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Understanding optical computing

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ABSTRACT
Optical computing is the use of optical systems to perform numerical computations or process information. It is the science of making computing work better using optics and related technologies. Optical computers are computers of the future that use light particles called photons. They come as a solution to a miniaturizing problem. They are the most feasible devices that can replace electronic computers with impressive speeds. This review discusses optical computing in its simplest form.

KEYWORDS
optical computing; photonic computing; quantum computing

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INTRODUCTION

Optical computing is also known as photonic computing, and it refers to the design of digital computer systems and interconnections using optical/optoelectronic technologies. It is the use of electromagnetic radiation to process information. It uses photons in visible light or infrared to perform digital computation instead of electrons used in conventional computers [1,2]. Optical computing is inherently quantum computing. Each photon is a quantum of a wave function describing the entire system [3]. In some devices, the energy of electrons can be converted to photons and vice versa. An optical computer might someday be developed that can perform operations 10 or more times faster than a conventional electronic computer and be smaller in size. Optical computing is a multidisciplinary area involving a spectrum of expertise in optical physics, materials science, optical engineering, electrical engineering, computer architecture, and computer theory [4]. Researchers around the globe are exploring the frontiers of computing with photons instead of electrons. The main objective is to devise a special-purpose machine that can better handle problems that do not lend themselves well to electronics or a machine that will be more impervious to undesired crosstalk or electromagnetic interference (EMI) [5]. Optical computing can be used to perform a variety of operations on signals. Several processing operations have proven to be more efficient with optical techniques than with their electronic counterparts. These include Fourier transforms, convolution, correlation, and spectrum analysis. However, optical signal processors are inflexible compared with electronic computers [6].

OPTICAL COMPUTING APPLICATIONS

To exploit the differences between photons and electrons, optical computing has been applied in several areas.

- **Application-specific devices**

Devices such as synthetic aperture radar (SAR), optical transistor, optical turing machine, antiballistic missile (ABM), and optical correlators use the principles of optical computing.

- **Digital communication**

Optical computing has given rise to fiber-optic communications, fiber-optical local area networks, and digital communications, where fiber optic data transmission has become commonplace. Optical fibers make optical interconnections and devices practical. They are immune to EMI and have been replacing metallic wired media. Today, optic computing technology has no challenger in the domain of telecommunications with the optical fibers and optical cables, the wavelength-division multiplexing (WDM), the optical amplifiers and the switches. The ultimate goal is the so-called photonic network.

• Digital optical computing

In order to compete efficiently with digital electronic computers, a very important research effort has been directed toward digital optical computing. In this application, a digital computing scheme is utilized as the foundation. Information is represented by discrete signals and is processed in the same manner as in digital electronics. Thus, digital optical computing is suitable for cooperating with the current electronic technologies [7].

• Integrated optics

This is attractive due to its potential for high switching speeds and its compatibility with fiber-optic communication links. It is basically a planar optical analog of electronic integrated circuits. Integrated optics technology is capable of fabricating guided-wave structures, electro-optic devices, sources, and detectors in a planar array. Integrated optics devices have the same logic and signal processing capabilities as semiconductor chips [8].

Other applications include massive parallel processing, medical imaging, and optical supercomputers.

BENEFITS AND CHALLENGES

The major benefit of optical computing comes from the many advantages that optical interconnections and optical integrated circuits have over their electronic counterparts. The advantages of optical computing include [9]:

• Parallelism

Light has inherent parallelism when it propagates. Parallelism is needed in massively parallel processing in modern computers. The parallel nature of light offers two dimensionalities in data representation.

• High speed

The highest speed is attained by using light as the medium of information in the material of interest. The speed and parallelism of light enable very high data rates, especially for signal processing and pattern recognition tasks.

• High-bandwidth

Light inherently has a large information capacity. When compared with radio frequency or microwaves used in conventional communication, light has from thousands to millions of times information capacity. The need for greater bandwidth driven by streaming video and other data-intensive applications has been steadily pushing the optical link speed to the 100Gb/s domain.

• Noninteraction

Light propagates in free space without interaction between light waves emitted from different sources. This is due to the fact that photons do not interfere with one another since they are uncharged particles. Optical computing is immune to EMI.

Although optical computing has been an active area of research for several decades, solutions have been elusive due to many challenges. Designing free-space optical computing architectures is a challenge due to system complexity, high cost, and lack of availability of devices. Optoelectronic devices lose 30% of their energy converting electronic energy into photons and back. Optical computing uses a coherent source that may cause imperfections or dust on the optical components and create unwanted interference.

CONCLUSIONS

Optical computing systems are fundamentally different from electronic systems. As electronics reaches its natural, technical limits, optics alone offers massive parallelism. Optical computing offers the possibility of non von Neumann architectures with different mechanisms for interconnections and communications.

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