Template Models of Bipedal Locomotion: The Spring Loaded Inverted Pendulum (SLIP) Model

Analysis and Modeling of Locomotion

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Introduction

Modeling and control of legged locomotion has been the field of interest and research from both biology and robotics viewpoints to understand the underlying locomotor mechanisms, as well as take inspiration to build efficient and powerful robotics platforms. Studies have been done at different levels of abstraction from very simplified models to sophisticated neuro-mechanical models [1]. The SLIP model is a two-state hybrid dynamical system consisting of a point mass attached to a massless springy leg. In this assignment session, we provide a tutorial and a SLIP model which simulates the dynamics of running systems. By following the steps, you can learn how these simple models can be used to explain the principles of running/walking dynamics and stability.

You are only required to deliver answers to the questions labeled "deliverable." You should work independently. Limit your answers to 1 pages of text in total (excluding figures). Each student needs to upload the assignment in PDF form to the Moodle before the deadline. Your report should be named SLIP_Name_Surname.pdf.

Get Started

Download the SLIP Assignment folder from Moodle and unzip it. This tutorial is provided in Matlab and is based on an open-source gait-creation framework designed and published by Remy et al. [2]. We have slightly changed the codes and added some steps to fit them with the questions you are going to answer in this session.[1] To launch the tutorial follow the steps below:

- Set the "Current Folder" in your Matlab session to this directory: SLIP Assignment/Models/SLIP.
- Run initTutorial in your Matlab Command Window.

Your Tutorial should now be initialized and ready to be used. If so, you will receive a confirmation message in your command window. Now you are prepared to follow the exercises below and for any of them you will be asked to run one of the provided functions.

Explore parameters

Play around with the system parameters and explore how they influence the simulated hopping leg behavior. Basically, you have to explore the role of the following parameters:

- **Physical properties** of the system such as mass, size, spring stiffness, etc.
- **Initial conditions** for the state variables of the system such as initial velocity and initial height.

The main goal is to choose a set of parameters able to guarantee as many as possible steps before the SLIP falls over. To make this search easier for you, we have selected most of the parameters for the first step. The only parameters that you need to explore at this step, are the *angle of attack* and the initial *forward speed*. Run the command "help exe_0" in Command Window. You will choose first what angle of attack and second what forward speed you want to command to the leg. The second option is just for visualization. Using the function "exe_0", go through the following steps:

- Enter the highest value for the angle of attack i.e. $\alpha = 90$ and zero value for the initial speed $dx = 0$. Observe how the leg behaves!
- Now give some other angle of attack to the leg but keep the initial speed still zero. What do you observe?
- Now keep the angle of attack fixed to some value between 45 and 90 degrees and change the forward speed. Try some values between 0 and 15 (as a hint!). Write down the solution which gives you the highest number of successful steps. You will need it later! (Note that the maximum number of steps simulated is set to 20).

Exercise - Examine the Running Stability

The idea in this exercise is to examine the effect of certain parameters on the running stability in a more systematic way. To do that you basically need to select two important parameters from the above-mentioned sets; the *system parameters* and the *initial conditions*. In this exercise you will do a systematic grid search on two main popular sets of parameters [3]. Follow the steps below:

- Do the systematic search for the combination of parameters K and α (spring stiffness and angle of attack). The main codes are provided in the tutorial but to use them you need to have a good solution from exe-0 (with at least 10 successful steps)! Whenever you are ready, follow these steps:
  - Run the command help exe 1 in your command window to get the function description.
  - Using the function exe 1, first you are asked to enter the value of dx (forward velocity) of your good solution.
  - Next you should select the boundaries you suggest for K and α. (Hint: again, use your solution from the exploration of parameters and distribute the boundaries around its K and α value.)
  - Select the number of sample points you want to use for the systematic search. You can start with low numbers (like 10 for both) when you are exploring the good boundaries. But once you have found the good boundaries, increase the number of sample points to have a finer search.
  - After each systematic search you do, you can ask for its graph and based on that improve your guess for the boundaries

Deliverable:

1) Plot a graph with several successful solutions as the ones shown in Figure 2 of Seyfarth et al. [3]
2) Explain the trend you observe in the graph and its meaning from a biomechanics perspective.
3) Do you think counting the number of steps is a good measure of stability? How can a Return Map (or Poincaré Map) be used to evaluate the system's stability? For more details on this method, please refer to the lecture notes as well as the reference [4].
4) Which aspects of human locomotion's biomechanics can be investigated with this type of model, ad which one cannot be investigated?

References

[1] P. Holmes, R.J. Full, D. Koditschek and J. Guckenheimer, The Dynamics of Legged Locomotion: Models, Analyses, and Challenges, SIAM Review, **48**, 2006.

[2] C. Remy, K. Buffinton, and R. Siegwart, "A matlab framework for efficient gait creation", International
Conference on Intelligent Robots and Systems, 2011.

[3] A. Seyfarth, H. Geyer, M. Gunther and R. Blickhan, A movement criterion for running *J. of Biomechanics*, **35**, 649655 (2001)

[4] A. Seyfarth, Hartmut Geyer and Hugh Herr, Swing-leg retraction: a simple control model for stable running, J. Exp. Biol., **206**, 2003.