Master of Technology in Communications and Signal Processing

Indian Institute of Technology Mandi

M.Tech. in Communications and Signal Processing (CSP)

Preamble

The program is designed giving importance to theory as well as exposure to industry needs. It consists of two parts: course work and a year-long project. The course work is structured to give solid theoretical foundations and practical, hands-on experience which would enable the student to tackle problems in the area of signal processing, communications, and machine learning in a holistic manner.

The one year long project is mostly industry-inspired to be in partnership with industry so that the students solve problems which are of relevance to product design and development. The project is done in-house, the problem definition and part of technical support comes from an industry or reputed government R&D laboratories.

In order to prepare the students for product development by the end of first year, courses like Advanced Programming Practicum, Embedded Systems, IoT Systems, and Systems Design are included in the curriculum. In addition to the post graduate project, these courses familiarize the students with the system design aspects relevant to signal processing, communications, and machine learning.

Objectives of the program

After the completion of the degree, students would

- Be prepared with a varied range of expertise in different aspects of signal processing and communications, such as signal processing, modern communication systems, estimation and detection theories.
- Acquire a good understanding of both the theory and application of signal processing, communications, and machine learning approaches to wide-variety of scenarios in diversified application areas.
- Be able to create models using the knowledge acquired from the program to solve future challenges and real-world problems requiring the knowledge of one or more of signal processing, communications, or machine learning.

- Be better trained professionals to cater to the growing demand for signal processing, communications, machine learning professionals.

Specializations offered

- Communications
- Signal Processing
- Machine Learning

Duration

The duration of this program is two years. Each year consists of two semesters, summer and winter terms.

Eligibility criteria

1. Candidates who have qualified for the award of Bachelor's degree in Engineering / Technology from a recognized University or Institute in Electrical/Electronics and Communication/Telecommunications Engineering (ECE), Telecommunications Engineering (T), Electrical & Electronics Engineering (EEE), Instrumentation (IN) with minimum 60% (CGPA 7.5), and have qualified and have a valid score in Graduate Aptitude Test in Engineering (GATE) in ECE are eligible to apply for admission to the this program.
2. For all B.Techs from IITs graduated with a CGPA of 8.0 or above, the requirement of GATE qualification is waived off.
3. A student sponsored by a recognized R&D organization, academic institution, government organization or industry is eligible to apply for this program on a full-time basis. The Institute does not provide any assistantship to such students.
4. A candidate with Associate Membership of Professional Bodies equivalent to B.Tech., as approved by the Senate and having valid GATE score in ECE shall also be eligible to apply for admission to this program with assistantship, subject to regulations approved by the Senate.

Assistantship (Fellowship/Scholarship)

The award of assistantship shall be in accordance with prevailing norms of the Institute.

Campus stay

Students admitted to these degree programs are required to stay on campus and to participate and complete all requirements of the program.

Placement and Career options

After completion of this program, a student can either go for jobs in public/private sectors or enrol in a PhD program within India or abroad.

Graduates of this program are currently placed in different R&D labs and MNCs, such as, **TCS Innovations Labs, Continental, National Instruments, Hughes Systique, Lekha and WNS** . Some of them are also currently pursuing Ph.D. in various IITs.

Course and Credit Details

General Details

1. There are five discipline core courses. The remaining courses (excluding the open electives) are grouped into three specialization baskets.
2. It is mandatory to take one course from each basket with minimum 9 credits.
3. Students who would like to go for a specialization must take at least 9 more credits (in addition to the mandatory credits in Point 2) from whichever basket they want to specialize in.
4. Those who do not want any specialization can take courses to satisfy 9 credits from across the baskets.
5. The post graduate project is of one year duration.
6. Post graduate projects are industry sponsored whenever possible.
7. Post graduate project starts from the summer following the first year and extends to the third and fourth semesters.

8. Students who would like to go for a specialization must have their post graduate project in the same basket.
9. Systems Design should be taken during the winter break after the first semester.

Minimum credit requirements

Course type	**Credits**
Discipline core (DC)	15
Specialization basket (SB)$	18*
Systems Design	2
Post graduate project	28
Outside discipline electives (OE)#	6
Technical communication	1
Total	**70**

$ Out of these 18 credits, at least 9 credits must be earned by taking one course each from the 3 baskets. At least 9 credits should be chosen from the same basket (if a specialization is desired) or from across baskets (if no specialization is desired.)

Any graduate level course outside of the Communication and Signal Processing discipline from the school or from other schools is acceptable as outside discipline elective.

List of Core courses for M.Tech. in Communications and Signal Processing Program

(Total Credits for discipline core = 15)

Sr. No.	Course title	Lecture	Tutorial	Practical	Total credits	Semester
1	Probability and Random Processes	3	0	0	3	I
2	Matrix Theory for Engineers	3	0	0	3	I
3	Programming Practicum	1	0	3	3	I
4	Applied Optimization	2	0	2	3	II
5	IoT Systems	2	0	2	3	II

I year, Semester 1

Code	Course title	Credits	Remarks
EE534	Probability and Random Processes	3	DC
EE522	Matrix Theory for Engineers	3	DC
CS571	Programming Practicum	3	DC
-	Specialization Basket	3	SB
-	Specialization Basket	3	SB
HS541	Technical Communication	1	
	Total credits	**16**	

I year, Winter break

Code	Course title	Credits	Remarks
EE532	Systems Design	2	Short duration project

I year, Semester 2

Code	Course title	Credits	Remarks
EE530	Applied Optimization	3	DC
EE536	IoT Systems	3	DC
-	Specialization Basket	3	SB
-	Specialization Basket	3	SB
-	Specialization Basket	3	SB
-	Outside discipline electives	3	OE
	Total credits	**18**	

II year, Semester 3

Code	Course title	Credits	Remarks
EE626P	Post Graduate Project	10	First part of the dissertation project
-	Specialization Basket	3	SB
-	Outside discipline electives	3	OE
	Total credits	**16**	

II year, Semester 4

Code	Course title	Credits	Remarks
EE627P	Post Graduate Project	18	Follow up of EE626P

Specializations and related courses

Signal processing

In the signal processing specialization, students are exposed to theoretical and practical aspects of modern signal processing. These include topics like multirate signal processing, graph signal processing and system implementations on embedded systems.

Signal processing basket courses

Code	Course title	L-T-P-C*
EE620	Advanced Digital Signal Processing	3-0-0-3
EE608	Digital Image Processing	3-0-2-4
CS609	Speech Processing	3-0-2-4
EE529	Embedded Systems	3-0-2-4
EE510	Mathematical Methods for Signal Processing	3-0-0-3

**L: Lecture, T: Tutorial, P: Practical, C: Credits*

Communications

Students opting for this specialization will be exposed to several theoretical courses that lay the mathematical foundation of modern digital communication, wireless networks and radio frequency (RF) system design. While the focus of some courses is to provide a foundation for this specialization, others aim at introducing students to the latest technologies, challenges and research opportunities. Students interested in this specialization must earn 9 credits by choosing courses from the following list in addition to the mandatory course requirement (please refer to the subsection Minimum credit requirement).

Communications basket courses

Code	Course title	L-T-P-C
EE503	Advanced Communication Theory	3-0-0-3
EE518	Information Theory	3-0-0-3
EE517	Wireless Communication and Networks	3-0-0-3
CS549	Performance Analysis of Computer Networks	3-0-0-3
EE530	Estimation and Detection Theory	3-0-0-3
EE507	Transmission lines and Basic Microwave engineering	3-1-0-4
EE621	Radiating Systems	3-1-0-4
EE529	Embedded Systems	3-0-2-4

Machine learning

In the machine learning specialization, students are exposed to data-driven techniques for analysis of real-world data. These include classical statistical techniques as well as deep learning based techniques.

Machine Learning basket courses

Code	Course title	L-T-P-C
CS669	Pattern Recognition	3-1-0-4
EE511	Computer Vision	3-1-0-4
CS671	Deep Learning and Applications	3-0-2-4
EE531	Estimation and Detection Theory	3-0-0-3

Making the students industry ready

The curriculum aims at equipping the students with tools and techniques that are needed for solving real-world problems, mostly the industry related ones. Systems design, a short duration design oriented course, and Postgraduate projects are both engineered keeping this in mind. A brief description of both these courses along with the respective evaluation schemes are provided below.

Systems Design

Preamble: The objective of this course is to provide hands-on experience in system design to the M.Tech. (CSP) students after completion of their first-semester course work. This course will not only help them in understanding the practical application of various core and elective courses, but also will prepare them for specializations they may plan to pursue.

The students are expected to deliver a product—a hardware prototype, a well-designed software, a high-level design of a complex system or, a tested and verified algorithm---at the end of the course. To ensure the engagement of each and every student, the projects are supposed to be done individually. Students are encouraged to pursue the same or similar projects as their dissertations.

Evaluation: There will be two evaluations—one in the beginning of the winter vacation and the other one in the beginning of the forthcoming even semester. In the first evaluation, the students will be graded based on the initial project proposals they have submitted. During the second evaluation, they will be evaluated based on their progress with respect to the promised deliverables, their project reports and the understanding they have gained from their respective projects.

Post graduate project (Dissertation)

Preamble: Post graduate project or dissertation provides a platform to the students where they can apply the knowledge they have gained from their coursework to solve problems related to one or more specializations of the curriculum. This year-long project aims at moulding the students to be independent researchers, innovators and system designers. For supervising their progress, the students are assigned to one or more mentors based on the domain of the problem. Students are allowed to carry out a part of their dissertation in industry or other academic institutes inside or outside India, provided they have a guide from within IIT Mandi. Students are encouraged to submit their work to reputed national/international conferences and journals for getting feedback on their respective projects.

Evaluation: Four evaluations, spanned across two semesters, are conducted to not only grade the students but also to help them in understanding the shortcomings of the work they have done. Every student is evaluated by a committee whose members are nominated by the faculty advisor. The students are evaluated based on their (i) project presentations, (ii) project reports, (iii) the understanding they have gained and (iv) novelty of the project.

Syllabi of the discipline core courses

Probability and Random Processes

Course Number : *EE 534*

Credits (L-T-P-C) : *3 (3-0-0-3)*

Prerequisites : *Linear algebra (MA512 or IC 111) and IC 252 or equivalent of both (MA512 and IC252)*

Intended for : *UG /MS/MTech (CSP)/PhD/M.Sc(Maths)*

Distribution : *Core for Mtech CSP, Elective for B.Tech. III/IV year, MS, Ph.D, M.Sc(Maths).*

Semester : *Odd (August to December)*

Preamble: Knowledge of random variables and random processes is essential in the following fields – signal processing, communications and machine learning. Starting with a review of basic concepts in probability the course aims to prepare a student to think in terms of random variables and processes. By the end of the course the student should be able to identify the type of process or variable involved and analyze a problem accordingly and obtain reasonable conclusions from the analysis. The course is oriented towards engineering applications rather than a mathematical one based on measure theory.

Course modules:

Sigma field. Review of axiomatic probability, conditional probability and independence.

Recap of random variables and functions of random variables.

Probability generating function, moment generating function and characteristic functions – properties and applications.

Markov chains, classification of states and chains, stationary distribution and limit theorem, Poisson process.

Convergence of random variables – basic results, inequalities (Markov and Chebyshev), law of large numbers (weak and strong), central limit theorem.

Concentration inequalities – Chernoff's bound, Hoeffding's inequality, Bennett's inequality, Bernstien's inequality and Efron-Stein inequality.

Random vectors and covariance matrix. Random processes – stationarity, WSS. Autocorrelation, cross correlation, power spectral density. Filtering of WSS processes. Basic notion of ergodicity. Wiener processes, Markov processes.

Queueing models - Little's law, M/M/1, M/M/m, M/M/m/m, M/G/1 queuing systems, priority queuing

Textbook:

1. Probability and Random Processes, Grimmett and Stirzaker, Oxford University Press, 2001.

Reference books:

1. Erhan Cinlar, Introduction to Stochastic Processes, Dover Books on Mathematics, 2013
2. R. G. Gallager, Stochastic Processes: Theory for applications, Cambridge University Press; 1 edition
3. S. M. Ross, Stochastic processes, 2nd Edition, 1996, John Wiley, New York
4. J. R. Norris, Markov chains, 1999, Cambridge University Press, Cambridge
5. Papoulis and Pillai, Probability, Random variables and Stochastic processes, McGrawHill Europe; 4th edition (January 1, 2002)

Programming Practicum

Course Number: *CS571*

Credits (L-T-P-C): *3 (1-0-3-3)*

Prerequisites: *Programming experience in any language (C/C++/Matlab/Python etc.)*

Students intended for: *MTech./M.S./Ph.D.*

Elective or Core: *Core for M.Tech. CSP, Elective for M.S./Ph.D.*

Semester: *Odd (August to December)*

Preamble: Programming skills are essential for any engineer. This course builds upon previous programming courses done by students during their previous degrees. A modern programming language with a large set of libraries suitable for data analysis or machine learning (such as Python) will be used. Emphasis will be given on programming for problems relevant to data analysis and information processing from domains such as signal processing, machine learning and communications.

Suggested implementation: The course will have weekly lab evaluations (related to the topic covered in the lecture), followed by a 3-4 week mini project. It is desirable for the mini project to have a pre-final evaluation and a final evaluation.

Learning outcome: After taking this course, students will become familiar in writing good code, using relevant libraries, using the right data structure, handling large data sets, plotting and visualizing information. They would have also become familiar with programming solutions to several problems in data analysis. They would also know how to do basic performance evaluation of programs.

Course Outline: 1 lecture per week, followed by 3 hours of lab.

Course Modules:

1. **Review of general programming constructs** Loops, conditionals, recursion, file i/o, data structures: strings, tuples, lists, dictionaries

2. **Introduction to scientific computing** Numerical precision in programs, IEEE 754 floating point representation, introduction to NumPy and Scipy

3. **Data manipulation** Pandas, handling large data files

4. **Data visualization** Various types of plots: histograms, scatter plots, box plots etc. Datasets can be provided and plots can be created from them

5. **Object oriented programming** Classes and objects, inheritance

6. **Implementing well known programs** Matrix factorizations, solving large order linear systems of equations, least squares approximations, simulating binary channels, signal denoising, K-means clustering, classification using Baye's rule etc.

7. **Introduction to parallelization** Cuda programming (conceptual level only)

8. **Program analysis** Performance tuning, profiling of programs, identifying performance bottlenecks

Text Books:

1. Python Data Science Handbook, Jake Vanderplas, O'Reilly, 2017

Reference Books:

1. Python Programming for the Absolute Beginner, Michael Dawson, ThirdEdition
2. How to Think Like a Computer Scientist: Learning with Python, Allen Downey, Jeffrey Elkner, Chris Meyers, Green Tea Press, 2016
3. Introduction to machine learning with Python, Muller and Guido, O'Reilly, 2017

Matrix Theory for Engineers

Course number: *EE 522*

Credits (L-T-P-C): *3 (3 - 0 - 0 - 3)*

Prerequisites: *IC 111 Linear Algebra, or a similar course or permission from the instructor.*

Intended for: *M.Tech./MS/PhD, 3rd/4th year B.Tech.*

Distribution: *Core for M.Tech. CSP. Elective for other postgraduates, third and final year B.Tech.*

Semester: *Odd semester (August to December)*

Preamble: Matrix theory has found application in several disciplines of engineering, such as, electrical, mechanical, structural engineering. As various branches of engineering deal with linear systems, which can be expressed using vectors and matrices, knowledge of matrix theory is a must for modern engineers. Though due to advances in computation technology large linear systems can be solved within a reasonable time limit, but some insights from matrix theory, in many cases, can reduce the computational task significantly.

Course Modules:

Background and review: Quick recapitulation of linear system of equations, and their solutions, Matrices, Determinant, Rank, Linear Vector spaces, Basis, Dimensions, Subspaces, Inner product and orthogonality, Range space and null space, Eigenvalues and eigenvectors.

Norms for vectors and matrices: Vector norms and their properties, Matrix norms, Error analysis in linear systems

Canonical forms, Symmetric and Hermitian matrices: Jordan Canonical form, Definition, properties, and characterization of Hermitian matrices, Congruence and simultaneous diagonalization of Hermitian and symmetric matrices.

Perturbation theory and Eigenvalue problems: The condition of Eigenvalues, Condition numbers and their application, location and perturbation of Eigenvectors, Generalized Eigenvalue problems, Rayleigh Quotient

Matrix factorization and Least square problems: Singular value decomposition, generalized pseudoinverses, QR factorization, PCA, Least square problems

Sparse matrices, their analysis and algorithms: Graphs and matrices, Linear solvers and their complexity, Sparse Gaussian elimination, Krylov-subspace iterations, Preconditioned methods: Incomplete factorization, Sparse approximate inverses, Sparse eigenvalue and singular value problems.

Different types and matrices, their properties and analysis: Irreducible, primitive, stochastic and doubly stochastic matrices; Properties of positive definite matrices, Sparse matrices and their analysis, Toeplitz and Circulant matrices

Random matrices and their applications: Introduction to randomness: concentration of measure, Lemma of Johnson and Lindenstrauss, Random matrices: Matrix norms, Golden-Thompson inequality, Non-commutative Bernstein inequality, Lieb's theorem, Applications: matrix multiplication and matrix completion

Numerical analysis and iterative methods: Overview of iterative methods, Arnoldi iterations, Generalized minimal residual method, Lanczos iterations, Conjugate gradients, Biorthogonalization method

Textbooks:

1. *Matrix Analysis,* Roger A. Horn and Charles R. Johnson, Cambridge university press, 2012.
2. *Matrix computations,* Gene H. Golub and Charles F. Van Loan, 3ed Ed., John Hopkins University Press, 2012..

Additional References:

1. *Matrix Theory,* David Lewis, 3rd edition, 2014, Allied Publishers
2. *Direct Methods for Sparse Linear Systems,* T. A. Davis, SIAM, 2006
3. *An Introduction to Matrix Concentration Inequalities,* Joel Tropp, 2015
4. *Topics in Random Matrix Theory,* Terence Tao, AMS, 2012
5. *Numerical linear algebra*, Lloyd N. Trefethen and David Bau III, Siam, 1997.
6. *Matrix analysis for scientists and engineers,* Alan J. Laub, Siam, 2005.
7. *Linear algebra in action,* Harry Dym, American Mathematical Soc., 2013.
8. *Linear Algebra and its application*, Gilbert Strang, 3rd Ed., Harcourth Brace Jovanovich Pubs.

Applied Optimization

Course Number : *EE 530*

Credits (L-T-P-C) : *3 (3-0-0-3)*

Prerequisites : *Linear algebra (MA512 or IC 111) or Matrix Theory for Engineers (EE522).*

Intended for : *UG /MS/M.Tech. CSP/PhD/M.Sc. (Applied Mathematics)*

Distribution : *Core for MTech. CSP, Elective for B.Tech. III/IV year, MS, Ph.D, M.Sc (Applied Mathematics).*

Semester : *Even (February to June)*

Preamble: This course is intended to be a core course for M.Tech Communication and Signal Processing students and elective for MS/Phd and senior B.Tech students. Many of the problems in communication as well as signal processing are solved using optimization. Many of these are non-convex in nature. This course is focused on enabling students to solve convex optimization problems and also to handle nonconvexity.

After finishing this course the students should be in a position to (i) convert a given problem to an appropriate optimization problem (ii) analyze the problem and (iii) choose an appropriate algorithm to solve the problem.

Specific applications from communication and signal processing which uses the theory developed in the initial modules is included in the last module. For these, in addition to the theory the students are expected to implement these algorithms and analyze the solvability in some of the cases.

Course modules:

Convex analysis: convex sets, convex cones, polyhedral sets, extreme points and directions. Convex functions, properties and tests for convexity, operations that preserve convexity, conjugate function.

Convex optimization: standard form, equality and inequality constraints, slack variables, eliminating equality and inequality constraints. Local and global optima. Optimality criterion for unconstrained, equality constrained and inequality constrained problems.

Convex optimization problems: Linear optimization problems with examples, linear and generalized linear-fractional programming. Quadratic problems with examples. Second order cone programming – robust linear programming, linear programming with random constraints. Geometric programming with examples. Generalized inequality constraints – conics form problems, semidefinite programming, examples.

Handling non-convexity: Lagrangian duality theory – Lagrangian dual function, strong and weak duality, duality gap. Certificate of suboptimality and stopping criteria, complementary slackness. KKT optimality conditions. Solving the primal via dual.

Applications of convex programming in communication and signal processing: The choice of applications is left to the faculty member handling the course. Examples that could be used are: Optimal decentralized estimation (single and multisensor case). Pulse shaping filter design. Quasi-ML detection via SDP relaxation (or any other problems in CSP).

Text book:

1. S. Boyd and L. Vandenberghe, Convex Optimization, Cambridge University Press, 2008.

Reference books:

1. M.S. Bazaraa, H.D. Sherali and C.M. Shetty, Nonlinear Programming, 3/e, Wiley, 2006.
2. D. P. Bertsekas, Nonlinear programming, Athena Scientific, 1999.
3. D. G. Luenberger and Y. Ye, Linear and nonlinear programming, 3/e, Springer, 2008.
4. Relevant literature.

IoT Systems

Course Number: *EE536*

Credits (L-T-P-C): *3 (2-0-2-3)*

Prerequisites: *Communication theory (EE304); Computer networks (CS406); Microcontroller programming and Digital systems design (IC161)*

Intended for: *B.Tech. III/IV year/ MS/M.Tech./PhD*

Distribution: *Core for M.Tech. (CSP)*

Semester: *Even (February to June)*

Preamble: The Internet of things can be seen as an agglomeration of various technologies that facilitate data acquisition, device-to-device communication, real-time monitoring and actuation for several real world applications. The objective of this course is to introduce the students to some of these constituent technologies and provide them hands-on experience in designing small-scale IoT systems. While the emphasis is given on the implementation aspects, the students will be briefed about the underlying theoretical concepts. They will be also introduced to several performance metrics that can be used to evaluate different IoT systems.

Learning outcome: After taking this course, students will

1. be familiar with different prototyping boards and their components. They will be able to choose an appropriate board/components for designing an IoT system.
2. have hands-on experience in programming off-the-shelf boards using respective IDEs. Additionally, they will be able to choose appropriate libraries for interfacing with external sensors, or communication modules.
3. be versed in different communication standards and technologies. They will be able to choose appropriate communication technology/technologies for designing an IoT system.
4. be knowledgeable about Medium Access Protocols, routing algorithms and their implementations.
5. be able to compare different IoT systems in terms of different performance metrics: network lifetime, power consumption, reliability of the network etc.
6. be able to design a small-scale IoT system for several real-world applications.

Course modules:

1. An introduction to IoT systems: Introduction and motivation of IoT systems.

2. Hardware components of IoT systems: A quick overview of different components---micro-controllers, SoCs, communication modules, power supply and sensing modules---of off-the-shelf prototyping boards, e.g., Arduino UNO, MSP430 LaunchPad; NodeMCU, STM32, Raspberry Pi.

3. Software component of IoT systems: Introduction to IDEs for off-the-shelf boards, e.g., Arduino IDE, Waspmote IDE, Code composer studio; Contiki-OS and RIOT OS; 6LowPAN network stack; Sensor interfacing; GPIO programming

4. Communication paradigm of IoT systems: Different wireless standards, e.g., IEEE802.15.4, ZigBee, BLE, IEEE802.11; link layer technologies, Medium Access Control; Routing; Application layer protocols; Network topologies.

5. Performance evaluation of IoT systems: Developing mathematical models for energy consumption, Optimal node placement, resource allocation over wireless sensor networks to meet QoS requirements.

6. Case studies/mini projects: Home automation; Building energy management; Indoor positioning; Air quality monitoring; Precision agriculture; Smart parking

Textbook:

1. David Hanes et al., IoT Fundamentals: Networking Technologies, Protocols and Use Cases for the Internet of Things, First edition, Pearson, 2017

Reference Books:

1. Parry Lea, Internet of Things for Architects: Architecting IoT Solutions by Implementing Sensors, Communication Infrastructure, Edge Computing, Analytics, and Security, Packt Publishing Limited, 2018
2. Shuang-Hua Yang, Wireless Sensor Networks: Principles, Design and Applications, Springer.
3. Kazem Sohraby, Daniel Minoli, Taieb F. Znati, Wireless Sensor Networks: Technology, Protocols, and Applications, Wiley Interscience, 2009
4. White papers, RFCs, survey articles on Wireless communication standards and technologies.
5. Antonio Linan Colina, Alvaro Vives, Antoine Bagula, Marco Zennaro and Ermanno Pietrosemoli, IoT in five Days, https://github.com/marcozennaro/IPv6-WSN-book/releases/

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