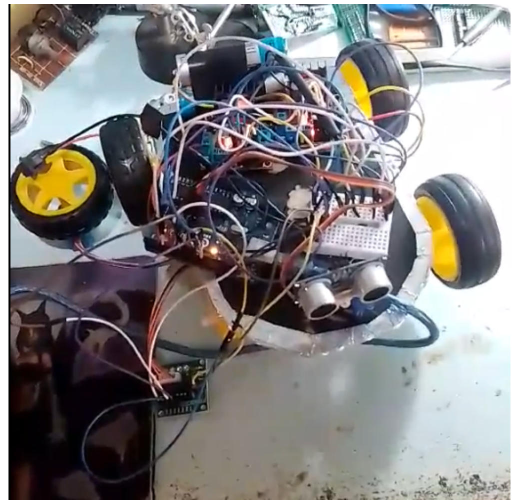

Fig. 2. Actual Testing of DC motor, Servo motor, Stepper motor

As the tractor's speed increase from 50% to 100% of its maximum allowed speed of 30 km/h, we observe how the tractor's movement and motor behavior change. At each speed level, we measured the angular velocity of both the front and rear wheels, which shows how fast the wheels are rotating to move the tractor forward.

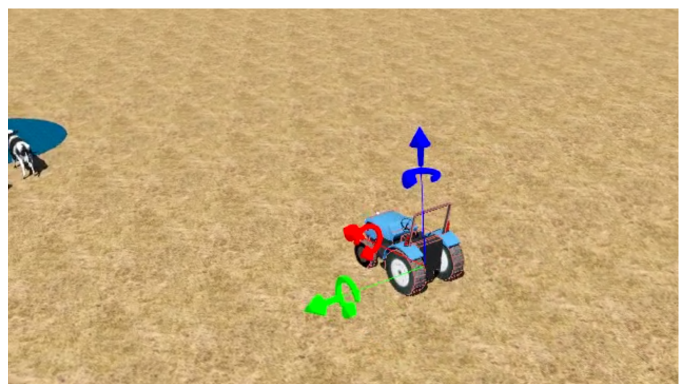

Fig. 3. Virvtual Robot's Simulation for Speed Testing from 50% to 100%

50% speed (15 km/h): At this speed, the tractor moves smoothly and steadily. The front wheels rotate at 10.96 rad/s, and the rear wheels rotate at 6.94 rad/s. The tractor is easy to control and can make sharp turns without difficulty. This speed is perfect for tasks that need precision, like moving through tight spaces or avoiding obstacles. The sensors, like the GPS, work well and provide accurate data.

60% speed (18 km/h): As the speed increases, the tractor becomes a little faster but still handles well. The front wheels rotate at 13.15 rad/s, and the rear wheels rotate at 8.33 rad/s. The vehicle is still stable, but it takes a little longer to stop. The tractor remains easy to control, and the sensors continue to work properly.

70% speed (21 km/h): At this speed, the tractor is noticeably faster. The front wheels rotate at 15.34 rad/s, and the rear wheels rotate at 9.72 rad/s. The tractor still maintains good control, but the GPS may show small delays, especially during sharp turns or quick steering changes. This speed is still acceptable for general use.

80% speed (24 km/h): At 80% speed, the tractor moves much faster. The front wheels rotate at 17.53 rad/s, and the rear wheels rotate at 11.11 rad/s. The tractor starts to take wider turns and is less responsive in tight spaces. The GPS may also show some small delays, which could make positioning a little less accurate, especially when the tractor is moving fast or making quick changes in direction.

90% speed (27 km/h): At 90% speed, the tractor is very fast. The front wheels rotate at 19.72 rad/s, and the rear wheels rotate at 12.5 rad/s. The tractor becomes harder to control, especially during turns. The sensors, including the GPS, may struggle to keep up, which could cause positioning errors. The tractor may not stay on track as easily when frequent adjustments are needed.

100% speed (30 km/h): At the maximum speed of 30 km/h, the tractor moves as fast as it can. The front wheels rotate at 21.91 rad/s, and the rear wheels rotate at 13.88 rad/s. At this speed, the tractor becomes harder to control. The turning radius is very wide, making sharp turns difficult, and the vehicle may miss turns. The sensors lag behind, making it harder to track the tractor's position accurately, especially in tight spaces. The tractor's behavior becomes less predictable at high speeds, and stopping becomes slower and less responsive.

If you wanted the vehicle to go faster, you could change the value 30 to a higher value, like 50 or 60. Removing or increasing this limit allows the vehicle to accelerate beyond the original cap, which can be helpful if you're testing high-speed scenarios or stress-testing motor controls. But this should be done carefully, because going too fast might cause the virtual vehicle to behave in ways that are not physically realistic, especially if the simulation wasn't designed to handle such speeds.

VI. Data Analysis

Speed %	Speed (km/h)	Front Wheel Angular Velocity (rad/s)	Rear Wheel Angular Velocity (rad/s)
50%	15	10.96	6.94
60%	18	13.15	8.33
70%	21	15.34	9.72
80%	24	17.53	11.11
90%	27	19.72	12.5
100%	30	21.91	13.88

TABLE II
Tractor's speed and angular velocity (Front and Rear Wheels) at different speed percentages

Angular Velocity Calculations

The angular velocity ω of a wheel can be calculated using the formula:

$$\omega = \frac{v}{r}$$

- ω is the angular velocity in radians per second (rad/s).
- v is the linear velocity of the wheel in meters per second (m/s).
- r is the radius of the wheel in meters (m).

Since the linear velocity v is related to the speed $v_{\text{km/h}}$ in kilometers per hour (km/h) by the following:

$$v = \frac{v_{\text{km/h}} \times 1000}{3600}$$

We can now calculate the angular velocity for different speeds. Based on the tractor's wheel measurements (in radius) provided in the Webot Simulator:

$$\text{For Front Wheels:} \quad r_{\text{front}} = 0.38\,\text{m(radius of the front wheel)}$$

$$\text{For Rear Wheels:} \quad r_{\text{rear}} = 0.6\,\text{m(radius of the rear wheel)}$$

Speed 50% (15 km/h)

$$v_{\text{front}} = \frac{15 \times 1000}{3600} = 4.1667\,\text{m/s}$$
$$\omega_{\text{front}} = \frac{4.1667}{0.38} = 10.96\,\text{rad/s}$$
$$v_{\text{rear}} = \frac{15 \times 1000}{3600} = 4.1667\,\text{m/s}$$
$$\omega_{\text{rear}} = \frac{4.1667}{0.6} = 6.94\,\text{rad/s}$$

Speed 60% (18 km/h)

$$v_{\text{front}} = \frac{18 \times 1000}{3600} = 5.0\,\text{m/s}$$
$$\omega_{\text{front}} = \frac{5.0}{0.38} = 13.15\,\text{rad/s}$$
$$v_{\text{rear}} = \frac{18 \times 1000}{3600} = 5.0\,\text{m/s}$$
$$\omega_{\text{rear}} = \frac{5.0}{0.6} = 8.33\,\text{rad/s}$$

Speed 70% (21 km/h)

$$v_{\text{front}} = \frac{21 \times 1000}{3600} = 5.8333\,\text{m/s}$$
$$\omega_{\text{front}} = \frac{5.8333}{0.38} = 15.34\,\text{rad/s}$$
$$v_{\text{rear}} = \frac{21 \times 1000}{3600} = 5.8333\,\text{m/s}$$
$$\omega_{\text{rear}} = \frac{5.8333}{0.6} = 9.72\,\text{rad/s}$$

Speed 80% (24 km/h)

$$v_{\text{front}} = \frac{24 \times 1000}{3600} = 6.6667\,\text{m/s}$$
$$\omega_{\text{front}} = \frac{6.6667}{0.38} = 17.53\,\text{rad/s}$$
$$v_{\text{rear}} = \frac{24 \times 1000}{3600} = 6.6667\,\text{m/s}$$
$$\omega_{\text{rear}} = \frac{6.6667}{0.6} = 11.11\,\text{rad/s}$$

Speed 90% (27 km/h)

$$v_{\text{front}} = \frac{27 \times 1000}{3600} = 7.5\,\text{m/s}$$

$$\omega_{\text{front}} = \frac{7.5}{0.38} = 19.72\,\text{rad/s}$$

$$v_{\text{rear}} = \frac{27 \times 1000}{3600} = 7.5\,\text{m/s}$$

$$\omega_{\text{rear}} = \frac{7.5}{0.6} = 12.5\,\text{rad/s}$$

Speed 100% (30 km/h)

$$v_{\text{front}} = \frac{30 \times 1000}{3600} = 8.3333\,\text{m/s}$$

$$\omega_{\text{front}} = \frac{8.3333}{0.38} = 21.91\,\text{rad/s}$$

$$v_{\text{rear}} = \frac{30 \times 1000}{3600} = 8.3333\,\text{m/s}$$

$$\omega_{\text{rear}} = \frac{8.3333}{0.6} = 13.88\,\text{rad/s}$$

VII. Discussion and interpretations

The observations from the Webots simulation and the actual test process provide some insights into how the tractor behaves at different speeds in various motor control scenarios. The DC motor, servo motor, and stepper motor were sequentially tested, with each motor running in a set order—first the DC motor, followed by the servo, and then the stepper motor. The DC motor's speed was varied between 50% and 100%, and during each transition, the servo motor's angle was changed from 0 to 180 degrees, and the stepper motor made one full revolution.

At the Webots simulation, the tractor's maximum speed was set at 30 km/h. This speed limit was declared in the code to prevent the tractor from moving too fast, which could lead to unexpected behavior. As expected, by manually adjusting the value increased the speed in small increments, and the tractor would stop accelerating once it reached the 30 km/h limit. This speed limit ensures that the simulation remains manageable and observable.

VIII. Conclusion

Overall, the Webots simulation and real-world tests showed how speed affects the tractor's movement and control. As the speed increased from 50% to 100%, it became harder to control the tractor. At lower speeds, the tractor was stable, easy to control, and the sensors worked well. While it is possible to test higher speeds by changing the cap, it could cause instability and unrealistic behavior in the simulation. That's why it is important to find the right balance between speed and control to keep the tractor reliable and functional for real-world use.

References

[1] Bolton, W. (2015). Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering (6th ed.). Pearson.

[2] Siciliano, B., & Khatib, O. (2016). Springer Handbook of Robotics. Springer.

[3] Craig, J. J. (2005). Introduction to Robotics: Mechanics and Control (3rd ed.). Pearson.

IX. Appendix

https://github.com/seth-paul/Elective-2-Robotics-Technology/tree/main/Laboratory%203