Preface

This book is primarily a graduate text on 3D imaging, shape analysis and associated applications. In addition to serving masters-level and doctoral-level research students, much of the text is accessible enough to be useful to final-year undergraduate project students. Also, we hope that it will serve wider audiences; for example, as a reference text for professional academics, people working in commercial research and development labs and industrial practitioners.

We believe that this text is unique in the literature on 3D imaging in several respects: (1) it provides a wide coverage of topics in 3D imaging; (2) it pays special attention to the clear presentation of well-established core techniques; (3) it covers a wide range of the most promising recent techniques that are considered to be state-of-the-art; (4) it is the first time that so many world-leading academics have come together on this range of 3D imaging topics.

Firstly, we ask: why is 3D imaging so interesting to study, research and develop? Why is it so important to our society, economy and culture? In due course, we will answer these questions but, to provide a wide context, we need consider the development of biological vision systems, the development of visual representations and the role of digital images in today's information society. This leads us to the field of computer vision and ultimately to the subject of this book: 3D imaging.

Biological Vision Systems

It is worth reflecting on the obvious fact that the importance of images, in their very general sense (paintings, digital photographs, etc.), is rooted in our ability to see. The ability to sense light dates back to at least the Cambrian period, over half a billion years ago, as evidenced by fossils of trilobites' compound eyes in the Burgess shale. For many animals, including humans, the eye-brain vision system constitutes an indispensable, highly information-rich mode of sensory perception. The evolution of this system has been driven by aspects of our particular optical world: with the Sun we have a natural source of light; air is transparent, which allows our environment to be illuminated; the wavelength of light is small enough to be scattered by most surfaces, which means that we can gather light reflected off them from many different viewpoints, and it is possible to form an image with a relatively simple structure such as a convex lens. It is easy to appreciate the utility and advantages of visual perception, which provides a means to sense the environment in a comprehensive, non-contact way. Indeed, evolutionary biologists have proposed that the development of vision intensified predation and sparked an evolutionary arms race between predators and prey. Thus biological vision systems exist as a result of evolutionary survival and have been present on Earth for a very long time.

Today, there is comprehensive research literature in visual psychophysics, the study of eyesight. Visual illusions suggest that, for some 3D cues, humans use a lot of assumptions about their environment, when inferring 3D shape. The study of how depth perception depends on several visual and oculomotor cues has influenced the development of modern techniques in 3D imaging. Ideas have also flowed in the opposite direction: results from computer vision indicate what information can be extracted from raw visual data, thereby inspiring theories of human visual perception.

Visual Representations from Paintings to Photographs

A drawing, painting or photograph can be viewed as a form of visual expression and communication. Drawing and painting has a very long history and several discoveries of very old cave paintings have been made, for example, those in the Chauvet cave (France) are more than 32,000 years old. Throughout the history of mankind, the use of paintings, drawings and automatically captured images has been culturally important in many different ways. In terms of the subject matter of this book, the advent of photography in the early 19th century was an important milestone, enabling light reflected from an object or scene to be recorded and retained in a durable way. Photographs have many advantages, such as an accurate, objective visual representation of the scene and a high level of autonomy in image capture. Once photography was born, it was soon realized that measurements of the imaged scene could be made; for example, a map could be built from photographs taken from a balloon. Thus the field of photogrammetry was born, which focuses on extracting accurate measurements from images (this is now often included under the banner of *remote sensing*). The work done in this field, from the mid-19th to the mid-20th century, is an essential historical precursor to the material presented in this book.

The Role of Digital Images in Today's Information Society

Today we live in an *information society*, which is characterized by the economic and cultural importance of information in its many forms. The creation, distribution, analysis and intelligent use of digital information now has a wide range of impacts on everyone in the developed world, throughout all stages of their lives. This can be anything from the way in which we do our jobs, to the way our health is managed by our doctors; to how our safety is secured on public transport, during air travel and in public spaces; to how our financial systems work; to how we manage our shopping and leisure time. Of course, many of these impacts have been brought about by the advances in computing and communications technology over the past few decades, with the most obvious examples being the Internet, the world wide web and, more recently, mobile access to these resources over wide-bandwidth, wireless technologies.

The information that we use is often described as being *multi-media*, in the sense that it includes text, audio, graphical figures, images, video and interactive content. Of these different forms, images have always played a hugely important role for obvious reasons: they can convey a huge amount of information in a compact form, they clarify concepts and ideas that are difficult to describe in words, they draw in their audience by making documents more visually appealing and they relate directly to our primary non-contact mechanism for sensing our environment (we humans live and interact in a visual world). For these reasons, images will always be important, but recent advances in both hardware and software technologies are likely to amplify this. For example, digital cameras are now embedded in many devices such as smartphones and the relatively recent explosion in social networking allows groups of people to share images.

Computer Vision

The information society brings with it such a large number of images that we can not hope to analyze them all manually-consider for example the number of images from the security surveillance of a large city over a 24 hour period. The goal of computer vision is to automate the analysis of images through the use of computers and the material presented in this book fits that high level aim. Since there are a large number of ways in which we use images, there is a correspondingly large number of applications of computer vision. In general, automation can improve image analysis performance (people get bored), it increases coverage, it reduces operating costs and, in some applications, it leads to improved safety (e.g. robots working in hazardous environments). The last four decades has seen the rapid evolution of imaging technology and computing power, which has fed the growth of the field of computer vision and the related fields of image analysis and pattern recognition.

The Limitations of Standard 2D Images

Most of the images in our information society are standard 2D color-texture images (i.e. the kind of images that we capture from our mobile phones and digital cameras), or they are effectively sequences of such images that constitute videos. Although this is sufficient for many of the uses that we have described, particularly if the images/video are for direct viewing by a human (e.g. for entertainment or social network use), single, standard 2D images have a number of difficulties when being analyzed by computers. Many of these difficulties stem from the fact that the 3D world is projected down onto a 2D image, thus losing depth information and creating ambiguity. For example, in a 2D image: how do we segment foreground objects from the background? How can we recognize the same object from different viewpoints? How do we deal with ambiguity between object size and distance from the camera? To compound these problems, there is also the issue of how to deal with varying illumination, which can make the same object appear quite different when imaged.

3D Imaging, Analysis and Applications

To address the problems of standard 2D images, described above, 3D imaging techniques have been developed within the field of computer vision that *automatically* reconstruct the 3D shape of the imaged objects and scene. This is referred to as a 3D scan or 3D image and it often comes with a registered color-texture image that can be pasted over the captured shape and rendered from many viewpoints (if desired) on a computer display.

The techniques developed include both active systems, where some form of illumination is projected onto the scene and passive systems, where the natural illumination of the scene is used. Perhaps the most intensively researched area of 3D shape acquisition has been focused on stereo vision systems, which, like the human visual system, uses a pair of views (images) in order to compute 3D structure. Here, researchers have met challenging problems such as the establishment of correspondences between overlapping images for the dense reconstruction of the imaged scene. Many applications require further processing and data analysis, once 3D shape data has been acquired. For example, identification of salient points within the 3D data, registration of multiple partial 3D data scans, computation of 3D symmetry planes and matching of whole 3D objects.

It is one of today's challenges to design a technology that can cover the whole pipeline of 3D shape capture, processing and visualization. The different steps of this pipeline have raised important topics in the research community for decades, owing to the numerous theoretical and technical problems that they induce. Capturing the 3D shape, instead of just a 2D projection as a standard camera does, makes an extremely wide array of new kinds of application possible. For instance, 3D and free-viewpoint TV, virtual and augmented reality, natural user interaction based on monitoring gestures, 3D object recognition and 3D recognition for biometry, 3D medical imaging, 3D remote sensing, industrial inspection, robot navigation, to name just a few. These applications, of course, involve much more technological advances than just 3D shape capture: storage, analysis, transmission and visualization of the 3D shape are also part of the whole pipeline.

3D imaging and analysis is closely associated with computer vision, but it also intersects with a number of other fields, for example: image processing, pattern recognition, computer graphics, computational geometry and physics. It involves building sensors, modeling them and then processing the output images. In particular, 3D image analysis bridges the gap between low-level and high-level vision in order to deduce high-level (semantic) information from basic 3D data.

Book Objective and Content

The objective of this book is to bring together a set of core topics in 3D imaging, analysis and applications, both in terms of well-established fundamental techniques and the most promising recent techniques. Indeed, we see that many similar techniques are being used in a variety of subject areas and applications and we feel that we can unify a range of related ideas, providing clarity to both academic and industrial practitioners, who are acquiring and processing 3D datasets. To ensure the quality of the book, all contributors have attained a world-class standing by publishing in the top conferences and journals in this area. Thus, the material presented in this book is informative and authoritative and represents mainstream work and opinions within the community.

After an introductory chapter, the book covers 3D image capture methods, particularly those that use two cameras, as in passive stereo vision, or a camera and light projector, as in active stereo vision. It also covers how 3D data is represented, stored and visualized. Later parts of the book cover the analysis and processing of 3D images, firstly in a general sense, which includes feature extraction, shape registration and shape matching, and then with a view to a range of applications including 3D object recognition, 3D object retrieval (shape search), 3D face recognition, 3D mapping and 3D medical imaging.

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