The Predator's Precision: Investigating Head Stabilisation in Cheetah Locomotion via 3D Reconstruction with Model-Based Optimisation

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Summary

The cheetah is well-adapted for excellent visual prey-tracking during complex manoeuvres, requiring advanced head stabilisation techniques. However, the dynamics of wild and endangered animals are difficult to study from a distance, and as technology evolves, it is important to understand these animals in increasingly impactful ways. Our work elicits a markerless motion capture method to produce 3D reconstructions of a subject, and a further analysis of this to provide insight into the control mechanisms used by a cheetah to stabilise its head during agile and high-speed locomotion. We use a dynamic model-informed optimisation to constrain the reconstruction points to within the bounds of a skeletal model. By leveraging this refined reconstruction, we performed a quantitative analysis on the 3D data to infer the mechanisms of the cheetah's head stabilisation.

Introduction

The cheetah is an exemplar of adaptation in the natural world. It is the fastest land mammal and has multiple morphological specialisations for high-speed manoeuvres, including vestibular adaptations to facilitate gaze and head stabilisation [1]. Due to the sensitivity of working with endangered wild animals, the analysis of the head stabilisation mechanics necessitated a non-invasive computer vision technique to collect 3D points of interest. We collected data to emulate a perturbed platform and isolate head stabilisation. Using MATLAB®, we built upon a method pioneered by AcinoSet [2] to quantitatively analyse the cheetah's head stabilisation using optimal control methods – working to identify the control mechanisms and optimised cost function associated with the stabilisation.

Methods

A unique dataset of cheetahs in a moving vehicle was collected using four GoPro Hero 12s, raised and angled towards the centre of the car's platform. The cameras recorded at 240 frames per second with a resolution of 1920×1080 pixels. The dataset includes inertial measurements from a sensor attached to the car. All recordings were time synchronised. The dataset included 2D labels for key points of the cheetah based off a skeletal model [2], by hand-labelling over 1000 video frames used in training a DeepLabCut [3,4] network. For calibration, we used a 10×7 checkerboard with square sizes of 40 mm and MATLAB® camera calibrator tools. The 2D key point labels from the DeepLabCut neural network were used in conjunction with an optimisation task, which minimised error between the 3D kinematic model of a cheetah adapted from [2], and the 3D triangulated position of a key point generated from two or more 2D labels to produce an optimal trajectory. This was used, alongside AcinoSet data [2], to inversely infer the cheetah's internal optimal stabilisation and control problem.

Results and Discussion

The cheetah's head and gaze are stabilised when running, during agile motions, and balancing on a moving platform. Preliminary analysis results suggest feedback control, and that the cheetah prioritises the maintenance of visual stability and balance. The prominent vestibular stability factors quantified include head roll, pitch, and vertical oscillation.

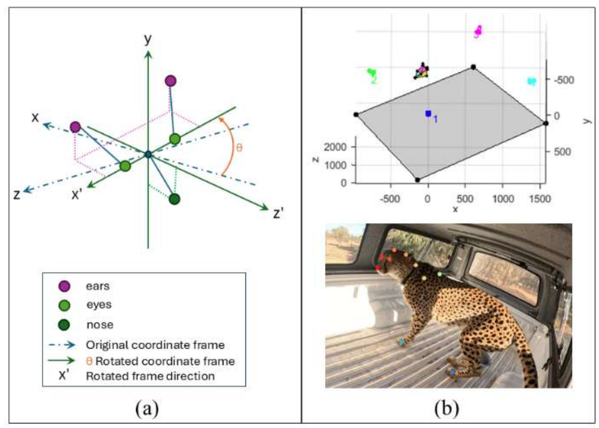

Figure 1: (a) 3D Model Analysis Framework
(b) 3D Reconstructed Head in Scene Compared to Camera 1 View

Conclusions

Markerless motion capture and noise reduction in 3D was successfully used to understand the fine-motor adjustments of the cheetah's balance and head stabilisation. Although further work is required to fully understand the implicit cost function, this work will potentially give more general neuromechanical insights into feedback control in animals and has implications for biomechanics, conservation, and the development of bio-inspired robotics where stability is a key consideration.

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References

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