

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  $1.0 \pm 2.2$  mm and a Y-position mean error of  $0.8 \pm 1.8$  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  $-13.7 \pm 7.5$  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