Analyzing tail-based maneuverability on mobile robots

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Introduction

Goal

This project aims to analyze the impact of an aerodynamic tail on the maneuverability of a mobile robot

Motivation

- Cheetahs rapidly reorient their tails when changing direction at high speeds
- Current literature [1] shows that the use of an inertial tail can increase the maneuverability of a mobile robot
- Tails have been used in other literature [2] to induce aerodynamic drag in a manner to allow for dynamic stabilization of a mobile robot

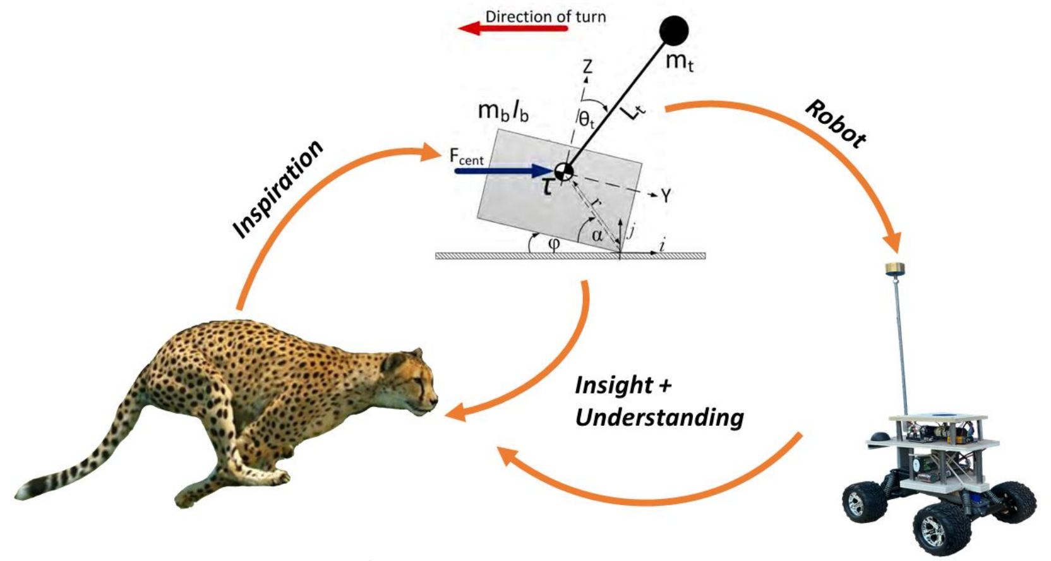

Figure 1: Project Motivation

Hypothesis

"We hypothesize that a lightweight aerodynamic tail can be utilized to increase the maneuverability of a wheeled mobile vehicle."

Methodology

Design

- The vehicle platform and inertial tail were designed with inspiration from the Dima robot [1]
- The aerodynamic tail was designed to maximize the drag coefficient
- Utilized an IMU to establish a roll angle threshold at which the tail would actuate

Figure 2: Inertial Tail

Figure 3: Aerodynamic Tail

Analysis

- Simulations and hand calculations were performed to determine the motor torque required to move the inertial tail
- The variation of Drag coefficient against tail velocity was simulated in ANSYS for varying sail angles
- Finite Element Analysis was performed to ensure components met the required standards

Torque Required:

Assumptions:

- No friction
- Constant accleration
- Point mass

System Parameters:

$m_{\text{rod}} = 0.1\,\text{kg} \quad m_w = 0.4\,\text{kg}$

$\ell_r = 0.5\,\text{m} \quad \ell_m = 0.1\,\text{m}$

$\theta_i = 0\,\text{rad} \quad \theta_f = \pi\,\text{rad}$

$t_f = 1\,\text{sec}$

Procedure:

$$\omega = \frac{\Delta\theta}{\Delta t} = \pi\ \frac{\text{rad}}{s}$$

$$\alpha = \frac{\Delta\omega}{\Delta t} = \pi\ \frac{\text{rad}}{s^2}$$

$$a = r\alpha = 0.55(\pi) = 1.728\ \frac{m}{s^2}$$

$$F = (m_r + m_w)a + (m_r + m_w)g = 5.769\,\text{N}$$

$$T = F\left(\ell_r + \frac{\ell_m}{2}\right) = 3.17\,\text{Nm}$$

Figure 4: Motor Torque analysis

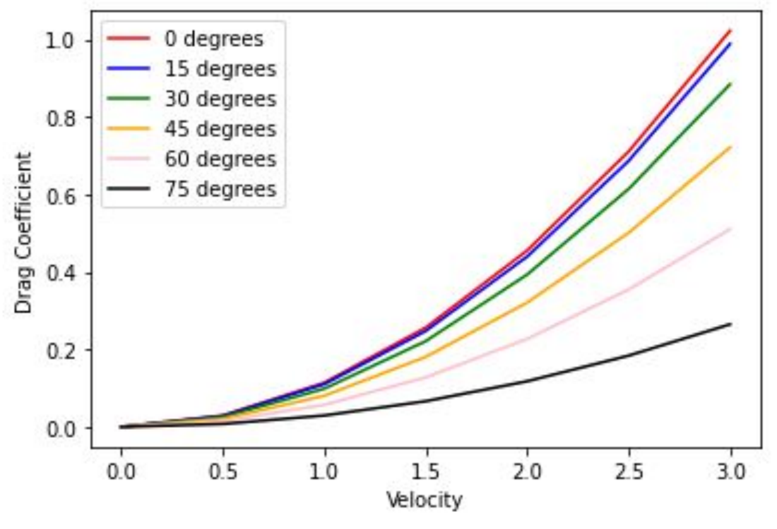

Figure 5: Drag coefficient Variation with tail velocity (m/s) for varying sail angles

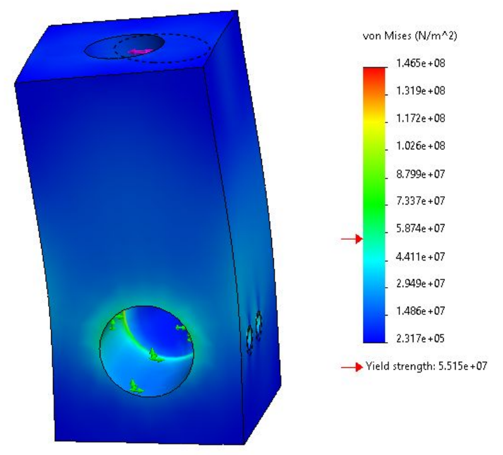

Figure 6: Coupler FEA

Experiments & Results

Test Groups

- Robot without a tail
- Robot with the inertial tail
- Robot with the aerodynamic tail

Procedure

- Drive the robot forward until constant velocity is reached
- Actuate the steering axle to induce a sharp turn (~4°) for less than 0.5 seconds
- For the test groups that include a tail, the control algorithm should execute a command to actuate the tail

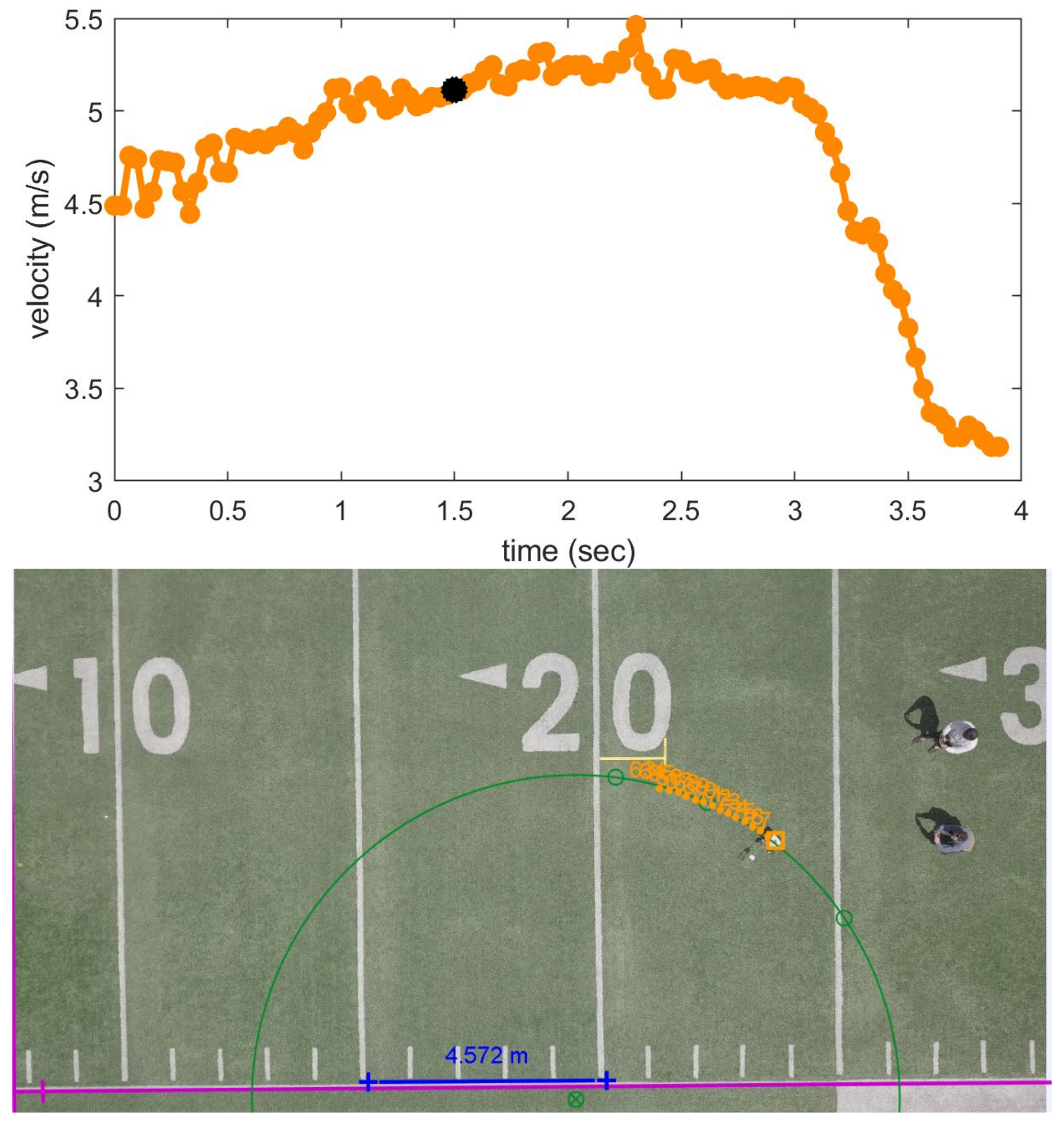

Figure 6: Velocity profile obtained via Tracker and drone footage.

Table 1: Maximum turning speed is defined as the speed at which the vehicle enters its turn. A successful trial results in the vehicle maintaining an upright position throughout the turn. Any turn not resulting in this is labelled as fail. Steering angle varied between 3-4 degrees throughout the trials.

Maximum Turning Speed [m/s]		
	Success	Fail
No Tail	6.2	5.9
Inertial Tail	4.7	5.9
Aerodynamic Tail	5.2	5.8

Conclusion & Future Work

- Our results suggest that the aerodynamic tail outperforms the inertial tail
- The findings are not consistent with those of Patel et.al with regard to the comparison between the no-tail and inertial tail cases
- Our dataset is not large enough to make substantial conclusions
- Future work would involve enlarging the dataset to help us establish a conclusion.
- We would also like to remove the factor of human bias by adding a controller to run the RC car
- We suggest adding the ability to log the IMU sensor data as another point of reference as well as using a more robust motor for the tail to reduce the likelihood of motor failure when turning

References

[1] A. Patel and M. Braae, "Rapid turning at high-speed: Inspirations from the cheetah's tail," 2013 IEEE/RSJ International Conference on Intelligent Robots and Systems, 2013, pp. 5506-5511, doi: 10.1109/IROS.2013.6697154.

[2] J. Norby, J. Y. Li, C. Selby, A. Patel and A. M. Johnson, "Enabling Dynamic Behaviors With Aerodynamic Drag in Lightweight Tails," in IEEE Transactions on Robotics, vol. 37, no. 4, pp. 1144-1153, Aug. 2021, doi: 10.1109/TRO.2020.3045644.

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