Uka Tarsadia University

B. Tech.

CSE / CSE (CC) / CE (SE)

Semester VII

Program Elective - VI
QUANTUM COMPUTING
CE6016

EFFECTIVE FROM July-2024

Syllabus version: 1.00

Subject Code	Subject Title
CE6016	**Quantum Computing**

Teaching Scheme				**Examination Scheme**				
Hours		**Credits**		**Theory Marks**		**Practical Marks**		**Total Marks**
Theory	Practical	Theory	Practical	Internal	External	Internal	External	
4	0	4	0	40	60	0	0	100

Objectives of the course:

- To provide the introduction of quantum computation.
- To provide the concepts related to algebra of complex vector spaces and quantum mechanics.
- To introduce the quantum algorithms and their applications to the different sectors.

Course outcomes:

Upon completion of the course, the student shall be able to,

CO1: Understand fundamentals of Qubits and their various representations.
CO2: Identify Operators and their matrix representations.
CO3: Compute Tensor products of matrices and applications of density operators.
CO4: Understand quantum measurement and error correction.
CO5: Understand quantum entanglement.
CO6: Demonstrate implementation of quantum gates, circuits and elementary Quantum algorithms.

Sr. No.	Topics	Hours
	Unit – I	
1	**Qubit & Quantum States**: Quantum bits, Bloch sphere representation of a qubit, Multiple qubits, Vector spaces, Linear combination of vectors, Uniqueness of a spanning set, Basis and dimensions, Inner products, Orthonormality, Gram-Schmidt, Orthogonalization, Bra-ket formalism, The Cauchy-Schwarez and triangle.	8
	Unit – II	
2	**Matrices & Operators**: Observables, The Pauli operators, Outer products, The closure relation, Representation of operators using matrices, Outer	12

	products & matrix representation, Matrix representation of operators in 2D spaces, Pauli matrix, Hermitian unitary and normal operator, Eigen values & Eigen vectors, Spectral decomposition, Trace of an operator, Important properties of Trace, Expectation value of operator, Projection operator, Positive operators, Commutator Algebra, Heisenberg uncertainty principle, Polar decomposition & singular values.	
	Unit – III	
3	**Tensor Products and Density Operators:** Postulates of Quantum Mechanics, Representing composite states in Quantum Mechanics, Computing inner products, Tensor products of column vectors, Operators and tensor products of matrices, Density operator of pure & mix state, Key properties, Characterizing mixed State, Practical trace & reduce density operator, Density operator & Bloch vector.	10
	Unit – IV	
4	**Quantum Measurement Theory:** Distinguishing Quantum states & measures, Projective measurements, Measurement on composite systems, Generalized measurements, Positive operator-valued measures.	8
	Unit – V	
5	**Entanglement:** Bell's Theorem, Bipartite systems and the bell basis, State entanglement, The pauli representation, Entanglement Fidelity, Using Bell states for density operator representation, Schmidt decomposition, Purification.	10
	Unit – VI	
6	**Quantum Gates, Circuits and Algorithms**: Classical logic gates, Single-Qubit gates, Exponentiation, The Z–Y decomposition, Basic Quantum circuit diagrams, Controlled gates, Gate decomposition,Classical computation on quantum computers, Relationship between Quantum and classical complexity classes, Deutsch's algorithm, Deutsch's-Jozsa algorithm, Shor factorization, Grover search.	12

Text book:

1. David McMahon, "Quantum Computing Explained", A John Wiley & Sons, Inc., Publication.

Reference books:

1. M A Nielsen and I L Chuang, “Quantum Computation and Quantum Information”, Cambridge University Press.
2. Pittenger, “An Introduction to Quantum Computing Algorithm”, Birkhauser.
3. P Kaye, R Laflamme and M Mosca, “An Introduction to Quantum Computing”.
4. G. Strang, “Linear Algebra and its Applications”.
5. Bhatia, “Matrix Analysis”.
6. “Principles of Quantum Computation and Information”, Vol. I: Basic Concepts, Vol II: Basic Tools and Special Topics, World Scientific.

E-Resources or courses:

1. Courses by: Andrew Childs, Ronald de Wolf, and John Watrous on “Quantum Theory and Computing”.

Course objectives and Course outcomes mapping:

- To provide the introduction of quantum computation: CO1, CO2.
- To provide the concepts related to algebra of complex vector spaces and quantum mechanics: CO3, CO4.
- To introduce the quantum algorithms and their applications to the different sectors: CO5, CO6.

Course units and Course outcomes mapping:

Unit No.	Unit Name	Course Outcomes					
		CO1	**CO2**	**CO3**	**CO4**	**CO5**	**CO6**
1	Qubit & Quantum States	✓					
2	Matrices & Operators		✓				
3	Tensor Products and Density Operators			✓			
4	Quantum Measurement Theory				✓		
5	Entanglement					✓	
6	Quantum Gates, Circuits and Algorithms						✓

Programme outcomes:

PO 1: Engineering knowledge: An ability to apply knowledge of mathematics, science, and engineering.

PO 2: Problem analysis: An ability to identify, formulates, and solves engineering problems.

PO 3: Design/development of solutions: An ability to design a system, component, or process to meet desired needs within realistic constraints.

PO 4: Conduct investigations of complex problems: An ability to use the techniques, skills, and modern engineering tools necessary for solving engineering problems.

PO 5: Modern tool usage: The broad education and understanding of new engineering techniques necessary to solve engineering problems.

PO 6: The engineer and society: Achieve professional success with an understanding and appreciation of ethical behavior, social responsibility, and diversity, both as individuals and in team environments.

PO 7: Environment and sustainability: Articulate a comprehensive world view that integrates diverse approaches to sustainability.

PO 8: Ethics: Identify and demonstrate knowledge of ethical values in non-classroom activities, such as service learning, internships, and field work.

PO 9: Individual and team work: An ability to function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO 10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give/receive clear instructions.

PO 11: Project management and finance: An ability to demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO 12: Life-long learning: recognition of the need for, and an ability to engage in life-long learning.

Programme outcomes and Course outcomes mapping:

Programme Outcomes	Course Outcomes					
	CO1	CO2	CO3	CO4	CO5	CO6
PO1	✓	✓				
PO2			✓			
PO3						
PO4				✓	✓	
PO5						✓
PO6						
PO7						
PO8						

PO9						
PO10						
PO11						
PO12						