UNIVERSITY OF TECHNOLOGY SYDNEY
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School of Mechanical and Mechatronic Engineering

Locomotion dynamics of agile canines

by

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Principal supervisor: Prof David Eager

Co-supervisors: Dr Paul Walker and Dr Terry Brown

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE

Doctor of Philosophy

Sydney, Australia

2019

Certificate of Authorship/Originality

I, Hasti Hayati declare that this thesis, is submitted in partial fulfillment of the requirements for the award of Doctor of Philosophy, in the school of Mechanical and Mechatronic, Faculty of Engineering and IT, at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

Production Note:
Signature: Signature removed prior to publication.

Date: 17/02/2020

ABSTRACT

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Greyhounds are the fastest of all canine breeds, capable of attaining 70 km/h in 30 metres. The greyhound's unique sprinting ability has made it an elite sprinter and racing animal throughout history. Greyhounds sustain specific injuries, mainly skeletal, that are believed to be race-related and are rarely seen in other breeds of dogs. This dissertation focuses on studying the locomotion dynamics and foot-surface interaction of greyhounds. Accordingly, a thorough review was conducted of the literature on severe musculoskeletal injuries in greyhounds, factors contributing to injury in greyhound racing, different methods of measuring the locomotion dynamics of legged mechanisms, and different approaches to simulating legged locomotion. This review is presented in Chapter 2. Chapter 3 outlines common types of severe race-related injuries in racing greyhounds drawn from two years' worth of injury data collected on New South Wales greyhound racing tracks by qualified on-track veterinarians between January 2016 and December 2017. In Chapter 4 the method used to study the functional properties of greyhound race track sand surfaces is described, and the findings of the effects of altering the moisture content and rates of compaction on the dynamic behaviour of sand surfaces are presented and compared with findings from relevant literature. The experimental method used to derive the stiffness and damping coefficients of sand samples is explained in detail. Chapter 5 shows how the galloping dynamics of greyhounds were measured using a single Inertial Measurement Unit (IMU). The IMU which was equipped with a tri-axial accelerometer was embedded in a pocket located approximately on the

greyhound's Centre of Mass. The acceleration signals could successfully identify the turning dynamics regardless of the type of track surface. Finally, Chapter 6 presents the results of simulations of the hind-leg dynamics during the most critical duration of the galloping gait using the Spring-Loaded-Inverted-Pendulum method. The primary purpose of the designed SLIP model was to estimate greyhound hind-leg dynamics by altering surface properties.

Dedication

To my family.

Acknowledgements

First and foremost, I would like to express my sincere gratitude, to my supervisor, David Eager, for his unconditional support and for sharing this journey alongside me. I cannot express in words how grateful I am and how much his supervision and mentorship meant to me. I would like to thank my co-supervisors Paul Walker and Terry Brown, for their support during my candidature. Beside my supervisory team, I would like to thank Benjamin Halkon and Sebastian Oberst for their insightful comments and encouragement. Also, special thanks to the kind-hearted Chris Chapman, the manager of UTS Dynamics and Mechanics of Solid laboratory, for his help in conducting my experiments.

I would like to thank my teammates in the RHISN team, Sanaz Mahdavi, Robert Stephenson, Nathan Thomas, and Imam Hossain, for the sleepless nights we were working together and all the fun we have had in the last four years.

I would like to express my deepest gratitude to UTS Women in Engineering and IT (WiEIT) team, who warmly welcomed me in the team in July 2019. To Arti Agruwal, whom I always look up to, to Eva Cheng, Lauren Black, Amy and Amelia, who all support my passion towards empowering women.

To all of my friends and colleagues, Jeri Childers, MaryAnn McDonald, Jacqui White, Kasra Khosusi, Sara Farahmandian, Anna Lidfors Lindqvist, Dana Rezazadegan, Hamid Lashgari, Mohammad Assefi and Pouria Khojaste who were all beside me and supported me during this journey.

To my dear friends back in Iran, who maintained their friendship regardless of 12,000 km distance. Zahra, my first friend in the world and Afsaneh, who I shared the best undergrads life with her.

To my mother-in-law, Mahnaz, the kindest soul in my life, my father in law, Saeid, for his endless support, my brother-in-laws, Behkam and Behdad and my sister-in-law Kimia, who are not in-laws for me, they are real brothers and sister.

To my mother, Mina, my role model and who taught me to be strong, to my father, Heshmatollah, who taught patience and spirituality, to my brother Pedram, whom talking to always keeps me motivated, to Tjasa, my sister-in-law, for her peaceful soul and to the youngest member of family Kaia, my niece, whom because of her I've learnt how to love unconditionally.

Last but not least, I dedicate this dissertation to my love, my soul-mate, my best friend, my dear husband Behnam. Without you, I couldn't be me. Love you forever.

Hasti Hayati

Sydney, Australia, 2019.

List of Publications

Journals

[**1**] **Hayati, H**, David E, and Paul W. "The effects of surface compliance on greyhound galloping dynamics." *Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics* 223(4): 1033-1043, 2019.

[**2**] **Hayati, H**, Mahdavi F, Eager D. "Analysis of agile canine gait characteristics using accelerometry." *Sensors* 19(20): 4379, 2019.

[**3**] Eager, D and **Hayati, H**. "Additional Injury Prevention Criteria for Impact Attenuation Surfacing Within Children's Playgrounds." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering* 5(1): 011002, 2019.

[**4**] **Hayati, H**, David E, and Paul W. "Locomotion dynamics of turning and sprinting on different surfaces in agile quadrupeds: racing greyhounds" *ASME Journal of Dynamic Systems, Measurement, and Control* [Under Review].

Conferences

[**1**] Eager D, **Hayati, H**, Chapman C. "Impulse Force as an Additional Safety Criterion for Improving the Injury Prevention Performance of Impact Attenuation Surfaces in Children's Playgrounds." In *ASME 2016 international mechanical engineering congress and exposition* 2016 Feb 8. American Society of Mechanical Engineers Digital Collection.

[**2**] **Hayati, H**, Eager D, Jusufi A, Brown T. "A study of rapid tetrapod running and turning dynamics utilizing inertial measurement units in greyhound sprinting." In *ASME 2017 International Design Engineering Technical Conferences and Com-*

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[3] **Hayati, H**, Eager D, Stephenson R, Brown T, Arnott E. "The impact of track related parameters on catastrophic injury rate of racing greyhounds." In *9th Australasian Congress on Applied Mechanics (ACAM9)* 2017 (p. 311). Engineers Australia.

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[6] Mahdavi F, Hossain MI, **Hayati, H**, Eager D, Kennedy P. "Track Shape, Resulting Dynamics and Injury Rates of Greyhounds." In *ASME 2018 International Mechanical Engineering Congress and Exposition* 2018 Nov 9. American Society of Mechanical Engineers Digital Collection.

[7] **Hayati H**, Mahdavi F, Eager D. "A single IMU to capture the fundamental dynamics of rapid tetrapod locomotion: Racing greyhounds". In *European Society of Biomechanics.* 2019 Jul 10.

[8] Mahdavi F, Hossain MI, **Hayati, H**, Eager D, Kennedy P. "Track Shape, Resulting Dynamics and Injury Rates of Greyhounds." In *ASME 2018 International Mechanical Engineering Congress and Exposition* 2018 Nov 9. American Society of Mechanical Engineers Digital Collection.

[9] **Hayati, H**, Eager D., Walker P. "An impact attenuation surfacing test to analyse the dynamic behaviour of greyhound racetrack sand surface." In *World Engineering Convention Australia 2019 proceeding* 2019 Nov 22. [Accepted].

Nomenclature and Notation

g	Gravitational acceleration
l	Hind-leg length
$\dot{l}$	Hind-leg linear velocity
$\ddot{l}$	Hind-leg linear acceleration
m_b	Overall mass of the greyhound
m_c	Mass of the Clegg hammer
m_l	Hind-leg mass of the greyhound
$[\ddot{x}]$	Vector of acceleration obtained from the accelerometers
$[\dot{x}]$	Vector of velocity obtained from the accelerometers
$[x]$	Vector of surface penetration obtained from the accelerometers
y	Surface compression
$\dot{y}$	Surface linear velocity
$\ddot{y}$	Surface linear acceleration
C_s	Surface damping coefficient
F	Impact force of the Clegg hammer
K_l	Hind-leg stiffness coefficient
K_s	Surface stiffness coefficient
T	Kinetic energy
U	Potential energy
$\mathcal{L}$	Lagrangian
θ	Hind-leg angle with respect to the ground
$\dot{\theta}$	Hind-leg angular velocity
$\ddot{\theta}$	Hind-leg angular acceleration
G_{max}	maximum acceleration
J_{max}	maximum jerk

w	moisture content
M_b	mass of the container and wet sand
M_c	mass of the container and dry sand
M_a	mass of the container

Abbreviation

AIS	anatomical injury severity
CFL	compressed flight phase
CoM	center of mass
CWT	continuous wavelet transform
DFT	discrete Fourier transforms
EFL	extended flight phase
FFT	fast Fourier transform
GPS	global positioning system
GRF	ground reaction force
HFR	high frame rate
iKMS	integrated kinematic measurement system
IMU	inertia measurement unit
ISS	injury severity index
LF	left fore-leg
LH	left hind-leg
NSW	new south wales
OTV	on track veterinarians
RF	right fore-leg
RH	right hind-leg

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