LIST OF FIGURES

Figure 1-1 Insight view power window DC Motor 12
Figure 1-2 Automotive power window.....14
Figure 1-3 The power window system structure.....15
Figure 1-4 Block diagram representation of power window system 16
Figure 1-5 Block diagram of Engine Control Unit (ECU) 17
Figure 1-6 Number of ECU per vehicle and its function per ECU with respect to time 17
Figure 1-7 ECU design and development classification.....19
Figure 2-1 Detailed literature review summary chart.....32
Figure 3-1 physical model circuit diagram of power window system.....38
Figure 3-2 Linear power window DC motor model 40
Figure 3-3 Rigid transmission shaft model with non-zero mass.....41
Figure 3-4 Circuit diagram of the transmission shaft 42
Figure 3-5 Open loop Control System.....43
Figure 3-6 Closed loop control system 44
Figure 3-7 Feedback based power window system 44
Figure 3-8 dSPACE internal system.....45
Figure 3-9 Block diagram of dSPACE Ace 1104 with multiple inputs.....46
Figure 3-10 Power window test bench system 50
Figure 3-11 Test Bench setup of power window system with dSPACE Kit. ..51
Figure 4-1 Electrical circuit of PMDC motor.....53
Figure 4-2 PMDC Motor Characteristics curve.....54
Figure 4-3 Simulation model of power window system using MATLAB/Simulink.....57
Figure 4-4 Software in loop testing 58
Figure 4-5 Experimental setup for current measurement 60
Figure 4-6 Functional module flow diagram 62
Figure 4-7 Current sensing circuit for power window DC motor.....63
Figure 4-8 Circuit diagram of flexi force sensor 65
Figure 4-9 Detailed Flexi force sensor configuration.....66
Figure 4-10 Block diagram of decision tree algorithm.....67
Figure 4-11 Decision tree classifier algorithm flow chart 68

Figure 5-1 Flexi force sensor configuration....70
Figure 5-2 Pneumatic circuit for force generation....71
Figure 5-3 Pneumatic circuit control using relay based components....71
Figure 5-4 Force versus voltage characteristics curve....74
Figure 5-5 Detailed hardware configuration of the Current sensor....74
Figure 5-6 Relationship between Torque and current drawn during load is active for the current sensor....77
Figure 5-7 Current and time behaviour of the power window....78
Figure 5-8 Voltage and time behaviour of the power window....79
Figure 5-9 RPM of motor and time behaviour of the power window....79
Figure 5-10 Illustrate Decision tree test set sample results....81
Figure 5-11 Illustrate Decision tree training set sample results....82
Figure 5-12 Illustrate Voltage Profile of Power window motor....83
Figure 5-13 Illustrate Current Profile of Power window system with different load....84
Figure 5-14 Experimental Setup of Power window....85
Figure 5-15 Comparison of upward and downward estimated time without obstacle....86
Figure 5-16 Comparison of downward estimated time with obstacle....88