Borko Furht *Editor*

Handbook of Augmented Reality

Springer

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Editor
Borko Furht
Department of Computer and Electrical Engineering
and Computer Science
Florida Atlantic University
Glades Road 777
33431 Boca Raton, Florida
USA
bfurht@fau.edu

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To my granddaughter Sophia Rolleri. Her contribution to augmented reality.

Preface

Augmented Reality (AR) refers to a live view of physical real world environment whose elements are merged with augmented computer-generated images creating a mixed reality. The augmentation is typically done in real time and in semantic context with environmental elements. By using the latest AR techniques and technologies, the information about the surrounding real world becomes interactive and digitally usable.

The objective of this Handbook is to provide comprehensive guidelines on the current and future trends in augmented reality technologies and applications. This Handbook is carefully edited book – contributors are worldwide experts in the field of augmented reality and its applications. The Handbook Advisory Board, comprised of 11 researchers and practitioners from academia and industry, helped in reshaping the Handbook and selecting the right topics and creative and knowledgeable contributors.

The Handbook comprises of two parts, which consist of 33 chapters. The first part on *Technologies* includes articles dealing with fundamentals of augmented reality, augmented reality technologies, visualization techniques, head-mounted projection displays, evaluation of AR systems, mobile AR systems, and other innovative AR concepts.

The second part on *Applications* includes various articles on AR applications including applications in psychology, medical education, edutainment, reality games, rehabilitation engineering, automotive safety, product development and manufacturing, military applications, exhibition and entertainment, geographic information systems, and others.

With the dramatic growth of augmented reality and its applications, this Handbook can be the definitive resource for persons working in this field as researchers, scientists, programmers, engineers, and users. The book is intended for a wide variety of people including academicians, designers, developers, educators, engineers, practitioners, researchers, and graduate students. This book can also be beneficial for business managers, entrepreneurs, and investors. The book can have a great potential to be adopted as a textbook in current and new courses on Augmented Reality.

The main features of this Handbook can be summarized as:

1. The Handbook describes and evaluates the current state-of-the-art in the field of augmented reality.
2. The book presents current trends and concepts of augmented reality, technologies and techniques, AR devices, interfaces, tools, and systems applied in AR, as well as current and future applications.
3. Contributors to the Handbook are the leading researchers from academia and practitioners from industry.

We would like to thank the authors for their contributions. Without their expertise and effort this Handbook would never come to fruition. Springer editors and staff also deserve our sincere recognition for their support throughout the project.

Boca Raton, Florida
2011

Borko Furht
Editor-in-Chief

Editor-in-Chief

Borko Furht is a professor and chairman of the Department of Computer and Electrical Engineering and Computer Science at Florida Atlantic University (FAU) in Boca Raton, Florida. He is also Director of the NSF-sponsored Industry/University Cooperative Research Center on Advanced Knowledge Enablement. Before joining FAU, he was a vice president of research and a senior director of development at Modcomp (Ft. Lauderdale), a computer company of Daimler Benz, Germany, a professor at University of Miami in Coral Gables, Florida, and a senior researcher in the Institute Boris Kidric-Vinca, Yugoslavia. Professor Furht received Ph.D. degree in electrical and computer engineering from the University of Belgrade. His current research is in multimedia systems, video coding and compression, 3D video and image systems, wireless multimedia, and Internet, cloud computing, and social networks. He is presently Principal Investigator and Co-PI of several multiyear, multimillion dollar projects including NSF PIRE project and NSF High-Performance Computing Center. He is the author of numerous books and articles in the areas of multimedia, computer architecture, real-time computing, and operating systems. He is a founder and editor-in-chief of *the Journal of Multimedia Tools and Applications* (Springer). He has received several technical and publishing awards, and has consulted for many high-tech companies including IBM, Hewlett-Packard, Xerox, General Electric, JPL, NASA, Honeywell, and RCA. He has also served as a consultant to various colleges and universities. He has given many invited talks, keynote lectures, seminars, and tutorials. He serves as Chairman and Director on the Board of Directors of several high-tech companies.

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Handbook Editorial Board

Contributors

Zhuming Ai Naval Research Laboratory, Washington, DC, USA

Frank Angermann Metaio, Munich, Germany, Frank.Angermann@metaio.com

Shu'nsuke Asai Shimane University, Shimane, Japan

Yohan Baillot Naval Research Laboratory, Washington, DC, USA

Francesca Beatrice Instituto Universitario de Automática e Informática Industrial, Universidad Politécnica de Valencia, Valencia, Spain

Selim Benhimane Research, metaio GmbH, Munich, Germany

Benjamin Berg SimTiki Simulation Center, University of Hawaii, Honolulu HI, USA, bwberg@hawaii.edu

Mark Billinghurst The Human Interface Technology Laboratory, New Zealand (HIT Lab NZ), The University of Canterbury, Christchurch, New Zealand, mark.billinghurst@canterbury.ac.nz

Lisa Blum Collaborative Virtual and Augmented Environments, Fraunhofer FIT, Schloss Birlinghoven, 53754 Sankt Augustin, Germany, lisa.blum@fit.fraunhofer.de

Fernando Boavida Centre for Informatics and Systems, University of Coimbra, Portugal

Markus M. Broecker University of South Australia, Wearable Computer Laboratory, Mawson Lakes, Australia, markus.broecker@unisa.edu.au

Wolfgang Broll Collaborative Virtual and Augmented Environments, Fraunhofer FIT, Schloss Birlinghoven, 53754 Sankt Augustin, Germany, wolfgang.broll@fit.fraunhofer.de

Department of Virtual Worlds and Digital Games, Ilmenau University of Technology, Ilmenau, Germany, wolfgang.broll@tu-ilmenau.de

Leonard D. Brown Department of Computer Science, The University of Arizona, Tucson, Arizona, USA

Dennis G. Brown Naval Research Laboratory, Washington, DC, USA

Julie Carmigniani Department of Computer and Electrical Engineering and Computer Sciences, Florida Atlantic University, Boca Raton, Florida, USA, jcarmign@fau.edu

Jeff Chastine Department of Computing and Software Engineering, Southern Polytechnic State University, Marietta, Georgia, USA, jchastin@spsu.edu

Mike Y. Chen Department of Computer Science and Information Engineering, National Taiwan University, Taiwan, mikechen@csie.ntu.edu.tw

Jean-Marc Cieutat ESTIA Recherche, Bidart, France, j.cieutat@estia.fr

Benjamin Close University of South Australia, Wearable Computer Laboratory, Mawson Lakes, Australia, benjamin.close@clearchain.com

Mathis Csisinko Institute of Software Technology and Interactive Systems, Vienna University of Technology, Vienna, Austria

Henry B.L. Duh Department of Electrical and Computer Engineering/Interactive and Digital Media Institute, National University of Singapore, Singapore, duhbl@acm.org

Andreas Dünser The Human Interface Technology Laboratory, New Zealand (HIT Lab NZ), The University of Canterbury, Christchurch, New Zealand, andreas.duenser@canterbury.ac.nz

J. Edward Swan II Naval Research Laboratory, Washington, DC, USA

Pedro Ferreira Centre for Informatics and Systems, University of Coimbra, Portugal, pmferr@dei.uc.pt

Jonas Fredriksson Chalmers University of Technology, Department of Signals and Systems, Gothenburg, Sweden, jonas.fredriksson@chalmers.se

Philippe Fuchs Virtual Reality and Augmented Reality Team, École des Mines ParisTech, Paris, France, philippe.fuchs@ensmp.fr

Borko Furht Department of Computer and Electrical Engineering and Computer Science, Florida Atlantic University, Boca Raton, Florida, USA, bfurht@fau.edu

Marina Gavrilova University of Calgary, Canada, mgavrilo@ucalgary.ca

Raphael Grasset HIT Lab NZ, University of Canterbury, New Zealand, raphael.grasset@canterbury.ac.nz

Institute for Computer Graphics and Vision, Graz University of Technology, Graz, Austria.

Jian Gu KEIO-NUS CUTE Center, National University of Singapore, Singapore, eledbl@nus.edu.sg

Pascal Guitton LaBRI (IPARLA), Université Bordeaux I & INRIA, Bordeaux, France, guitton@labri.fr

Jan Herling Department of Virtual Worlds and Digital Games, Ilmenau University of Technology, Ilmenau, Germany, jan.herling@tu-ilmenau.de

Masahito Hirakawa Shimane University, Shimane, Japan, hirakawa@cis.shimane-u.ac.jp

Hong Hua College of Optical Sciences, The University of Arizona, Tucson, Arizona, USA, hhua@optics.arizona.edu

Yetao Huang Beihang University, Beijing, China, 6666@bit.edu.cn

Olivier Hugues ESTIA Recherche, MaxSea, LaBRI, Bidart, France, o.hugues@net.estia.fr

Tia Jackson Metaio, Munich, Germany, tia.jackson@metaio.com

Zhiguo Jiang Beihang University, Beijing, China

M. Carmen Juan Instituto Universitario de Automática e Informática Industrial, Universitat Politècnica de València, C/Camino de Vera, s/n, 46022-Valencia, Spain, mcarmen@dsic.upv.es

Simon J. Julier Naval Research Laboratory, Washington, DC, USA

Denis Kalkofen Institute for Computer Graphics and Vision, Graz University of Technology, Graz, Austria, kalkofen@icg.tugraz.at

Tai-Wei Kan Graduate Institute of Networking and Multimedia, National Taiwan University, Taiwan, 7533967@gmail.com; d99944001@ntu.edu.tw

Shuhei Kanagu Roots Co. Ltd, Shimane, Japan, kanagu@roots.selfip.com

Hannes Kaufmann Institute of Software Technology and Interactive Systems, Vienna University of Technology, Vienna, Austria, kaufmann@ims.tuwien.ac.at

Kazuhiro Koyama Roots Co. Ltd, Shimane, Japan, koyama@roots.selfip.com

Antonio Krüger German Research Center for Artificial Intelligence DFKI, University of Saarland, Saarbrücken, Germany

Georg Kuschk Research, metaio GmbH, Munich, Germany

King Lai Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI, USA

Marion Langer Research, metaio GmbH, Munich, Germany

Hongen Liao The University of Tokyo, Tokyo, Japan, liao@bmpe.t.u-tokyo.ac.jp

Sebastian Lieberknecht Research, metaio GmbH, Munich, Germany, Sebastian.Lieberknecht@metaio.com

Gunnar Liestøl Department of Media & Communication, University of Oslo, Norway, gunnar.liestol@media.uio.no

Yue Liu Beijing Institute of Technology, Beijing, China

Mark A. Livingston Naval Research Laboratory, Washington, DC, USA, mark.livingston@nrl.navy.mil

Markus Löchtefeld German Research Center for Artificial Intelligence DFKI, University of Saarland, Saarbrücken, Germany, markus.loechtefeld@dfki.de

Paul Maassel Naval Research Laboratory, Washington, DC, USA

Michael R. Marner University of South Australia, Wearable Computer Laboratory, Mawson Lakes, Australia, michael.marner@unisa.edu.au

Peter Meier Metaio, Munich, Germany

Alessandro Mulloni Institute for Computer Graphics and Vision, Graz University of Technology, Graz, Austria, mulloni@icg.tugraz.at

Olivier Nannipieri Université du Sud, Toulon, and Université de la Méditerranée, Marseille, France, fk.olivier@mac.com

A.Y.C. Nee Department of Mechanical Engineering, National University of Singapore, Singapore, mpeneeyc@nus.edu.sg

Jonas Nilsson Vehicle Dynamics and Active Safety Centre, Volvo Car Corporation, Gothenburg, Sweden

Department of Signals and Systems, Chalmers University of Technology, Gothenburg, Sweden, jnilss94@volvocars.com

Anders C.E. Ödblom Volvo Car Corporation, Gothenburg, Sweden, aodblom1@volvocars.com

S.K. Ong Department of Mechanical Engineering, National University of Singapore, Singapore, mpeongsk@nus.edu.sg

Leif Oppermann Collaborative Virtual and Augmented Environments, Fraunhofer FIT, Schloss Birlinghoven, 53754 Sankt Augustin, Germany, leif.oppermann@fit.fraunhofer.de

David Pérez Instituto de Investigación en Bioingeniería y Tecnología Orientada al Ser Humano, Universitat Politècnica de València, Valencia, Spain

Shane R. Porter University of South Australia, Wearable Computer Laboratory, Mawson Lakes, Australia, shane.porter@unisa.edu.au

Michael Rohs Department of Applied Informatics and Media Informatics, Ludwig-Maximilians-University (LMU) Munich, Munich, Germany

Lawrence J. Rosenblum Naval Research Laboratory, Washington, DC, USA

Kengo Sakata Shimane University, Shimane, Japan

Christian Sandor Magic Vision Lab, University of South Australia, Adelaide, South Australia 5001, Australia, christian.sandor@unisa.edu.au

Dieter Schmalstieg Institute for Computer Graphics and Vision, Graz University of Technology, Graz, Austria, schmalstieg@icg.tugraz.at

Gregory S. Schmidt Naval Research Laboratory, Washington, DC, USA

Jie Shen School of Computer Science and Engineering, University of Electronic Science and Technology of China, Chengdu, China, zeropoint17@hotmail.com

Y. Shen Mechanical Engineering Department, National University of Singapore, Singapore

Andrei Sherstyuk Avatar Reality Inc., Honolulu HI, USA, andrei@avatar-reality.com

Ross T. Smith University of South Australia, Wearable Computer Laboratory, Mawson Lakes, Australia, ross@r-smith.net

Bo Song Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI, USA

Yasuhiro Sota Roots Co. Ltd, Shimane, Japan, sota@roots.selfip.com

Quintus Stierstorfer Research, metaio GmbH, Munich, Germany

Takehiro Tawara Riken, 2-1 Hirosawa Wako-Shi, 351-0198 Saitama, Japan, takehirotwr@riken.jp

Chin-Hung Teng Department of Information and Communication, Yuan Ze University, Taiwan, 7533967@gmail.com

Bruce H. Thomas University of South Australia, Wearable Computer Laboratory, Mawson Lakes, Australia, bruce.thomas@unisa.edu.au

Anton Treskunov Samsung Information Systems America Inc (SISA), San Jose, CA, USA, anton.t@sisa.samsung.com

Daniel Ulbricht Research, metaio GmbH, Munich, Germany

Dale Vincent Internal Medicine Program, Tripler Army Medical Center (TAMC), Honolulu HI, USA, dale.vincent@amedd.army.mil

Yongtian Wang Beijing Institute of Technology, Beijing, China, 6666@bit.edu.cn

Richard Wetzel Collaborative Virtual and Augmented Environments, Fraunhofer FIT, Schloss Birlinghoven, 53754 Sankt Augustin, Germany, richard.wetzel@fit.fraunhofer.de

Sean White Nokia Research Center, Santa Monica, CA, USA, sean.white@nokia.com

Ning Xi Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI, USA, xin@egr.msu.edu

Ruiguo Yang Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI, USA

Adeel Zafar Volvo Car Corporation, Gothenburg, Sweden, azafar3@volvocars.com

J. Zhang Department of Mechanical Engineering, National University of Singapore, Singapore

Rui Zhang College of Optical Sciences, The University of Arizona, Tucson, Arizona, USA, hhua@optics.arizona.edu

Part I
Technologies

Chapter 1
Augmented Reality: An Overview

Julie Carmigniani and Borko Furht

1 Introduction

We define Augmented Reality (AR) as a real-time direct or indirect view of a physical real-world environment that has been enhanced/*augmented* by adding virtual computer-generated information to it [1]. AR is both interactive and registered in 3D as well as combines real and virtual objects. Milgram's Reality-Virtuality Continuum is defined by Paul Milgram and Fumio Kishino as a continuum that spans between the real environment and the virtual environment comprise Augmented Reality and Augmented Virtuality (AV) in between, where AR is closer to the real world and AV is closer to a pure virtual environment, as seen in Fig. 1.1 [2].

Augmented Reality aims at simplifying the user's life by bringing virtual information not only to his immediate surroundings, but also to any indirect view of the real-world environment, such as live-video stream. AR enhances the user's perception of and interaction with the real world. While Virtual Reality (VR) technology or Virtual Environment as called by Milgram, completely immerses users in a synthetic world without seeing the real world, AR technology *augments* the sense of reality by superimposing virtual objects and cues upon the real world in real time. Note that, as Azuma et al. [3], we do not consider AR to be restricted to a particular type of display technologies such as head-mounted display (HMD), nor do we consider it to be limited to the sense of sight. AR can potentially apply to all senses, augmenting smell, touch and hearing as well. AR can also be used to augment or substitute users' missing senses by sensory substitution, such as augmenting the sight of blind users or users with poor vision by the use of audio cues, or augmenting hearing for deaf users by the use of visual cues.

J. Carmigniani (✉)
Department of Computer and Electrical Engineering and Computer Sciences,
Florida Atlantic University, Boca Raton, Florida, USA
e-mail: jcarmign@fau.edu

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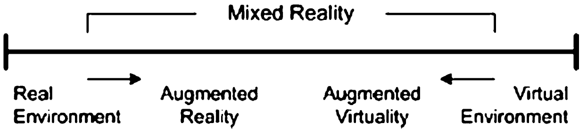

Fig. 1.1 Milgram's reality-virtuality continuum [1]

Azuma et al. [3] also considered AR applications that require removing real objects from the environment, which are more commonly called *mediated* or *diminished reality*, in addition to adding virtual objects. Indeed, removing objects from the real world corresponds to covering the object with virtual information that matches the background in order to give the user the impression that the object is not there. Virtual objects added to the real environment show information to the user that the user cannot directly detect with his senses. The information passed on by the virtual object can help the user in performing daily-tasks work, such as guiding workers through electrical wires in an aircraft by displaying digital information through a headset. The information can also simply have an entertainment purpose, such as Wikitude or other mobile augmented reality. There are many other classes of AR applications, such as medical visualization, entertainment, advertising, maintenance and repair, annotation, robot path planning, etc.

2 History

The first appearance of Augmented Reality (AR) dates back to the 1950s when Morton Heilig, a cinematographer, thought of cinema is an activity that would have the ability to draw the viewer into the onscreen activity by taking in all the senses in an effective manner. In 1962, Heilig built a prototype of his vision, which he described in 1955 in "The Cinema of the Future," named Sensorama, which predated digital computing [4]. Next, Ivan Sutherland invented the head mounted display in 1966 (Fig. 1.2). In 1968, Sutherland was the first one to create an augmented reality system using an optical see-through head-mounted display [5]. In 1975, Myron Krueger creates the Videoplace, a room that allows users to interact with virtual objects for the first time. Later, Tom Caudell and David Mizell from Boeing coin the phrase Augmented Reality while helping workers assemble wires and cable for an aircraft [1]. They also started discussing the advantages of Augmented Reality versus Virtual Reality (VR), such as requiring less power since fewer pixels are needed [5]. In the same year, L.B Rosenberg developed one of the first functioning AR systems, called Virtual Fixtures and demonstrated its benefit on human performance while Steven Feiner, Blair MacIntyre and Doree Seligmann presented the first major paper on an AR system prototype named KARMA [1]. The reality virtuality continuum seen in Fig. 1.1 is not defined until 1994 by Paul Milgram and Fumio Kishino as a continuum that spans from the real environment to the virtual environment. AR and AV are located somewhere

Fig. 1.2 Ivan Sutherland's HMD [5]

in between with AR being closer to the real world environment and AV being closer to the virtual environment. In 1997, Ronald Azuma writes the first survey in AR providing a widely acknowledged definition of AR by identifying it as combining real and virtual environment while being both registered in 3D and interactive in real time [5]. The first outdoor mobile AR game, ARQuake, is developed by Bruce Thomas in 2000 and demonstrated during the International Symposium on Wearable Computers. In 2005, the Horizon Report [6] predicts that AR technologies will emerge more fully within the next 4–5 years; and, as to confirm that prediction, camera systems that can analyze physical environments in real time and relate positions between objects and environment are developed the same year. This type of camera system has become the basis to integrate virtual objects with reality in AR systems. In the following years, more and more AR applications are developed especially with mobile applications, such as Wikitude AR Travel Guide launched in 2008, but also with the development of medical applications in 2007. Nowadays, with the new advances in technology, an increasing amount of AR systems and applications are produced, notably with MIT 6th sense prototype and the release of the iPad 2 and its successors and competitors, notably the Eee Pad, and the iPhone 4, which promises to revolutionize mobile AR.

3 Augmented Reality Technologies

3.1 *Computer Vision Methods in AR*

Computer vision renders 3D virtual objects from the same viewpoint from which the images of the real scene are being taken by tracking cameras. Augmented reality image registration uses different method of computer vision mostly related to video tracking. These methods usually consist of two stages: tracking and reconstructing/recognizing. First, fiducial markers, optical images, or interest points are detected in the camera images. Tracking can make use of feature detection, edge detection, or other image processing methods to interpret the camera images. In computer vision, most of the available tracking techniques can be separated in two classes: feature-based and model-based [7]. Feature-based methods consist of discovering the connection between 2D image features and their 3D world frame coordinates [8]. Model-based methods make use of model of the tracked objects' features such as CAD models or 2D templates of the item based on distinguishable features [7]. Once a connection is made between the 2D image and 3D world frame, it is possible to find the camera pose by projecting the 3D coordinates of the feature into the observed 2D image coordinates and by minimizing the distance to their corresponding 2D features. The constraints for camera pose estimation are most often determined using point features. The reconstructing/recognizing stage uses the data obtained from the first stage to reconstruct a real world coordinate system.

Assuming a calibrated camera and a perspective projection model, if a point has coordinates $(x,y,z)^T$ in the coordinate frame of the camera, its projection onto the image plane is $(x/z,y/z,1)^T$.

In point constraints, we have two principal coordinate systems, as illustrated in Fig. 1.3, the world coordinate system W and the 2D image coordinate system. Let $p_i(x_i,y_i,z_i)^T$, where $i=1,\ldots,n$, with $n \geq 3$, be a set of 3D non-collinear reference points in the world frame coordinate and $q_i(x'_i,y'_i,z'_i)^T$ be the corresponding camera-space coordinates, p_i and q_i are related by the following transformation:

$$q_i = Rp_i + T \tag{1.1}$$

where

$$R = \begin{pmatrix} r_1^T \\ r_2^T \\ r_3^T \end{pmatrix} \text{ and } T = \begin{pmatrix} t_x \\ t_y \\ t_z \end{pmatrix} \tag{1.2}$$

are a rotation matrix and a translation vector, respectively.

Let the image point $\mathbf{h}_\mathrm{i}\ (\mathrm{u_i}, \mathrm{v_i}, 1)^\mathrm{T}$ be the projection of $\mathbf{p}_\mathrm{i}$ on the normalized image plane. The *collinearity equation* establishing the relationship between h_i and p_i using the camera pinhole is given by:

$$h_i = \frac{1}{r_3^T p_i + t_z}(Rp_i + T) \tag{1.3}$$

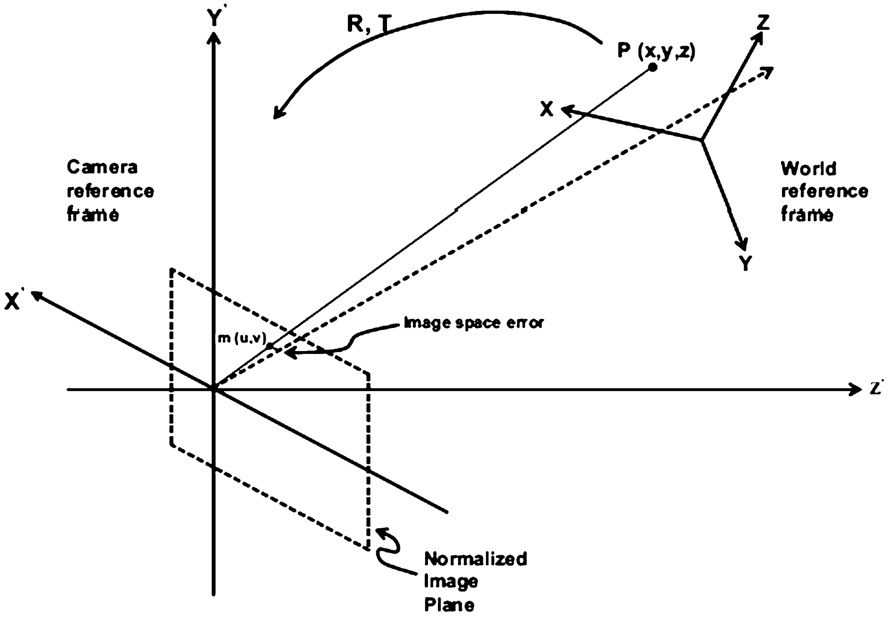

Fig. 1.3 Point constraints for the camera pose problem adapted from [9]

The image space error gives a relationship between 3D reference points, their corresponding 2D extracted image points, and the camera pose parameters, and corresponds to the point constraints [9]. The image space error is given as follow:

$$E_i^p = \sqrt{\left(\overset{\wedge}{\underset{i}{u}} - \frac{r_1^T p_i + t_x}{r_3^T p_i + t_z}\right)^2 + \left(\hat{v}_i - \frac{r_2^T p_i + t_y}{r_3^T p_i + t_z}\right)^2} \tag{1.4}$$

where $\overset{\wedge}{\underset{i}{m}}\left(\overset{\wedge}{\underset{i}{u}}, \overset{\wedge}{\underset{i}{v}}, 1\right)^T$ are the observed image points.

Some methods assume the presence of fiducial markers in the environment or object with known 3D geometry, and make use of those data. Others have the scene 3D structure pre-calculated beforehand, such as Huang et al.'s device AR-View [10]; however, the device will have to be stationary and its position known. If the entire scene is not known beforehand, Simultaneous Localization And Mapping (SLAM) technique is used for mapping fiducial markers or 3D models relative positions. In the case when no assumptions about the 3D geometry of the scene can be made, Structure from Motion (SfM) method is used. SfM method can be divided into two parts: feature point tracking and camera parameter estimation.

Tracking methods in AR depend mostly on the type of environment the AR device will be introduced to as well as the type of AR system. The environment might be indoor, outdoor or a combination of both. In the same way, the system might be mobile or static (have a fixed-position). For example, if the AR device is a fixed-position device for an outdoor real environment, such as Huang et al.'s device AR-View [10], the developers can use mechanical tracking since the movements to be tracked will all be mechanical, as the position of the device is known. This type of environment and system makes tracking of the environment for augmenting the surroundings easier. On the other hand, if the AR device is mobile and designed for an outdoor environment, tracking becomes much harder and different techniques offer some advantages and disadvantages. For example, Nilsson et al. [11] built a pedestrian detection system for automotive collision avoidance using AR. Their system is mobile and outdoor. For a camera moving in an unknown environment, the problem for computer vision is to reconstruct both the motion of the camera and the structure of the scene using the image and additional sensor data sequences. In this case, since no assumption about the 3D geometry of the scene can be made, SfM method is used for reconstructing the scene.

Developers also have the choice to make use of existing AR libraries, such as the ARToolKit. ARToolKit, which was developed in 1999 by Hirokazu Kato from the Nara Institute of Science and Technology and was released by the University of Washington HIT Lab, is a computer vision tracking library that allows the user to create augmented reality applications [12]. It uses video tracking capabilities to calculate in real time the real camera position and orientation relative to physical markers. Once the real camera position is known, a virtual camera can be placed at the same exact position and 3D computer graphics model can be drawn to overlay the markers. The extended version of ARToolKit is ARToolKitPlus, which added many features over the ARToolKit, notably class-based APIs; however, it is no longer being developed and already has a successor: Studierstube Tracker.

Studierstube Tracker's concepts are very similar to ARToolKitPlus; however, its code base is completely different and it is not an open source, thus not available for download. It supports mobile phone, with Studierstube ES, as well as PCs, making its memory requirements very low (100KB or 5–10% of ARToolKitPlus) and processing very fast (about twice as fast as ARToolKitPlus on mobile phones and about 1 ms per frame on a PC) [13]. Studierstube Tracker is highly modular; developers can extend it in anyway by creating new features for it. When first presenting Studierstube in [13], the designers had in mind a user interface that "uses collaborative augmented reality to bridge multiple user interface dimensions: Multiple users, contexts, and locales as well as applications, 3D-windows, hosts, display platforms, and operating systems." More information about Studierstube can be found at [13–15].

Although visual tracking now has the ability to recognize and track a lot of things, it mostly relies on other techniques such as GPS and accelerometers. For example, for a computer to detect and recognize a car it is very hard. The surface of most cars is both shiny and smooth and most of the feature points come from reflections and thus are not relevant for pose estimation and even sometimes recognition [16]. The few stable features that one can hope to recognize, such as the windows corners or wheels, are extremely difficult to match due to reflection and transparent parts. While this example is a bit extreme, it shows the difficulties and challenges faced by computer vision with most objects that have irregular shape, such as food, flowers, and most objects of art.