Course guide
2301117 - QBAP - Qubit Applications

Last modified: 14/06/2024

Unit in charge: Barcelona School of Telecommunications Engineering
Teaching unit: 739 - TSC - Department of Signal Theory and Communications.

Degree: MASTER'S DEGREE IN PHOTONICS (Syllabus 2013). (Optional subject).

Academic year: 2024 **ECTS Credits:** 3.0 **Languages:** English

LECTURER

Coordinating lecturer: Juan P. Torres, professor at Signal Theory and Communications (TSC) Department, Universitat Politecnica de Catalunya (UCP), and Group Leader of Quantum Engineering of Light group at ICFO-Institute of Photonic Sciences

Others: Juan P. Torres, professor at Signal Theory and Communications (TSC) Department, Universitat Politecnica de Catalunya (UCP), and Group Leader of Quantum Engineering of Light group at ICFO-Institute of Photonic Sciences

PRIOR SKILLS

Basic knowledge of algebra and quantum physics

REQUIREMENTS

No requisites

TEACHING METHODOLOGY

- Lectures
- Resolution of exercises in the classroom

LEARNING OBJECTIVES OF THE SUBJECT

Quantum theory is not only a great achievement of human thinking, but almost since its beginning, also a source of new technologies that eventually affect the daily life of people everywhere. The laser, the transistor, atomic clocks and Positron Emission Tomography (PET) are examples of this, just to name a few. In the last few decades, a surge of new ideas that make use of quantum thinking and concepts coming from information theory (quantum information) are finding its way towards applications. Quantum applications with high expectations nowadays can be arguably grouped in four main areas: quantum communications, quantum computing, quantum simulations and quantum imaging and sensing. Many of these applications are still in its infancy, and what level of development and societal impact they will reach is uncertain.

In this course we will focus on quantum applications for imaging and sensing. In one sentence, quantum imaging and sensing aims at using quantum tools, and quantum states of light, to design and implement imaging systems and sensors with an advantage over alternative approaches. For instance, a more favorable relationship between their sensitivity and the number of photons used for probing the sample under investigation. On the theoretical side, tools from quantum estimation theory can be used to determine the sensitivity limits of imaging and sensing schemes, even in the classical domain. On the practical side, quantum sensing schemes can give access to the detection of extremely tiny quantities of a variable of interest. We aim at unveiling what fundamental quantum concepts make special a quantum application. The goal is to isolate the specific features that make quantum a quantum application. We will do this by considering relevant, specific but simple examples, and analyzing experimental implementations. The detailed analysis of these examples will ease the exploration of the quantumness of the applications considered.

STUDY LOAD

Type	Hours	Percentage
Hours large group	24,0	32.00
Self study	51,0	68.00

Total learning time: 75 h

CONTENTS

1. Tools from quantum estimation theory.

Description:
Accuracy and Precision. Classical and quantum Fisher information. The classical and quantum Cramer-Rao bounds. Propagation of errors formula. Examples.

Full-or-part-time: 12h
Theory classes: 2h
Practical classes: 2h
Self study : 8h

2. Imaging and sensing with quantum coherent states

Description:
The Shot-noise limit. Overview of phase estimation with coherent light. Detection of tiny phases (nanoradians)

Full-or-part-time: 12h
Theory classes: 2h
Practical classes: 2h
Self study : 8h

3. Beyond the Shot-noise limit: The Heisenberg limit

Description:
The quantum concept: exotic quantum states with peculiar properties. Entanglement for reaching the Heisenberg limit: quantum NOON states. The Heisenberg limit with non-entangled quantum states.

Full-or-part-time: 18h
Theory classes: 4h
Practical classes: 2h
Self study : 12h

4. Quantum imaging and sensing based on quantum coherence and quantum correlations

Description:
Imaging and sensing based on quantum and classical correlations. Sensing based on the Hong-Ou-Mandel effect. SU(1,1) interferometers. Quantum optical coherence tomography. Quantum-inspired, but classical, imaging and sensing systems.

Full-or-part-time: 30h
Theory classes: 6h
Practical classes: 4h
Self study : 20h

GRADING SYSTEM

1) One or two exams (40%)
2) Homework assessments, individual or in groups (60%)

BIBLIOGRAPHY

Complementary:

- Susskind, Leonard ; Friedman, Art. Quantum Mechanics: The theoretical minimum. New York: Basic Books, 2014. ISBN 9780465036677.
- Haroche, S.; Raimond, J.-M. Exploring the quantum: atoms, cavities and photons. Oxford: Oxford University Press, 2006. ISBN 0198509146.
- Furusawa, Akira. Quantum states of light [on line]. Tokyo: Springer, 2015 [Consultation: 10/01/2024]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/978-4-431-55960-3. ISBN 9784431559603.
- Peres, Asher. Quantum Theory: Concepts and Methods [on line]. New York: Kluwer Academic Publishers, 2002 [Consultation: 26/06/2023]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/0-306-47120-5. ISBN 9781280609497.
- Nielsen, Michael A.; Chuang, Isaac L. Quantum Computation and Quantum Information. Cambrodge: Cambridge University Press, 2010. ISBN 9781107002173.
- Gisin; N. Quantum chance: nonlocality, teleportation and other quantum marvels [on line]. Cham: Springer International Publishing, 2014 [Consultation: 04/07/2023]. Available on: https://ebookcentral.proquest.com/lib/upcatalunya-ebooks/detail.action?docID=1782235. ISBN 9783319054735.
- Cox, Brian; Forshaw, Jeff. The quantum universe. Da Capo Press, 2013. ISBN 9780306821448.
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- Ball, P. Beyond weird: why everything you thought you knew about quantum physics is ... different. London: Vintage, 2019. ISBN 9781784706081.