Colour in calibration points indexing

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Abstract— The paper presents the way that colour can serve solving the problem of calibration points indexing in a camera geometrical calibration process. We propose a technique in which indexes of calibration points in a black-and-white chessboard are represented as sets of colour regions in the neighbourhood of calibration points. We provide some general rules for designing a colour calibration chessboard and provide a method of calibration image analysis. We show that this approach leads to obtaining better results than in the case of widely used methods employing information about already indexed points to compute indexes. We also report constraints concerning the technique.

Nowadays we are witnessing an increasing need for camera geometrical calibration systems. They are vital for such applications as 3D modelling, 3D reconstruction, assembly control systems, etc. Wherever possible, calibration objects placed in the scene are used in a camera geometrical calibration process. This approach significantly increases accuracy of calibration results and makes the calibration data extraction process easier and universal.

There are many geometrical camera calibration techniques for a known calibration scene [1]. A great number of them use as an input calibration points which are localised and indexed in the scene.

In this paper we propose the technique of calibration points indexing which uses a colour chessboard. The presented technique was developed by solving problems we encountered during experiments with our earlier methods of camera calibration scene analysis [2]-[3]. In particular, the proposed technique increases the number of indexed points points in case of local lack of calibration points detection.

At the beginning of the paper we present a way of designing a chessboard pattern. Then we describe a calibration point indexing method, and finally we show experimental results.

A black-and-white chessboard is widely used in order to obtain sub-pixel accuracy of calibration points localisation [1]. Calibration points are defined as corners of chessboard squares. Assuming the availability of rough localisation of these points, the points can be indexed.

Noting that differences in distances between neighbouring points in calibration scene images differ slightly, one of the local searching methods can be employed (e.g. [2]). Methods of this type search for a calibration point to be indexed, using a window of a certain size. The position of the window is determined by a vector representing the distance between two previously indexed points in the same row or column. However, experiments show that this approach has its disadvantages, as described below.

Firstly, there is a danger of omitting some points during indexing in case of local lack of calibration points detection in a neighbourhood (e.g. caused by the presence of non-homogeneous light in the calibration scene). A particularly unfavourable situation is when the local lack of detection effects in the appearance of separated regions of detected calibration points. It is worth saying that such situations are likely to happen for calibration points situated near image borders. Such points are very important for the analysis of optical nonlinearities, and a lack of them can significantly influence the accuracy of distortion modelling.

Secondly, such methods may give wrong results in the case of optical distortion with strong nonlinearities when getting information about the neighbouring index is not an easy task.

Beside this, the methods are very sensitive to a single false localisation of a calibration point. Such a single false localisation can even result in false indexing of a big set of calibration points.

To avoid the above-mentioned problems, we propose using a black-and-white chessboard which contains the coded index of a calibration point in the form of colour squares situated in the nearest neighbourhood of each point. The index of a certain calibration point is determined by colours of four nearest neighbouring squares (Fig.1). An order of squares in such foursome is important.

Because the size of a colour square is determined only by the possibility of correct colour detection, the size of a colour square can be smaller than the size of a black or white square. The larger size of a black or white square is determined by the requirements of the exact localisation step which follows the indexing of calibration points [3]. In this step, edge information is extracted from a black-and-white chessboard. This edge information needs larger

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squares in order to provide the accuracy of localisation at acceptable level.

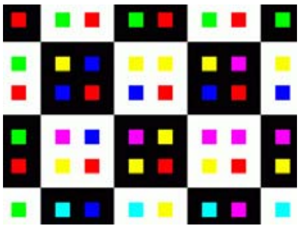

Fig. 1. Proposed colour chessboard with coded indexes of calibration points for six indexing colours

The colours of the squares should be as distant as possible from one another and from black and white in a colour space. The selection of the colours should also guarantee as high as possible probability of their true detection in calibration image. Therefore, we propose selecting them as equidistant points on the circumference of the base of an HSV cone ($S=1, V=1$).

The minimal number of colours needed to index all calibration points in the chessboard is determined by the number of calibration points. The number of needed colours is calculated basing on the fact, that the permutation with repetitions of possible foursomes of colours must be equal or greater than the number of calibration points:

$$n_c^4 \geq n_p \qquad (1)$$

where n_c is the number of needed colours and n_p is the number of calibration points in the chessboard.

Having defined the colour chessboard we will describe the calibration points indexing method. We assume that the rough localisation of calibration points is available (it can be obtained using, for example, a method of neighbourhood analysis [3]).

In the case of significant noise, denoising of calibration image should be the first step of analysis. Next, pixels are classified on the basis of localisation of their colour in the clustered HSV colour space. In Fig. 2 we illustrate exemplary clustering of an HSV cone in the case of eight colours. A cluster is bounded by the following planes: a plane which contains the axis of the cone ($S=0$) and the points which are equidistant from the current colour (C_i) and the previous colour (C_{i-1}), a plane which contains the axis of the cone ($S=0$) and the points which are equidistant from the current colour (C_i) and the next colour (C_{i+1}), and the surface of a cylinder which excludes a white and black colour ($S=a$, where $a \in (0,1)$). For example, in Fig. 2, the borders of a cluster for colour C_3 are marked in blue on the base of an HSV cone.

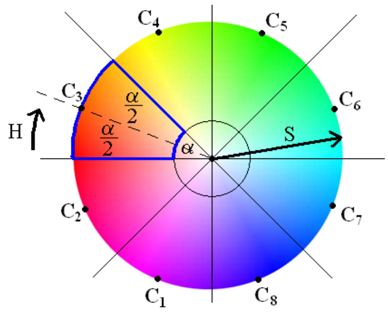

Fig. 2. Exemplary clusters for pixel classification in the case of eight colours ($C_1, C_2, \ldots, C_8$)

Simultaneously with the pixel classification process, colour region segmentation is done, in which the same label is assigned to already classified neighbouring pixels having the same colour. The problem of differently labelled pixels belonging to the same region can be solved by using a connected components analysis [4]-[5]. This method allows an effective segmentation using only two passes through image pixels.

In the next step the centres of big enough colour regions are computed. After that, we assign the nearest four colour regions to each rough localisation of a calibration point using the criterion of the smallest distance from the centre of the region. The position of regions with regard to the calibration point is analysed to determine which colour is first, second, etc., in the previously fixed order of a foursome code.

We can imagine a situation when it is impossible to determine which region represents the first item of a foursome. It can take place if we deal with very untypical optical distortion. Then a foursome code is recommended, which property is such that if we build a circularly-linked list consisting of elements of each foursome, then no two lists of this kind will be the same.

Tests of the technique presented here were conducted with off-the-shelf cameras (SONY DSC-S600, OLYMPUS C-7070). The experiments show that the analysis method provides correct results in the case of false detection of some calibration points or lack of detection. The method also increases the number of indexed points near the image borders. However, we encountered some problems related to colour distortion in contemporary image acquisition devices, which leads us to define the constraints of the above technique.

The effect of a diverse light refraction coefficient in a lens for different light wave lengths results in appearance of additional colours on the borders of both colour squares and black and white squares. Especially, it is visible near image borders. The real data example of that

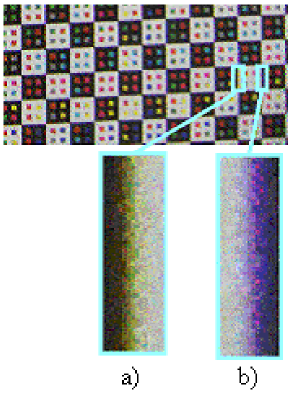

Fig. 3. Effect of diverse light refraction coefficient in lens for a different light wavelength

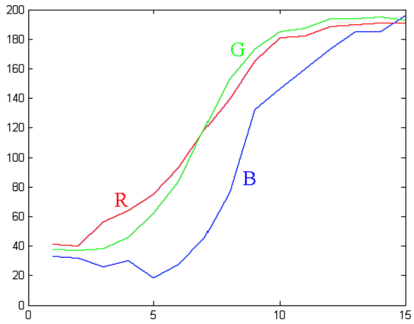

Fig. 4. Average level of RGB pixel values (8 bits for every component) in columns of the rectangle presented in Fig. 3a

effect is shown in Fig. 3 and Fig. 4. This additional colour may sometimes result in the appearance of undesirable colour regions during colour region segmentation. However, this effect can be avoid applying segmentation only inside black and white squares of a chessboard. The interiors of the squares can be localised on the basis of available rough localisation of calibration points.

We also encountered problems with colour classification in the case of a large number of square colours. Pixels corresponding to the same colour in a chessboard, can create a wide set of hue values in the image of the chessboard. In the case of many colours used in the chessboard, the sets corresponding to the neighbouring colours of the colour space can overlap each other. In Fig. 5 we show an example of overlaping sets of colours. This overlaping is a constraint on maximal number of colours that can be used for colour squares, which implies the constraint on the maximal number of calibration points that can be indexed (1).

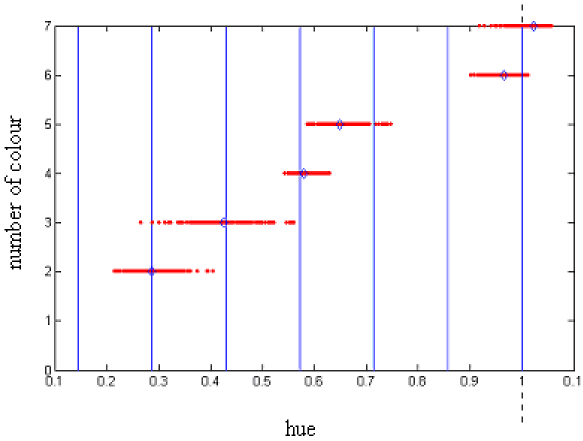

Fig. 5. The effect of overlaping of different colour pixel sets for six indexing colours – hue value of acquired indexing pixel colours

In the paper we presented a new calibration points indexing technique. The technique uses colour squares in a black-and-white chessboard.

The technique includes the method for analysing a calibration image. The method increases the number of indexed points near the image borders. It is not sensitive to false calibration points detection or lack of detection due to the computation of the index which does not use the information about indexes in the neighbourhood.

However, the number of calibration points which can be indexed is limited by camera properties of colour imaging. Strong colour distortions can also be a constraint on the method.

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