Indian Institute of Technology Kanpur
Proposal for a New Course

1. Course No: ME6##
2. Course Title: Intelligent Manufacturing
3. Per Week Lectures: 3 (L), Tutorial: 0 (T), Lab: 0 (P), Additional Hours [0-2]: 0 (A), Credits: (3*L+2*T+P+A): 9; Course Duration: Full Semester
4. Proposing Department: ME
   Other Departments/IDPs which may be interested in the proposed course: -
   Other faculty members interested in teaching the proposed course: -
5. Proposing Instructor: Mohit Law
6. Course Description: This course examines the principles of Intelligent Manufacturing. Topics include sensor-based data acquisition, experimental design, signal and image analytics, and statistical and machine learning methods for monitoring, diagnosis, and prognosis. Through structured case studies and laboratory exercises, students explore how predictive models enable adaptive decision-making, self-optimizing processes, and cyber-physical manufacturing systems.

A) Objectives:

1. Design measurement and data acquisition strategies for manufacturing processes and systems.
2. Apply statistical and machine learning methods to model and monitor manufacturing processes.
3. Assess the deployment considerations of intelligent models in manufacturing systems.

B) Contents:

S. No	Broad Title	Topics	# Lectures
1	Introduction to Intelligent Manufacturing	Definitions and scope (Industry 4.0, IIoT, digital twins, OEE, AI in manufacturing); overview of manufacturing processes; global trends; why/what/how to measure; role of data in decision-making. Scope will exclude: inventory management for manufacturing, and supply chain related issues.	2-3
2	Data Acquisition	Sensor selection; force, temperature, vibration, acoustics, imaging sensors and their working principes; hardware platforms; communication protocols and data exchange standards.	4-5
3	Design of Experiments for Data Generation	Factors and responses; full and fractional factorial designs; interaction effects; Taguchi methods; response surface methodology.	3-4
4	Data Analysis and Visualization	Signal preprocessing; Time-, frequency-, and time–frequency feature extraction; stationary and non-stationary signals and processes; image processing and feature extraction (edge detection, optical flow, motion magnification); data visualization and overview HMI design.	6-8
5	Data-Based Decision Making and Machine Learning	Monitoring–diagnosis–prognosis framework; regression and classification; overview of SVM, decision trees, ANNs, CNNs, and reinforcement learning; self-optimizing systems; adaptive model updating; data augmentation; model validation and explainability; standards for machine health monitoring.	6-8
6	Cyber-Physical Manufacturing Systems	Concept of CPS; digital models, shadows, and twins; edge vs cloud analytics; human-in-the-loop decision systems.	2-3
7	Statistical Foundations of Intelligent Process Monitoring	Statistical stability, process variability, and control limits; capability indices; integration of SPC with machine learning-based monitoring; drift detection and adaptation.	3-4

8	Closed-Loop Intelligent Monitoring	Closed-loop monitoring; adaptive parameter control; predictive maintenance deployment; integration with controllers; alarm thresholds.	2-3
9	Case Studies and Applications	Spindle monitoring; tool wear monitoring; weld/part inspection; structural monitoring; friction stir welding; deformation processes; chatter detection; thermal error compensation, corrosion, energy and emission monitoring.	5-6
10	Deployment and Implementation Challenges	Legacy machine integration; labelling; latency constraints; interoperability; ROI and economic considerations.	2

C) Pre-requisites, if any: None; however, basic knowledge of manufacturing processes, linear algebra, and programming is desirable.

D) Short summary for including in the Courses of Study Booklet: This course introduces Intelligent Manufacturing, covering sensor-based data acquisition, experimental design, signal and image analytics, and statistical and machine learning methods for process monitoring and prognosis. Through case studies and laboratory exercises, students learn how predictive models enable adaptive decision-making and self-optimizing manufacturing systems.

7. Reference material: There are no standard text books for this course/subject. We will instead rely on published papers and reference books. A representative list is provided below:

   Key papers:

- Jay Lee, Behrad Bagheri, Hung-An Kao, A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems, Manufacturing Letters, Volume 3, 2015, Pages 18-23, ISSN 2213-8463, https://doi.org/10.1016/j.mfglet.2014.12.001.
- A.C. Pereira, F. Romero, A review of the meanings and the implications of the Industry 4.0 concept, Procedia Manufacturing, Volume 13, 2017, Pages 1206-1214, ISSN 2351-9789, https://doi.org/10.1016/j.promfg.2017.09.032.
- Jay Lee, Hossein Davari, Jaskaran Singh, Vibhor Pandhare, Industrial Artificial Intelligence for industry 4.0-based manufacturing systems, Manufacturing Letters, Volume 18, https://doi.org/10.1016/j.mfglet.2018.09.002.
- Guodong Shao, Moneer Helu, Framework for a digital twin in manufacturing: Scope and requirements, Manufacturing Letters, Volume 24, 2020, Pages 105-107, ISSN 2213-8463, https://doi.org/10.1016/j.mfglet.2020.04.004.
- S. Joe Qin, Survey on data-driven industrial process monitoring and diagnosis, Annual Reviews in Control, Volume 36, Issue 2, 2012, Pages 220-234, ISSN 1367-5788, https://doi.org/10.1016/j.arcontrol.2012.09.004.
- Andrew K.S. Jardine, Daming Lin, Dragan Banjevic, A review on machinery diagnostics and prognostics implementing condition-based maintenance, Mechanical Systems and Signal Processing, Volume 20, Issue 7, October 2006, Pages 1483-1510, https://doi.org/10.1016/j.ymssp.2005.09.012
- Wu, H.; Ji, P.; Ma, H.; Xing, L. A Comprehensive Review of Digital Twin from the Perspective of Total Process: Data, Models, Networks and Applications. Sensors 2023, 23, 8306. https://doi.org/10.3390/s23198306
- Aiwina Heng, Sheng Zhang, Andy C.C. Tan, Joseph Mathew, Rotating machinery prognostics: State of the art, challenges and opportunities, Mechanical Systems and Signal Processing, Volume 23, Issue 3, April 2009, Pages 724-739, https://doi.org/10.1016/j.ymssp.2008.06.009
- Robert X. Gao, Jörg Krüger, Marion Merklein, Hans-Christian Möhring, József Váncza, Artificial Intelligence in manufacturing: State of the art, perspectives, and future directions, CIRP Annals, Volume 73, Issue 2, 2024, Pages 723-749, ISSN 0007-8506, https://doi.org/10.1016/j.cirp.2024.04.101.
- Andreas Archenti, Wei Gao, Alkan Donmez, Enrico Savio, Naruhiro Irino, Integrated metrology for advanced manufacturing, CIRP Annals, Volume 73, Issue 2, 2024, Pages 639-665, ISSN 0007-8506, https://doi.org/10.1016/j.cirp.2024.05.003.
- Hoda ElMaraghy, Laszlo Monostori, Guenther Schuh, Waguih ElMaraghy, Evolution and future of

manufacturing systems, CIRP Annals, Volume 70, Issue 2, 2021, Pages 635-658, ISSN 0007-8506, https://doi.org/10.1016/j.cirp.2021.05.008.

- Robert X. Gao, Lihui Wang, Moneer Helu, Roberto Teti, Big data analytics for smart factories of the future, CIRP Annals, Volume 69, Issue 2, 2020, Pages 668-692, ISSN 0007-8506, https://doi.org/10.1016/j.cirp.2020.05.002.
- N. Anwer, R. Stark, F. Tao, J.A. Erkoyuncu, Developing and leveraging digital twins in engineering design, CIRP Annals, Volume 74, Issue 2, 2025, Pages 843-868, ISSN 0007-8506, https://doi.org/10.1016/j.cirp.2025.05.002.
- Mert Onuralp Gökalp, Ebru Gökalp, Kerem Kayabay, Altan Koçyiğit, P. Erhan Eren, Data-driven manufacturing: An assessment model for data science maturity, Journal of Manufacturing Systems, Volume 60, 2021, Pages 527-546, ISSN 0278-6125, https://doi.org/10.1016/j.jmsy.2021.07.011.
- Fei Tao, Qinglin Qi, Ang Liu, Andrew Kusiak, Data-driven smart manufacturing, Journal of Manufacturing Systems, Volume 48, Part C, 2018, Pages 157-169, ISSN 0278-6125, https://doi.org/10.1016/j.jmsy.2018.01.006.
- H.-C. Möhring, P. Wiederkehr, K. Erkorkmaz, Y. Kakinuma, Self-optimizing machining systems,
- CIRP Annals, Volume 69, Issue 2, 2020, Pages 740-763, ISSN 0007-8506, https://doi.org/10.1016/j.cirp.2020.05.007.
- Other key papers from the Journal of Intelligent Manufacturing and the Journal of Manufacturing Systems.

Reference Books:

- Bentley, J., Principles of Measurement Systems, 4th edition.
- Randall, R.B., Vibration-Based Condition Monitoring
- Richard DeVor, Tsong-how Chang, John Sutherland, Statistical Quality Design and Control: Contemporary Concepts and Methods
- Lihui Wang and Xi Vincent Wang, Cloud-Based Cyber-Physical Systems in Manufacturing,

8. Any other remarks: Classroom lectures will be complemented by laboratory exercises. These exercises will be conducted in lieu of some classroom lectures, and as such no separate laboratory credits are factored into the course. Four potential lab concepts are listed below:
   - Lab 1: Acquisition and analysis of vibration data from a rotating system (for example, a spindle), including signal preprocessing and extraction of time- and frequency-domain features for condition monitoring.
   - Lab 2: Design and execution of factorial experiments to model process responses (for example, machining processes or other primary/secondary manufacturing processes) and construct surrogate models for parameter optimization.
   - Lab 3: Development and validation of statistical and machine learning models for manufacturing condition monitoring using industrial-style datasets (for example, spindle bearing health monitoring).
   - Lab 4: Implementation of a simple reinforcement learning or adaptive control scheme for process parameter optimization.

Dated: 8th March 2026 Proposer: Mohit Law, ME

Dated:_____ DPGC Convener:_____

The course is approved / not approved

Chairman, SUGC/SPGC

Dated:_____