

TABLE OF CONTENTS

Page

APPROVAL PAGE.....	ii
STATEMENT	iii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	vi
TABLE OF FIGURES	x
TABLE OF TABLES	xii
LIST OF SYMBOLS.....	xiii
ABSTRACT	xvi
CHAPTER I INTRODUCTION	17
1.1 Research Background.....	17
1.2 Research Problem.....	21
1.3 Research Scope	22
1.4 Research Objective.....	23
1.5 Research Benefit	23
1.6 Research Contribution.....	23
CHAPTER II LITERATURE REVIEW	25
2.1 Vehicle Detection.....	29
2.1.1 Segmentation	30
2.1.2 Feature-Based.....	31
2.1.3 License Plate Detection	31
2.1.4 Learning-Based.....	32
2.2 Vehicle Tracking	33
2.2.1 Kalman Filter.....	33
2.2.2 Tracking by Detection	34
2.2.3 Optical Flow	34
2.3 Camera Calibration.....	35
2.3.1 Methods Based on Acquired Line and Point Markings.....	38
2.3.2 Method Based on Vehicles' Movement	40

2.3.3 Method Using Manual Measurement	42
2.4 State-of-The-Art Vehicle Speed Estimation.....	42
CHAPTER III THEORETICAL BASIS	45
3.1 Vehicle Speed Estimation	45
3.2 Artificial Neural Network	46
3.3 Convolutional Neural Network	47
3.3.1 Convolution Layer.....	47
3.3.2 Non-linearity Layer	48
3.3.3 Pooling Layer	48
3.3.4 Fully Connected Layer	48
3.4 Residual Neural Network	49
3. 5 Loss Function	49
3. 6 VGG16	49
3.7 YOLOv8	50
3.8 ByteTrack	50
3.9 Multiple Linear Regression	51
3.10 Ridge Regression.....	52
3.11 Lasso Regression	52
3.12 ElasticNet Regression.....	53
3.13 Decision Tree Regression.....	53
3.14 Multi-Layer Perceptron Regression	54
3.15 Support Vector Regression.....	54
3.16 Camera Calibration.....	55
3.17 Homography Transformation	58
CHAPTER IV RESEARCH METHODOLOGY.....	59
4. 1 Research Description.....	59
4. 2 Proposed Method.....	60
4. 3 Dataset	61
4. 3. 1 Data Acquisition.....	61
4. 3. 2 Ground Truth Values.....	63

4. 4 Pre-Processing	66
4. 5 Homography Prediction.....	67
4. 6 Deep Homography.....	71
4.7 Detection and Feature Tracking	73
4.8 Scale Factor	74
4.9 Speed Estimation	75
4.10 Speed Estimation in Consecutive Frames	76
4.11 Regression Model.....	77
4.12 Evaluation Method	78
CHAPTER V DEEP HOMOGRAPHY TRANSFORMATION NETWORK	
RESULTS AND DISCUSSION	79
5. 1 Deep Image Homography Results.....	79
5.2 Focal Length, Roll, and Tilt of the DeaSpeedDataset Estimated by Deep Image Homography	81
5.3 Limitation on Hand-crafted Vanishing Point	82
5.4 Discussion and Limitation.....	83
CHAPTER VI VEHICLE SPEED ESTIMATION RESULTS AND	
DISCUSSION	84
6. 1 DeaSpeedDataset Detail Information	84
6.2 Vehicle Speed Estimation Results.....	86
6.3 Comparison of Traffic Conditions	92
6.4 Comparison of Vehicle Directions.....	93
6.5 Analysis of The Regression Model using RMSE	95
6.6 Analysis of The Regression Model using MAE	98
6.7 Analysis of The Weight of The ElasticNet Model.....	101
6.8 Analysis of The Regression Model Using R-Squared	102
6.9 State of The Art Comparison Study	103
6.10 Discussion and Limitation	106
6.10.1 Limitation on Detection and Tracking.....	106
6.10.2 Limitation on Vehicle Classification	107

6.10.3 Limitation on Dealing with Light Conditions	109
CHAPTER VIII CONCLUSIONS	111
7.1 Conclusions	111
7.2 Limitations	111
7.3 Recommendations for Future Research	112
REFERENCE	113
APPENDICES	123
Appendix 1. List of Publications	123
Appendix 2. Vehicle Speed Estimation Results	123