A Simplified Field-of-View Calibration Technique for an Operating Microscope

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Abstract. We present a simplified camera calibration algorithm taking advantage of the geometry of our operating microscope, and requiring no special calibration target. Simulations showed that this algorithm is moderately sensitive to inaccuracies in S and f. For nominal values of $S_n=6$ pix/mm and $f_n=300$ mm, we found that a 5% deviation in the value of S results in a mean error of 0.99 mm, while a 5% deviation in the actual value of f results in a 0.81 mm mean error.

1 Introduction

Our goal is to use the operating microscope's field of view (FOV) as a means to track shift between a preoperative MR and the operating field. This will provide data to update the preoperative study and compensate for the shift [1]. A necessary step consists of being able to predict where a point in world coordinates will appear in the FOV. Determining the required transformation matrices is usually referred to as the „camera calibration“ problem. Camera calibration has been investigated by many and recent contributions include: Zhang [2], Devy et al. [3], Luong et al. [4], Stein [5], Hartley [6], Wei et al. [7], Faugeras [8], and Weng et al. [9], Caprile et al. [10]. It is also discussed in a textbook Gonzalez & Wintz [11] and Tsai [12]. We sought a much simpler approach allowing calibration on the fly during a procedure, and requiring no special calibration setup.

2 Materials and Methods

With a readily identifiable focal point, and the ability to physically make it coincide with any desired world feature we devised a method to express its location in world space using a suitable transformation matrix [13]. The result of this procedure is a vector V_f representing the location of the focal point in tracker coordinates. The series of transformations needed to map a point from world to image coordinates is:

$${}^I P = {}^I T_C \cdot {}^C T_T \cdot {}^T T_W \cdot {}^W P \quad (1)$$

where the subscript and superscripts indicate image (I), camera (C), tracker (T) and world (W) coordinate systems. In equation 1, the location of the world-coordinates

point, wP , is known; ${}^T T_w$, the world to tracker transformation, is provided by the 3D positioning system; ${}^c T_T$, the tracker to camera transformation, needs to be computed and the camera to image transformation, ${}^I T_C$, is determined as explained here.

In the following discussion the desired point is known in tracker coordinates (i.e. the right-most multiplication in (1) has been performed). We expand here equation 1 in matrix form:

$$\begin{bmatrix} c \cdot x_I \\ c \cdot y_I \\ c \end{bmatrix} = \begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & 1/f & 0 \end{bmatrix} \cdot \begin{bmatrix} r_1 & r_2 & r_3 & t_x \\ r_4 & r_5 & r_6 & t_y \\ r_7 & r_8 & r_9 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_T \\ y_T \\ z_T \\ 1 \end{bmatrix} \quad (2)$$

From (2), it can be seen that $c=z_C/f$, where z_C is the z coordinate of the point in camera coordinates. This coefficient is the nonlinear component of the overall transformation process, since it includes the z_C term and since the homogenous image coordinates must be normalized, (divided by c) to obtain x_I and y_I . S_x and S_y are the scaling factors translating distance (mm) to pixels in our system $S_x=S_y$ (square pixels). The term f is the focal length of the optical system; when the focal point is aimed at the point of interest, $z_C=f$ and $c=1$. Because of the nonlinear term in the camera to image transformation ${}^I T_C$ it is not possible to compute it directly. We chose to determine S_x and S_y directly from images and we also assume f to be the focal length specified by the microscope's manufacturer. The matrix containing the $r_1 \dots r_9$ and $t_x \dots t_z$ elements (${}^I T_C$) relates tracker and camera spaces, and is the only term that needs computing. Having obtained estimates of the components of ${}^I T_C$, we are able to solve for the remaining unknown terms using points whose coordinates are known in tracker and image frames.

3 Results

3.1 FOV Calibration: Simulations Results

S_x and S_y were found from images of a ruler in the focal plane at each magnification setting. Evaluation of the FOV calibration is based on computer simulations at 4 different magnification settings with nominal values for $S_n=6, 12, 24$ and 48 pix/mm, (zoom factors of 1, 2, 4 and 8) and a fixed nominal value of 300 mm for the focal length f_n . We used a 9×9 grid of test points forming a 20 mm square in camera space. From the test points defined in camera coordinates, homologous sets were produced in tracker, world and image coordinates. The image coordinates were computed using an actual focal length f_a and an actual scaling factor S_a . These were varied by $\pm 10\%$ from their nominal values f_n and S_n in 21 increments. Errors were computed from the Euclidean distances between the correct and calibrated points are summarized in table 1.

4. Tables

Table 1. Error in image point projection due to a disparity between the nominal (S_n , f_n) values for the scaling factor and focal distance and their actual values.

Conditions	10% error				5% error			
All units mm	S		f		S		f	
	mean	max	mean	max	mean	max	mean	max
$S_n = 6$, $f_n = 300$	1.715	2.8808	1.8865	3.0641	0.9928	1.7552	0.8097	1.4142
$S_n = 12$, $f_n = 300$	1.7175	2.8808	1.6824	2.7735	1.0373	1.7552	0.8244	1.3176
$S_n = 24$, $f_n = 300$	0.9545	1.4404	0.8591	1.2964	0.5816	0.8776	0.4407	0.6482
$S_n = 48$, $f_n = 300$	0.5464	0.7202	0.4918	0.6482	0.3329	0.4388	0.2459	0.3241

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