# Integrated Sensor Systems

## Centre for Interdisciplinary Program, IIT Hyderabad

**Background:**

Since 2020, IIT Hyderabad has started an interdisciplinary MTech degree program in Integrated Sensor Systems (ISS). Candidates admitted into the program will be required to do 52 credits which included 28 credits for course work and 24 credits for thesis work. The course work will provide all necessary basic and applied skills for design, fabrication and testing of integrated sensor systems in all areas of importance by using the concept of interdisciplinary science and technology. During the course work, candidates may take courses in Basic Concepts of Smart Materials and Devices, Physics of Low Dimensions Devices, Computational Modelling Techniques, Micro and Nanofabrication Technologies, Circuit and Packaging, Embedded Programming (Design and Lab), Intelligent Signal Processing using AI/IoT, and elective courses in other allied fields. Additionally, in thesis project, a candidate is required to design, analyze, fabricate, and characterize a device to achieve an excellent thesis grade which will enable him/her to get confidence and skills in Integrated Sensor Systems. Most of the projects will be based on industry oriented problems. The program will help the candidates to get excellent industrial as well as academic careers. The program also includes Industry lectures and a course in English communication. The overall program will develop manpower and technopreneurs in the area of sensor technology.

**Duration:** Two Years/Project Sponsored Three Years

**Eligibility:**

BE / B Tech or equivalent degree in any discipline with GATE paper in AE, BT, BM, CE, CH, EE, EC, IN, ME, MT, PH, XE OR MSc or equivalent degree in Electronics, Physics, Chemistry with GATE paper in CY, EC, IN, PH.

**Selection Procedure:**

The MHRD supported candidates will be selected based on **GATE Score**. Self-Sponsored and Industry sponsored candidates will be selected based on **written exam and/or interview**.

Departments: MAE, EE, PHY, CE, MS, BM

Laboratories:

1. Advanced Embedded Systems and Digital IC Design Lab, EE
2. Design of Analog RF Mixed Integrated Circuit Lab, EE
3. Nano-X Clearroom and Characterization Lab, EE
4. Nano Photonics Lab, EE
5. SenAct Lab, ME
6. Micro Mechanics Lab, ME
7. MEMS and Micro/Nanosystems Lab, PHY
8. Many other associated labs in CH, BM, EE, PHY, MS.

A) Name of faculties associated with the program:

1. Dr. Naresh Kumar Emani, EE, Program Co-ordinator
2. Dr. Ashok Kumar Pandey, MAE,
3. Dr. Prem Pal, PHY
4. Dr. Shiv Govind Singh, EE
5. Dr. Asudeb Dutta, EE
6. Dr. Viswanath Chinthapenta, MAE,
7. Dr. Surya Jammalamadaka, PHY
8. Dr. J Mohanty, PHY
9. Dr. Siva Vanjari, EE
10. Dr. K Nayak, EE
11. Dr. Amit Acharyya, EE
12. Dr. Sushmee Badhulika, EE
13. Dr. Shishir Kumar, EE
14. Dr. Abhishek Kumar, EE
15. Dr. Arabinda Haldar , PHY
16. Dr. Chandrasekhar Murapaka, MSME
17. Dr. Ranjith Ramadurai, MSME
18. Dr. Bhabani Shankar Mallik, CHY
19. Dr. Saswata Bhattacharya, MSME
20. Dr. CH. Gajendranath Chaudhury, EE
21. Dr. Suhanya Duraiswamy, CHE
22. Dr. Rajalakshmi Pachamuthu, EE
23. Dr. Falguni Pati , BME
24. Dr. Jyotsnendu Giri, BME
25. Dr. Aravind Kumar Rengan, BME
26. Dr. Shourya Dutta Gupta , MSME
27. Dr. Suresh Kumar Garlapati, MSME

B) Name of Students registered in 2020

1. Mr. Rajan Kumar, 2 Year MTech
   Project title: “Elimination of production cycle induced market inefficiencies with the help of sensor networks and Machine learning”
   Guide Name: Dr. P. Rajalakshmi, EE.

2. Mr. Ashutosh Bilthara, 2 Year MTech
   Project title: “Water pollution monitoring and remedy through Digital systems design using the IoT framework”
   Guide Name: Dr. Amit Acharyya, EE

3. Mr. Dungaram D, 2 Year MTech

Project title: “Design, Fabrication, and Characterization of Uncooled Microbolometer for Thermal Imaging Applications”
Guide Name: Prof. Shiv Govind Singh, EE

4. Mr. Shashi Preetham R, 2 Year MTech
   Project title: “Multiple sensor fusion using kalman filtering”
   Guide Name: Dr. Ketan Detroja., EE

5. Mr. Vipul Prakash, 2 Year MTech
   Project title: “Video Stabilization for Real-time 360 degrees see-through awareness”
   Guide Name: Dr. Amit Acharyya, EE

6. Ms. Sudarshan Yadao, 2 Year MTech
   Project title: “Real time structural health monitoring system design using Acoustic emission sensor”
   Guide Name: Dr. Amit Acharyya, EE

7. Ms. Haimanti De, 2 Year MTech
   Project title: “Real time video acquisition, stitching and systems design for 360 degree see through awareness”
   Guide Name: Dr. Amit Acharyya, EE

8. Ms. Debalina Bhattacharyya, 2 Year MTech
   Project title: “Nanogenerators”
   Guide Name: Dr. Sushmee Badhulika, EE

9. Mr. Tushar Deshpande, 2 Year MTech
   Project title: “Application of AI and ML in predicting heart attacks”
   Guide Name: Prof. Shiv Govind Singh, EE

10. Mr. Supravat Debnath, 3 Year MTech(RA)
    Project title: "Design of power management system for wireless IoT systems"
    Guide Name: Dr. Asudeb Dutta, EE

Name of Students registered in 2021

| S No | Name |
|---|---|
| 1 | VENKATA SAI RAJESH MALLADI |
| 2 | HIMANSHU YADAV |

| | |
|---|---|
| 3 | POONAM KUMARI |
| 4 | SUNNI SAGAR |
| 5 | NIKHITHA AVULA |
| 6 | DEBANGANA DUTTA |
| 7 | AMREEN KAUR |
| 8 | MOHIT GAUR |
| 9 | PALLI VENKATA AISHWARYA |
| 10 | HERSHITA SHUKLA |
| 11 | REHANA SULTANA |
| 12 | NITISH PANI |
| 13 | KRUNAL KANYO BADLANI |
| 14 | SHIKARI SRIKER |
| 15 | ABHINAV PUBBI |
| 16 | MATCHA SAHADEV |
| 17 | PIYUSH PUSHKER |
| 18 | NIKHIL LOHAR |
| 19 | VINAYAK |

**2 Yrs. MTECH (ISS-Integrated Sensor Systems)**

**Total Credit: 52 (28 Theory + 24 Thesis)**

| **Course Code** | **Semester 1** | |
|---|---|---|
| **IS5010** | Smart Material and Transducers | 2 |
| **IS5013** | Fabrication Technology and Characterization | 3 |
| **IS5020** | Physics of low dimensional systems and quantum devices | 3 |
| **IS5030** | Computational modelling techniques | 2 |
| **ISXXXX** | Elective –I (Fundamental/Generic) | 2 (or 3)* |
| **IS5050** | Industry Lecture Series | 1 |
| | Total | 13 |

| | **Semester 2** | |
|---|---|---|
| **IS5023** | Circuits and Packaging | 3 |
| **ISXXXX** | Elective – II | Each 2 (or 3)* |
| **ISXXXX** | Elective – III | |
| **ISXXXX** | Elective – IV | |
| **IS5033** | Embedded Programming | 3 |
| **IS5040** | Intelligent Signal Processing using AI/IoT | 2 |
| **LA5180** | English Communication Skills: Advanced | 1 |
| | Total | 15 |

*** Total elective credits (I+II+III+IV) should not exceed 8.**

| | Semester 3 | |
|---|---|---|
| **IS5015** | Thesis stage -1 | 12 |

| | Semester 4 | |
|---|---|---|
| **IS5025** | Thesis stage -2 | 12 |

**3 Yrs MTECH (ISS-Integrated Sensor Systems) - Interdisciplinary Department**

**Total Credit: 52 (28 Theory + 24 Thesis)**

| Course Code | Semester 1 | |
|---|---|---|
| **IS5010** | Smart Material and Transducers | 2 |
| **IS5013** | Fabrication Technology and Characterization (Theory+Lab) | 3 |
| **IS5020** | Physics of low dimensional systems and quantum devices | 3 |
| **IS5030** | Computational modelling techniques | 2 |
| **ISXXXX** | Elective –I (Fundamental/Generic) | 2 (or 3)* |
| **IS5050** | Industry Lecture Series | 1 |
| | Total | 13 |

| | Semester 2 | |
|---|---|---|
| **IS5023** | Circuits and Packaging | 3 |
| **ISXXXX** | Elective – II | Each 2 (or 3)* |
| **ISXXXX** | Elective – III | |
| **ISXXXX** | Elective – IV | |
| **IS5033** | Embedded Programming (Design+ Lab) | 3 |
| **IS5040** | Intelligent Signal Processing using AI/IoT | 2 |
| **LAXXXX** | English Communication | 1 |
| | Total | 15 |

*** Total elective credits (I+II+III+IV) should not exceed 8.**

| | Semester 3 | |
|---|---|---|
| **IS5035** | Thesis stage -1 | Variable** |

| | Semester 4 | |
|---|---|---|
| **IS5045** | Thesis stage -2 | Variable** |

| | Semester 5 | |
|---|---|---|
| **IS5055** | Thesis stage -3 | Variable** |

| | Semester 6 | |
|---|---|---|
| **IS5065** | Thesis stage -4 | Variable** |

****Total thesis credit = 24 and the distribution per semester to be decided by Guide.**

**Guidelines for Guide and Elective Selection**

1) Guide selection at the end of 1st Semester.
2) For project sponsored student, guide to be assigned at the start of first semester

   Elective I should be taken in consultation with MTech Convener or PI.
3) Electives II, III, and/or IV should be taken in consultation with the guide or PI.
4) Electives I, II, III, and/or IV can be selected from the other departments mentioned previously or any other courses only with the approval of Guide/PI/MTech Convener.
5) Total elective grades (I+II+III+IV) should not exceed 8 credits.
6) Course and thesis credits allocation per semester to be decided with the approval of Guide/PI's for 3 Year MTech.
7) Emphasis can be given on development of sensors or actuators for the thesis work. However, guides/PIs are free to allot the topic of thesis relevant to Integrated Sensors System.

**Electives:**

**I. List of electives under different baskets**

| **Course Code** | **First Semester Electives: Electives I** | |
|---|---|---|
| BM4190 | Biofabrication | 2 |
| MS5010 | Properties of Materials | 3 |
| CY7230 | Nanochemistry and Applications | 3 |
| PB5220 | Advanced Fabrionics | 2 |
| MS5030 | Materials Synthesis and Characterization | 3 |
| EE 5181 | Semiconductor Devices Modeling | 3 |
| EE6410 | Biomedical IC Design | 3 |
| EE5183 | Analog IC Design | 3 |
| | | |

| **Course Code** | **2nd Semester Electives II + III + IV** | |
|---|---|---|
| PH6168 | Spintronics | 2 |
| EE6151 | Topics in Nanophotonics | 2 |
| EE6320 | Wireless sensor network | 3 |
| EE6160 | Mesoscopic Carrier Transport | 2 |
| EE6151 | Topics in Nanophotonics | 2 |
| EE5137 | Mixed Signal Circuit Design | 2 |
| EE5192 | Integrated Circuits for Wireless Communication | 3 |
| EE6120 | Nanoelectronics: Principles and Devices | 3 |
| EE5186 | Digital IC design Theory | 2 |
| EE5187 | Digital IC Design Lab | 1 |
| CH5390 | Microfluidic Platform for Cell Culture & Diagnostics (3D Printer) | 1 |
| EE5188 | Analog IC Design Lab | 1 |
| EE 6180 | Semiconductor Heterojunction Devices Physics | 3 |
| EE 6170 | Mesoscopic Device Electronics | 3 |
| CC 5130 | Atmospheric Electricity | 2 |
| IS5060 | 3D Printed Sensors | 1 |

**II. Complete Lists of Electives:**

With the permission of Guide/MTech co-ordinator, a student can select alternate elective from the below mentioned list or any other suitable course from other department.

| Course Code | Courses from other departments | Credits |
|---|---|---|
| BM4190 | Biofabrication | 2 |
| BM6110 | Nano medicine | 2 |
| PB5220 | Advanced Fabrionics | 2 |
| CH5390 | Microfluidic Platform for Cell Culture & Diagnostics | 1 |
| CH5290 | Introduction to Microfluidics and Micro reactors | 2 |
| CY7040 | Organic Electronics and Photonics | 3 |
| CY7230 | Nanochemistry and Applications | 3 |
| CY5230 | Statistical Thermodynamics and Surface Science | 3 |
| CY5220 | Solid State Chemistry | 3 |
| EE6150 | Nanophotonics and Metamaterials | 3 |
| EE5611 | Machine Learning Applications for Wireless Communications | 2 |
| EE5607 | ML – Hardware Implementation | 1 |
| EE5167 | Embedded System Hardware and Design | 2 |
| EE5147 | Digital IC Design | 2 |
| EE5148 | Digital IC Design Lab | 1 |
| EE5127 | Analog IC Design | 2 |
| EE5128 | Analog IC Design Lab | 1 |
| EE5158 | Advanced Digital IC Design | 2 |
| EE5159 | Microfabrication and Device Simulation Laboratory | 2 |
| EE5110 | Semiconductor Device Modeling | 3 |
| EE6120 | Nanoelectronics: Principles and Devices | 3 |
| EE6160 | Mesoscopic Carrier Transport | 2 |
| EE6410 | Biomedical IC Design | 3 |
| EE7110 | More Than Moore Electronics | 3 |
| ME5010 | Mathematical Methods for Engineers | 3 |
| ME5130 | Finite Element Method | 3 |
| ME5080 | Scaling Laws and Multi-scale Manufacturing | 1.5 |
| MS5010 | Properties of Materials | 3 |
| MS5030 | Materials Synthesis and Characterization | 3 |
| MS5080 | Thin Films Technology | 3 |
| MS5140 | Introduction to Computational Methods in Materials Science | 3 |
| MS5270 | 2d Materials: Synthesis, Characterization and Applications | 3 |
| PH6168 | Spintronics | 2 |
| PH6448 | Microfabrication Techniques | 2 |
| PH7013 | Advanced Optical Instrumentation | 3 |
| CS6510 | Applied Machine Learning | 3 |
| IS5060 | 3D Printed Sensors | 1 |

**IS5010: Smart Material and Transducers (Credit 2)**

**Instructors:** *Ranjith Ramadurai and Sushmee Badhulika*

Introduction to band formation in metals and semiconductors, Classification of materials in band theory - Semiconductor Quantum structures - Thermodynamics of Materials property, Nye-Pyramid- Introduction to Smart materials - dielectrics - Pyro/Piezo electrics - Ferroelectrics - Piezoelectric MEMS. Electrostatic actuation in MEMS.

Different types of sensors and their sensing mechanisms (Temperature sensors, Metal oxide sensors, Potentiometric sensors, Chemical sensors), Introduction to smart systems and their applications

References:


1. K.Uchino "Advanced Piezoelectric materials science and technology" Woodhead publishing
2. J.F. Nye "Physical properties of Crystals, Oxford Science publishers
3. S. D. Senturia, "Microsystem Design", Springer, NewYork, USA.
4. Alberto Corigliano, Raffaele Ardito, Claudia Comi, Attilio Frangi, Aldo Ghisi, Stefano Mariani "Mechanics of Microsystems", John Wiley & Sons, 20-Nov-2017.
5. Harmeet Bhugra, Gianluca Piazza, "Piezoelectric MEMS Resonators", Springer, 09-Jan-2017.


**IS5013: Fabrication Technology and Characterization (Credit 3)**

**Instructors:** *Prem Pal and Shiv Govind Singh*

Fabrication methods for Microelectromechanical systems (MEMS): Microstereolithography, Lithography, Galvanoformung, Abformung (LIGA), Micromachining, etc., Surface micromachining, Bulk micromachining, Dry bulk micromachining, Deep reactive Ion Etching (DRIE), Wet chemical-based micromachining. Thin film, 3-D ICs Fabrication, Modelling challenges, Material, Mechanical and Electrical characterization.

References


1. M. Gad-el-Hak, "The MEMS Handbook". 2nd edition. CRC Press.
2. M. Tilli. T. Motooka, V. M. Airaksinen, S. Franssila, M. P. Krockel, V. Lindroos, "Handbook of Silicon Based MEMS Materials and Technologies", William Andrew
3. P. Pal, and K. Sato, "Silicon wet bulk micromachining for MEMS". CRC Press.
4. M. Elwenspoek, H. Jansen, "Silicon Micromachining". Cambridge University Press, UK.
5. T. R. Hsu, "MEMS & Microsystems: Design and Manufacture", Tata McGraw-Hill Publishing Company Ltd, New Delhi, India.
6. Marc Madou, "Fundamental of microfabrications: the science of miniaturization", 2nd Edition, CRC Press, New York.


**IS5050: Industry Lecture Series (Credit 1)**

**Instructors:** *Amit Acharya and Asudeb Dutta*

There will be 12 to 14 lecture series by different industry experts.

**IS5020: Physics of Low Dimensional Devices and Quantum Devices (Credit 3)**

**Instructors:** *Surya Jammalamadaka + Jyoti Mohanty*

Phonons and lattice dynamics, Free electron theory and Band theory of solids, Density of states, 1D, 2D and 3D, Effective mass tensors in low dimensions. Heterostructure concepts and low dimensional systems such as quantum wells, nanowires and quantum dots. Quantum physics applied to such systems. Optical properties of low dimensional systems (transition rules, polarization etc.). Transport properties of 2D and 1D systems. Quantized conductance with Landauer-formalism. Scattering phenomena in 1D. Devices based on quantum phenomena and Coulomb blockade. Magnetic nanowires, Domain wall motion devices, Magnetic nanoparticles and applications to data storage, the dielectric function and optical absorption. Excitons and plasmonics, Raman scattering and photoluminescence.

References


1. Davies, J H, “The Physics of Low-dimensional Semiconductors: An Introduction”, Cambridge University Press 1997. ISBN: 052148491X
2. Kittel, Charles, “Introduction To Solid State Physics” 8Th Ed
3. Martin T. Dove, “Structure and dynamics”, Oxford University press, 2002
4. John Singleton, “Band Theory and Electronic Properties of Solids”, Oxford University press, 2001.
5. Stephen Blundell, “Magnetism in condensed matter”, Oxford University press, 2001.
6. F.Iacomi, “Spectroscopia vibraţională a materialelor zeolitice,” Ed. Stef, Iasi, 2007
7. L.David, C.Craciun, O.Cozar, V.Chis, Rezonanta “Electronica de Spin. Principii. Metode. Aplicatii”. Presa Universitara Clujeana, Cluj-Napoca, 2001
8. S. E. Lyshevski, “Nano and Molecular Electronics”, CRC Press Taylor & Francis Group 2007


**IS5030: Computational modelling techniques (Credit 2)**

**Instructors:** *Ashok Kumar Pandey, Bhabani S. Mallik, Vishwanath Chinthpenta*

Review of computational techniques in linear and nonlinear algebra equations, Ordinary and partial differential equations. Minimization of function and functionals. Euler-Lagrange equation. Modeling across different length and time scales in micro and nanosystems. Theory of Atomistic simulations: Molecular Dynamics and Monte Carlo methods and their applications in materials modelling. Introduction to Finite Element Method in Multiphysics Modeling Multiphysics Simulations

References:


1. Richard Lesar, “Introduction to Computational Materials Science”, Materials Research Society, Publisher: Cambridge English; First South Asian Edition edition (2016).
2. Daan Frenkel and Berend Smit, “Understanding Molecular Simulation: From Algorithms to Applications”, 2nd Edition -, Academic Press.
3. J N Reddy, “An Introduction to the Finite Element Method”, J N Reddy, McGraw Hill Education, July 2017.
4. Attilio Frangi, “Advances in Multiphysics Simulation and Experimental Testing of MEMS”, World Scientific, 2008
5. John A. Pelesko, David H. Bernstein, “Modeling MEMS and NEMS”, CRC Press, 25-Nov-2002.


**IS5023: Circuits and Packaging (Credit 3)**

**Instructors:** *Asudeb Dutta, Ch. Gajendranath Chaudhary, Ashutosh Kumar*

RLC circuits, Amplifier, OPAMP/OTA, Comparator, Data Converter, Clock generation. MOSFET Fundamentals, CMOS logic Circuits, Memory, RTL coding, Die-bonding, Chip Packaging, SiP/SoP

References


1. Behzad Razhavi, “Fundamentals of Microelectronics”, Wiley 2013
2. Bob Dobkin, Jim Williams, “Analog Circuit Design: A Tutorial Guide to Applications and Solutions” Newnes; 1 edition (January 9, 2013)
3. William J. Greig, “Integrated Circuit Packaging, Assembly and Interconnections”, Springer, Boston, MA, 2003
4. John P. Uyemura, “CMOS Logic Circuit Design”, Kluwer Academic Publishers, New York, 2002.


**IS5033**: **Embedded Programming (Credit 3)**

**Instructor:** *Shishir Kumar*

Introduction to Embedded Systems, Architectures of embedded processors, Memory hierarchy and its management Basics of Microcontrollers –timers, interrupts, analogy to digital conversion, bootloaders Interaction with devices -buses, memory management, device drivers and wireless comm., Interfacing sensors, actuators and peripherals. Real-time principles - multi-tasking, scheduling, synchronization Building low-power high-performance systems – code profiling and optimization Architecture, Case Studies of Real time. Microcontrollers/Microprocessor: Arduino, Raspberry-pi, ARM, FPGA, ESP32, RL78etc)

References


1. Hennessy & Patterson "Computer architecture a quantitative approach", Morgan Kaufmann; 5 edition (25 October 2011).
2. Randal E. Bryant & David R. O'Hallaron "Computer Systems: A Programmer's Perspective" Pearson; 2 edition (4 February 2010).
3. https://github.com/gadepall/IOT
4. https://github.com/gadepall/arm-embedded
5. https://github.com/gadepall/arduino
6. https://github.com/gadepall/FPGA


**IS5040: Intelligent Signal Processing using AI/IoT (Credit 2)**

**Instructor:** *Amit Acharya, P. Raja lakshmi*

Algorithms, IC Design Perspective. Different types of signal processing techniques, Traditional Signal Processing algorithms vs. Practical Constraints; Need of an holistic view of Algorithm and VLSI Architecture, Hardware complexity analysis of resource constrained system; Computational Delay analysis of resource constrained system; Trade-off analysis : Arithmetic complexity vs Signal parameters; Wireless Sensor Networks, Network characteristics, Network Design and Challenges, Wireless Sensor Node Architecture and Design, Wireless Sensor Network Architecture, Data Aggregation, Sensor Data storage, Data Management and Processing, Time Synchronisation, Wireless Sensor and Actuator Networks, Network design, Control on Sensor Networks. Role of AI and ML in overall data aggregation, management and processing.

References:


1. Morris Mano “Digital Design-With an Introduction to the Verilog HDL”, Pearson, Prentice Hall, New Jersey.
2. Hennessey and Patterson, Morgan Kaufmann “Computer Architecture Computer Architecture: A Quantitative Approach” 5 edition (September 30, 2011).
3. Israel Koren, A K Peters, “Computer Arithmetic Algorithms”, CRC Press; 2 edition (November 30, 2001).
4. Jan M. Rabaey, Anantha Chandrakasan, Borivoje Nikolic “Digital Integrated Circuits: A design perspective”, Pearson Education India; Second edition (25 May 2016).
5. Hyeji Kim, Yihan Jiang, Ranvir Rana, Sreeram Kannan, Sewoong Oh, Pramod Viswanath. “Communication Algorithms via Deep Learning”, https://arxiv.org/abs/1805.09317
6. Hyeji Kim, Yihan Jiang, Sreeram Kannan, Sewoong Oh, Pramod Viswanath, “Deepcode: Feedback Codes via Deep Learning”. https://arxiv.org/abs/1807.00801
7. Timothy J. O'Shea, Jakob Hoydis, “An Introduction to Deep Learning for the Physical Layer”, https://arxiv.org/pdf/1702.00832.pdf
8. Timothy J. O'Shea, Tugba Erpek, T. Charles Clancy, “Deep Learning Based MIMO Communications”, https://arxiv.org/pdf/1707.07980.pdf
9. Fayçal Ait Aoudia, Jakob Hoydis, “End-to-End Learning of Communications Systems Without a Channel Model”, https://arxiv.org/pdf/1804.02276.pdf

**IS5040: 3D Printed Sensors (Credit 1)**

**Instructor:** *Suresh Kumar Garlapati, Suhanya Duraiswamy*

Introduction to additive manufacturing and fabrication, 3D printing techniques, principles and applications, principles of sensing, characteristics of sensors, physical sensors, chemical sensors, biosensors, nano and microsensors (nanoparticles, microfluidics)..

References:

1. J. Fraden, Handbook of modern sensors: physics, designs, and applications Springer, 2010.

2. R. Noorani, 3D printing: technology, applications, and selection, CRC Press, 2017.

3. V.K. Khanna, Nanosensors: physical, chemical, and biological, CRC Press, 2011.