Analysis of a Dynamic Vertical Climbing Two-arm Model

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***Abstract*— We report on the development of a new two-arm and pendulum-style climbing model. The arm lengths and the rotational configuration of the arms are actively controllable inputs. The numerical analysis is extensively executed to evaluate the effects of model parameters to the overall model dynamic behavior.**

I. Introduction

Animals perform robust and agile locomotion in natural environment. The researchers found that dynamic climbing motion of several small species can be approximated by a reduced-order two-arm model [1]. Following this work, a robot with this specific morphology has been developed [2]. However, the reported work only concerns either mapping from the animals to the model or experimental validation of dynamic behaviors of the model. None of them carefully explores the dynamics of the model itself. Thus, the effects of model parameters as well as their interactions remain unclear. Here, together with the development of a new dynamic vertical climbing robot [3], we construct a simplified version of the two-arm model and carefully analysis its characteristics and dynamics. By doing so, we are able to find the general guideline of designing dynamic robots as well as to use the model as the priori behavior analysis before the empirical robot experiments, easing and speeding up the development process.

II. Methods and Results

The morphology of the model is designed based on the development model [1] and the built robot as shown in Fig. 1(a), which is simply composed of a rigid body with two massless arms. The arm lengths and the rotational configuration of the arms are active and controllable parameters. Several assumptions are made to ease the analysis: (i) The hand is treated as a revolute joint fixed to the wall during climbing (i.e., the robot moves like a pendulum with variable length). (ii) The resultant friction and damping effects are set to act on the robot center of mass (COM). (iii) The linear momentum in the non-constrained direction is continuous. Following these setup, the equation of motion of the model can be derived by using Lagrangian method:

$$\left(r^2 + R_g^{\,2}\right)\ddot{\theta} + 2r\dot{r}\dot{\theta} + gr\cos(\theta) = \pm R_g^{\,2}\left(\ddot{\psi} + \ddot{\theta}_m\right) - F_r \quad (1)$$

where r, θ_m, θ, ψ, R_g, and F_r are the equivalent length of the pendulum, the opening angle between two hands, the orientation of the vector from the robot COM to the hand w.r.t. world frame, the angle between the arm and the pendulum, the radius of gyration w.r.t the model COM, and resistance force, respectively. Next, with given initial conditions (I.C.s), the dynamic behavior of the model can be quantitatively evaluated in numerical environment. Fig 1(b) plots the planar trajectory of the model.

The parameters are varied to check their effects on overall

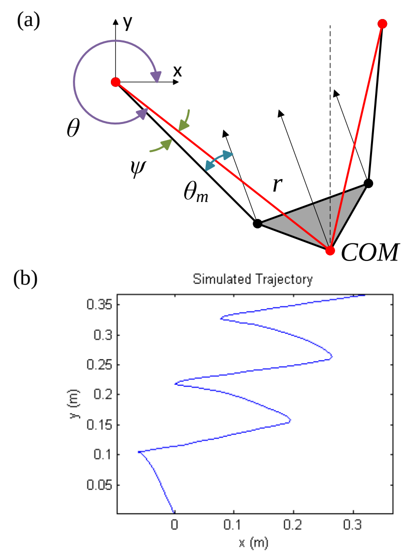

Fig. 1 (a) Parameters of the model. (b) One of the simulation results.

model dynamics, and several important model behaviors are concluded: (i) The model is a self-stabilized system. No matter what I.C.s are given, motion of the robot always converges to the same periodic swing motion identical to the periodic arm motion. (ii) The upward climbing speed increases with the increase of the radius of gyration, arm length, and resistance force. In the meantime, the body swing amplitude behaves in a opposite manner.

III. Conclusion

The analysis of the developed dynamic model helps us have better understanding of model behavior, and more importantly, this analysis also serves as the guideline of developing robot behaviors and control strategy.

References

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