Honors Project Literature Review (Update #1)
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I Overview

I plan to design and iterate upon a single-legged robotic system utilizing Marc H. Raibert's, H. Benjamn Brown Jr's, and Micheal Chepponis's work on a one-legged hopping robot at the CMU (later MIT) Leg Laboratory as a reference. Their research was conducted beginning in 1982 and was published through a series of progress reports. My proposal is to use these detailed documents, which provide schematics and instructions, to reproduce a self-stabilizing, one-legged hopping robot.

In the Leg Laboratory reports, the following topics are also covered: gait as a coupled oscillation, 3D path controls, planar bounding, quadrupeds, bipedal robots, and much more. I plan to focus on the one-legged hopping machine, creating a planarized model of the robot as an intermediate step.

In terms of a final deliverable, I plan on leaving my end goal open-ended. Given advancements in SLAM methodologies, computer vision, and semantic goal navigation since this work was originally done, there are many locomotion-based problems I could address with existing models using the one-legged hopping robot as a platform. I am particularly interested in the idea of a hopping robot that can semantically navigate a 3D environment–once I am successful in implementing a working model of the one-legged robot, I will likely pursue this as a final goal.

II Timeline

To begin, I will read through the progress reports and other related papers (listed in the reading list section) and create a list of materials needed to build the robot. Initially, I expect to only need to use ordered parts and 3D printed materials from the Bowdoin MakerSpace–therefore, I will hold off on familiarizing myself with the machine shop until I need to fabricate custom parts. I will also begin to familiarize myself with a variety of software simulation tools, such as Gazebo or Webots, to model the robot in a virtual environment. Both aforementioned simulation environment have *ROS* support, a tool for programming robotic systems, which I have prior experience with. A preliminary reading list is provided in section III below. I expect this initial phase to take until November 1st.

Following my initial research, I will develop a plan for the design for a simple model restricted to vertical hopping; this will include a finalized list of materials, a roadmap for the build, and a plan for the software development. At first I plan to use a Arduino in place of the original microcontroller, as I have experience with the Arduino platform. Eventually, past an initial prototype, I will likely switch to a custom PCB design as I move to building a planarized model, then further to a unrestricted model. During this phase, I plan to produce the following documents detailing the design of my robot:

- CAD drawing(s) of the robot
- Simulation results, including a video of the robot in action
- A material list
- Actuator list, including motors and sensors
- A software plan
- An overview of the kinematics of the robot

I expect the design phase for the simple model to take until November 8th.

Once the design phase for the simple vertical hopping model is complete, I will begin assembling the robot using the parts from my finalized materials list. The assembly process will involve a combination of ordered components and 3D-printed parts from Bowdoin's MakerSpace. During this phase, I will focus on the integration of mechanical, electrical, and software components. I anticipate potential challenges during assembly, particularly in aligning the actuators and sensors, but will address these through iterative adjustments. After assembly, I will conduct preliminary testing to verify that the robot can perform basic vertical hops, ensuring proper communication between the microcontroller (initially an Arduino) and the actuators. This phase can be further broken down into the following categories:

(1) Assembly

> **Note:-**
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> This will involve 3D printing parts, ordering parts, and assembling the robot. I expect this to take until November 22nd.

(2) Programming

> **Note:-**
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> This will involve writing code for the robot, including the control system. This will also require some preliminary testing, although for vertical Oscillation I do not expect this to be too challenging. I expect this to mostly be finished by November 15th.

(3) Testing

> **Note:-**
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> This will involve testing the robot in a controlled environment. I expect this to take *at least* until November 22nd for initial results, but likely longer.

Initial testing will focus on basic functionality—such as stability, jump height, and energy efficiency. I will use ROS for interfacing with the robot's hardware and for capturing real-time data on the robot's performance. During this stage, I plan to collect sensor data (e.g., acceleration, force) to evaluate and improve the hopping motion. Testing will include a mix of physical and simulated trials. Simulations will be used to model the robot's environment, providing a controlled context for analysis. I expect to finalize testing for the basic hopping model by November 22nd as listed above, documenting any design adjustments needed, performance evaluations, and key insights from both physical and simulated environments.

After completing the testing of the vertical hopping model, I will proceed to implement a more advanced planarized model, which will introduce an additional degree of freedom for the robot. This model will allow the robot to move not only vertically but also horizontally within a two-dimensional plane, requiring further refinement of the kinematics and control systems. During this phase, I will continue using an Arduino microcontroller, but will likely need to upgrade to a custom PCB design once moving to the untethered 3D model.

In this stage, I will extend the simulation environment to accommodate the planarized motion, incorporating lateral forces, dynamic balancing, and trajectory optimization into the software models. The robot's control system will need significant revisions, and I will implement a more sophisticated PID (proportional-integral-derivative) control system for stability. The CAD designs, actuator lists, and sensor arrays will also be updated to reflect the new functional requirements. I expect this phase to run through the first few weeks of December, at which point I will begin a similar testing cycle to ensure the robot can navigate its 2D environment effectively.

The final phase of the project will involve the development of a fully functional hopper capable of unrestricted movement in three dimensions. Building on the planarized model, I will introduce additional functionality to enable the robot to perform dynamic hopping maneuvers in a 3D environment. The robot will need kinematic modeling and trajectory planning algorithms, but not ones too dissimilar from the planarized case.

Finally, if time allows, I will extend this project into using the 3D hopping robot as a platform for semantic navigation, or a similar autonomously navigating algorithm, depending on the reliability of the robot. This will involve integrating SLAM (simultaneous localization and mapping) techniques, computer vision, and machine learning algorithms to enable the robot to navigate autonomously in a complex environment. This phase will likely extend into the spring semester if pursued.

III Reading List

1. Raibert, Marc H., et al. "Dynamically Stable Legged Locomotion", 1986. Leg Laboratory, The Robotics Institute and Department of Computer Science, Carnegie-Mellon University.

2. Rutschmann, Martin. "Control of a planar, one legged hopping robot model on rough terrain", 2012. Robotics Laboratory, University of California Santa Barbara.

3. Slotine, Jean-Jacques E., and Weiping Li. *Applied Nonlinear Control*. Prentice Hall, 1990.

4. Khatib, Oussama. "Real-time obstacle avoidance for manipulators and mobile robots." *The International Journal of Robotics Research* 5.1 (1985): 90-98. next, cite the NOMAD paper:

5. Ajay Sridhar, et al. "NoMaD: Goal Masking Diffusion Policies for Navigation and Exploration". *The International Conference on Robotics and Automation (ICRA)*, 2024.

6. Naoki Yokoyama, et al. "VLFM: Vision-Language Frontier Maps for Zero-Shot Semantic Navigation" *The International Conference on Robotics and Automation (ICRA)*, 2024.

IV Expectations

Given the complexity of the project, and my relative inexperience with robotics, I expect that the timeline may need to be adjusted as the project progresses. I will keep a log of my progress, including any setbacks or unexpected challenges, and will update my schedule accordingly. If need be, I may additionally adjust the expectations for the final deliverable.

Note:-

This proposal is a living document and will be updated as the project progresses.

Begun on October 18th, 2024. – *Last updated on October 24th, 2024.*

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