CAMERA LOCALIZATION
USING INCOMPLETE CHESSBOARD PATTERN

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Abstract: This paper introduces the approach for the real-time camera localization by capturing the plane of chessboard pattern. This task has been already solved by several different approaches, but we present the novel method of the chessboard reconstruction from its incomplete image, that enables successful camera localization even if the captured chessboard plane is partially covered by an unknown object. The camera position and orientation is during the processing of the videosequence tracked with the Kalman filter that enables correct localization also in the closeup views on the pattern.

1 INTRODUCTION

The process of automatic camera localization is a non-trivial task. Usually some auxiliary marks or patterns featuring easy detectability are used in the scene to enable the successful localization process. One of the most common pattern is the chessboard plane due to its geometric simplicity and good contrast visibility.

In this paper we propose the novel approach for the camera localization using the incomplete chessboard pattern. This means that there is no need to capture the whole chessboard plane to reach the proper localization. The algorithm was designed to deal with the situation when an unknown object or obstacle is occluding the chessboard pattern.

2 RELATED WORK

Over the past years numerous different aproaches for the camera localization and auxiliary marks definition have been presented. These works include the description of the marks in the form of the plain squares (Kato and Billinghurst, 1999), labelled self-identifying squares (Fiala and Shu, 2008), circular elements ((Ahn et al., 2001), (Forbes et al., 2002)) and others.

Camera localization using the chessboard pattern have been examined in number of works that include methods employing Delaunay triangulation (Shu et al., 2003), characteristics of local intensity and the grid line architecture of the pattern (Wang et al., 2010) and mainly the symmetric characteristics of chessboard corner areas - (Weixing et al., 2009), (Bevilacqua et al., 2008) and (Ha, 2007).

Unlike other approaches, the method proposed in (de la Escalera and Armingol, 2010) uses a chessboard pattern when no information regarding the number of rows or columns is supplied and the approach presented in (Bevilacqua et al., 2008) aims for the ability to detect the chessboard from the incomplete set of the inner chessboard corners.

3 SYSTEM DESIGN

This section introduces our approach for the camera localization using the incomplete chessboard pattern. The scenario is that there is a planar pad with the chessboard pattern that is observed by the moving camera. In each frame of so obtained videosequence, it is desired to retrieve the position and orientation of the camera relative to the observed chessboard plane. The chessboard plane can be partially covered by unknown object so the crucial part of this process is the chessboard area detection, reconstruction and follow-up tracking.

The video processing begins with the initialization phase, when the chessboard plane is detected and reconstructed, and the initial camera position and orientation is determined. After the initialization, the track-

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ing phase continues with the frame-by-frame updating of the camera position and orientation, this time with less restrictions on the view itself. This means that during the tracking phase the camera can move close to the chessboard plane and still the proper localization is possible.

4 THE ALGORITHM

4.1 Image Analysis

The main visual marker, inner corner of the chessboard pattern, features strong gradient changes and the neighbourhood that is according to the color (or intensity) values separable into two distinct groups arranged into four perspectively distorted rectangles. This perspective distortion nevertheless does not curvate the lines forming the borders between the chessboard fields which is the key feature used in the procesing.

The detector is based on mentioned properties of a corner neighbourhood and with slight implementation changes and enhancements originally comes from the work (Bevilacqua et al., 2008).

The chessboard reconstruction algorithm (see Section 4.2) takes as its input the set of chessboard pattern line segments, which are the lines connecting two adjacent corner points.

To check whether two corner points lie on the same line segment, their join is iteratively divided in halves. At every dividing point, the difference of two side pixels intensities is evaluated. The side pixels are found on the normal to the corner join in specified distance. The difference of all side pixel intensities should be in the case of proper line segment alongside the joint merely the same, as can be seen on Figure 1.

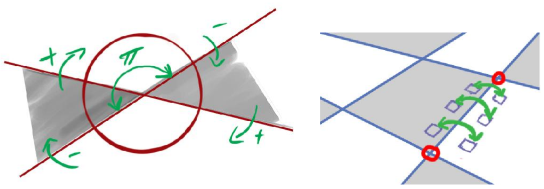

Figure 1: Properties of chessboard corner neighbourhood (left). Sampling of the line segment (right).

4.2 Chessboard Assembly

In order to compute the position and rotation of camera, the known planar structure of calibration chessboard and its image in camera's projection plane can be exploited. During the extraction, the mutual positions of the corners are not preserved, so the structure of detected corners is unknown. We propose an algorithm that focuses on finding the chessboard grid - inner vertical and horizontal lines.

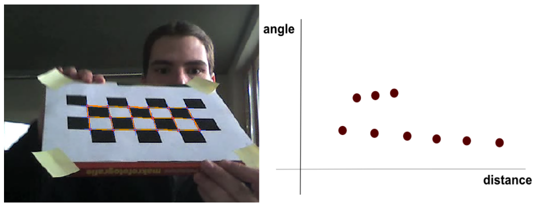

Figure 2: The detected line segments form points in Hough space.

To extract lines of chessboard grid, we exploit the fact that every two adjacent corners form a line that passes through other corners of the same row/column. If at least one such line from each row and column is detected, the whole chessboard grid can be assembled in three steps:

1. All detected line segments are transformed into 2D Hough space. This transformation maps a line into a point such that the lines with same angle and distance are mapped to the same point (Figure 2), thus defining the same row or column of chessboard pattern.
2. The parallel lines lie in the Hough space on the same line. The chessboard is composed of two sets of parallel lines - horizontal and vertical, so two sets of collinear points should be in Hough space, which can be found using RANSAC (Forsyth and Ponce, 2002) algorithm.
3. Points from each set are sorted, so numbered lists of vertical and horizontal lines are created. These lines intersect in points, where the chessboard corners should lie in image from camera, so the small areas around intersections are searched for best corner candidates.

Knowing the structure of chessboard corners, the 2D to 3D correspondences can be easily found.

4.3 Camera Localization and Tracking

The localization of the camera is a process of finding camera's exact position and rotation in arbitrary world coordinate frame. The real camera can be approximated with pinhole camera model which describes relationship between the coordinates of 3D point and its image in camera's projection plane.

The mapping between 3D scene points and their images is defined by equation:

$$\mathbf{x} = A[R| - T]\mathbf{X} \tag{1}$$

where vector **x** represents the image coordinates of 3D point **X**, matrix A contains intrinsic camera parameters and joint matrix $[R|-T]$ represents external camera parameters - rotation matrix R and translation vector T, which relate the camera orientation and position to a world coordinate system.

With known intrinsic camera parameters, the position and rotation of camera can be estimated using at least 4 coplanar 3D points and their corresponding images in camera projection plane. Algorithm such as Levenberg-Marquadt (Forsyth and Ponce, 2002) can be used to minimize projection error, which is computed as distance between corners extracted from image, and their projections using estimates of unknown parameters.

The initialization step is applied only once, next the camera movement is tracked using Kalman filter (Forsyth and Ponce, 2002), because it can cope with unstable motion of hand-held camera.

Because any 4 non-collinear corners have to be found to compute new camera positions, the camera motion is not restricted by detecting whole chessboard, so various angles and camera close-ups are possible without losing track of camera position.

5 EXPERIMENTS AND RESULTS

The system has been tested on both real and synthetic data. The test scenes have been captured in the resolution of 640x480 pixels by several cameras featuring different capture properties and also rendered by 3D software.

5.1 Stability

The test data were captured to contain intrusive factors that can significantly worsen the image quality and therefore affect the reliability of the proposed algorithms. These factors include shaky or fast camera movements, poor scene lighting (insufficient contrast, strong shadows), image noise, complex background or an object occluding the chessboard area.

The experiments with different kinds of occlusions proved the ability of correct initialization also in the cases, when there are false positive detections of chessboard corners in the object or background area.

Fast or shaky camera movements lead to blurred videosequences which causes losing of limited number of detected chessboard corners. Such failures within short time (several successive frames at most) are suppresed due to the usage of Kalman filter.

Very fast camera movements can lead to the undetectable failure when the located chessboard is shifted and placed on incorrect chessboard lines. This aliasing happens when the movement of the chessboard image between adjacent frames is close or greater than the size of the pattern squares.

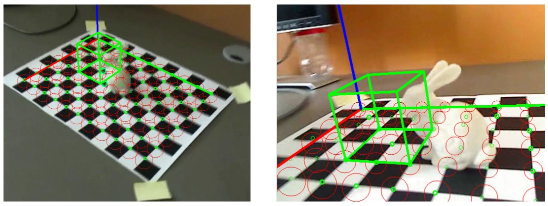

Figure 3: Examples of the chessboard detection in distant and closeup view. The correctness of the localization is demonstrated by drawn world coordinate axis and virtual cube.

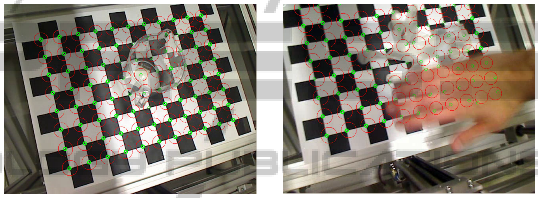

Figure 4: Examples of the chessboard detection during the initialization (left) and tracking phase (right).

5.2 Accuracy

The evaluation of localization accuracy has been based on synthetic data. In the case of a general camera movement, the information about rotation of the camera turned out to be more precise than the camera position. The average deviation of the precise and computed camera position was about the tenth of the size of chessboard square side, the average deviation in the rotational space did not exceeded 0.01 radians.

The accuracy of the output is directly affected by the distance of the camera from the chessboard plane. The smaller the distance is the more precise is the computed camera position (see Figure 5). The relative disparity, that is an average of the measured value divided by the distance of the camera to the chessboard plane, was smaller than 0.006.

5.3 Performance

The speed of the initialization part depends primarily on the amount of the inner chessboard corners within the pattern, the distance of the camera to the chessboard plane, image resolution setting and background complexity.

In the case of the chessboard pad with 11x8 inner corners that was used during the tests, the processing time of single initialization step did not exceeded

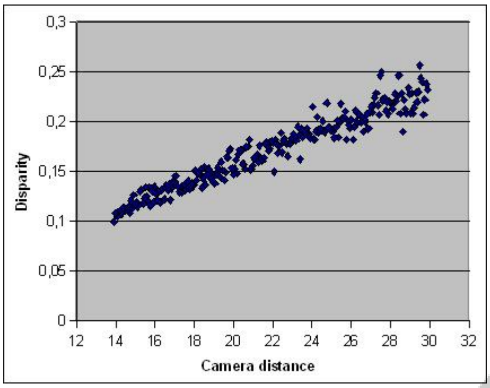

Figure 5: The dependance of the computation accuracy to the distance between camera and chessboard pad (1 unit equals the size of the chessboard square side).

80ms. The average time of the processing during the tracking phase was 16 miliseconds which corresponds to more than 60 frames per second. This period includes all steps of frame processing, including the querying for the frame image, camera prediction and localization.

Processing times were measured on the notebook having Core 2 Duo processor and 2 GB of RAM.

6 CONCLUSIONS

The approach for the automatic camera localization and tracking using the chessboard pattern has been presented. The described approach has been designed to perform in real-time so it can be used in various tasks such as augmented reality, user interfaces (the camera or a small chessboard plane can be used as a 6 DOF device), 3D scene reconstruction or in combination with object scanner.

The chessboard reconstruction algorithm is rather original and performs well with the occluded or incomplete chessboard plane. Nevertheless, the possibilty of the line skip alias in the tracking phase is the weak part of the process and could be improved in future work. This skip is usually caused by quick camera movements, so increasing the framerate of the camera could reduce the risk of failure.

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