UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Modelling and Simulation of Multiple Galloping Quadrupedal Dynamics

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Certificate of originality

This is to confirm that to the best of my knowledge and belief, the content of this dissertation is my work and has not been previously submitted for a degree, nor it has been submitted as a part of the requirements for another degree.

I hereby declare that the material of this thesis is the product of my own work, except where appropriately referenced. I certify that all information sources and literature are properly quoted in the thesis.

Finally, this research is supported by the Australian Government Research Training Program.

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ABSTRACT

MODELLING AND SIMULATION OF MULTIPLE GALLOPING QUADRUPEDAL DYNAMICS

by

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The work presented in this dissertation is comprised of three distinct parts. Namely data modelling and analysis for galloping quadruped dynamics, numerically modelling race track path design, and numerically simulating multiple galloping quadrupeds race dynamics. Fundamentally, all the parts are interlinked to one another at the level of searching for dynamics stability of galloping quadrupeds. A holistic approach was taken for information synthesising, ranging from data acquisition to modelling and simulation. The dissertation presents an overview of the current progress in the field, approaches the problem by linking information from modelling, then derives numerical solutions to come to conclusions.

Data modelling demonstrated greyhound galloping gait performance and existing race track design conditions. The techniques utilised for data gathering and analysis allowed effective retrieval of diverse information. Racing greyhound galloping gait performance was verified including speed, acceleration, yaw rate, stride frequency, stride length and paw dynamics. Also, reviewing of existing tracks revealed track designs limitations.

Data modelling showed that trajectory dynamics could significantly influence race dynamics stability. Thus, methods were derived for modelling and designing galloping greyhound ideal path trajectory between a straight and curve track path segments. To do this, clothoid and algebraic curved segments were numerically generated using a sequential vector transformation method that allows the inclusion of greyhound kinematic parameters. And an equation was derived to model suitable clothoid segments which represents greyhound kinematic parameters and boundary conditions of a track. Finally, results from race data modelling and past injury data are also provided to support transition curve segments improving the dynamics and safety of racing greyhounds while reducing injuries.

A race simulation platform was created which emulates greyhound racing. The race simulation explained various aspects of race dynamics affecting overall dynamical outcomes. Results were derived for yaw rate, speed, and the congestion pattern through numerical modelling race simulations. The simulation results presented are also correlated to actual race data to validate modelling performance and reliability. The fundamental tasks carried out include the development of a numerical model for greyhound veering and race-related supporting models. The results from race simu-

lations showed circumstances causing unstable conditions and relationships between various race factors.

Finally, this project is useful as it is being applied to optimising quadrupeds racing track design. It could also be used in various other fields such as analysing and numerical modelling and simulation of games, animations and multi-body dynamical physical systems.

This dissertation was supervised by Professor David Eager and Dr Paul Walker within the School of Mechanical and Mechatronic Engineering.

Keywords: Quadruped Racing, Quadruped Kinematics, Galloping Dynamics, Numerical Simulation, Numerical Modelling, Rigid Body Dynamics, Path Smoothing, Injury Prevention, Animal Welfare.

Dedication

To my parents Hajji Md Hossain (late) and Hajji Salma Begum. I remember my dad always used to call me Mr. engineer whenever he could and buy different hardware to play with. Once he bought me a small dynamo from a shipyard after seeing I was very much involved in knowing electrical power generation from motors. He very much encouraged me to get into engineering from a very early age. Essentially, he created a passion for engineering in me. My mom always pushed me to study and she would always remind me of studying for learning different subject matters which I can apply rather than just passing and completing courses from the school with a high grade. So, I used to do things like reading books from science subjects outside of my school syllabus. I am grateful to have both of them in my life.

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Md Imam Hossain
Sydney, Australia, 2020

Journals, conferences and reports

The contents of this thesis are based on the following papers and reports which have been published, or accepted to peer-reviewed journals, conferences, and the industry as well as institutional repositories.

Journal publications

J-1. **Hossain, M.I.**, Eager, D. and Walker, P. (2020). Greyhound racing ideal trajectory path generation for straight to bend based on jerk rate minimization. Scientific Reports.

Conference papers

C-1. **Hossain, M.I.**, Eager, D. and Walker, P. (2019). Simulation of racing greyhound kinematics. In Proceedings of the 9th International Conference on Simulation and Modeling Methodologies, Technologies and Applications, pages 47–56. SCITEPRESS-Science and Technology Publications.

C-2. Mahdavi, F., **Hossain, M.I.**, Hayati, H., Eager, D. and Kennedy, P. (2018). Track shape, resulting dynamics and injury rates ofgreyhounds. In ASME 2018 International Mechanical Engineering Congress and Exposition. American Society of Mechanical Engineers Digital Collection.

Industry reports

R-1. Eager, D. and **Hossain, M.I.** (2019). Traralgon: Preliminary review of the track path dynamics for 60 m 1-turn, 57 m 2-turn and 70 m 1-turn designs.

R-2. Eager, D. and **Hossain, M.I.** (2019). Design analysis for the proposed Goulbourn track (drawing no. 5143).

R-3. Eager, D. and **Hossain, M.I.** (2019). Cranbourne: Preliminary review of the path dynamics for a 57 m 1-turn and 2-turn track designs.

R-4. Eager, D. and **Hossain, M.I.** (2018). Mt. Gambier track design analysis of drawing 5135 (UTS2018-0003).

R-5. Eager, D. and **Hossain, M.I.** (2018). Grafton track analysis.

R-6. Eager, D. and **Hossain, M.I.** (2018). Cranbourne track comparison.

R-7. Eager, D., Hayati, H., Mahdavi, F., **Hossain, M.I.**, Stephenson, R. and Thomas, N. (2018). Identifying optimal greyhound track design for greyhound safety and welfare Phase II – Progress Report 1 January 2016 to 31 December 2017. Retrieved from Sydney: https://opus.lib.uts.edu.au/handle/10453/126775

R-8. **Hossain, M.I.** and Eager, D. (2018). Wentworth park track review.

R-9. Eager, D., Mahdavi, F. and **Hossain, M.I.** (2018). The Meadows new start distance analysis report.

R-10. Eager, D., Hayati, H. and **Hossain, M.I.** (2018). Mt Gambier track injury analysis and preliminary design report.

R-11. Eager, D. and **Hossain, M.I.** (2017). The Gardens track starting boxes alignment analysis.

R-12. Eager, D., Hayati, H. and **Hossain, M.I.** (2017). A preliminary investigation into the Cranbourne Track for GRV.

R-13. Eager, D. and **Hossain, M.I.** (2017). Alternative track designs for Tweed Heads (options A – D). Retrieved from Sydney: https://opus.lib.uts.edu.au/handle/10453/121928

R-14. Eager, D., Hayati, H. and **Hossain, M.I.** (2017). Identifying optimal greyhound track design for greyhound safety and welfare Phase I Report Jan 2016 to 31 Dec 2016. Retrieved from Sydney: https://opus.lib.uts.edu.au/handle/10453/136854

R-15. **Hossain, M.I.**, Hayati, H. and Eager, D. (2016). A comparison of the track shape for Wentworth Park and proposed Murray Bridge. Retrieved from Sydney: https://opus.lib.uts.edu.au/handle/10453/122021

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Abbreviations

2D	two-dimensional
3D	three-dimensional
AOA	angle of attack
CAD	computer aided design
CBF	callback function
CF	centrifugal force
CJ	centrifugal acceleration jerk
CG	centre of gravity
CS	continuous simulation
CSV	comma-separated values
DES	discrete-event simulation
DFT	discrete Fourier transform
DTS	deterministic simulation
EM	Euler method
FDM	finite difference method
fps	frames per second
GR	greyhound racing
GRNSW	Greyhound Racing New South Wales
GRS	greyhound racing sport
GRV	Greyhound Racing Victoria
HFR	high frame rate
IMU	inertial measurement unit
LRP	lure rail path
ML	machine learning
OOP	object-oriented programming
PY	Python programming language
RLT	real-time location tracking
ROC	rate of change
ROR	Rate of rotation
SD	survey data
SP	superposition principle
SCS	stochastic simulation

TM	transformation matrix
UML	unified modeling language
UTS	University of Technology Sydney

Nomenclature

Units

km	kilometer
mm	millimeter
m	meter
s	second
N	Newton
kg	kilogram
g	g-force
Hz	Hertz
rad	radian
deg	degree