LIST OF ENTRANCE EXAM QUESTIONS

FOR THE INTERNATIONAL MASTER'S DEGREE PROGRAM

ITMO

ROBOTICS AND ARTIFICIAL INTELLIGENCE

Please note: Questions are separated to 4 (four) different topic areas. At the start of the exam you can select any 2 (two) of these topic areas, and your exam questions will be only from the selected topic areas.

I. CONTROL THEORY

1. Control system design. Basic components of control system and system configurations.
2. Standard mathematical models of systems: input-output models, state-space models.
3. Dynamic system linearization with evaluation of Jacobian matrix.
4. Block diagram transformations: series, parallel and feedback connection.
5. Structural properties of systems: controllability and observability.
6. First-order and second-order systems: transfer functions, step response, impulse response.
7. Stability of continuous-time systems: definition, the s-plane root location, Routh-Hurwitz stability criterion.
8. Lyapunov's method of determining the stability of continuous-time systems.
9. The Nyquist stability criterion. Stability of time-delay systems.
10. Performance characteristics (specifications) of system: overshoot, settling time, steady-state error, relative stability, damping ratio.
11. Steady-state accuracy. Steady-state errors in unity-feedback control systems with different type number (the number of integrations).
12. Standard characteristic polynomials: Butterworth polynomials, binomial polynomials.
13. Stabilization of linear system by modal control (pole placement).
14. Full-order and reduced-order state observers for continuous-time systems (Luenberger observer).

RECOMMENDED READING

1. Karl Johan Åström and Richard M. Murray, Feedback systems: an introduction for scientists and engineers // Princeton University Press, 2008.
2. Dorf, Richard C., and Robert H. Bishop. Modern Control Systems, Pearson, 13th Edition, 2017.
3. F.W. Fairman, Linear control theory. The state space approach, John Wiley & Sons, 1998.
4. K. Ogata, Modern Control Engineering, Prentice-Hall, Englewood Cliffs, NJ, USA, 3rd edition, 1997.

II. ML AND IMAGE PROCESSING

1. Machine learning. Types of ML Problems. Supervised learning. Overfitting, detection, and prevention.
2. Single-layer Neural Networks (Perceptrons). Linearly separable classifications. Solving XOR problem with a single perceptron and several perceptrons.
3. Artificial neural networks. Kolmogorov's theorem. Neural network architectures and applications.
4. The Backpropagation Algorithm. The gradient descent method. Training feed-forward neural networks using the gradient descent method and its modifications.
5. Reinforcement learning. Basic concepts. Optimal strategy. The Bellman equation.
6. Model-based reinforcement learning algorithms. Dynamic Programming.
7. Temporal Difference Learning. On-policy vs off-policy algorithms: advantages and disadvantages.
8. Temporal Difference Learning: SARSA. Advantages and disadvantages.
9. Temporal Difference Learning: Q-Learning. Advantages and disadvantages.

10. High-Pass Filtering of Digital Images. Canny Algorithm.
11. Nonlinear Filtering of Digital Images. Weighted Nonlinear Filtering.
12. Geometric Transformation of Digital Images. Conformal, Affine, Projection Transformations.
13. Digital Images. General Parameters, Contrast, Histograms, Profiles, Projections.
14. Morphological Operations for Binary Digital Images.

RECOMMENDED READING

1. Peter Corke, Robotics, Vision and Control // Advanced Textbooks in Control and Signal Processing – Springer London, 2017. https://petercorke.com/books/robotics-vision-control-all-versions/
2. Lonza, Andrea. Reinforcement Learning Algorithms with Python: Learn, understand, and develop smart algorithms for addressing AI challenges. Packt Publishing Ltd, 2019.
3. Sutton, R.S. and Barto, A.G. Reinforcement learning: An introduction. MIT press, 2018
4. Haykin, S.S. Neural networks and learning machines, 2009.
5. Shalev-Shwartz, S. and Ben-David, S. Understanding machine learning: From theory to algorithms. Cambridge university press, 2014.
6. Rolf Isermann, Digital Control Systems: Volume 1: Fundamentals, Deterministic Control, 2nd Edition, ISBN 978-3-642-86417-9, Springer Science & Business Media, 2013, P. 336.
7. M. Sami Fadali, Antonio Visioli, Digital control engineering: analysis and design, Second edition. ISBN 978-0-12-394391-0, Academic Press, 2012, P. 600.

III. ROBOTIC SYSTEMS HARDWARE

1. Executive drives of robotic systems: electromechanical, pneumatic, hydraulic. Classification, principles of work and features.
2. Brushless and brushless DC motors. Stepper motors.
3. Compliant drives. Constant and variable compliance drives. Principles of operation and classification.
4. Excitation circuits of DC motors.
5. Methods for regulating the rotor speed of asynchronous motors.
6. Speed and acceleration sensors of robotic systems. Types, main characteristics.
7. Force and moment sensors for robotic systems. Types, main characteristics.
8. Distance sensors of robotic systems: ultrasonic rangefinders, time-of-flight cameras, lidars, structured light cameras. Principles of operation and design features.
9. Main interfaces for data transmission: RS-485, RS-232, CAN. Features of work and basic parameters.
10. Main data transfer protocols: I2C, SPI, UART. Features of work and basic parameters.
11. Processor architectures. Comparison of von Neumann architecture and Harvard architecture.
12. Bitwise operations. Bit shifts.
13. ARM architecture description.
14. Microcontroller registers. Principles of working with microcontroller peripherals.

RECOMMENDED READING

1. David Cook. Robot Building for Beginners (Technology in Action). Apress; 3rd edition, 2015.
2. ST Microcontrollers & Microprocessors Documentation https://www.st.com/en/microcontrollers-microprocessors.html#documentation

IV. MECHANICS AND MODELLING OF ROBOTS

1. Purpose, classification, and design features of industrial, collaborative, service, wearable, and rehabilitation robotic systems and devices.
2. Structural analysis of robotic systems. Classification of joints. Degree of freedom.
3. Mechanisms for robotic systems. Robots' classification with respect to kinematic structures.
4. Kinematic analysis of multi-link robots of open and closed kinematics. Direct and inverse kinematics.
5. Generalized coordinates and configuration spaces. Choice of local coordinate systems. Rotation matrices and homogeneous transformation matrices, their purposes, and main properties.
6. Holonomic and nonholonomic constraints.
7. The Euler-Lagrange equation. A dynamic model of a multi-link robot. Derivation of the equations of motion and main properties.
8. Direct and inverse dynamics.
9. Motion transformation by means of gears: cylindrical, bevel, planetary, differential.
10. Motion transformation by means of gears: worm, strain wave, friction.
11. Motion transformation by means of planar and spatial linkages.
12. Motion transformation by means of flexible elements. Chain, belt, and cable transmissions in robotics.
13. Guides, axles, and shafts. Rolling and sliding bearings. Articulation with motors' shafts and sensors.
14. Choice of materials for essential elements and body parts for robotic and mechatronic systems: steels, non-ferrous metals, cast irons and their alloys, plastics, and composite materials.

RECOMMENDED READING

1. Spong, Mark W., Seth Hutchinson, and M. Vidyasagar. Robot Modeling and Control. — Hoboken, NJ: John Wiley & Sons, 2006.
2. Lynch, Kevin M., and Frank C. Park. Modern Robotics. Cambridge University Press, 2017.
3. Murray, R. M., Li, Z., Sastry, S. S., & Sastry, S. S. (1994). A mathematical introduction to robotic manipulation. CRC press.