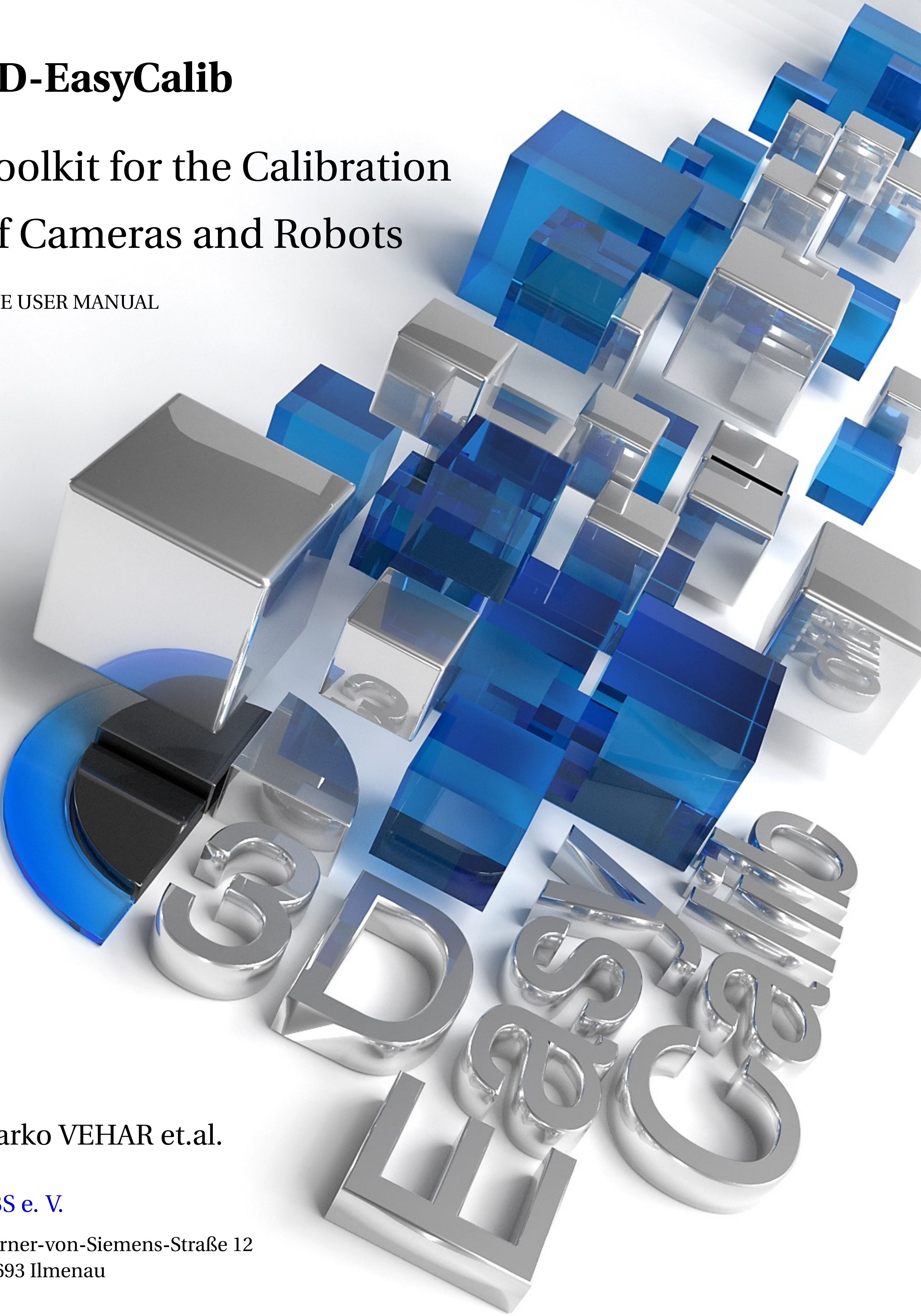
3D-EasyCalib

Toolkit for the Calibration of Cameras and Robots

THE USER MANUAL



Darko VEHAR et.al.

ZBS e. V.

Werner-von-Siemens-Straße 12
98693 Ilmenau

Legal Notice

Werner-von-Siemens-Straße 12, 98693 Ilmenau, Germany
info@zbs-ilmenau.de
www.zbs-ilmenau.de

ZBS Publication Series

ISSN: 1432-3346

Contents

CHAPTER

1 Introduction to Camera Calibration

A camera creates planar images of the three-dimensional physical world by using perspective projection. This technique was first studied and understood in detail during the Renaissance by artists and mathematicians. The painters of that time (see fig. 1.1) derived the geometric construction of perspective projection and applied it to their paintings to create a sense of depth and realism. When photography was invented in the 19th century, the measurement of scenes from perspective images also became interesting for scientific purposes. Since that time, photogrammetry, which addresses this question, has continually evolved. In the same century, mathematicians defined projective geometry, a branch of mathematics that studies properties of geometric figures preserved under projections. This field also deals with points at infinity, which are points where parallel lines appear to meet in a perspective drawing.

Projective geometry provides the theoretical foundation for perspective projection and photogrammetry. However, in practice, it is necessary to account for the specific characteristics and distortions of each camera. This is the subject of camera calibration, which we will discuss in the subsequent sections.

1.1 History of camera calibration

The first methods and procedures for practical camera calibration were motivated by aerial photogrammetry during WWI [7]. The goal was to estimate distances according to the stereoscopic principle from aerial photos and to map the Earth's surface. Since the ideal mathematical camera model differed greatly from a real camera, particularly due to lens distortion, significant effort was initially put into developing mathematical models for lens distortion. The manufacturing tolerances of the time meant the

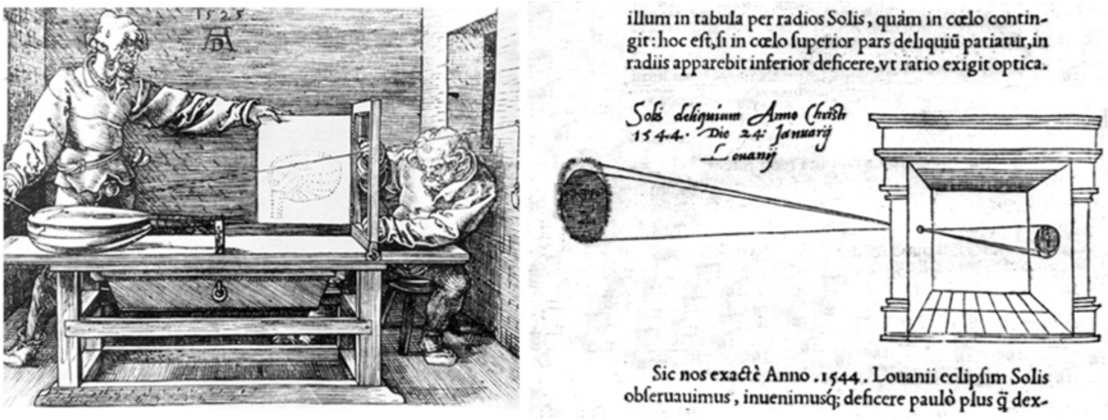


Fig. 1.1: Albrecht Dürer, 1525, Underweysung der Messung (left). The first illustration of a pinhole camera, the so-called Camera Obscura by Reinerus Gemma-Frisius, 1544 (right).

parameters provided by manufacturers for focal length and radial distortion were not precise enough. A correction for decentering distortion was also necessary due to the imprecise alignment of lens elements along the optical axis caused by the manufacturing process.

In 1956, Brown [5] summarized and evaluated the scientific advances in camera lens modeling up to that point. He combined and experimentally investigated the model for radial and tangential distortion presented by Conrady in 1919 [8]. This lens distortion model is still valid today and is explained in **??**. Brown also laid the foundation for modern bundle adjustment for determining the camera parameters in [4].

Determining camera parameters was quite time-consuming before the invention of computers. Originally, star images were used to manually calculate the image formation parameters. This method was replaced by the rotation collimator, based on the goniometer principle, because it was less complex. Again, it was Brown who presented a much simpler method: the so-called plumb-line calibration [6]. Brown described a mathematical model for determining lens distortion parameters based on images of straight lines. This technique proved very useful and was used to calibrate cameras for various applications - from microscopic imaging to aerial photography.

With the advent of the digital era, the optimization of parameters from calibration on computers significantly accelerated. In 1986, Tsai presented a robust, two-step method for determining the intrinsic and extrinsic parameters from a 3D target. This method became popular almost ten years later when Willson [22] provided the first freely available implementation. At this time, ZBS e. V. began working with camera calibration for the first time and has been expanding its competencies in this field ever since. The origins of the 3D-EasyCalib toolkit trace back to the Matlab implementation by Bouguet [2]. He adopted the method presented by Zhang [23], which uses multiple planar targets and optimizes the parameters with a Levenberg-Marquardt gradient descent method. Bouguet recognized that the precision of the determined coordinates of calibration points played a decisive role in effective calibration. The visualization of these errors and the ability to correct them manually set his toolkit apart from the rest. Since there is no reliable method to automatically remove the incorrectly recognized control points, it is important to visualize them to enable manual corrections. His methods were later ported to C++ in the open-source library OpenCV [3]. The methods implemented back then are still used today in almost unchanged form.

1.2 What is camera calibration used for?

Geometric camera calibration is used for various applications that require accurate measurements or 3D reconstruction from images, such as computer vision, robotics, augmented reality, medical imaging, and photogrammetry. Some use-cases of geometric camera calibration are:

- In computer vision, camera calibration can help to correct lens distortion, perform image rectification, and estimate the relative pose and scale of multiple cameras.
- In robotics, camera calibration can enable robots to perceive their environment and perform tasks such as navigation, manipulation, and obstacle avoidance.
- In augmented reality, camera calibration can allow the overlay of virtual objects on real-world scenes with consistent perspective and occlusion.
- In medical imaging, camera calibration can facilitate the registration of images from different modalities, such as X-ray, MRI, and ultrasound.
- In photogrammetry, camera calibration can improve the accuracy and quality of 3D models generated from aerial or terrestrial images.

1.3 What distinguishes a good camera calibration?

Calibration target should be designed based on the working range of the camera and the image resolution. It should also be precisely manufactured.

Image sequence: A sufficient number of images of the target, captured at different distances and orientations to the camera, are required. The camera should move as little as possible while the picture is being taken, and the lens settings should remain unchanged (particularly, auto-focus should be switched off).

The camera parameters to be optimized should be selected based on the camera and optics used. Avoid using too many free parameters, as they may reduce calibration errors but not guarantee an accurate computed model.

Outlier detection and elimination: Ideal methods for camera calibration include all calibration points in the optimization. Since the coordinates of the control points can be detected imprecisely or incorrectly in real images, e.g., due to occlusion, shadows, camera noise or movement during capture, it is necessary to remove the outliers.

CHAPTER

2 Pinhole Camera Model

The pinhole camera model defines the transformation of three-dimensional Euclidean space onto a two-dimensional image plane based on the principle of central projection. It is used to approximate real cameras. In a pinhole camera, a point in space is imaged into a picture point collinearly by a ray passing through the projection center of the camera.

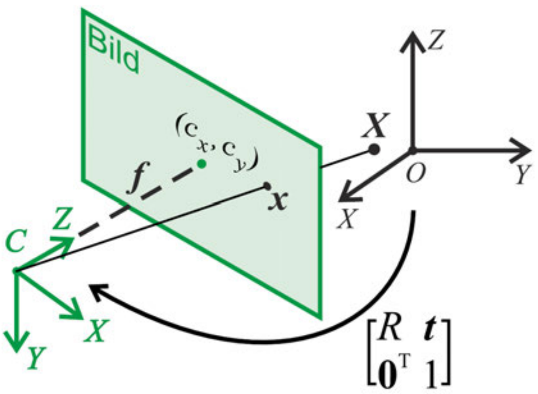


Fig. 2.1: The transformation components of a 3D space to a 2D plane, as implemented with a pinhole camera, consist of the image plane, point C (which does not lie on the image plane), the optical center, and the image distance f (the distance between point C and the image plane). The optical axis is the line passing through C and perpendicular to the image plane. It intersects the image plane at the principal point (c_x, c_y). The mapping $\mathbf{x}$ of a point in space $\mathbf{X}$ is the intersection of the optical ray (C,X) with the image plane.

Would you like to see more?
Send us an enquiry
by e-mail to

3d-easycalib@zbs-ilmenau.de !