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A software program for semi-automated measurement of building façades

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A B S T R A C T

The dimensions of façades and window openings in buildings are usually determined by direct measurements using tapes and plummets. In this paper, we present a semi-automated application that makes it possible to obtain building measurements by means of an indirect method based on close-range photogrammetry. This application is intended to be used with a single planar-surface measuring system that permits measurements to be made without contact with the building. This system combines the output from a digital off-the-shelf camera and a laser distance meter. These data are used within our application for image orientation and scaling. Next, the software permits calculation of the dimensions of elements on the planar façade and also provides an estimate for the precision of those dimensions. This indirect approach avoids time-consuming and risky procedures in building measurement and permits the user to take inventory of a building under construction.

1. Introduction

There are several measurements to make in a building under construction that involve the measurement of planar features, such as the dimensions of façades and faces, window and door openings and curtain walls. These measurements are usually determined by direct methods that involve the use of tapes and plummets. These direct methods imply the presence of the operator inside the building under construction, with the inherent risks and the lack of precision of the field-work. Such issues make it preferable to replace direct methods with indirect methods, like the photogrammetric approach, because one of the features of photogrammetry is the fact that measurements are usually taken without any contact to the object to be measured. With the increasing ratio of quality/prices of digital photography, low-cost close-range photogrammetry has become more popular, and there are several photogrammetric applications that permit the measurement of objects from two or more images. These photogrammetric projects based on photographs consist of obtaining a metric 3D model of the object. The work flow for obtaining 3D objects from images consists of orienting the photographs, referencing points in two or more oriented images and reconstructing the 3D point by mathematical calculating the intersecting point [1]. Because it is usually difficult to obtain a set of photographs with good geometric conditions in construction environments, the software we present in this work is based in single-image photogrammetry and makes use of the system developed in [2] to obtain measurements on planar features of a building under construction, such as façades, window and door openings and curtain walls. Also, we describe a method to estimate the precision of the measurement based on the propagation of uncertainties.

2. Related research

Visual systems can recover geometric information from multiple views [3]. It is also possible to solve the problem

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of obtaining object coordinates from a single image, with the key being that it is necessary to provide geometric constraints to the view. In [4], two sets of constraints are described, object constraints and topology constraints, and applying more constraints than needed leads to an adjustment process. The object constraints described are parallelism, perpendicularity and symmetry. Topology constraints are plane (coplanarity), line and point constraints. Line constraints are widely used. Van den Heuvel describes in [5] the use of coplanar parallel lines to determine the exterior orientation of the view. The orientation is achieved in two steps using parallelity information in the first step and introducing at least seven object coordinates to determine the exterior orientation in the second step. In [6], a method for 3D reconstruction using user-provided collinearity, perpendicularity and parallelism constraints is presented. In that work, vanishing points are computed as the intersection of sets of images of parallel 3D line segments. Vanishing points are widely used in the literature for camera calibration, as in [7,8], as well as in single image 3D reconstruction [9,10]. In [11], some new methods for vanishing point detection are presented. The methods described are used in [12] to find a metric reconstruction from single images.

In [12,13], the goal is the metric reconstruction of façades of damaged or destroyed historical buildings using historical single-view photographs. In [14], a camera is presented as a plane measuring device, and in [15], the authors describe how to obtain 3D measurements as well as uncertainties from a single perspective view. In [16], authors propose a method for using single-image measurement to determine the dimensions of flat surfaces such as billboards. Image orientation is achieved through horizontal and vertical lines, and the scale of the image is determined from the distance read in a laser distance meter parallel to the optical axis. In [17], a similar system is presented, in which the distance meter is positioned above the digital camera and the laser beam is deflected with a half mirror. The system permits rotations in vertical and horizontal directions in order to make precise measurements from the centre of the camera to feature points in object space. In [2], the authors proposed an improvement of the method described in [16] that permits relative rotations between the laser distance meter and the digital camera and applied this method to the measurement of façade window apertures. Orientation is based on the vanishing line of the reference plane of the façade, and scaling is achieved with a laser distance meter.

3. Theoretical background

In this section, we provide an explanation for the different algorithms implemented in the computer program. Please find a detailed description of this system in [2]. The CaM-DisT system is formed by a digital camera, a laser distance meter and a support for combining these two parts. The measuring process with CaM-DisT is based on triangulation between the digital photograph taken by the camera and the laser beam of the distance meter. To model this triangulation, it is necessary to know:

- the distance meter measurement center position vector, relative to the camera optical center:

$$\vec{L} = (X_L - X_0, Y_L - Y_0, Z_L - Z_0)^T \tag{1}$$

- the unit direction vector of the laser beam of the distance meter, relative to the camera orientation:

$$\vec{V} = (V_x, V_y, V_z)^T \tag{2}$$

These parameters are determined from a calibration process.

The camera is modeled as a pin-hole camera whose parameters are obtained by a calibration procedure. The parameters that model the camera are the focal length, the principal point and the parameters of the radial distortion. The relationship between the image coordinates and the object coordinates of the pointer of the laser distance meter is

$$\begin{aligned}\vec{L} + d\vec{V} &= (X_L - X_0, Y_L - Y_0, Z_L - Z_0)^T + d(V_X, V_Y, V_Z)^T \\ &= k(x_{LP}, y_{LP}, -c)^T\end{aligned} \tag{3}$$

where c is the focal length of the camera, d is the distance read in the distance meter, k is the scale factor of the point, $(X_L - X_0, Y_L - Y_0, Z_L - Z_0)^T$ are the coordinates of the center of the distance meter in the image coordinate system, $(V_X, V_Y, V_Z)^T$ are the coordinates of the direction vector of the distance meter in the image coordinate system and, $(x_{LP}, y_{LP}, -c)^T$ are the coordinates of the pointer of the distance meter in the image coordinate system.

To make measurements in a 3D space from photographs, it is necessary to know the exterior orientation of every image and the scale factor between the oriented image coordinates and the object world coordinates. In the case of single image orientation, we need to apply constrains to the image [4–6,16]. Images are oriented using the vanishing line of the measurement plane. We can obtain the vanishing line of the plane if we know at least two vanishing points on it, so we need two sets of parallel lines in the object. Using the redundancy in the number of points, the vanishing point is calculated through the least squares method (LSM) [18]. Using the vanishing line, we can then orient the image, by reversing the effects of camera rotation in pan and tilt angles. We denote α and ν as the rotation angles in pan and tilt, respectively. We will assume swing rotation to be null, because we are only interested in the distance measurement between points in the object and not in its real orientation in the plane. Once we have at least two vanishing points, we form the vanishing line of the measurement reference plane. The parametric equation of the vanishing line can be written as:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \lambda \begin{pmatrix} x_b - x_a \\ y_b - y_a \end{pmatrix} + \begin{pmatrix} x_a \\ y_a \end{pmatrix} \tag{4}$$

where $(x, y)^T$ are the coordinates of the points on the vanishing line, λ is the parameter of the line and, $(x_a, y_a)^T$ and