Preface

Smart cameras are vision systems that do not only take images but also understand them. The primary idea behind this book was to create a pioneering reference to the topic of *smart cameras* by providing a collection of works in one volume. The resulting book reconciles several disparate scientific, technological, and commercial aspects related to smart cameras: detectors, pixels, signal processing, image sensor architectures, embedded systems, computer vision, sensor network, applications of smart cameras, and market trends. While excellent textbooks exist in many of those fields, there was a need to have a single publication that adopts the perspective of linking the specific mechanisms in the context of smart cameras.

The concept of the smart camera has existed for more than three decades. Tremendous progress has been made in the smart camera technologies and approaches both at academic level and at industrial level. Cameras are getting increasingly intelligent and more and more attractive for a wide range of applications: in surveillance and monitoring, in industrial applications, in robotics, in transportation, and in many other fields. This edited book aims to provide background information, fundamentals, an overview of the historical evolution, applications, and the latest trends in smart cameras concepts to professionals, practitioners, and students.

It integrates contributions from different authors with outstanding competence and experience in the fields of hardware electronics, signal processing, embedded computing, computer vision, sensors networks, and smart cameras applications in surveillance, machine vision, and the automotive industry. Furthermore, this publication includes a concrete analysis on smart camera market evolution through interviews with market leaders and exhibiting companies at the *Vision Expo*[1] in Stuttgart, Germany.

The invention of the camera can be traced back to the 10th century when the Arab scientist Al-Hasan Ibn al-Haytham alias *Alhacen* provided the first clear description and correct analysis of the (human) *vision process*. Although the effects of single light passing through the pinhole have already been described by the Chinese Mozi (Lat. Micius) (5th century BC), the Greek Aristotle (4th century BC), and the Arab

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[1] Web site of the annual *Vision Expo* at http://cms.messe-stuttgart.de/

Al Kindi (9th century), none of them suggested that what is being projected onto the screen is an image of everything on the other side of the aperture. The Greeks described the vision process in two ways. Aristotle and his followers supported the *intromission theory* such that vision occurs when physical forms enter the eye from an object. The second theory is the *emission theory*, and Euclid (3rd century BC) and Ptolemy (2nd century) believed that visual perception occurs when the eye emits rays of light. Ibn al-Haytham argued that seeing occurs neither by physical forms entering the eyes nor by rays emitted from it. He described *vision* as a process which takes place in the brain rather than the eyes. He proved in experiments that rays of light travel in straight lines from each point of an object on the outside to project its image on the inside. He designed the first camera obscura to be the first to shift physics from a philosophical to an experimental basis. One hundred and fifty years later, Averroes pioneered neuroscience by attributing the photoreceptor properties to the retina and describing the organ of sight. The Latin term *camera obscura* was first used by the German scientist Johannes Kepler in 1604. Since the 10th century, models of the camera obscura were large darkened rooms. The first portable model was initiated by Robert Boyle and Robert Hooke in the late 17th century. In 1839, the first produced photographs[2] were announced using cameras developed by the French Louis Daguerre *(Daguerreotype)* and the English William Fox Talbot *(Calotype)*. These inventions ushered in a new era of technologies, e.g., the Morse's telegraph (communications), photographic cameras (visual arts and cinematography), and later digital photography by the pioneer American scientist Eugene F. Lally in 1961.

The above-listed inventions and contributions helped to further the understanding of vision and inspired the development of technologies to realize this process in a so-called camera. But when did the camera get intelligence to be a *smart camera*?

The invention of the digital computer in 1937 by George Stibitz can be considered as the starting point for intelligent cameras. The smart camera concept was born in the context of military and/or space applications at *National Aeronautics and Space Administration* (NASA)'s Jet Propulsion Laboratory motivated by having a stand-alone vision system for scene interpretation onboard space shuttles. In 1961, at the annual convention of the American Rocket Society Eugene F.Lally intruduced the idea of having an integrated imaging device and a processing unit. He proposed manned Mars missions with cameras employing mosaic arrays of photodetectors with their output being processed in the digital domain to provide on-board guidance and navigation. Hans Moravec reported in his PhD thesis about a cart built in the early 1960s for navigation and obstacle avoidance. This cart was an electric vehicle, remote controlled by a computer, and equipped with a TV camera through which the computer was able to see in order to run simple but realistic obstacle courses.

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[2] The first permanent photograph was taken by the French Joseph Nicéphore Niépce. This earlier photographic process required hours for successful exposure. In 1839, results were published from the first commercially viable photographic process to permanently record and fix an image in shorter exposure time compatible with portrait photography.

The name *smart camera* was published for the first time by Ron Schneidermann in 1975 who described techniques used by camera manufacturers to achieve automatic exposure control toward developing systems for controlling the shutter.

The breakthrough of the smart camera was the invention of the optical mouse by Richard Lyon in 1981. It was the first realized smart camera combining an imaging device and an embedded processing unit in a compact system. The mouse used a 16-pixel visible-light image sensor with integrated motion detection on the same chip and tracked the motion of light dots in a dark field of a printed paper or similar mouse pad. This mouse was successfully commercialized and sold for Xerox systems in the 1980s. Agilent (a spin-off company of HP) developed a high-speed and high-resolution mouse camera in 1999, with 18×18 pixels and 1500 images per second, using a built-in DSP to allow real-time detection and tracking of changes in the images. The Agilent optical mouse was very successful as it was commercialized for the home-use market and is recorded to be the most widely sold *smart camera*. Lyon's optical mouse ushered in an era of novel sensor technology and concepts called *vision chips*, which are reviewed in detail in Alireza Moini's book published in 1997. Vision chips, or smart visual sensors, are sensors with integrated image acquisition and parallel processing, often at the pixel level, using analog and digital circuits. In the late 1980s, Carver Mead introduced the neuromorphic concept to describe VLSI systems containing analog and asynchronous digital electronic circuits that mimic neural architectures present in biological nervous systems. This concept revolutionized the frontier of computing and neurobiology to such an extent that a new engineering discipline emerged, with the aim to design and build artificial neural systems, such as vision systems, auditory processors, or autonomous roving robots. Besides the optical mouse, machine vision can be regarded as the driving field for emerging smart cameras because of the lucrative market. Many companies have emerged since the early 1980s with a focus on building inexpensive machine vision systems for industrial applications. Many of these companies also exhibit at the annual *Vision Expo* in Germany.

The book comprises 20 chapters organized into 8 parts.

Part I comprises three chapters which provide a detailed introduction to smart cameras. Chapter 1 narrates the historical evolution of smart cameras from the early beginnings until the most recent achievements. A technical definition of smart cameras is given in Chapter 2, along with a classification based on their fundamental system architecture. Chapter 3 describes typical smart camera technologies, design requirements, and applications.

Part II provides in two chapters important background information on imaging technologies. Chapter 4 describes the detectors, pixels, and signal processing of image sensors. The sensor architecture, geometry, and read-out techniques are featured in Chapter 5.

Part III presents three chapters which investigate embedded vision aspects. Chapter 6 highlights design and application challenges of embedded computer vision in smart cameras. Chapter 7 describes high-performance embedded computing for smart cameras in machine vision applications. Embedded vision design and applications for smart stereo cameras are presented in Chapter 8.

Part IV provides examples of three computer vision methods for smart cameras. Chapter 9 outlines self-calibration aspects for smart video cameras. Chapter 10 shows techniques for object segmentation and change detection for smart camera applications. Object tracking on embedded hardware is described in Chapter 11.

Part V comprises four chapters that deal with distributed smart cameras. Chapter 12 presents the design, architecture, and application of a high-performance wireless smart camera. Chapter 13 tackles the aspects of geo-registration and inter-sensor calibration in large sensor networks. The management methodologies of large-scale smart camera networks are described in Chapter 14. Chapter 15 shows methods for applying stereo vision in a cooperative camera network.

Part VI features three selected applications of smart cameras. Chapter 16 presents with smart cameras for machine vision. Chapter 17 features visual surveillance applications. Camera-based automotive systems are presented in Chapter 18.

Part VII comprises Chapter 19, which highlights the market evolution of smart cameras. Interviews conducted at the "Vision Expo 2008" in Germany provide facts and figures to illustrate the current market situation and requirements for smart cameras.

Part VIII comprises Chapter 20, which provides future perspectives and directions of smart cameras by considering the scientific interest, application needs, and the market evolution.

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