Indian Institute of Technology Kharagpur
Kharagpur 721302, India

Machine Learning for Cyber-Physical Systems

A Course Proposal for Tata Sons

Industry 4.0 envisages wide spectrum application of digital technologies for intelligent control, health monitoring, analytics, and optimization of industrial processes. Machine learning techniques are key enablers for infusing intelligent self-learning and diagnostic capabilities in industrial processes. Machine learning provides automated options for preparing digital twins, model predictive control, what-if analysis, and prognosis.

While machine learning is widely practiced in cognitive domains, such as NLP, computer vision, speech recognition, etc, its impact on cyber-physical systems is only recently being understood. An important hurdle towards the deployment of machine learning in industrial systems is that machine learning has developed in Computer Science, where as its applications in industrial domains require significant domain knowledge in disciplines that are remote from Computer Science. On the other hand, a large arsenal of ready-to-use machine learning tools and libraries exist (including ones supported by standard industrial modeling platforms like MATLAB), and therefore the domain expert can be readily trained to use these tools and techniques for advancing their industrial processes and design (R&D) activities. This is precisely the aim of this course.

Lecture-wise Course Contents: Duration: 42 hrs

1. PART-1 Models of Cyber-Physical Systems (4 hrs)

- 1.1. Introduction to Cyber Physical Systems(1 hrs)
  - 1.1.1. Motivational discussions:
    Industry 4.0, Key issues: intelligence, autonomy, safety, reliability
- 1.2. Models for Cyber Physical Systems
  - 1.2.1. Dynamical Systems: Continuous/Discrete Representations, Open/Closed loop dynamics (0.5 hrs)
  - 1.2.2. Modeling CPS using Hybrid Automata(1 hrs)
  - 1.2.3. CPS with AI components: e.g. DNN based controllers (performance and safety issues) (1.5 hours)

2. PART-2 Machine Learning Tools and Techniques (28 hrs)

2.1. Introduction to ML Supervised, Unsupervised, Reinforcement Frameworks (2 hrs)

2.2. Introduction to Matlab/Python/Numpy (2 hrs)

2.3. Preprocessing and Dimensionality Reduction (2 hrs)

2.4. Regression (~~2~~ 1 hrs)

2.5. Classification Algorithms
- 2.5.1. Bayes Classifier and Bayesian Networks (1 hrs)
- 2.5.2. K-Nearest Neighbor (1 hrs)
- 2.5.3. Decision Trees and Random Forest (2 hrs)
- 2.5.4. Support Vector Machines (2 hrs)
- 2.5.5. Feedforward Neural Networks (2 hrs)
- 2.5.6. Recurrent Neural Networks and LSTM (1 hr)
- 2.5.7. Deep Learning and CNN (2 hrs)
- 2.5.8. Domain Adaptation and Fine Tuning of Existing Models (1 hr)
- 2.5.9. Boosting (1 hrs)

2.6. Clustering
- 2.6.1. K-Means Clustering (1 hr)
- 2.6.2. Graph theoretic and Density Based Clustering (1 hr)

2.7. Analysis of time-series context-based data (2 hrs)
2.8. Reinforcement Learning (2 hrs)
2.9. Design Choices for Machine Learning Algorithms (1 hr)
2.10. Open Source Software for Machine Learning (1 hr)

3. PART-3 Applications of Machine Learning in Cyber-Physical Systems (10 hrs)

3.1. Machine Learning Challenges in Cyber Physical Systems

3.2. Case Studies

Industry 4.0 aims to use digital interventions to optimize industrial processes, including product development, quality improvement, fault detection, waste reduction etc. Case studies related to application of statistical and machine-learning techniques such as regressions, data mining, clustering, classification using support vector machine, and neural networks will help generate awareness for such advanced solutions in the industry. The following are suggested use case, but our industrial partners may contribute many others.

- 3.2.1. <u>Case Study 1: Predicting Product design (3 hrs)</u>

Application of machine learning in product design phase is emerging as a promising area for the analysis of large scale data and use of the extracted knowledge for the design of optimal product and system.

In recent years, several machine learning techniques such as Neural Network, Support Vector Machine, and a few other are popularly deployed in different ways to support the product design including material selection.

A few case studies are related to automotive disc brake design, bicycle/hydraulic support system will be discussed to explain how the clustering with machine learning approach can be applied to above problem.

3.2.2. Case Study 2:Tool/Machine condition monitoring and fault diagnosis (3 hrs)

Fault detection and diagnosis have an effective role for the safe operation and long life of systems. This case study will help in understanding SVM-NN based classification for detecting fault in tool machine with different attributes such as temperature, pressure, vibration etc.

3.2.3. Case Study 3: Surface roughness prediction for quality control (3 hrs)

In many steel industry products, surface roughness is the indicator of product quality and achieving the desired surface quality is of great importance for the best functional behavior of the product. This case study will help in understanding the role of process parameters such as tool geometry, cutting conditions (i.e. feed rate, cutting speed, depth of cut, etc.) and work-piece properties in predicting the surface roughness using SVM and related methods.

3.3. Future Research Problems and Conclusion (1 hrs)