

Contents

1. Introduction	1
1.1. Hypotheses	3
1.2. General Objectives	3
1.3. Specific Objectives	3
1.4. Resources Available for this Thesis	3
2. Theoretical Background	5
2.1. System-Level PHM definition	5
2.2. Machine Learning	5
2.2.1. Classification and Regression Problems	6
2.2.2. Supervised Learning	6
2.3. Deep Learning	6
2.3.1. Artificial Neural Networks	7
2.3.2. Convolutional Neural Networks	7
2.3.3. Recurrent Neural Networks	8
2.3.4. Training of Neural Networks	11
2.4. Variational inference	13
2.4.1. Weight Perturbations	15
2.4.2. Bayes by Backprop	17
2.5. Putting all Pieces Together	18
3. Methodology	20
4. Proposed Bayesian Recurrent Neural Networks	23
4.1. Bayesian Recurrent Neural Networks	23
4.2. Training of Bayesian Recurrent Neural Networks	25
4.3. Performance Metrics for Bayesian Recurrent Neural Networks	26
4.4. Implementation	26
5. Case Studies	28
5.1. Validation Dataset: RUL Prediction in Turbofan Engine Degradation Simulation (CMAPSS)	28
5.1.1. Data Description	28
5.1.2. Data Preparation	30
5.1.3. Results for Bayes VRNN Cell in CMAPSS Dataset	31
5.1.4. Results for Bayes JaNet Cell in CMAPSS Dataset	41
5.1.5. Comparison Against different frequentist models	49

5.2.	RUL Prediction in Wind Turbine High Speed Bearings	51
5.2.1.	Data Description	51
5.2.2.	Data Preparation	52
5.2.3.	Results and Discussion	54
5.3.	Health Indicator Prediction in Cracks	60
5.3.1.	Data Description	60
5.3.2.	Data Preparation	61
5.3.3.	Results and Discussion	61
5.4.	Health State Diagnosis Bearings: University of Ottawa	69
5.4.1.	Data Description	69
5.4.2.	Data Preparation	70
5.4.3.	Results and Discussion	72
5.5.	Politecnico di Torino rolling bearing test rig	78
5.5.1.	Data Description	78
5.5.2.	Data Preparation	80
5.5.3.	Results and Discussion	80
6.	Concluding Remarks	86
Bibliography		87