Legged Robots

MICRO-507

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Project 1: Bipedal Locomotion Control based on Divergent Component of Motion

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1 Basic Walking Analysis

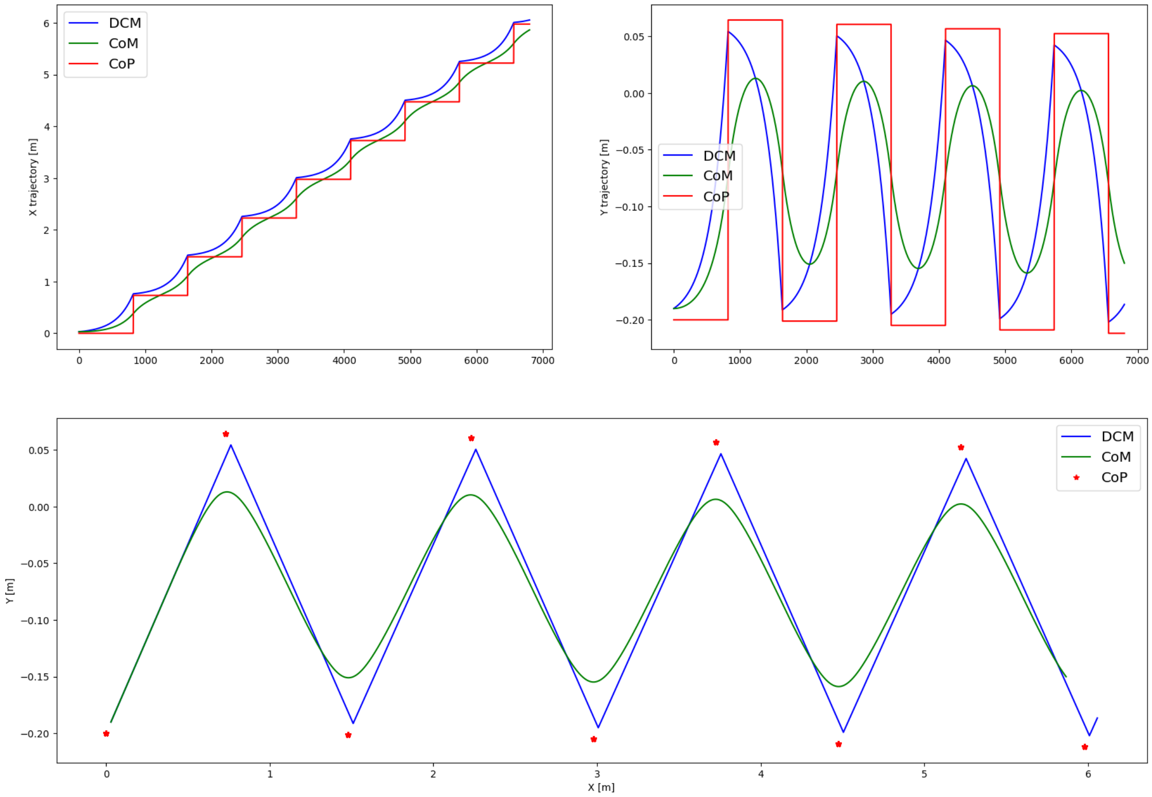

Figure 1: X and Y trajectories of DCM, CoM and CoP in basic walking.

Figure 1 shows the X and Y trajectories of DCM, CoM and CoP respectively.

For the X trajectory, the DCM shows a smooth, oscillatory increase, with each oscillation matching the steps of the CoP. As DCM is the divergent component that should be constrained, the smooth and periodic variation leads to a stable response from the CoM. The CoM trajectory also shows a gradual increase but with a smoother transition compared to the DCM. The CoM follows the DCM, maintaining stability. This behavior is consistent with a balanced walking motion where the CoM remains centered around the support polygon. The CoP changes in a stepwise manner, indicating the foot placements. Each step transition in the CoP aligns with the changes in the DCM direction, providing stability and support to the CoM forward motion.

For the Y trajectory, the DCM oscillates more significantly, reflecting lateral motion as the robot balances during stepping. These lateral swings correspond to the alternating support phases as the robot shifts its weight from one foot to the other. The CoM trajectory is smoother and has a smaller amplitude compared to the DCM. It oscillates in sync with the DCM but at a reduced range. The CoP trajectory shifts sharply between positive and negative values, corresponding to the alternating foot placements. These discrete transitions help stabilize the lateral oscillations in the DCM.

The X-Y plot matches the analysis above.

2 Questions

2.1 Question 1

The rate of divergence of the DCM dynamics in equation (9) is primarily influenced by the natural frequency $\omega = \sqrt{\frac{g}{h}}$, where g is the gravitational acceleration and h is the height of the center of mass (CoM). A higher CoM height leads to a smaller ω, resulting in slower divergence, while a lower CoM height causes faster divergence. Moreover, the difference between the initial DCM position ξ_0 and the initial Center of Pressure ($\mathbf{cop}_0$) also affects how quickly the DCM moves away from the $\mathbf{cop}_0$, with a larger difference leading to faster divergence.

$$\xi = (\xi_0 - cop_0)e^{\omega t} + cop_0 \tag{9}$$

2.2 Question 2

In optimization-based DCM motion planning, the stability of DCM movement is maintained by controlling the relationship between the DCM and the Center of Pressure (CoP). The optimization process ensures that the CoP stays within the robot's support polygon, preventing excessive divergence of the DCM and keeping the robot balanced. The system minimizes the error between the desired and actual DCM trajectories, triggering recovery actions when the error exceeds a certain threshold. Also, the maximum achievable velocity is constrained to prevent the DCM become too divergent from the CoM, which is included in the inequality constraint. Additionally, step parameters like the duration, length, and foot placement are dynamically adjusted to correct the DCM trajectory. The natural frequency of the DCM dynamics is also considered to regulate the DCM's rate of convergence or divergence, ensuring stable locomotion.

2.3 Question 3

An error between the real and desired DCM can exist even without an external push due to model inaccuracies, sensor noise, or imperfect control actions.The DCM model is established based on the linear inverted pendulum model, which may not fully match the real dynamics. The numerical methods are used to solve the model, where the tolerance exists and the numerical error may happen. Additionally, factors like discretization errors from numerical integration or delays in actuation and feedback loops can contribute to the discrepancy between the real and desired DCM trajectories.

2.4 Question 4

In addition to the stepping strategy, other balance recovery strategies include lowering the center of gravity and using the arms to regain balance. Lowering the center of gravity by bending the knees or crouching is commonly used in sports like surfing or skiing. This helps to stabilize the body by increasing the base of support and reducing the impact of external disturbances. Another strategy involves using the arms for balance; by extending or moving the arms, we can shift the body's mass and generate counteracting forces to maintain stability. These strategies help in different dynamic situations, where adjusting posture or redistributing body weight can counterbalance external forces.

2.5 Question 5

DCM provides a simplified yet effective way to predict and control the robot's motion, focusing specifically on maintaining balance. The DCM captures the most critical aspect of balance recovery which is the movement of the center of mass relative to the center of pressure. This allows for faster computation and real-time control, as it reduces the complexity of the problem by focusing on the robot's stability rather than solving the full dynamics. Using the entire dynamic equation of the robot, which includes detailed joint-level forces and torques, would be computationally expensive and less efficient, making it harder to achieve real-time control.

2.6 Question 6

Figure 2 shows the x-value of CoM (Center of mass) verse time steps. The unit of the vertical axis is the meter. The parameter GAP is the step range constraint. We made it a square area with side length equals to 2*GAP. The minimum speed we can achieve is around 0.27mm/timestep (The bright blue curve), where we utilize small NominalStepLength and decrease the NominalStepDuration. The maximum speed we can achieve is around 7.76mm/timestep (The yellow curve)

2.7 Question 7

We set the push force to 2100N and made the block close to the robot. And then we adjust the Nominalstepwidth to 0.15 and Nominalsteplength to 0.1. Figure 3 shows the CoP result. We can see the robot took 14 steps to recover from being pushed.

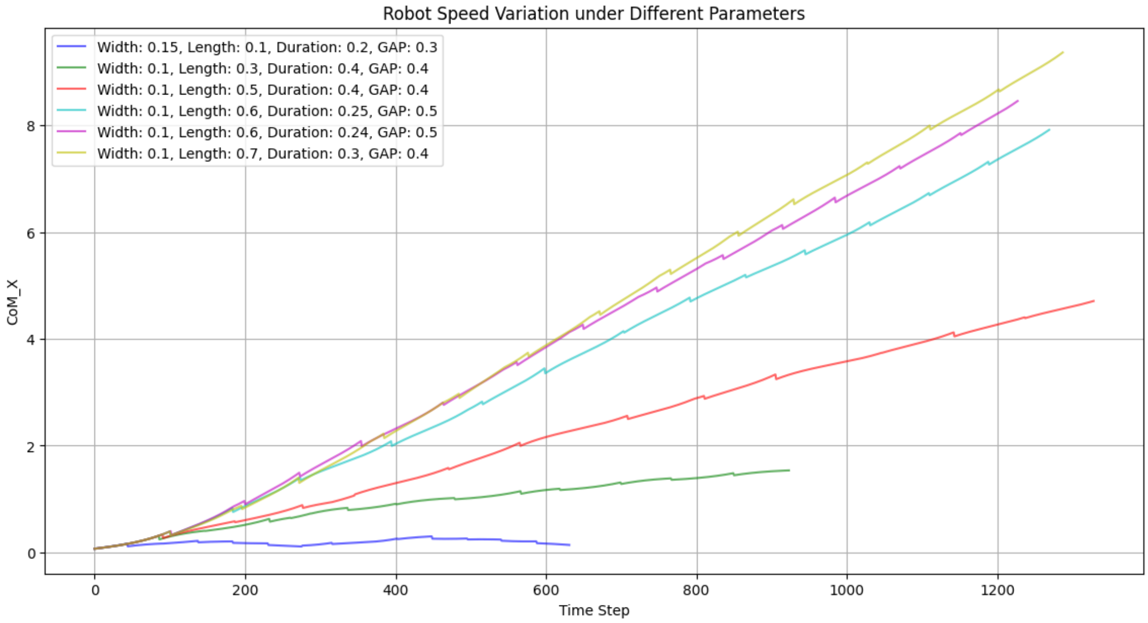

Figure 2: CoM vs time step

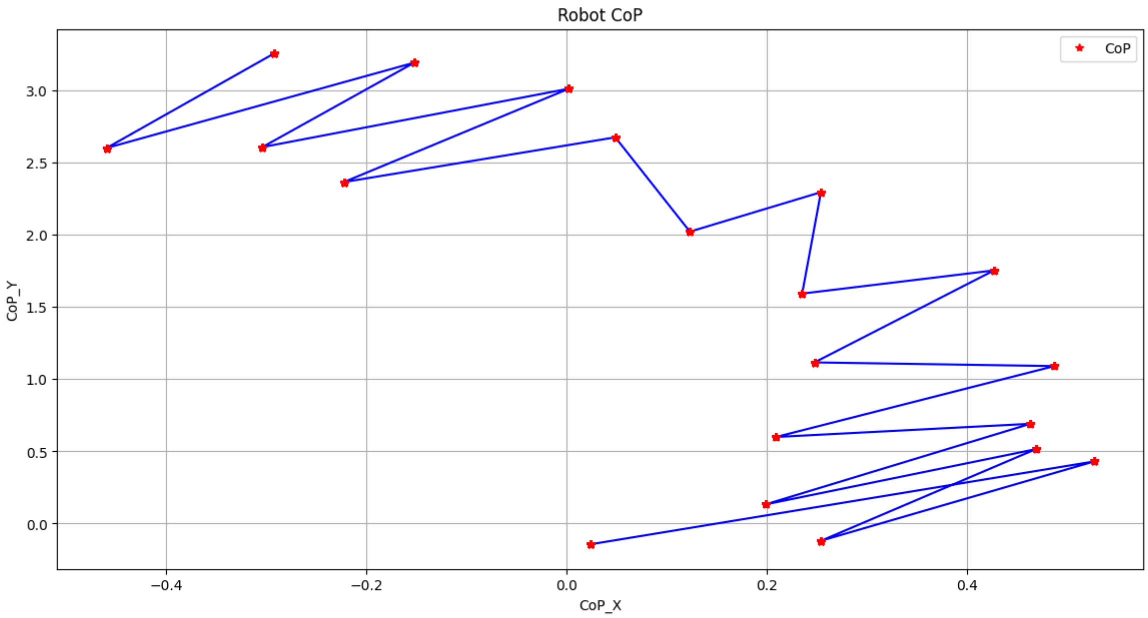

Figure 3: CoP Change of Robot