Laboratory 1*

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***Abstract*—This laboratory activity explores the design and simulation of a quadrupedal walking robot using the Webots platform. By implementing a sinusoidal gait algorithm through C programming, the robot is able to perform stable and coordinated movements across all four legs. The study focuses on the synchronization of joint angles using phase offsets to simulate natural locomotion. Observations show that fine-tuning of gait parameters significantly impacts stability and speed, validating the effectiveness of the chosen control strategy. This activity not only strengthens students' understanding of robotic motion and control but also introduces practical applications in fields like disaster response, agriculture, and exploration.**

I. Rationale

This activity aims to help students understand quadrupedal robot movement through virtual simulation in Webots. By programming a walking algorithm using sinusoidal functions, students learn how to coordinate motor functions and manage stable gait cycles. The simulation builds practical skills in robotics control, motion planning, and real-world applications such as search and rescue or agriculture, preparing students for future innovation in the field.

II. Objectives

- To simulate and control a quadrupedal robot using the Webots environment.
- To implement a sinusoidal gait algorithm for stable walking motion.
- To understand the coordination between motors, joints, and control logic.
- To develop skills in robotic programming and motion planning.
- To explore potential real-world applications of quadrupedal robots.

III. Materials and Software.

- **Webots Simulation Software** – for virtual robot modeling and testing
- **C Programming Language** – for robot control algorithm
- **Personal Computer or Laptop** – to run simulations and edit code
- **Robot Model (Quadruped with 12 DOF)** – provided within the simulation environment
- **Keyboard and Mouse** – for coding and simulation control
- **Internet Connection** – for downloading software or accessing documentation (if needed)

Identify applicable funding agency here. If none, delete this.

A. Procedure

1) **Set Up Environment**
   - Install and launch Webots simulation software.
   - Load the quadrupedal robot model with 12 DOF.
2) **Initialize Robot Motors**
   - Use `wb_robot_get_device` to identify and control each joint motor.
   - Set initial positions and velocities using Webots motor functions.
3) **Implement Gait Algorithm**
   - Write a C program using sinusoidal functions for walking motion.
   - Apply phase offsets to synchronize diagonal leg movement.
4) **Simulate Robot Movement**
   - Run the program and observe the robot's gait in the simulation.
   - Adjust parameters (e.g., phase increment or amplitude) for better stability.
5) **Debug and Optimize**
   - Test for smoothness, balance, and consistency of gait.
   - Refine code as needed for improved motion.
6) **Document Results** Record observations and discuss potential applications of the robot.

B. Observations and Data Collection

- The robot performed a stable walking gait when the sinusoidal functions and phase offsets were correctly applied.
- Diagonal leg coordination (front-left with rear-right, and front-right with rear-left) contributed to balanced motion.
- Adjusting the **phase increment** affected the walking speed and smoothness.
- The **elbow joints** lifted and lowered in sync with the gait cycle, simulating realistic leg movement.

- Minor instability was observed when phase values were too large or too small, requiring tuning.
- No collisions or errors were observed during the simulation run under optimal parameters.
- Data such as joint angles and timing could be logged using Webots tools for further analysis (if required).
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C. Data Analysis.

The simulation demonstrated that the quadrupedal robot's walking performance relies heavily on the precise timing and coordination of joint movements. By using sinusoidal functions with appropriate phase offsets, the robot achieved a natural and balanced gait. The analysis showed that synchronized diagonal leg movements are key to maintaining stability. Any deviation in phase increment or amplitude resulted in irregular motion, proving the importance of fine-tuning gait parameters. Overall, the control algorithm effectively translated into smooth robotic motion within the Webots environment, validating the success of the implemented walking cycle.

Walking Gait Equation

The motion of each joint in the robot's gait cycle can be modeled using a sinusoidal function:

$$\theta(t) = A \cdot \sin(\omega t + \phi)$$

Where:

- $\theta(t)$ is the joint angle at time t
- A is the amplitude (maximum joint angle)
- ω is the angular frequency (controls the speed of motion)
- t is time
- ϕ is the phase offset (used to synchronize legs)

D. Discussion and Interpretations

The successful simulation of a quadrupedal walking robot highlights the importance of coordinated joint control in achieving stable and realistic movement. By applying sinusoidal functions with phase offsets, each leg moved in a rhythmic and synchronized pattern, mimicking the natural gait of a four-legged animal. The phase offset allowed diagonal legs to move alternately, improving balance and reducing instability during motion.

Small adjustments to the phase increment and amplitude significantly affected gait performance. A higher phase increment increased speed but risked losing balance, while lower values made the movement sluggish but more stable. This demonstrates the trade-off between speed and stability in robotic locomotion.

The use of Webots for virtual testing provided a safe environment to refine the control algorithm without risking hardware damage. The robot's performance validates the effectiveness of the sinusoidal gait strategy and shows potential for real-world use in uneven or hazardous environments, where wheeled or bipedal robots might struggle.

E. Conclusion

The laboratory activity successfully demonstrated how a quadrupedal robot can achieve stable walking motion using sinusoidal gait control in a virtual simulation. Through the Webots environment, students were able to apply theoretical concepts in robotics and observe the effects of joint coordination and phase synchronization. The activity not only enhanced programming and simulation skills but also highlighted the robot's potential for real-world applications in complex terrains. Overall, it provided valuable insights into the fundamentals of legged robotic locomotion.

Figures and Tables

article graphicx

Measurement Number	Distance Measured (m)	Expected Distance (m)	Accur
1	1.02	1.00	98
2	2.10	2.00	95
3	5.05	5.00	99
4	3.15	3.00	95
5	0.98	1.00	98

TABLE I
DISTANCE MEASUREMENTS AND ACCURACY