Slip Assignement

Spring-Loaded Inverted Pendulum

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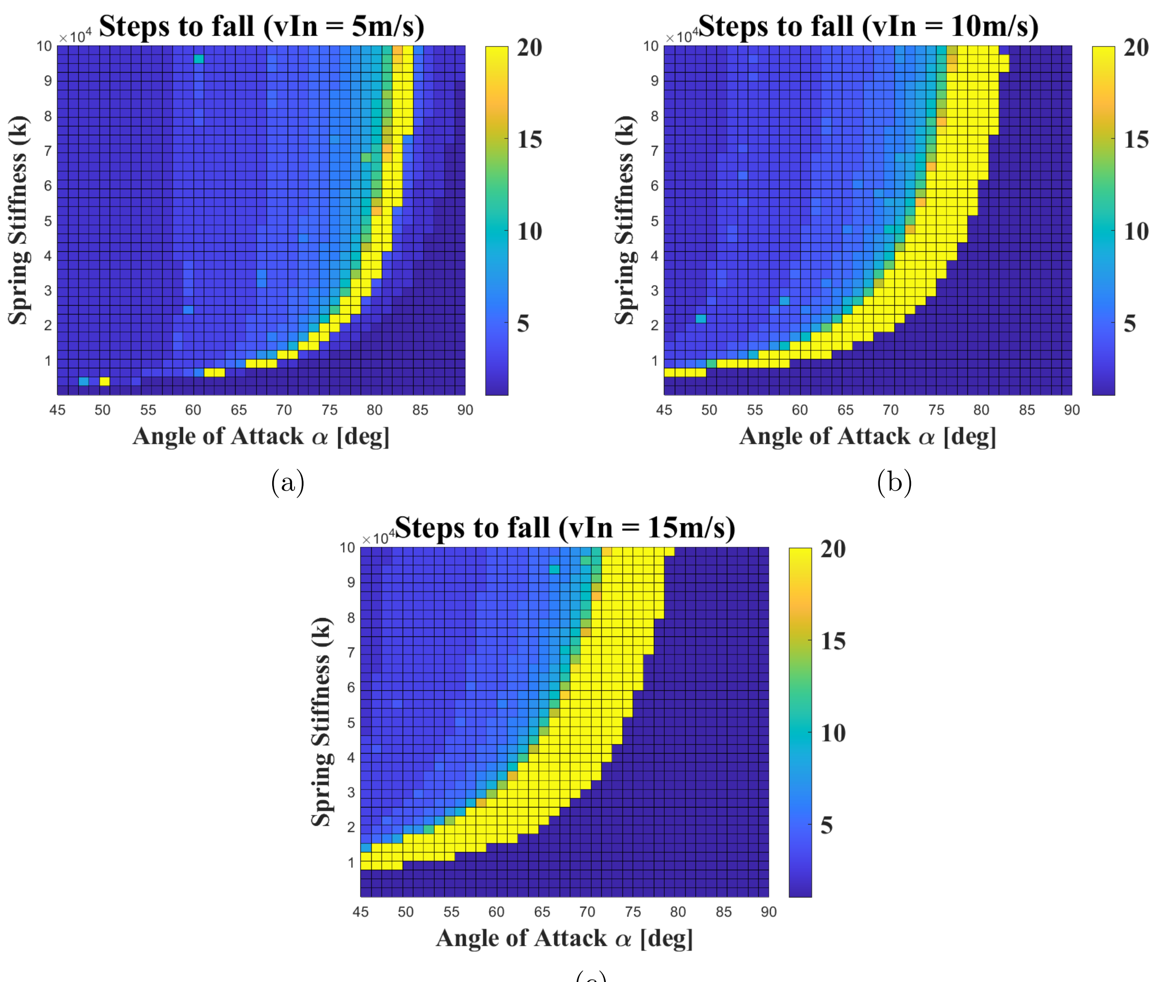
Question 1



(a) (b) (c)

All spring stiffness' are expressed in N/m.

Question 2 Three main trends can be taken from these graphs. Firstly, there is always a lower bound for the spring stiffness under which no stability can be achieved. This is understandable from a mechanical point of view, as the point of mass would directly crash without bouncing.

Secondly, the greater the angle of attack, the stiffer the spring needs to be to reach the maximum number of steps (here 20). The relationship seems exponential. It is also to be noted that the greater the angle of attack, the larger the band of compatible spring stiffness that brings stability.

Thirdly, the exponential band of stability is shifted to the left with growing speed: the angle of attack must be smaller to achieve the same stability with fixed spring stiffness. This is understandable from an energetic point of view, as the lower the angle of attack, the higher the spring must absorb the forward kinetic energy to avoid falling forward in the motion. Furthermore, higher speed also broadens the band of compatible spring stiffness and angle of attack and is, therefore, more easily stabilized.

Such features can easily be observed while running and walking in humans. With growing speed, we make larger steps and thus have a lower angle of attack. With a larger angle of attack, the gravity force from the point of mass on the spring is greater as the vectors of direction are closer to being aligned: the spring, therefore, needs to be stiffer to support its motion.

Question 3 Counting the number of steps is a way of measuring stability, as a higher number of steps naturally denotes higher stability. However, it is not a very precise measure and does not always describe the true stability state of a SLIP configuration. For instance, a scenario with chaotic unstable hopping can reach a high number of steps.

To study resistance to perturbation (one key feature of stability), we can use a Return Map to extract one feature and observe how it evolves. In this case, we can use the apex height i.e. the maximum height of the centre of mass during a step, and evaluate how it changes over time.

The returned map investigates how the apex height changes from one apex height (index 'i') to the next one (index 'i+1') in the following flight phase (after one contact phase) [from A.Seyfarth, Biol., 206, 2003.]. This function is obtained by numerical integration of the SLIP model equations, for a given set of parameters. It can then be said that the system is stable if, after a small perturbation, the system always converges over time to the same apex height.

Question 4 The SLIP model can provide insight into the following several aspects. First, there is **energy efficiency**: the model is good to investigate how changes in leg stiffness, leg length, and other factors affect the energy efficiency of human locomotion. Another aspect is **stability** of locomotion, the model can investigate how changes in terrain, speed, and gait pattern affect stability, for instance with pointcarré maps, or counting the number of steps in different conditions.

However, some aspects cannot be investigated using the SLIP model alone, such as:

Muscle activation patterns: The model cannot provide insights into the specific muscle forces and activations required to move. Joint mechanics: Movements of the hip, knee, and ankle joints are ignored. Therefore, it cannot provide insights into joint-specific forces or torques. Also, the SLIP model does not take advantage of the fact that we use 2 legs in human locomotion i.e. it only models the stance and propulsion phases, but not the swing phase.