Information Photonics

Fundamentals, Technologies, and Applications

Asit Kumar Datta
Soumika Munshi

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To our Teachers, Peers, Friends, and Families

Preface

Information photonics is an emerging area of interest as it interfaces with the scientific and technological developments in photonics, and the ever-expanding all pervasive applications of information technology. Photonics deals with the generation, transmission, and detection of light in the broader sense, and mostly encompassing the spectra from ultraviolet and visible to the far-infrared wavelengths. On the other hand, information technology deals with the applications of computers and telecommunication equipment to store, retrieve, transmit, and manipulate data. Since the application areas of both photonics and information technology have merged along with the advancement of technology, the area of information photonics is identified as an approach to developing photonic information processing systems, innovatively created by the fusion between photonics technology and information technology.

The word photonics appeared in the late 1960s to describe a research field whose technological goal in those days, was to use light to perform functions that traditionally fell within the typical domain of electronics, such as telecommunication, computation, and other information processing systems. Moreover, photonics was identified as a subset of physics, particularly semiconductor physics, when interest grew in the development of devices after the evolution of laser and optical fibre. As the photonics technologies are entering and expanding into every conceivable domain of public use, the individual boundaries of subject areas are becoming merged. This scenario is unfolding the advantages of today's information age, marked by the high speed of information communication with large bandwidth, which cannot be made without the applications of photonics technology. Information photonics is therefore identified as an approach to developing photonic information processing systems, which are innovatively created as an enabling technology of our information age.

At the outset it is necessary to establish a generic terminology that might be advantageously used in information photonics. During the last 50 years or so, every then-conceivable development in the area of today's photonics was designated with the name of applied optics, optical technology, or optical engineering. When the domain of photonics began to evolve from optics and electronics, various terminologies such as optical-electronic, optronics, and optoelectronics were interchangeably used. Optoelectronics is now considered to be the study and application of electronic devices that can source, detect, and control light, and so optoelectronics is now a sub-field of photonics.

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In this book we shall only consider the devices and systems which are governed by the laws of optics to be optical devices and system. On the other hand, when the role of photons and the laws governing them are in play we shall consider those devices and systems to be photonic devices and photonic systems. Therefore, optical fibres are optical devices, but when a system is studied with the addition of sources and detectors, and is used for communication, those systems will be termed photonic communication systems instead of optical communication systems. In the same vein, optical computers will be termed photonic computers, the sources, detectors, and modulators shall be termed photonic detectors, photonic sources, and photonic modulators. A system evolved with the combination of optical and photonic devices shall be called a photonic system.

The main aim of this book is to introduce, to post-graduate students, researchers, engineers, and scientists, the concept of photonic information processing technologies as applied in various fields. It will help readers to get insight into the concepts of photonic information processing as a system, and photonic devices as system components required and applied in the areas of communication, computation, and intelligent pattern recognition. As an extension of these concepts, the areas of quantum communication and computation, where photons have a major role to play, shall also be introduced. The book converges in the last chapter by introducing the emerging areas of nanophotonics, where over and above the systems, photonic crystal and plasmonic devices will have an important role to play in the near future.

The first chapter deals with the basic philosophy of information communication in linear channels in the light of probability and Shannon's theorems. The second chapter introduces the properties of photons, concepts of electromagnetic theory, and an introduction to optical systems and laws. The third chapter deals with the human vision system and the ideas of visual perception, which is an integral part of human interface with systems. Photonic devices play a crucial role in establishing photonic system architectures and therefore the devices required for the generation of photonic signals (sources), those required for the detection of photons, are introduced in the fourth chapter. This chapter, expectedly, will describe the building blocks of the systems. The fifth chapter continues to introduce the devices required for the manipulation of photonic signals (the modulators and switches) and ultimately the photonic storage and display devices.

An important aspect of information processing is the analysis of two dimensional images in space and frequency domains. Chapter 6 addresses this aspect by discussing space and time transform domain information processing techniques by Fourier, fractional Fourier and wavelet transforms. Some other transforms which are helpful in detection problems are also discussed. Chapter 7 deals with low-level information processing of images with the help of operators and morphological processing. This chapter also elaborates photonic instrumentations required for range acquisition and profiling of an object.

Having introduced the photonic devices and basic processing techniques in space and time domain, Chapter 8 of the book deals with the major application of photonic processing in communication and networking. Propagation of light waves in optical fibres, communication in free space, and techniques of secure communication are discussed. Another major area of photonic information processing is photonic computation. Chapter 9 introduces the ideas and architectures of photonic computations, bringing out the arithmetic and logic required for carry-less two-dimensional operations. Since interconnects and switching are integral parts of photonic computing, a portion of this chapter is devoted to the interconnection and switching methods. Chapter 10 deals with the application areas involving photonic information processing in intelligent pattern recognition, mostly using neural network models and image correlation filters. Chapter 11 deals with quantum communication and computation as an aspect of photonic information processing, which is treated as a fusion between photonics and quantum mechanics. The mathematical preliminaries of qubits and devices required are also discussed. The last chapter (Chapter 12) introduces the latest developments in nanophotonic devices and systems. The theories and applications of photonic crystals and plasmonic devices form an integral part of this chapter. The book concludes with a note on the evolution of nanophotonic information systems.

Nowhere in the book are attempts made to derive the equations required to establish a theory behind photonic devices and information processing techniques. Only major equations are mentioned. A large number of books are referred to as additional and supporting reading at the end of each chapter, where the derivations of the equations can be found. Important references are also included at the end of each chapter.

Thanks are due to our colleagues who have assisted us during many phases of preparing the manuscript of the book. Our special gratitude goes to Gagandeep Singh, CRC Press editorial manager and senior editor (engineering/environmental sciences) without whose support and constant encouragement this book would not have been possible.

Asit Kumar Datta, Soumika Munshi

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