# Mini Cheetah Sensor Suite for Visual Perception

by

Lillian C. Papalia

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Author . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
Department of Mechanical Engineering
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Certified by . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
John J. Leonard
Professor
Thesis Supervisor

Accepted by . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
Kenneth Kamrin
Associate Professor of Mechanical Engineering
Undergraduate Officer

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## Abstract

The mini cheetah robot is a small lightweight quadruped capable of dynamic movements. Currently, the mini cheetah does not have a method of collecting stabilized perception data. Research has been conducted at the University of Michigan, where a sensor suite for collecting perception data has been created. While the sensor suite is able to collect perception data, it is heavy and affects the agility of the mini cheetah robot and does not incorporate any active stabilization into the design. A lightweight sensor suite was designed and manufactured incorporating a commercial gimbal. Three tests were conducted on a rigid mounted camera and a gimbal stabilized camera. AprilTag detection as well as visual qualitative analysis determined the rigid mounted camera performed better than the current gimbal configuration. Further work involving active stabilization will be needed to determine a satisfactory solution, particularly when the mini cheetah is pronking.

Thesis Supervisor: John J. Leonard
Title: Professor

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# Contents

# Chapter 1

# Introduction

The mini cheetah robot is a small lightweight quadruped capable of dynamic movements built in the lab of Professor Sangbae Kim at MIT. Currently there is not a method of collecting stabilized perception data from the mini cheetah robot. In previous research from Professor Pulkit Agrawal's lab at MIT, a camera was mounted to the front of the mini cheetah to allow for real time decision making while navigating uneven terrain. This allows the mini cheetah robot to utilize the processed perception data to move about any terrain autonomously[1]. While the stationary mounted camera works for this application, the resulting video data is unstable. This project had two goals: (1) create a compact sensor suite for robot perception that can be attached to the mini cheetah robot, and (2) stabilize the image during locomotion, particularly for visual navigation tasks. To accomplish these goals, an attachment was manufactured to attach to the back of the mini cheetah holding a battery, intel nuc, and camera.

First, a sensor suite with a rigidly mounted camera was constructed, and later modifications were made to attach a commercial gimbal system. The rigid and gimbal sensor suites were tested in three situations: stationary trotting, stationary pronking, and trotting movement. To determine the success of perception data, AprilTag detection was run on the video data and the number of tags detected were counted. Along with the quantitative data from the AprilTag detection, the video data was also qualitatively analyzed by observing the resulting perception data.

# Chapter 2

# Background

## 2.1 Previous Research

Similar research has been conducted at the University of Michigan with CURLY's Minicheetah Sensor Suite v2.0. The sensor suite consists of a Krisdonia portable battery, Intel RealSense D435 depth camera, and Nvidia AGX Jetson Xavier, as shown in Figure 2-1. An enclosure was 3D printed to attach the sensor suite to the mini cheetah.

University of Michigan's sensor suite is able to collect perception data, but the attachment is heavy, affecting the agility and stability of the mini cheetah. The goal for this project was to create a lightweight sensor suite for the mini cheetah with little impact on the movements of the robot.

## 2.2 Mini Cheetah Gaits

The mini cheetah is capable of both trotting and pronking gaits. Trotting is when diagonal pairs of legs move at the same time. During pronking the front and back pairs of legs move together, resulting in a more aggressive movement than trotting. This makes it more difficult to stabilize. Both gaits were analyzed in the study.

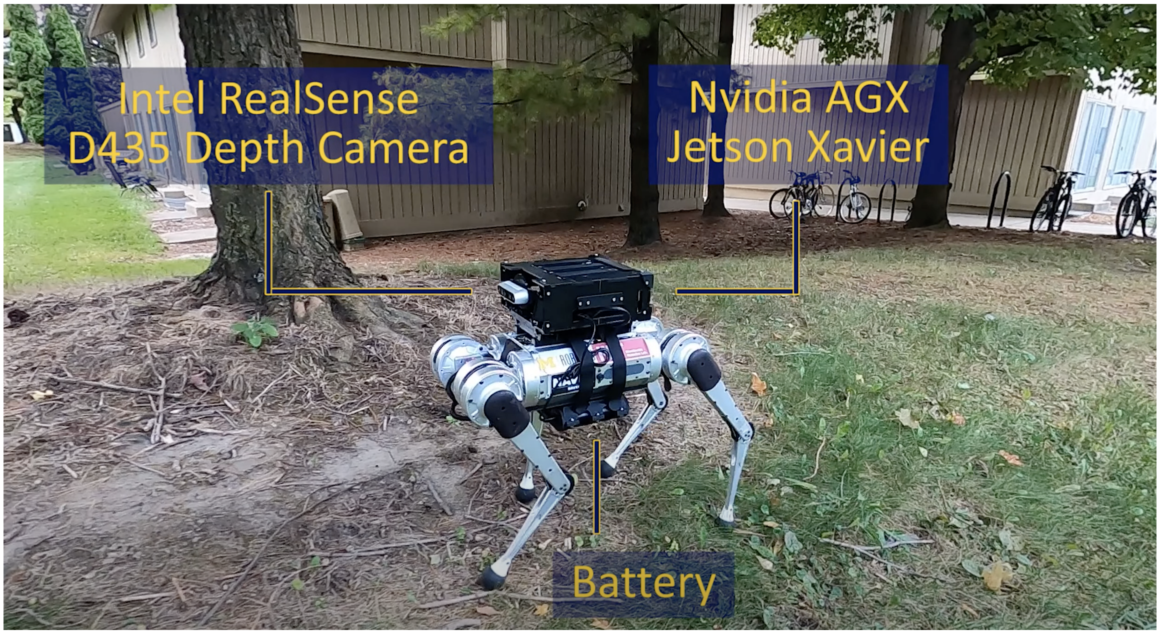


Figure 2-1: University of Michigan with CURLY's Minicheetah Sensor Suite v2.0 [2]

## 2.3 AprilTags

AprilTags were used to quantify the stability of the collected video data. AprilTags originated at University of Michigan and are a visual fiducial system commonly used in robotics applications. The tags can provide 3D positioning, orientation, and identity of the tags relative to the camera [3]. As displayed in Figure 2-2, AprilTags consist of black and white squares, which make them easy to detect, even in low light areas.

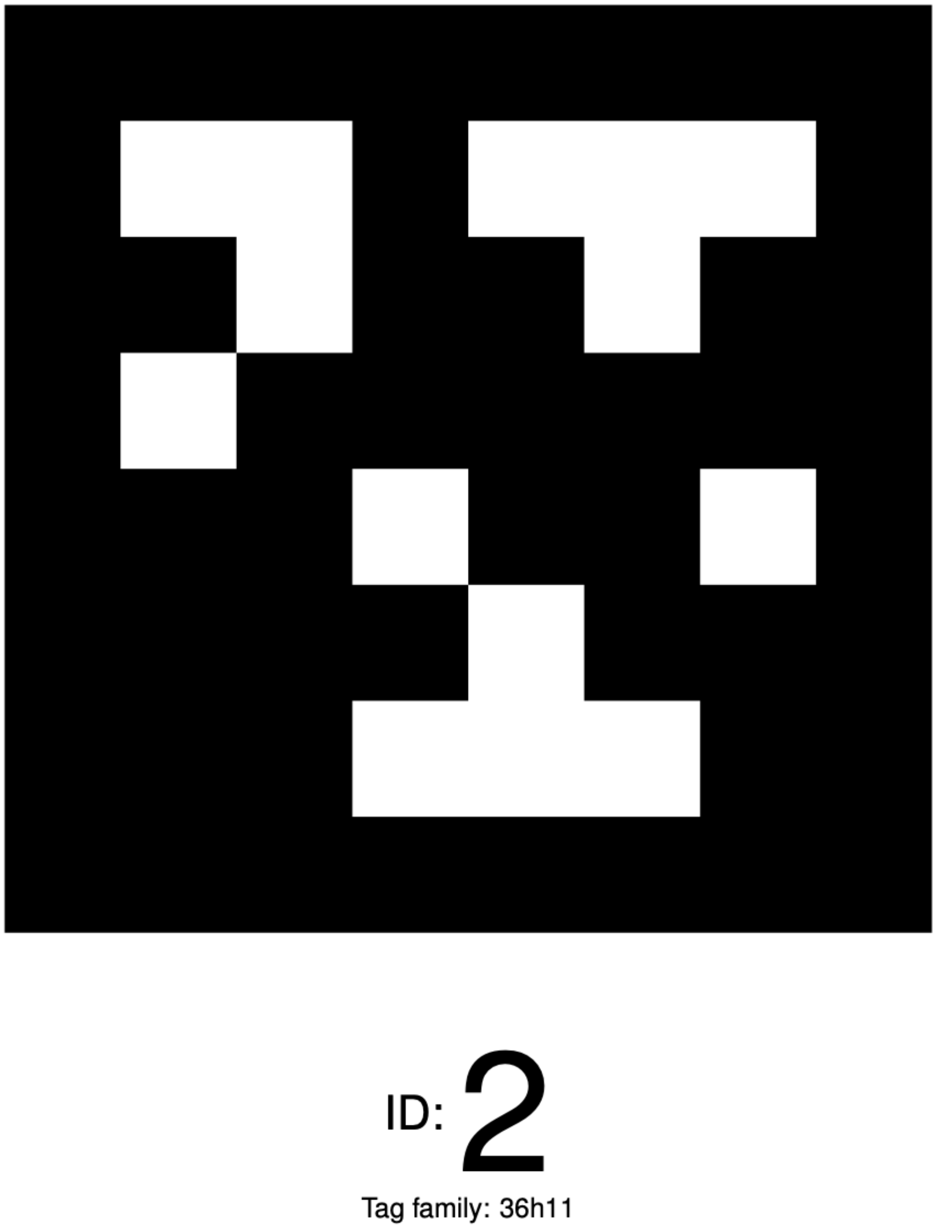


Figure 2-2: An example of AprilTag used in this experiment. AprilTags are commonly used in robotic applications because of simplicity and the ability to provide 3D positioning, orientation, and identity of tags.

# Chapter 3

# Design

The initial mini cheetah sensor suite consists of four main components: Intel Nuc, Krisdonia battery, ZED stereo camera, and a custom acrylic plate for attaching the hardware to the cheetah. For the first iteration of the sensor suite, the ZED camera was rigidly mounted to the acrylic plate, as shown in Figure 3-1. With the rigidly mounted camera, there was no active image stabilization integrated into the design.

For the second iteration of the sensor suite, a Zhiyun-Tech Smooth-Q3 Smartphone Gimbal Stabilizer was attached to the acrylic plate as shown in Figure 3-2. The gimbal system allowed for active stabilization during locomotion, theoretically improving the video quality. The smartphone stabilizer was selected because of the similar shape to the ZED stereo camera, and therefore the best option from commercial stabilizers. The gimbal adds height to the camera placement relative to the mini cheetah, changing the angle of the camera relative to the ground.

The ZED camera has a smaller width than a smartphone. Because of this, to attach the camera to the gimbal, a custom 3D printed part was designed. The attachment is shown in Figure 3-3.

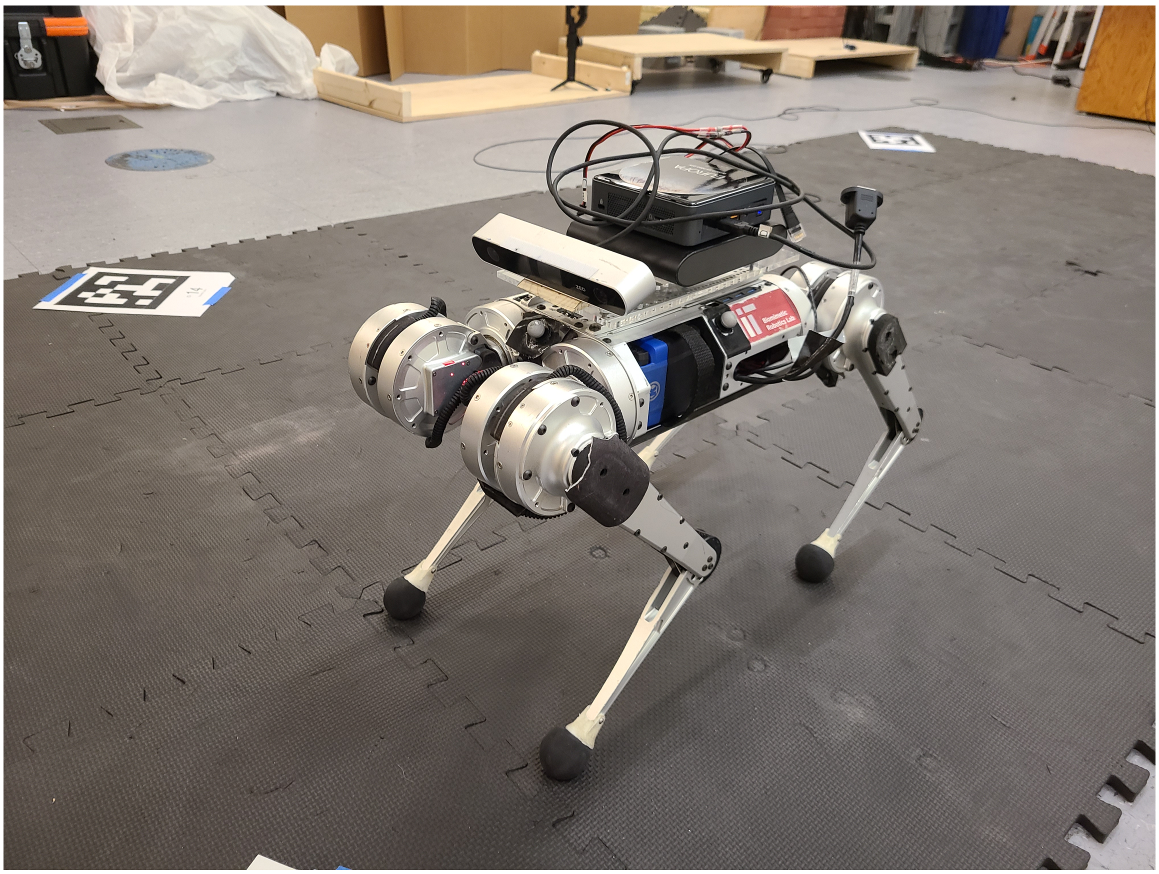

Figure 3-1: Image showing rigidly mounted ZED Stereo Camera. With this version of the sensor suite, there is no active image stabilization while the cheetah is in motion.

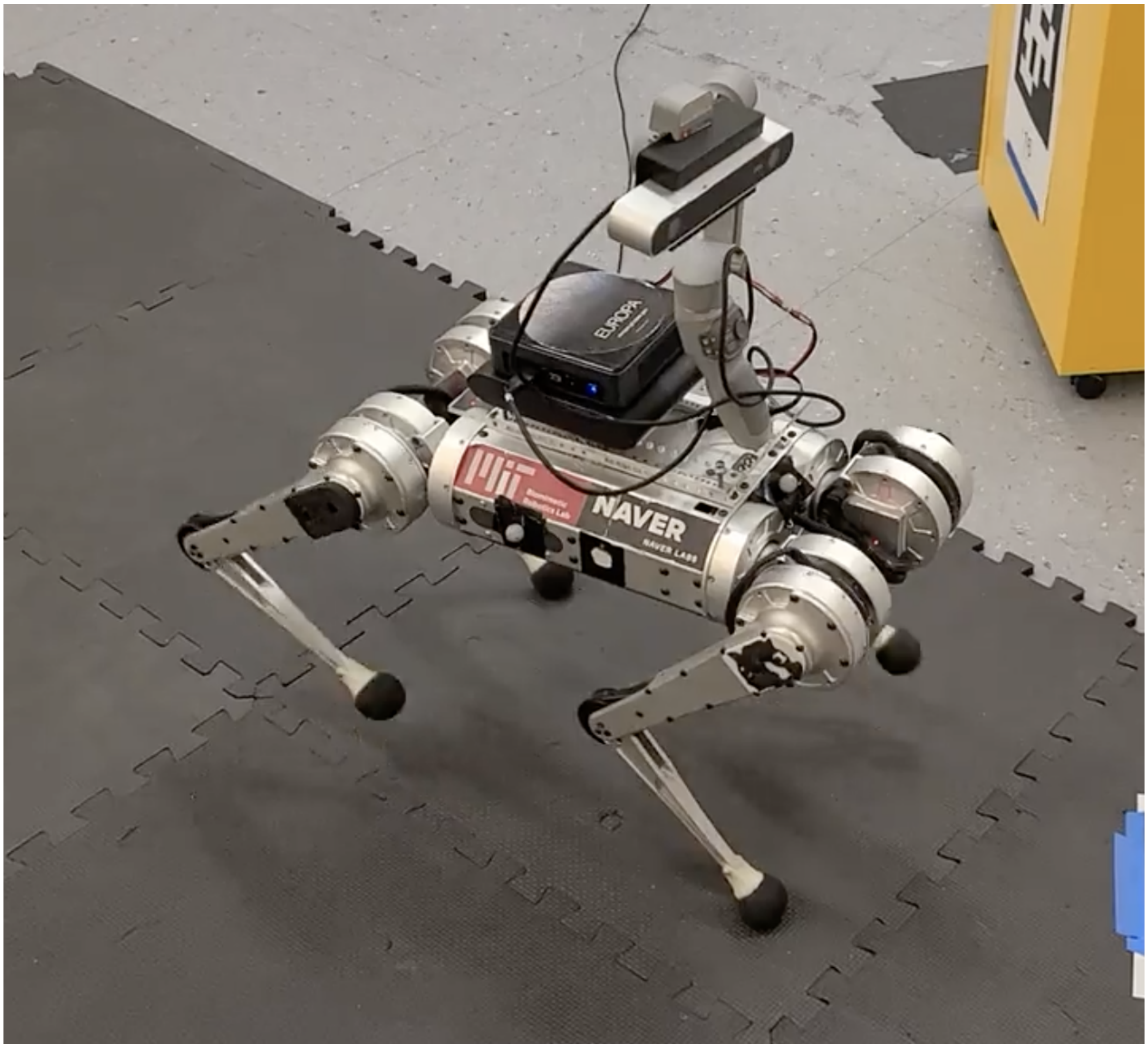


Figure 3-2: Image showing the sensor suite with the gimbal system attached. The gimbal system provides active stabilization while the mini cheetah is moving. The gimbal places the camera at a higher point relative to the robot, changing the camera angle.

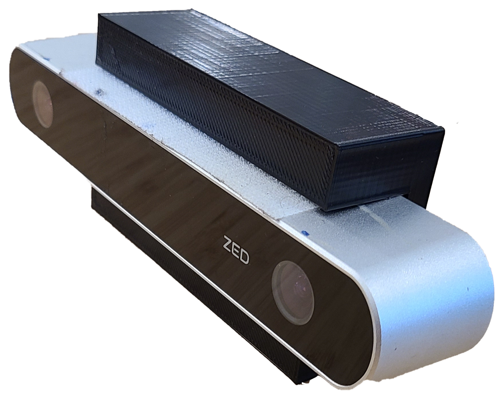


Figure 3-3: Custom 3D printed part for attaching the ZED stereo camera to smartphone gimbal system.

# Chapter 4

# Experimental Design

There were three different experimental tests conducted with the two versions of the sensor suite. In the first test, the mini cheetah was placed in front of an AprilTag and trotted in place. In the second test, the mini cheetah switched gaits and pronked in place. The final test consisted of seven AprilTags, four on the ground, and three mounted on rolling drawers to more directly face the camera. An image of the experimental set up is shown in Figure 4-1. The mini cheetah was moved using the controller in a similar pattern for the two different camera mountings. AprilTag detection, as well as qualitative visual analysis, was used to determine the stability of the various configurations.


Figure 4-1: Experimental set up for final test, moving trot. There were three April-Tags on rolling drawers, and four on the ground. The cheetah did two laps of the course for the test.

# Chapter 5

# Evaluation

## 5.1 Stationary Trotting

Comparing the visual data from the rigidly mounted camera (Figure 5-1) to the gimbal system (Figure 5-2) shows the rigid mounting is more stable for stationary trotting. The quick impulses from the mini cheetah movements make it difficult for the gimbal to react quickly enough to provide a stabilizing effect. Instead, the gimbal added more degrees of freedom to the camera, instead of stabilizing the image.

AprilTag detection on both videos shows the initial conclusion from the visual interpretation was correct. While both the rigid camera and gimbal system were able to detect the AprilTag, the rigid mounting is more consistent. As shown in Figure 5-1, with the rigid mounting the AprilTag is always detected. With the gimbal system, the AprilTag detection is occasionally lost, as displayed in Figure 5-2.

## 5.2 Stationary Pronking

Comparing the visual data from the rigidly mounted camera (Figure 5-3) to the gimbal system (Figure 5-4) shows the rigid mounting is more stable for stationary pronking. Pronking is a more aggressive moment than trotting, which is evident from the video data. Since it is a more aggressive movement, both the rigid and gimbal data are more unstable than the trotting counterpart. The gimbal was very unstable

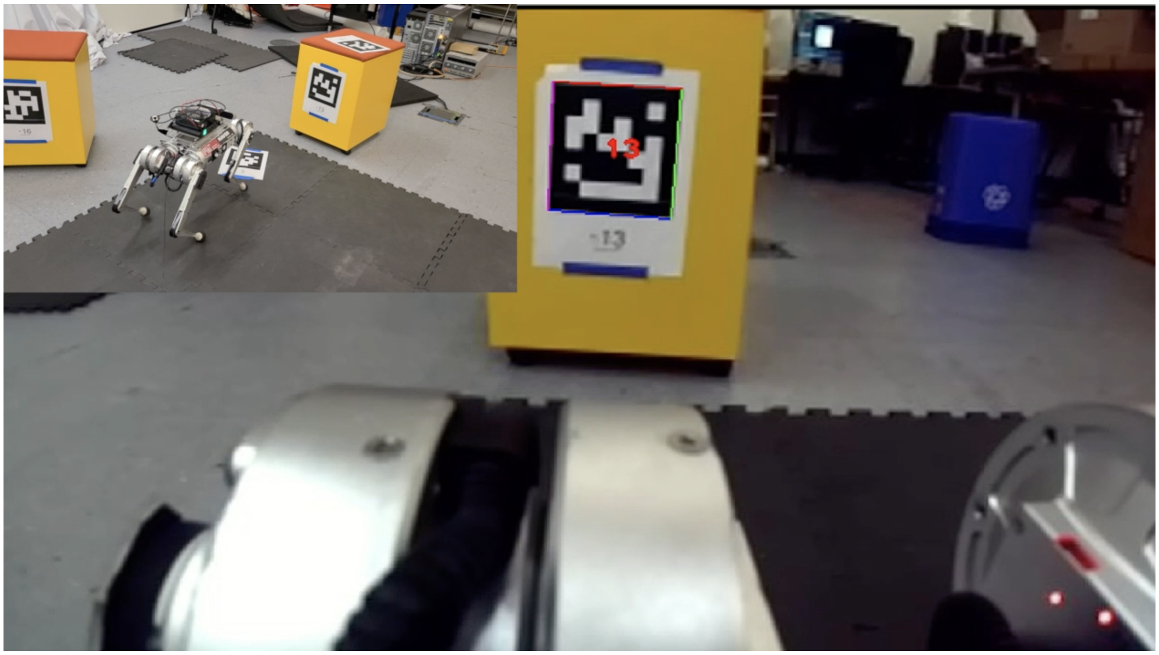

Figure 5-1: Visual data including AprilTag detection of rigidly mounted camera with stationary trotting. The video shows the view from the ZED camera, with the view of the whole cheetah in the left corner. The AprilTag was consistently detected throughout the test. The video can also be accessed here.

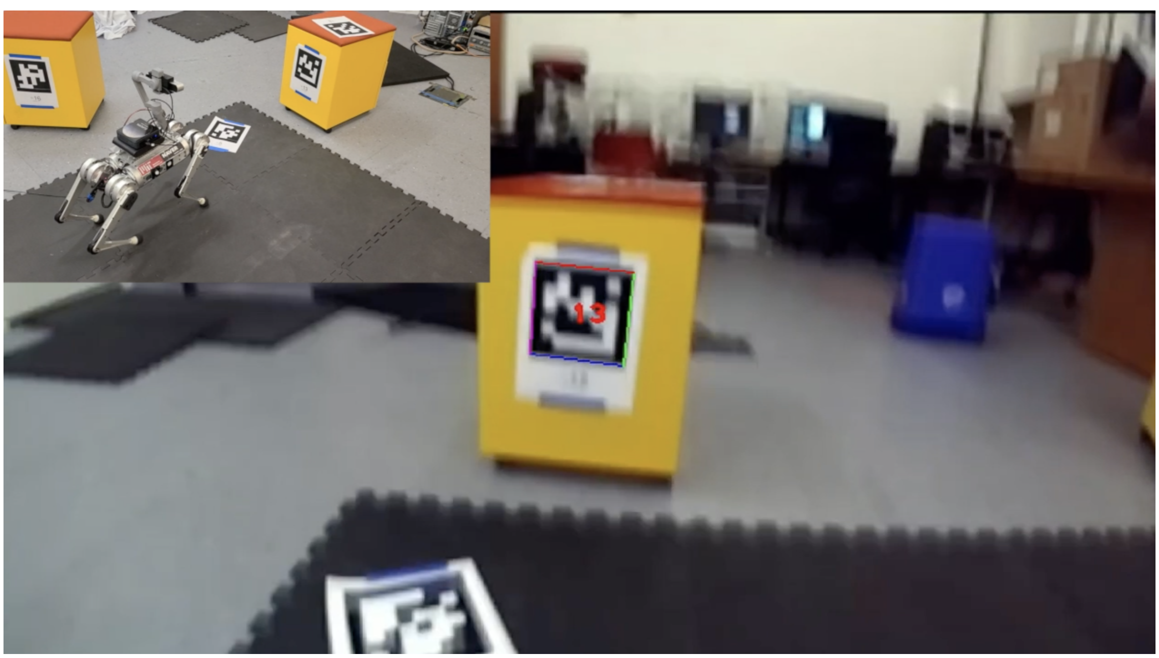

Figure 5-2: Visual data including AprilTag detection of gimbal stabilized camera with stationary trotting. The AprilTag detection was less consistent than the rigid mounted camera throughout the test. The video can also be accessed here.


Figure 5-3: Visual data of rigidly mounted camera with stationary pronking. The AprilTag was detected throughout most of the test, even with the pronking gait. The video can be accessed here.

with pronking, and significantly decreased the clarity of the resulting video.

AprilTag detection again agrees with the initial conclusion from the visual interpretation. While both the rigid camera and gimbal system were able to detect the AprilTag, the rigid mounting is more significantly more consistent. As shown in Figure 5-3, with the rigid mounting the AprilTag is consistently detected throughout the test. The tag detection is not as consistent as trotting because of the more aggressive gait. With the gimbal system, the AprilTag is detected for a fraction of a second at a time as shown in Figure 5-4. While the rigid mounting is significantly better than the gimbal, neither set up is consistent for pronking. Further research and design iterations will need to be conducted to find a solution suitable for the rapid impulses occurring during pronking.

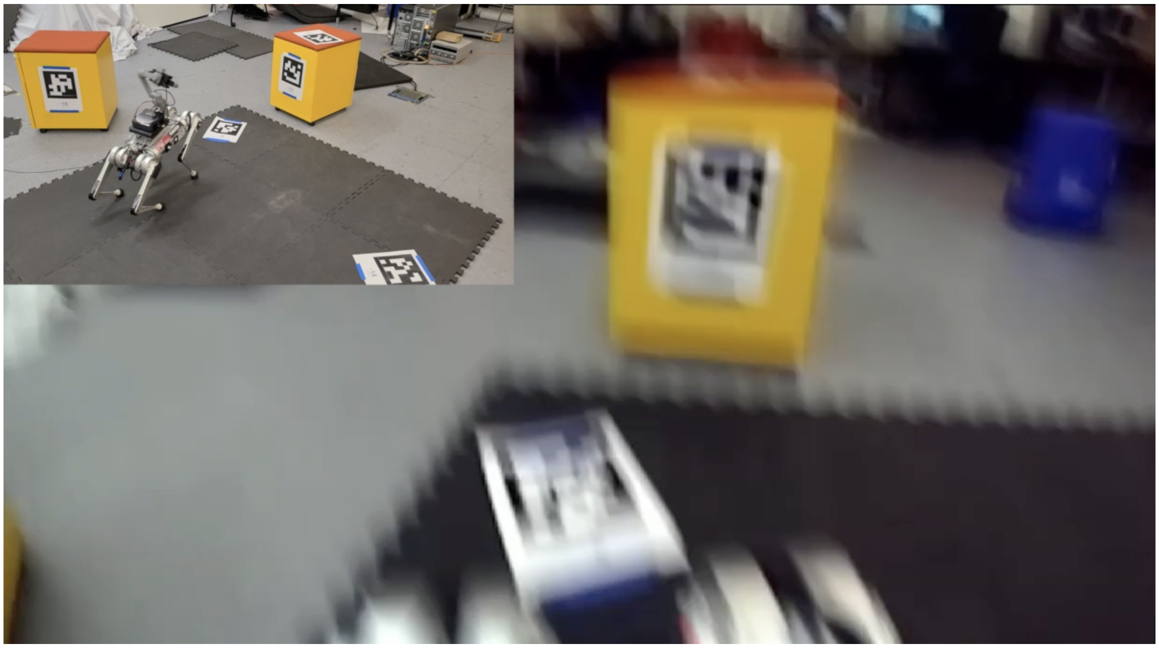

Figure 5-4: Visual data of gimbal stabilized camera with stationary pronking. The resulting video data was unstable, and the AprilTag was only detected sporadically. The video can be accessed here.

## 5.3 Trotting Movement

From an initial visual analysis of the data, the rigid mount again appears to be much more stable than the gimbal system. The rigid mount detected four of the seven AprilTags. As shown in Figure 5-5, the tags on the ground were a challenge for the rigid mounted camera to detect. Only one of the four AprilTags on the ground were detected, but the tags that were mounted to the rolling drawers were consistently detected while in frame.

On the other hand, as shown in Figure 5-6 the gimbal mount detected six of the seven AprilTags while following a similar movement pattern. The tags on the rolling cabinets were not detected as consistently as the rigid mounted camera with a similar movement pattern. While visually the data is less stable, the gimbal system was able to briefly detect two more AprilTags than the rigid mounted camera. With the gimbal, the camera is mounted much higher off the ground, allowing for the camera to see the AprilTags on the ground from above versus from the side.

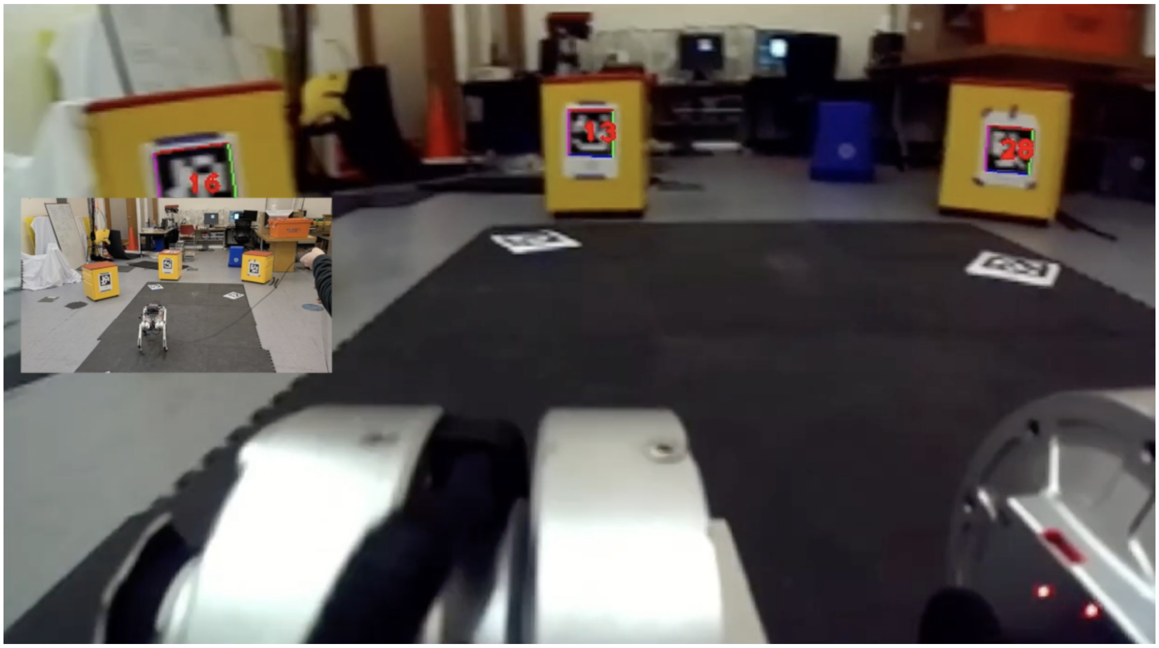


Figure 5-5: Visual data of rigidly mounted camera with trotting movement. Four of the seven AprilTags visible to the camera were detected with the rigid mounting. The video can be accessed here.


Figure 5-6: Visual data of the gimbal system with trotting movement. Six of the seven AprilTags visible to the camera were detected with the gimbal mounting. The video can be accessed here.

# Chapter 6

# Conclusion

Collecting stabilized video data from the mini cheetah robot is a difficult task. Rigidly mounting the camera on top of the cheetah works consistently for stationary trotting, and detecting AprilTags attached to the rolling drawer during the trotting moving test. The gimbal system was able to detect AprilTags on the ground that the rigidly mounted camera was not able to detect. The gimbal places the camera much higher off the ground than the rigid mount. This puts the camera at a different angle with respect to the AprilTags on the ground. Watching the data from the rigid and gimbal system shows that the rigid video appears more stable, but the gimbal system was able to detect more tags. In future research, the camera should be rigidly mounted higher off the ground to test if the AprilTags on the ground can therefore be detected.

A custom gimbal will likely be needed to successfully react to the mini cheetah's impulse movements, particularly in regards to pronking. Many commercial gimbals are not meant for such rapid impulses, and can not respond quickly enough to benefit the video data. Another design choice to consider is a gimbal with less height. The extra height from the gimbal amplifies the impulse movements of the robot, resulting in a shakier video. In conclusion, more research will need to go into this problem to reach a consistent solution for each gait of the mini cheetah.

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