JUMPING ON GRANULAR MEDIA

FINAL PRESENTATION
12/2?/2014

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Outline

- Introduction/Background
  - Motivation
  - History
  - Objectives
- Experimental Setup
  - Parameters
  - Measurements taken
  - Test video
- Results
  - Hard ground
  - Granular media
- Conclusion

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Introduction

- Granular media, as well as the dynamics of jumping on granular media, is not well-understood.
- We will expand on current knowledge and models using jumping robots

Motivation

- By studying the mechanics of jumping on granular media, we can gain insight into the physics of the media itself (media dispersion, packing, and more)

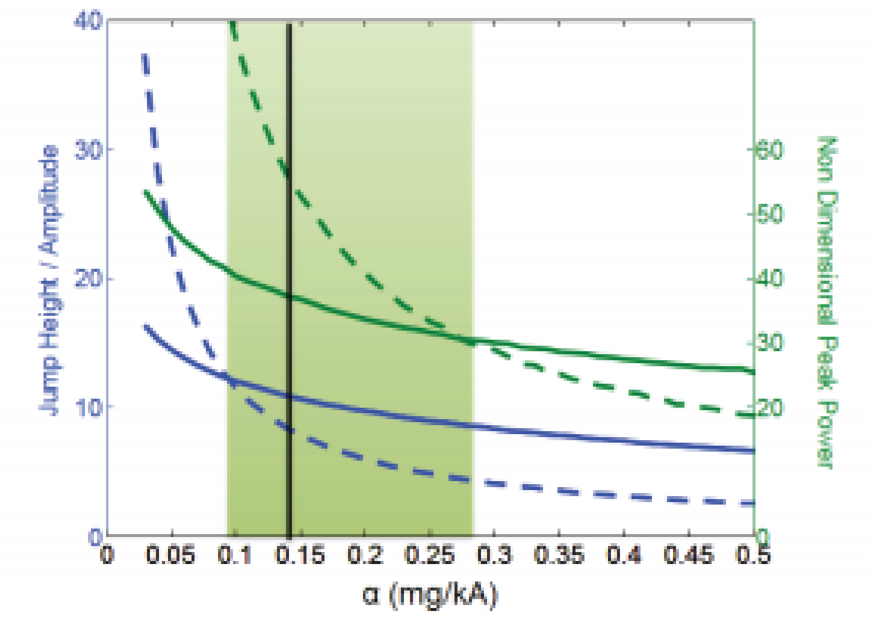
- From the research that has been done, we know of two modes of jumping
  - Single jump
  - Stutter jump

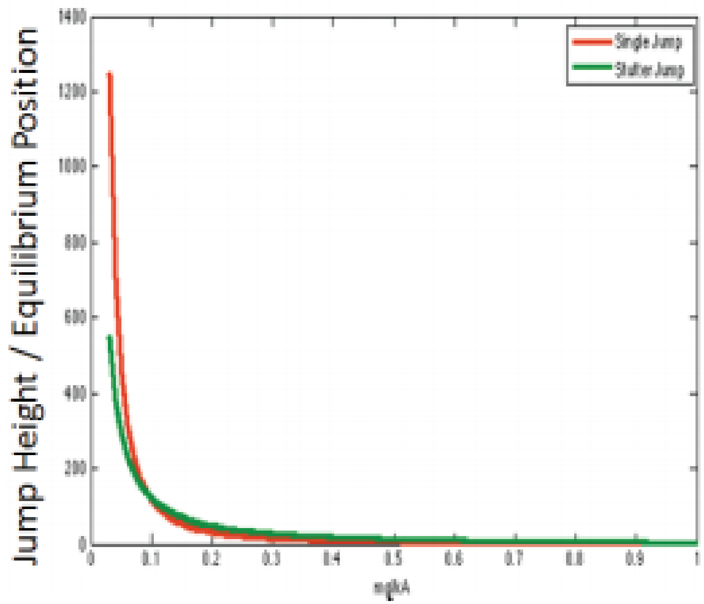
What Has Been Done?

- Georgia Tech’s CRAB Lab has taken experimental data about lift-off dynamics for a jumping robot
- Results showed stutter jump requires less energy to achieve comparable height on solid ground but performed worse in granular media
- Little to no literature on jumping in fluidized granular media

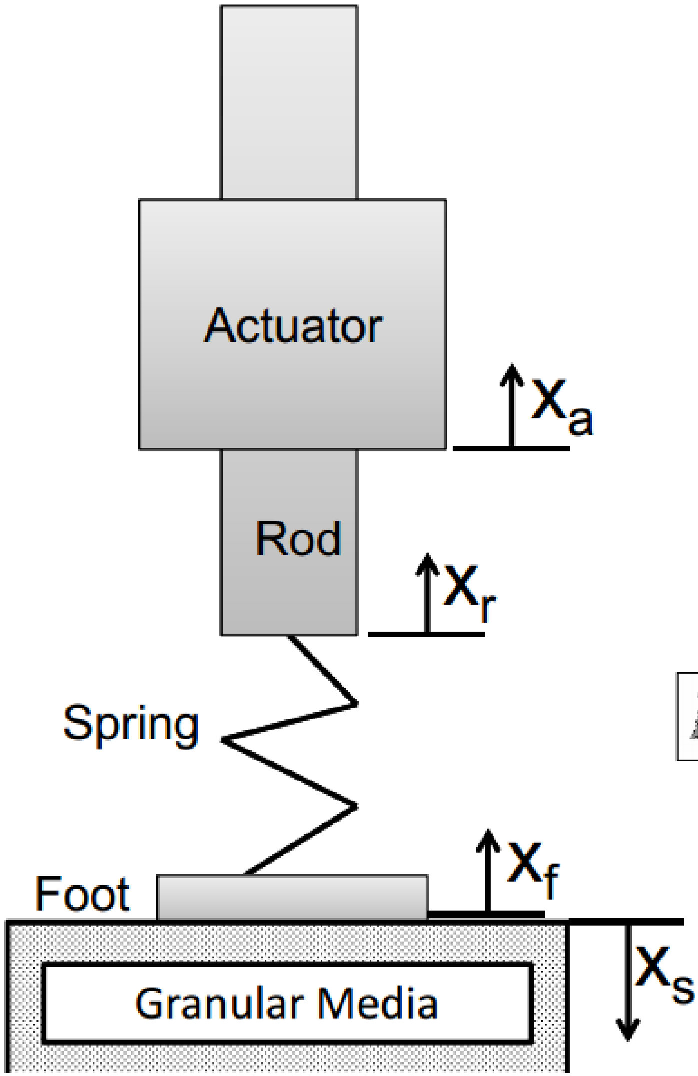
Hard Ground Theory

- Simulations show exponential relationship between nondimensionalized jump height and nondimensional parameter mg/kA for hard ground tests

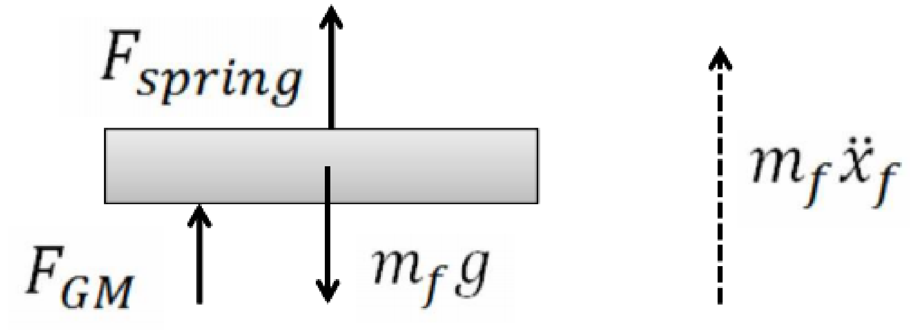




GM Equation of Motion



Free Body Diagram



Force Balance

$$m_f \ddot{x}_f = F_{spring} + F_{GM} - m_f g$$

$$F_{GM} = \mathrm{k}(foot\ depth) + \propto (foot\ speed)^2$$

Katsuragi, H., & Durian, D. J. (2007). Unified force law for granular impact cratering. Nature Physics, 3(6), 420–423.
Umbanhowar, P., & Goldman, D. (2010). Granular impact and the critical packing state. Physical Review E, 82(1), 1–4.
Li, C., Zhang, T., & Goldman, D. (2012), A resistive force model for legged locomotion on granular media, CLAWAR

Objectives

- Experimentally verify hard ground theory (exponential relationship)
- Observe effects of jumper stiffness on jumping on granular media
- Collect experimental data of jumping on fluidized granular media

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Experiment Architecture

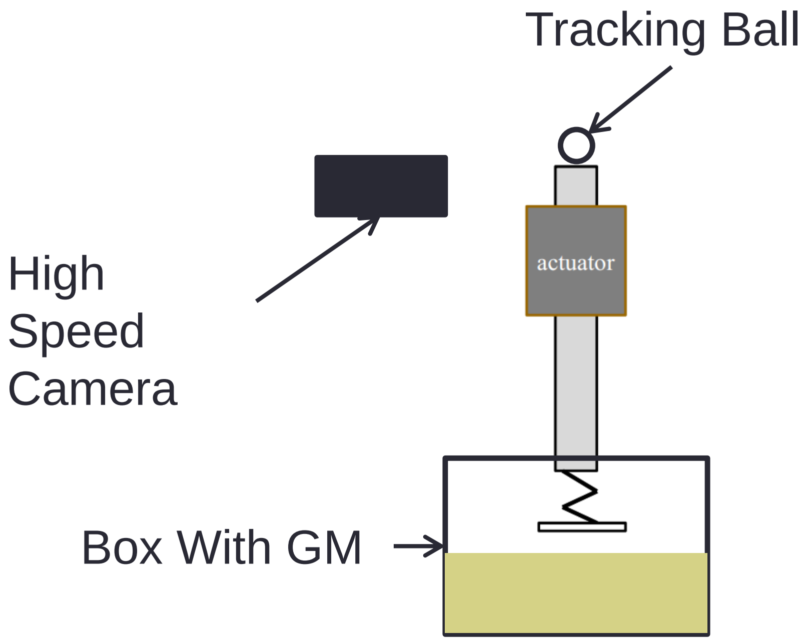
- Hard ground parameter sweep
  - Spring stiffness
  - Forcing frequency
  - Forcing amplitude
  - Jump type

- Granular media parameter sweep
  - Spring stiffness
  - Forcing frequency
  - Fluidization
  - Jump type

Experimental Setup

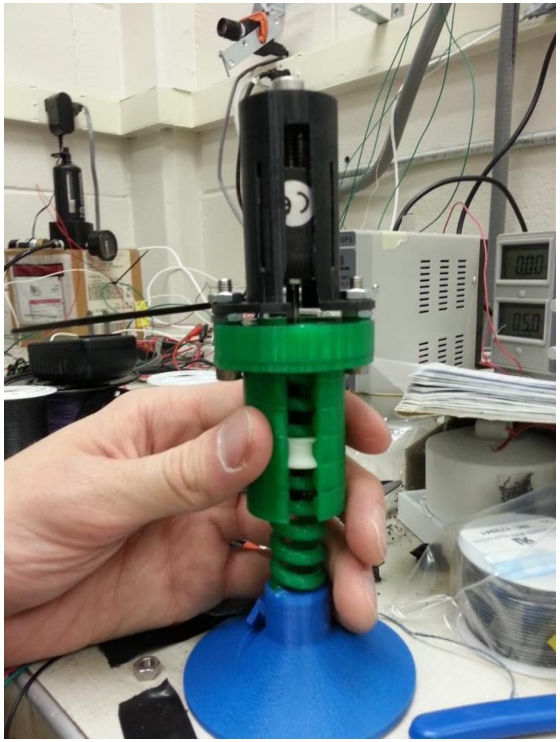
- Vary forcing frequency and amplitude, stiffness, airflow through GM

- Measurements:
  - Force imparted by the actuator
  - High speed camera tracking motion of robot



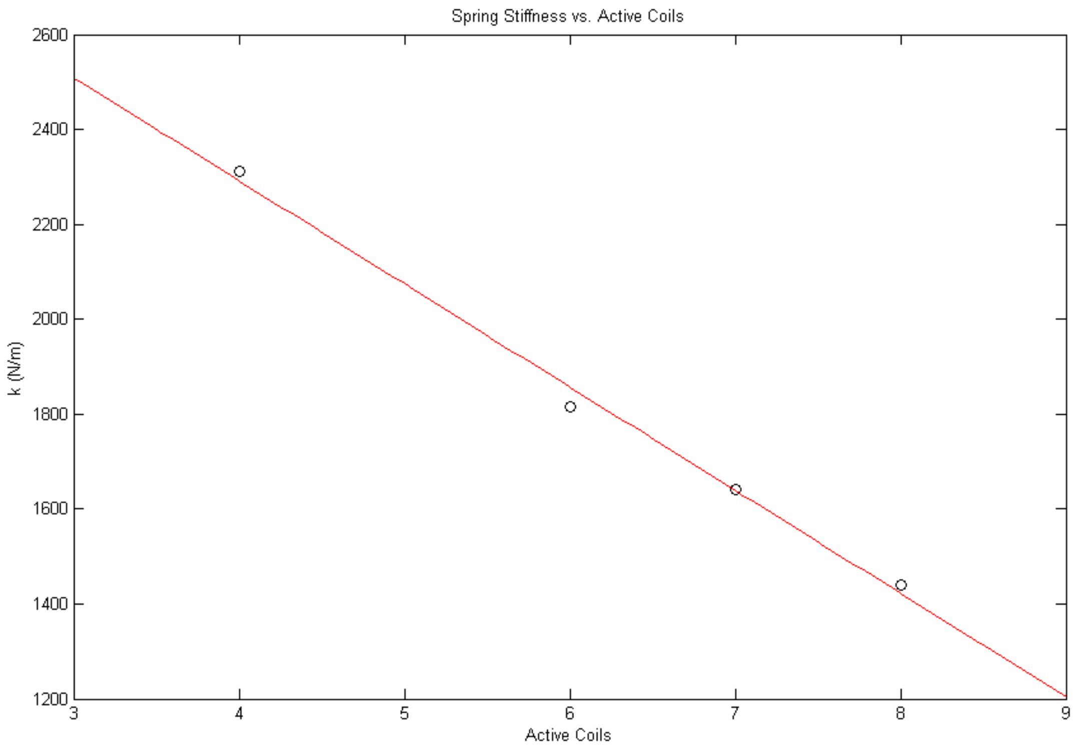
Changing the Spring Stiffness

- 3-D printed variable stiffness spring
- Stepper motor mounted to automate stiffness change and track position

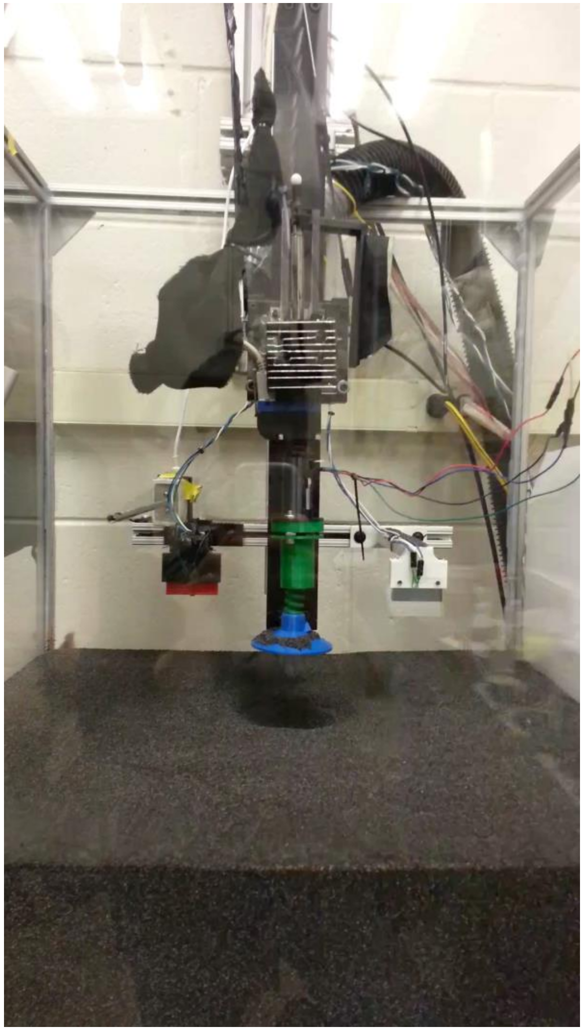


Determining Stiffness

- Number of active coils determines stiffness
- Force/compression for various active coil amounts measured using experimental apparatus



Test Videos



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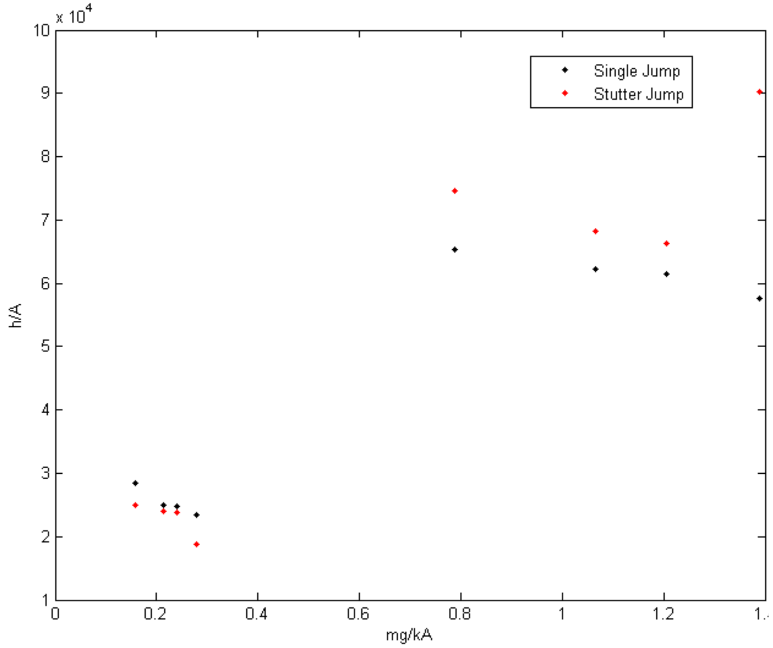
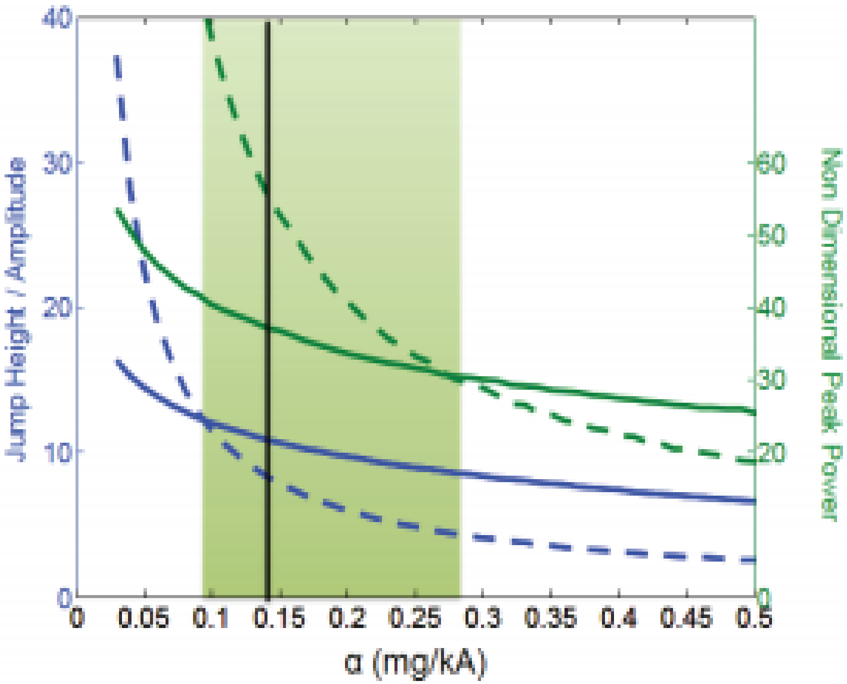
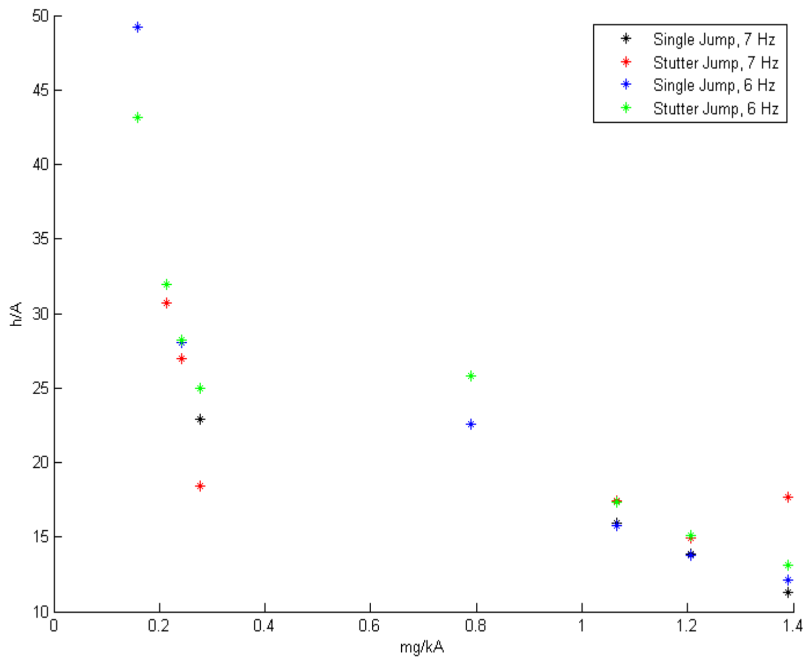
Hard Ground Results

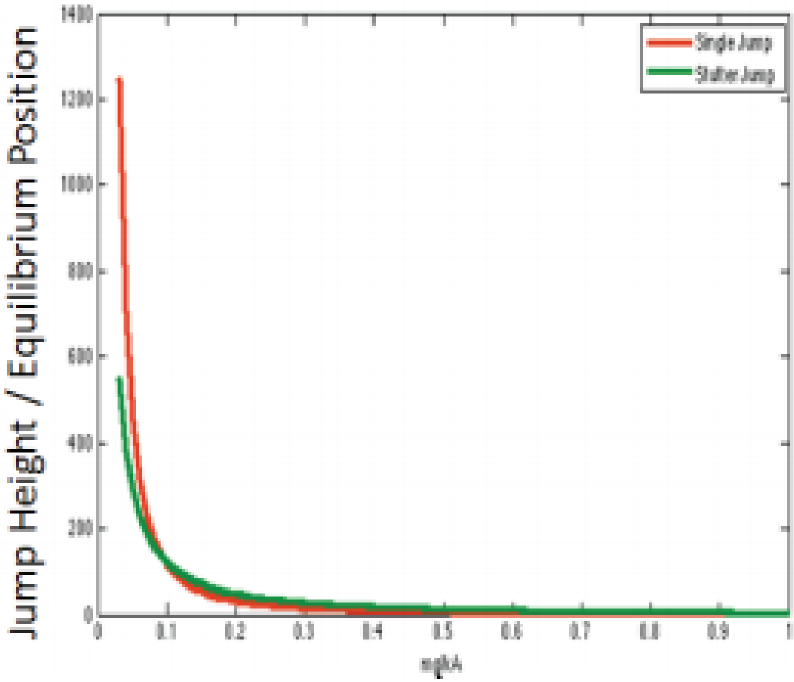
- *Extrapolation



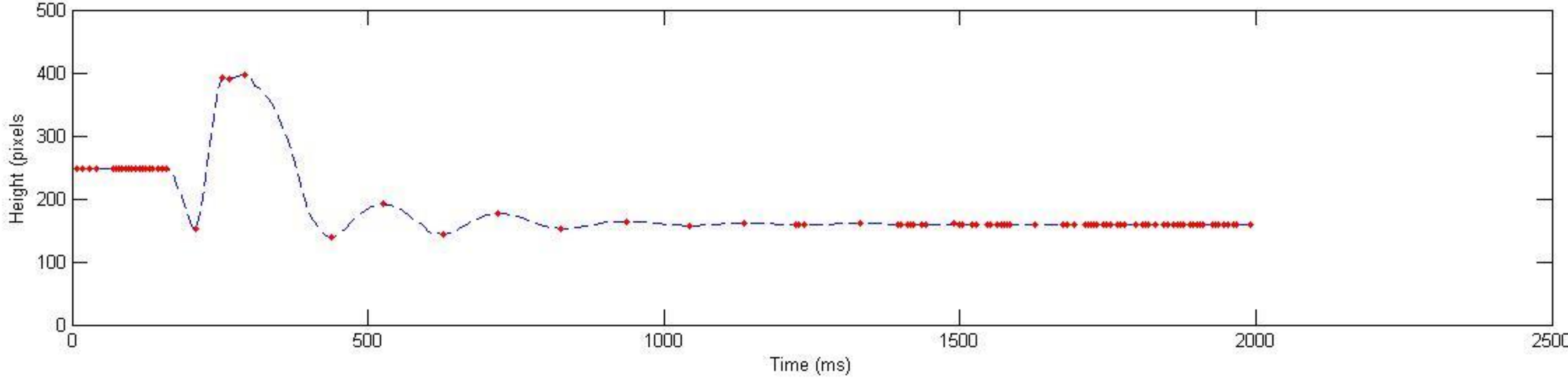


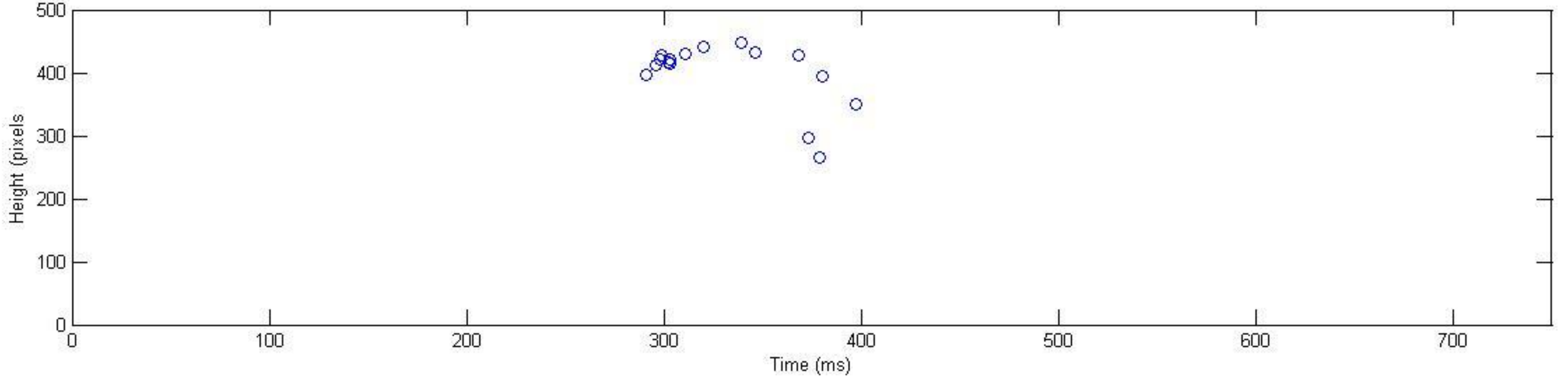
Hard Ground Results



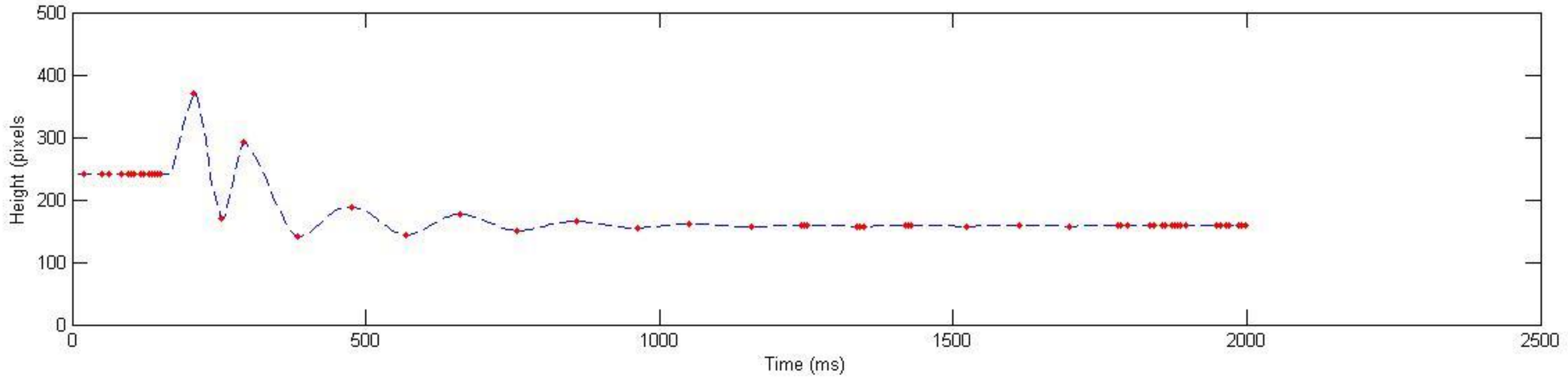


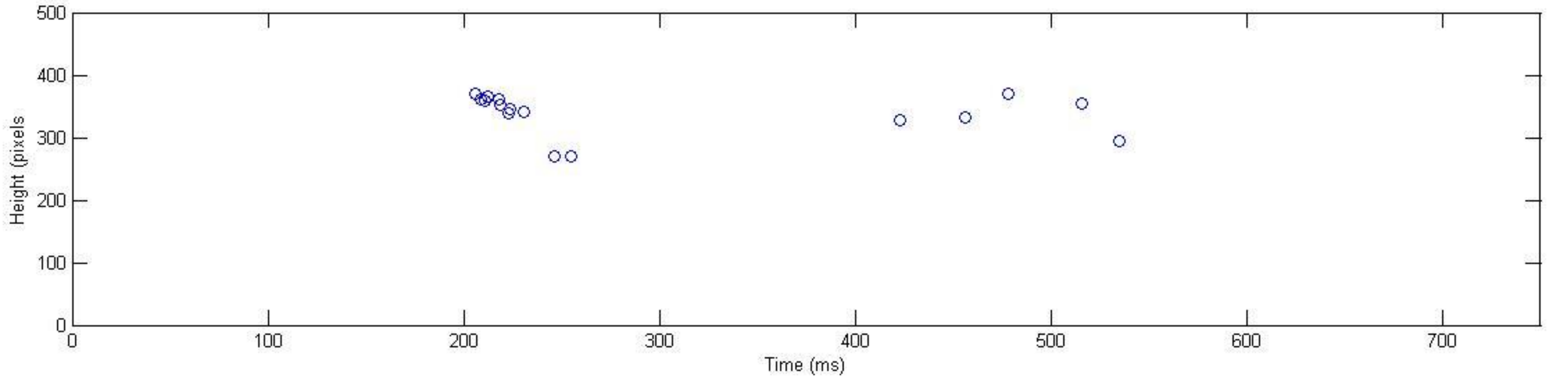
GM Results: Single Jump



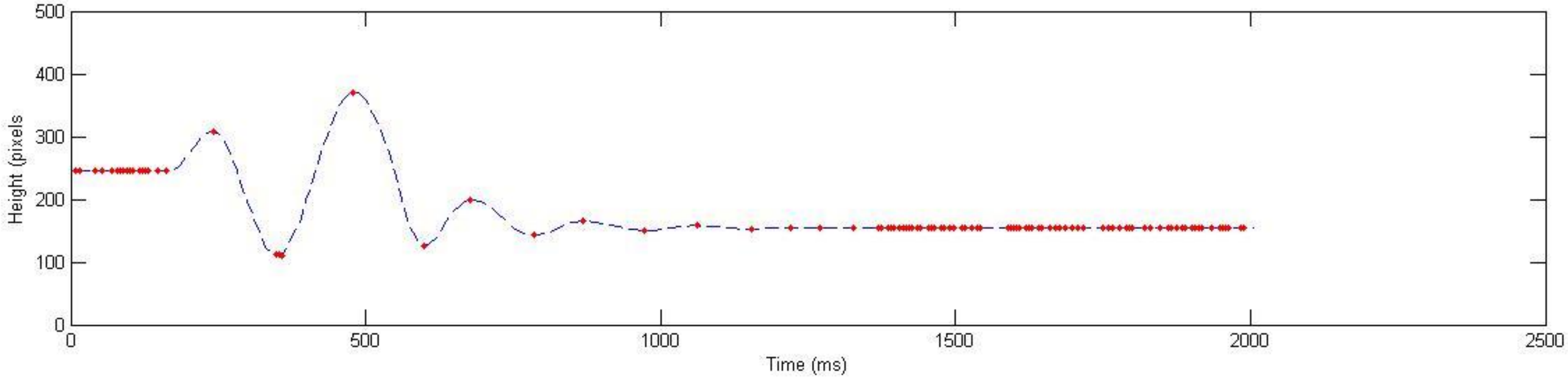


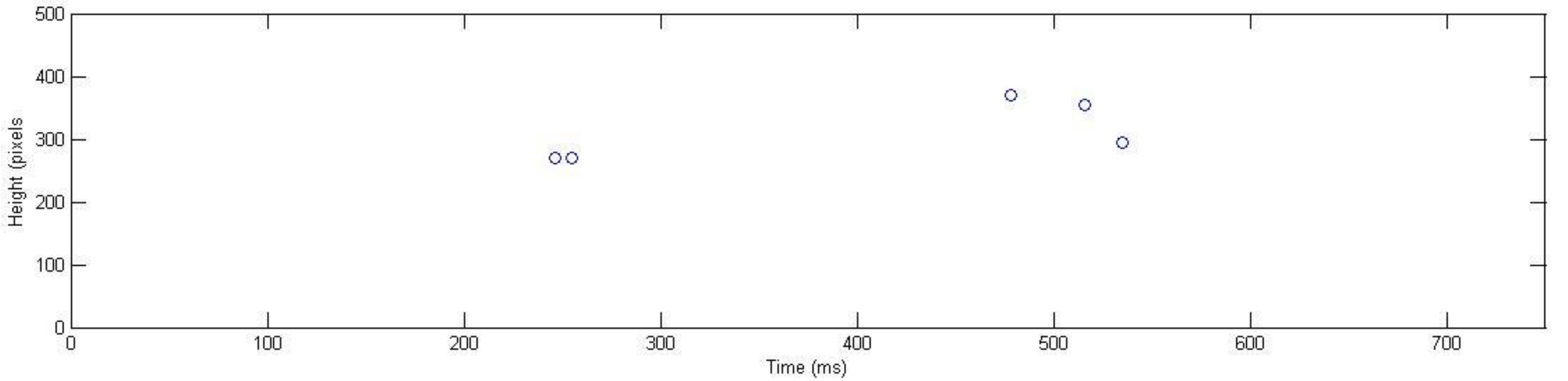
GM Results: Stutter Jump





GM Results: Second Peak





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Conclusions

- Summary of goals
  - Effect of spring stiffness on hard ground and GM
  - Effect of fluidizing GM
- Summary of results
  - Hard ground tests do not show exponential behavior when nondimensionalized with respect to amplitude
  - Did see exponential behavior when normalized with respect to equilibrium position
  - Interesting stutter jump dynamics in fluidized GM
- Future work
  - Determine discrepancy between hard ground simulation and experimental results
  - Finer parameter sweep

Acknowledgements

- Jeff “The Man” Aguilar
- Prof. Goldman
- Will Savoie

Questions