

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.



MASSEY UNIVERSITY
ENGINEERING

**SCHOOL OF ENGINEERING AND
ADVANCED TECHNOLOGY**

**DEVELOPMENT OF AN AUTOMATIC
LAMENESS DETECTION SYSTEM FOR DAIRY
CATTLE**

A thesis presented in partial fulfilment of the requirements
for the degree of

Master of Engineering
in
Mechatronics

at Massey University, Manawatu, New Zealand.

Aaron Dalbeth

2016

SUPERVISORS

- a. Gourab Sen Gupta
- b. Ken Mercer

Abstract

Lameness in dairy cattle negatively effects the welfare of affected cows and is the third biggest cause of economic loss to the dairy industry in New Zealand. As the cost and frequency of lameness continues to increase, profitability will further decrease, unless a more effective and efficient method of detecting cattle lameness is found.

The main objective of this study was to investigate whether differences between healthy and lame cattle could be identified by capturing ground reaction forces when the dairy cattle walked over the designed platform. The designed walkover platform (WoP) has four independent platform segments, with each segment containing four ASB1000 shear beam load cells, a 24 bit sigma-delta analogue-to-digital converter and an ATmega328 microcontroller. Software was developed in Python 2.7 to record the captured load cell signals and process them to determine the three basic kinematic variables associated with lameness: force, position and duration. Based on these variables a wide range of typical gait parameters such as stride length, abduction, stance time, etc. were calculated. Laboratory testing of the positional and weight accuracy of a platform segment found a maximum weight error of 0.4%, a X-position mean error of 1.0 ± 2.2 mm and a Y-position mean error of 0.8 ± 1.8 mm.

The WoP was tested on two farms during the winter of 2015. During this period approximately 9500 hooves landed on the platform from 200 cows. 95% of all hoof falls were captured implying that the segment length and lead on platform were the correct dimensions for an averaged sized herd of dairy cattle. The dynamic weighing of the cattle on the WoP showed a mean deviation of -13.7 ± 7.5 kg. On farm and video analysis lameness scoring was conducted by a trained observer. The lame and healthy cows were compared to see the differences in variable values and signal signatures. Two-sample t-tests proved that the most significant variables are a combination of weight, position and duration parameters with these being: asymmetry in front limb weight, asymmetry in rear limb weight, asymmetry in diagonal weight, asymmetry in side weight, average step overlap left-side, average step overlap right-side, asymmetry in step overlap L Vs R, average step overlap, average abduction left-side, average abduction, asymmetry in stance time left-side, asymmetry in stance time L vs. R, asymmetry in stance time front hoof and asymmetry in stance time hind hoof. Statistical techniques were used to build classification models based on significant variables associated with lameness. The model that demonstrated the most promise is logistic regression using six predictor variables; this technique correctly classified all 86 cow trials in relation to the observer score. Although there is still much work to be done to provide an automated solution to lameness detection, this research provides novel contributions towards the architecture of a commercial low cost system that can determine cattle lameness in any limb.

Acknowledgements

I would like express my very great appreciation to Associate Professor Gourab Sen Gupta and Ken Mercer from the School of Engineering and Advanced Technology at Massey University for their valuable and constructive suggestions during the planning and development of this project. The willingness of my supervisors to give their time so generously has been very much appreciated. Weekly meetings were very helpful and the discussions on and off topic steered me in a positive direction.

I would like to thank Johann Nel who also completed his Masters working on this project during an earlier phase. His assistance towards software and hardware development has been a valuable contribution. The platform mechanical manufacturing and Python software development would have taken a considerable amount of time without your help. The team work and comradery shared throughout my time on the project was an added bonus.

I could not have achieved (or survived) without the financial assistance of Callaghan Innovation, C. Alma Baker Trust, Massey University and Ken & Elizabeth Powell Postgraduate Scholarships that I received, so thank you very much.

Massey University production veterinarians Associate Professor Richard Laven and Dr Lisa Hine helped immensely freely giving their time and expertise towards the project. Without the cattle anatomy lessons or the locomotion scoring reports the project outcome would not have been as confident, so thank you. Also from Massey University, Dr Russell Wilson provided commercialisation and IP knowledge during meetings which was very helpful.

I would like to thank Matthew Collis from Palmerston North for free access to his farms milking shed to set up the walkover platform. The data captured from the 400 + cows over the two month period was essential. The farm employees were also very helpful which contributed to the high quality of data that was captured.

I would also like to thank Tru-Test Limited for being the industrial sponsor and providing all the resources necessary to develop a system that is suitable for an industrial application. In particular, Dr Ross Nilson, Brendan O'Connell and Lawrence Blount who regularly provided technical knowledge and industrial mentoring.

Finally, I wish to thank my family and friends for their support and encouragement throughout my project, namely my parents, Briahna Dalbeth, Tobin Hall and Brendan Taylor. Last but not least, my amazing girlfriend Karin Sievwright who is always willing to edit my work and keep me on track.

Table of Contents

Abstract.....	ii
Acknowledgements.....	iii
Chapter 1: Introduction	1
Chapter 2: Background Information.....	3
2.1. Lameness Research.....	3
2.1.1. The New Zealand Dairy Industry	3
2.1.2. Cause of Lameness	3
2.1.3. Identifying Lameness – Point Scoring System	4
2.1.4. Cost of Lameness	5
2.1.5. Weight Distribution Patterns	6
2.1.6. Severity for Intervention.....	6
2.2. Current Lameness Detection Systems	7
2.2.1. The StepMetrix System	7
2.2.2. The GAITWISE System	9
2.2.3. Royal Veterinary College Lameness System	10
2.2.4. Common Variables Indicative of Lameness	10
2.2.5. Requirements for a Practical Lameness Detection System	12
Chapter 3: System and Hardware	15
3.1. Project Phases.....	15
3.2. Prototype Scales.....	15
3.2.1. Requirements	15
3.2.2. System Block Diagram	16
3.2.3. Mechanical Platform Development.....	17
3.2.4. Signal Conditioning.....	20
3.2.5. Embedded Software	25
3.3. PC Software Test Harness	30
3.3.1. Load Cell Calibration.....	30
3.3.2. Calculating Load Cell Weight.....	30
3.3.3. Calculating Centre of Pressure.....	31
3.3.4. Recording Data.....	32
3.3.5. Plotting Weight and Position.....	33
Chapter 4: System Integration and Methods	35
4.1. Statistical Analysis Techniques	35
4.1.1. Two Sample T-test.....	35
4.1.2. Novelty Detection.....	35
4.1.3. Principal Component Analysis	36
4.1.4. Discriminant Analysis.....	36
4.1.5. Logistic Regression	37
4.2. Cattle Identification	37
4.2.1. Video Recording	38

4.3.	Farm Trials.....	38
4.3.1.	Trial 1 Setup.....	38
4.3.2.	Trial 2 Setup.....	39
4.3.3.	Trial 3 Setup.....	41
Chapter 5:	Data Exploration	42
5.1.	Post Processing Algorithms	42
5.1.1.	Splitting Peaks	42
5.1.2.	Detecting Hoof Side	43
5.1.3.	Walkover Weigh Algorithm Development	44
5.1.4.	Calculating Variables Indicative of Lameness	51
5.1.5.	Writing Variables to Excel File	55
Chapter 6:	Experimentation and Results.....	55
6.1.	Laboratory Testing.....	55
6.1.1.	Positional Coordinate and Weight Accuracy	55
6.1.2.	Step Length Accuracy.....	57
6.1.3.	Dynamic Response.....	60
6.2.	Farm Trial 1 Results	61
6.3.	Farm Trial 2 Results	63
6.3.1.	Lameness Assessment.....	63
6.3.2.	Data Analysis	63
6.3.3.	Score 3 Cows	66
6.3.4.	Lameness Assessment – Part 2	67
6.4.	Farm Trial 3 Results	67
6.4.1.	Novelty Detection Results.....	68
6.4.2.	T- Test Results	72
6.4.3.	Discriminant Analysis Results.....	74
6.4.4.	Logistic Regression Results	76
6.5.	Farm Trial Discussion	78
Chapter 7:	Conclusions and Future Improvements.....	82
References	86
Appendices	89
Appendix 1:	Critical Component Datasheets	89
	AD7193 Datasheet.....	89
	REF5040 Datasheet	90
	AD8656 Datasheet.....	91
	MAX487 Datasheet.....	92
	ATmega328 Datasheet	93
	ASB1000 Datasheet	94
Appendix 2:	Experimental Results	95
2.1.	Load Cell Calibration Experiment	95
2.2.	Load Cell Serial Numbers and Positions	97
2.3.	Test Results from First Human Walkover Dynamic Weighing.....	99

Appendix 3: Farm Trial Results	100
3.1. Test Results from Weight/Position Trial	100
3.2. Test Results from Stride Length Trial	102
3.3. Trial 1 – Static and Dynamic Results.....	104
3.4. Trial 2 – Data Analysis	105
3.5. Trial 3 – Two Sample T-test.....	107
Appendix 4: AD7193 Programming Flow Diagrams	109
Appendix 5: Load Cell Calibration	112
Appendix 6: Excel Spreadsheet Example	115
Appendix 7: Altium Schematic	119

List of Figures

Figure 2.1: Trends in the number of dairy herds (DairyNZ, 2015).....	4
Figure 2.2: StepMetrix system components (Boumatic, 2015).....	8
Figure 2.3: StepMetrix platform layout found in patent (Tasch <i>et al</i> , 2004).....	8
Figure 3.1: Project phases block diagram.....	15
Figure 3.2: WoP concept with four sections.....	15
Figure 3.3: Functional block diagram.....	16
Figure 3.4: Constructed prototype platform.....	17
Figure 3.5: 650 mm platform segment spacing.....	19
Figure 3.6: CAD model of final platform design.....	20
Figure 3.7: Functional block diagram of AD7193 (Analog Devices, 2015).....	22
Figure 3.8: Schematic diagram of initial prototype.....	23
Figure 3.9: Final prototype PCB (Dalbeth, 2014).....	24
Figure 3.10: Test setup of master/slave communications.....	26
Figure 3.11: Program layout of AD7193.....	27
Figure 3.12: Actual data rate received per slave segment.....	29
Figure 3.13: Centre of pressure calculation diagram.....	32
Figure 3.14: Author walking across platform – load cell signals and positions.....	33
Figure 3.15: Steady state noise.....	34
Figure 4.1: RF antenna positioned in middle of platform.....	38
Figure 4.2: WoP installed at milking shed.....	39
Figure 4.3: Herd of cows in feed shed.....	40
Figure 4.4: WoP during use in raceway	40
Figure 5.1: Example of splitting peaks on segment A (Nel, 2015).....	43
Figure 5.2: Positional data from walking cow on segments A and B.....	43
Figure 5.3: Signal showing moving average while author walking over platform.....	45

Figure 5.4: Walkover weight method comparison.....	45
Figure 5.5: Simulating a cow walking pattern to test algorithm.....	47
Figure 5.6: Walkover running average method comparison.....	47
Figure 5.7: Walkover weighted average method comparison.....	47
Figure 5.8: Example of how weighted average signal behaves.....	48
Figure 5.9: Example of front right limb signals.....	49
Figure 5.10: Example of rear right limb signals.....	50
Figure 5.11: Moving average of combined signals.....	50
Figure 5.12: Positional data with coordinate definitions.....	51
Figure 5.13: Example showing step length and step width.....	52
Figure 5.14: Example showing step overlap and abduction.....	52
Figure 5.15: Example showing stride length.....	53
Figure 5.16: Example of hoof duration variables.....	54
Figure 6.1: Calibration weight on point load stand.....	55
Figure 6.2: Laser cut test jig.....	55
Figure 6.3: Step length testing setup (GoPro 3 wide angle lens).....	57
Figure 6.4: Test results from one trial of 600 mm step length.....	57
Figure 6.5: 600 mm layout.....	57
Figure 6.6: Average simulated step length (600 mm).....	58
Figure 6.7: Average simulated step length (650 mm).....	58
Figure 6.8: Average simulated step length (670 mm).....	59
Figure 6.9: Dynamic response without rubber mat.....	60
Figure 6.10: Dynamic response with rubber mat.....	60
Figure 6.11: Manual lameness scoring results from trained observer.....	63
Figure 6.12: Weight and positional signal signature of a healthy cow (ID: 55).....	64
Figure 6.13: Weight and positional signal signature of a lame cow, RH (ID: 123).....	64
Figure 6.14: NGRF of a healthy cow.....	64
Figure 6.15: NGRF of a lame cow (RH).....	64
Figure 6.16: Asymmetry in weights of healthy cow.....	65

Figure 6.17: Asymmetry in weights of lame cow.....	65
Figure 6.18: Lame level 3 cow signal signature.....	66
Figure 6.19: 20 independent healthy cow trials (weights normalised).....	68
Figure 6.20: 80 independent healthy cow signals normalised.....	68
Figure 6.21: Healthy signal boundary envelope.....	69
Figure 6.22: Healthy cow signals percentage of time outside boundary.....	70
Figure 6.23: Lame cow signals (red) with healthy cow envelope.....	70
Figure 6.24: Lame cow signals percentage of time outside boundary.....	71
Figure 6.25: Average percentage of time outside of boundary.....	72
Figure 6.26: Load cell calibration issue (platform C).....	78
Figure 6.27: Total cow weight signal by taking summations of platform segments.....	79

List of Tables

Table 1: Locomotion Scoring Criteria (Zinpro, 2015)	4
Table 2: LS - Within and between observer agreement (Schlageter-Tello <i>et al</i> , 2013)	5
Table 3: Description of gait variables calculated from kinematic measurements (Maertens <i>et al</i> , 2011. Tasch <i>et al</i> , 2004)	10
Table 4: Sampling rate modes of AD7193.....	28
Table 5: Comparison of calculated and measured incoming data frequencies	29
Table 6: Mean and standard deviation of X & Y Position	56
Table 7: Mean and standard deviation of Weight.....	56
Table 8: Summary of step length testing	58
Table 9: Comparison of dynamic weight to static weight of 10 dairy cows	62
Table 10: Two sample T-test between all healthy and lame cows	73
Table 11: Linear discriminant analysis classification (29 variables).....	75
Table 12: Linear discriminant analysis classification using five predictors.....	75
Table 13: Quadratic discriminant analysis classification using five predictor variables	76
Table 14: Significance of predictor variables in the Binary Logistic Regression model	77
Table 15: Classification table summary of Binary Logistic Regression	78
Table 16: Experimental calibration results for full scale output of 2.000 mV/V	113

List of Abbreviations

NGRF Normalised ground reaction force

RF Right front hoof

LF Left front hoof

RH Right hind hoof

LH Left hind hoof

StDev Standard deviation

DA Discriminant analysis

LS Locomotion scoring

WoP Walkover platform

PCB Printed circuit board

COP Centre of pressure

BLG Binary logistic regression

Platform background – one main platform called WoP separated into four individual platform sections/segment