UG Minor program in Quantum technologies @ IIT Mandi

IIT Mandi

Course Name	: **Survey of Quantum Technologies and Applications**
Course Number	: QT 301
Credits	: 3-0-0-3
Prerequisites	: Engineering Mathematics (Linear Algebra, Complex algebra, basics of 2nd of ODEs and initial value problems, 2nd order PDEs and boundary value problems, Probability and Statistics, Random variables). Maxwell's equations and EM theory at the level of the core physics syllabus from AICTE model
Curriculum Intended for	: UG/PG/PhD
Distribution	: Elective PG/Elective UG
Semester	: Odd/Even

1. **Preamble:** This course is meant to give an overview of the field of quantum technologies and make the students familiar with the state-of-the-art in all four verticals. The emphasis is not on depth in this course, but on covering the exciting aspects of the field. Students of this course learn: (i) The general physical principles of realising qubits for computation, (ii) The various hardware implementations of qubits for computation, (iii) The basic ideas of quantum sensing, (iv) The applications of quantum sensing, (v) The implementations of quantum communications protocols in fibre-based and free-space

2. **Course Content:**

- Quantum Technologies – four verticals (1 lecture)
    - Motivation for Quantum Technologies
- A qualitative overview of salient aspects of quantum physics (1-2 lectures)

- Quantum Computation (10-12 lectures)
    - Basics of qubits -- what is a qubit?
    - How is it different from a classical bit? – Review of classical logic gates
    - Di Vincenzo criteria for realising qubits
    - Basics of qubit gates and quantum circuits
    - Physical implementation of qubits (very qualitative description)
        - Solid State Qubits
            - Semiconducting Qubits – quantum dots, spins
            - Superconducting Qubits – charge, flux and phase
            - Topological Qubits – proposals and advantages
        - Atoms and Ions
            - Trapped ions
            - Rydberg atoms
            - Neutral atoms
        - Photonic Qubits
            - Conventional linear optical setups

            - Integrated Photonics
        - NMR qubits
            - Conventional NMR qubits
            - NV centres
    - Overview of applications and recent achievements
        - RSA and Shor's algorithm
        - Quantum Advantage
    - Long term goals and strategies being followed
        - Error correction
- Quantum Sensing (8-10 lectures)
    - Basics of quantum sensing
    - Basics of Photon (single and entangled) generation and detection
    - Gravimetry
    - Atomic clock
    - Magnetometry
    - State of the art in Quantum Sensing
- Quantum Communications (8-10 lectures)
    - Basics of digital communication
    - Quantifying classical information – Shannon entropy
    - Basic ideas of quantum communication, security, eavesdropping
    - Overview of quantum communication achievements
        - Terrestrial – fibre-based
        - Free space, Satellite-based

- Brief overview of Computational Complexity (6-7 lectures)
    - Qualitative ideas of a Turing machine
        - Types of Turing machines
    - Time and Space complexity – P vs NP, PSPACE
    - Quantum complexity classes – Q, EQP, BQP, BPP, QMA
    - Post Quantum Cryptography (PQC)

3. Course Test Books and References:

1. Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press (2023)
2. Quantum computation and quantum information – Nielsen M. A., and Chuang I. L., 10th Anniversary edition, Cambridge University Press (2010)
3. Elements of Quantum Computation and Quantum Communication, A. Pathak, Boca Raton, CRC Press (2015)
4. An Introduction to Quantum Computing, Phillip Kaye, Raymond Laflamme, and Michele Mosca, Oxford University Press (2006)
5. Quantum computing explained, David McMahon, Wiley (2008)
6. Introduction to the Theory of Computation, Michael Sipser, 3rd edition, Cengage India Pvt. Ltd. (2014)