ROBOTICS AND EMBEDDED SYSTEMS

LABORATORY 1

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***Abstract*—This laboratory exercise investigates the design and simulation of a quadrupedal walking robot within the Webots environment. By implementing a sinusoidal gait algorithm through C programming, the robot achieves stable and coordinated motion across all four limbs. The focus of the study is on the synchronization of joint angles through phase offsets to replicate natural locomotion patterns. Results indicate that careful adjustment of gait parameters plays a crucial role in enhancing both stability and speed, thereby validating the efficacy of the selected control strategy. This activity not only deepens students' comprehension of robotic motion and control but also introduces practical applications in domains such as disaster response, agriculture, and exploration.**

I. Rationale

This activity is designed to facilitate students' understanding of quadrupedal robot locomotion through virtual simulation in Webots. By developing a walking algorithm based on sinusoidal functions, students gain insight into coordinating motor functions and managing stable gait cycles. The simulation provides valuable hands-on experience in robotics control, motion planning, and the application of these concepts to real-world scenarios, such as search and rescue operations or agricultural tasks, thereby preparing students for future advancements in the field.

II. Objectives

- To simulate and control a quadrupedal robot within the Webots environment.
- To implement a sinusoidal gait algorithm to achieve stable walking motion.
- To comprehend the coordination of motors, joints, and control logic for efficient movement.
- To cultivate expertise in robotic programming and motion planning.
- To investigate potential real-world applications of quadrupedal robots.

III. Materials and Software.

- **Webots Simulation Software** – utilized for virtual robot modeling and testing.
- **C Programming Language** – employed for the development of the robot control algorithm.
- **Personal Computer or Laptop** – required for running simulations and editing code.
- **Robot Model (Quadruped with 12 DOF)** – available within the simulation environment.
- **Keyboard and Mouse** – essential for coding and controlling the simulation.
- **Internet Connection** – necessary for downloading software and accessing documentation, as required.

A. Procedure

1) **Set Up Environment**
   - Install and launch the Webots simulation software.
   - Load the quadrupedal robot model with 12 Degrees of Freedom (DOF)
2) **Initialize Robot Motors**
   - Utilize the `wb_robot_get_device` to identify and control each joint motor.
   - Configure initial positions and velocities using Webots motor functions.
3) **Implement Gait Algorithm**
   - Develop a C program that employs sinusoidal functions to generate walking motion.
   - Apply phase offsets to synchronize the movement of diagonal legs.
4) **Simulate Robot Movement**
   - Execute the program and observe the robot's gait in the simulation environment.
   - Fine-tune parameters (such as phase increment or amplitude) to enhance stability.
5) **Debug and Optimize**
   - Evaluate the smoothness, balance, and consistency of the gait.
   - Refine the code as necessary to improve the robot's movement.
6) **Document Results** Record observations and analyze potential applications for the robot's capabilities.

B. Observations and Data Collection

- The robot exhibited a stable walking gait when the sinusoidal functions and phase offsets were applied correctly.

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- Coordination of diagonal legs (front-left with rear-right, and front-right with rear-left) facilitated balanced movement.
- Modifying the phase increment influenced the walking speed and smoothness of the gait.
- The elbow joints moved in synchrony with the gait cycle, replicating realistic leg movement.
- Minor instability was noted when phase values were either too large or too small, necessitating fine-tuning.
- No collisions or errors occurred during the simulation when the parameters were set optimally.
- Joint angles and timing data could be logged using Webots tools for subsequent analysis, if needed..
- The robot demonstrated stable walking motion when the sinusoidal functions and phase offsets were accurately applied.
- The synchronization of diagonal legs (front-left with rear-right, and front-right with rear-left) played a key role in achieving balanced movement.
- Modifying the phase increment influenced both the speed and smoothness of the walking gait.
- The elbow joints moved in sync with the gait cycle, effectively simulating realistic leg movements.
- Minor instability was observed when the phase values were excessively large or small, necessitating fine-tuning.
- No collisions or errors occurred during the simulation when optimal parameters were applied.
- Data, such as joint angles and timing, could be logged using Webots tools for additional analysis, if required.

Fig. 1. Webots Simulation.

C. Data Analysis.

The simulation revealed that the walking performance of the quadrupedal robot is highly dependent on the precise coordination and timing of joint movements. By employing sinusoidal functions with carefully adjusted phase offsets, the robot achieved a stable and natural gait. The analysis highlighted that synchronized diagonal leg movements are essential for maintaining balance. Any variation in phase increment or amplitude led to irregular motion, underscoring the importance of fine-tuning gait parameters. In conclusion, the control algorithm successfully facilitated smooth and efficient robotic motion within the Webots environment, demonstrating the effectiveness 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 the quadrupedal walking robot underscores the critical role of coordinated joint control in achieving stable and realistic movement. By employing sinusoidal functions with phase offsets, each leg moved in a rhythmic, synchronized pattern, replicating the natural gait of a four-legged animal. The phase offset facilitated the alternate movement of diagonal legs, enhancing balance and minimizing instability during motion.

Minor adjustments to the phase increment and amplitude had a significant impact on gait performance. A higher phase increment increased speed but compromised balance, whereas lower values slowed the movement but enhanced stability. This illustrates the inherent trade-off between speed and stability in robotic locomotion.

The use of Webots for virtual testing provided a risk-free platform for refining the control algorithm without the potential for hardware damage. The robot's performance affirms the effectiveness of the sinusoidal gait strategy and demonstrates its potential for real-world applications, particularly in uneven or hazardous environments where wheeled or bipedal robots may face limitations.

E. Conclusion

The laboratory exercise effectively demonstrated how a quadrupedal robot can achieve stable walking motion through sinusoidal gait control within a virtual simulation. Using the Webots environment, students were able to apply theoretical principles of robotics and observe the impact of joint coordination and phase synchronization. The activity not only enhanced programming and simulation capabilities but also emphasized the robot's potential for practical applications in navigating complex terrains. Overall, it offered valuable insights into the core principles of legged robotic locomotion.