DIGITAL TWIN
(AEI3233)

Time Allotted : 2½ hrs **Full Marks : 60**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 4 (four) from Group B to E, taking one from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A

1. Answer any twelve: **12 × 1 = 12**

Choose the correct alternative for the following

(i) Which of the following is a key characteristic of a Digital Twin?
(a) Manual synchronization (b) One-way data flow
(c) Closed-loop feedback (d) Offline processing

(ii) In a Digital Model, how is data transferred from the physical system to the digital system?
(a) Automatically (b) Manually
(c) In both directions automatically (d) Continuously without control

(iii) In a cyber-physical system, what does a Digital Twin mainly represent?
(a) Historical lifecycle data
(b) Only the design of the system
(c) The current real-time condition of the system
(d) The cost of manufacturing

(iv) What is the main purpose of modelling paradigms in a Digital Twin?
(a) To store sensor data
(b) To represent the physical system digitally
(c) To design hardware components
(d) To replace cloud computing

(v) What is a major limitation of data-driven models?
(a) High computational cost (b) Cannot predict unseen scenarios
(c) Requires physical equations (d) Works only offline

(vi) What is the main function of a Kalman Filter
(a) To store data
(b) To visualize signals
(c) To combine model predictions with sensor measurements
(d) To replace sensors

(vii) Why are NumPy arrays faster than Python lists?
(a) They allow mixed data types
(b) They are stored in contiguous memory
(c) They use more memory
(d) They avoid indexing

(viii) What is SciPy primarily used for?
(a) Web development (b) Scientific and engineering computations
(c) Database management (d) Graphics design

(ix) What is the main idea of Deep Learning?
(a) Using single-layer models
(b) Using multi-layer neural networks to learn complex patterns
(c) Storing large datasets
(d) Performing sorting operations

(x) What is the purpose of backpropagation?
(a) To initialize weights
(b) To compute gradients of loss with respect to parameters
(c) To store model outputs
(d) To visualize data

Fill in the blanks with the correct word

(xi) A Digital Twin is a _____ representation of a physical system that stays synchronized in real time.

(xii) Automatic two-way data exchange between physical and digital systems is called _____.

(xiii) The SciPy library is built on top of the _____ library.

(xiv) In a neural network, the function used to measure prediction error is called the _____ function.

(xv) In Reinforcement Learning, the _____ function provides feedback to the agent based on its actions.

Group - B

2. (a) Explain the concept of a Digital Twin and its key characteristics. *[(CO1)(Analyse/HOCQ)]*
(b) Differentiate between Digital Model, Digital Shadow, and Digital Twin with suitable examples? *[(CO2)(Remember/LOCQ)]*
(c) Describe the role of Digital Twin in Cyber-Physical Systems. *[(CO2)(Apply/IOCQ)]*
4 + 5 + 3 = 12

3. (a) Define Digital Twin and explain its core components. *[(CO3)(Analyse/HOCQ)]*
(b) Compare Digital Twin and Digital Thread in terms of functionality and purpose. *[(CO1)(Remember/LOCQ)]*
(c) Explain how Digital Twins improve decision-making in industrial systems. *[(CO2)(Apply/IOCQ)]*

(d) Discuss the role of IoT in enabling Digital Twin technology. *[(CO2)(Apply/IOCQ)]*

4 + 4 + 2 + 2 = 12

Group - C

4. (a) Define physics-based modelling and state its key features. *[(CO3)(Analyse/HOCQ)]*
   (b) Explain the limitations of physics-based models. *[(CO4)(Remember/LOCQ)]*
   (c) Analyse the trade-off between accuracy and computational cost. *[(CO2)(Apply/IOCQ)]*
   (d) Discuss the application of physics-based modelling in engineering systems. *[(CO2)(Apply/IOCQ)]*

3 + 3 + 2 + 4 = 12

5. (a) Define hybrid (grey-box) modelling with a suitable example. *[(CO3)(Analyse/HOCQ)]*
   (b) Explain how hybrid models combine physical laws with data-driven corrections? *[(CO4)(Remember/LOCQ)]*
   (c) Analyse why hybrid models often outperform purely physics-based or purely data-driven models. *[(CO2)(Apply/IOCQ)]*
   (d) Suggest practical engineering applications where hybrid modelling is essential. *[(CO2)(Apply/IOCQ)]*

3 + 3 + 4 + 2 = 12

Group - D

6. (a) Compare and contrast the mathematical objectives of Non-linear Curve Fitting versus Data Interpolation when analysing discrete sampled sensor data. *[(CO3)(Analyse/HOCQ)]*
   (b) Describe how scipy.optimize.curve_fit can be utilized to map a thermistor's non-linear voltage output to a physical temperature quantity using least squares? *[(CO4)(Remember/LOCQ)]*
   (c) Explain the mechanism of Cubic Splines in data interpolation and how it ensures smooth first and second derivatives between discrete data points. *[(CO5)(Apply/IOCQ)]*
   (d) Discuss the application of scipy.linalg for solving inverse matrices and linear systems (Ax=b) in state-space control. *[(CO4)(Apply/IOCQ)]*

3 + 3 + 3 + 3 = 12

7. (a) Define the core concept of a Digital Twin and identify its three pillars Physical Entity, Virtual Entity, and Data Link. *[(CO3)(Analyse/HOCQ)]*
   (b) How does continuous real-time synchronization via IoT streams differentiate a Digital Twin from a traditional static simulation? *[(CO4)(Remember/LOCQ)]*
   (c) Outline the roles of Cloud Computing and 5G Connectivity as the technological backbone required to host and synchronize Digital Twins across factory floors. *[(CO3)(Apply/IOCQ)]*
   (d) Explain how Artificial Intelligence and Machine Learning models predict future system states and complex failures within a Digital Twin environment. *[(CO3)(Apply/IOCQ)]*

3 + 3 + 3 + 3 = 12

Group - E

8. (a) Discuss why Neural Networks are required to approximate Q(s,a) in Deep Q-Networks (DQN) for continuous state spaces. *[(CO3)(Analyse/HOCQ)]*

   (b) Formulate the DQN Loss Function and describe how the target y_t is calculated. *[(CO4)(Remember/LOCQ)]*

   (c) Explain the concept of Experience Replay in DQN and how it stabilizes training. *[(CO6)(Apply/IOCQ)]*

   (d) Detail the necessity of maintaining a frozen Target Network (θ^-) in DQN architectures. *[(CO2)(Apply/IOCQ)]*

3 + 3 + 3 + 3 = 12

9. (a) Define the role of Keras Callbacks in managing the deep learning training loop. *[(CO4)(Analyse/HOCQ)]*

   (b) Compare the Early Stopping callback with the Model Checkpoint callback in their methods of optimizing model deployment. *[(CO4)(Remember/LOCQ)]*

   (c) Explain how the ReduceLROnPlateau scheduler assists the optimization process over multiple epochs. *[(CO5)(Apply/IOCQ)]*

   (d) Using the Keras Functional API, describe how to merge multiple input branches (e.g., numerical data and text embeddings) before a dense output layer. *[(CO5)(Apply/IOCQ)]*

3 + 3 + 3 + 3 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	28.12	44.79	27.09