CAMERA-PROJECTOR SYSTEM AUTOMATIC CALIB-RATION

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ABSTRACT

Multi-camera-projector optical systems are commonly used for virtual reality systems. Such systems allow effective user interaction, thereby increasing immersion. Aim of this article is to describe such system and solution of its calibration using epipolar constraints and point correspondences.

1. INTRODUCTION

Virtual reality systems are nowadays common part of many research institutes due to their low cost and effective visualization of data. They mostly allow visualization and exploration of virtual worlds, but many don't allow user interaction. Several ways to achieve user interaction exist, e.g. handheld computers, haptic devices or camera systems. The advantage of a camera system is its relatively low cost, and a possibility of immersion. However, beforehand calibration process of this multi-camera system is a complex task. To achieve precise interaction with virtual world, the location of projection plane should be known. Factorization based algorithm presented by Strum & Triggs [1] could be effectively used to do camera calibration and if projection plane is in field of view (FOV) of at least one camera, location of projection plane can follow.

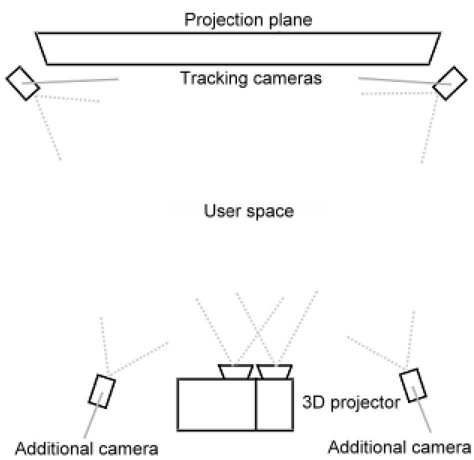

Image 1: Scene structure. Two tracking cameras will be used to track positions of user's body parts. Additional camera is necessary for calibration and location of projection plane.

2. FINDING CORRESPONDING POINTS

The calibration process consists of following steps. First, the corresponding coordinates of visible 3D points between cameras have to be known. In our experiments, we set quick shutter on cameras and used high luminous LED diode, therefore it was clearly visible in camera’s image and its position could be easily extracted. The corresponding points between all cameras images could be obtained by moving the LED diode in common FOV of all cameras. Image 1 shows camera-projector system, at least 3 cameras are needed to obtain its calibration, fourth is optional for easier location of projection plane. In next step, we have to recover camera’s intrinsic (focal lengths, principal point) and extrinsic (position and rotation) parameters.

3. RECOVERING CAMERA PARAMETERS

Suppose we obtained at least 8 non-coplanar corresponding points with method mentioned in previous section. These points are enough to find epipolar relations between cameras, and factorization algorithm [1] can be used to recover camera’s projective matrices and 3D structure of calibration points.

For further use, it is necessary to know camera parameters, not only projection matrices. We assume we have estimated projection matrices with algorithm above, expressed in following form:

$$P = \begin{bmatrix} p_1^T & \\ p_2^T & p_4 \\ p_3^T & \end{bmatrix} \tag{1}$$

Where p_i is 3x1 vector. Parameters, we are looking for are focal lengths f_x, f_y, principal point c_x, c_y, elements of rotation matrix r_{ij} and elements of translation vector t_x, t_y, t_z. Knowing that rows and columns of a rotation matrix form orthonormal basis, we can compute above parameters with following equations:

$$c_x = p_1^T p_3 \,,\ c_y = p_2^T p_3$$

$$f_x = \sqrt{p_1^T p_1 - c_x^2} \,,\ f_y = \sqrt{p_2^T p_2 - c_y^2}$$

$$r_{1i} = (c_x q_{3i} - q_{1i}) / f_x \,,\ r_{2i} = (c_y q_{3i} - q_{2i}) / f_y \,,\ r_{3i} = q_{3i} \,, \qquad i = 1,2,3$$

$$t_x = (c_x q_{34} - q_{14}) / f_x \,,\ t_y = (c_y q_{34} - q_{24}) / f_y \,,\ t_z = q_{34}$$

Where q_{ij} is element of matrix P, i-th row, j-th column.

4. LOCATION OF PROJECTION PLANE

After we obtain all camera intrinsic and extrinsic parameters, we can estimate location of projection plane. Projection plane can be located even if it is only in FOV of one camera, but that would require user assistance and would be inaccurate. Optimal scenario is when projection plane is in FOV of two and more cameras (Image 1 left).

Location of projection plane will be achieved followingly. Projector will be used to project image with highlighted corners. These corners will be easy to extract in camera images. As shown in Image 2, knowing location of camera centers $P_{1,2}$ in scene coordinate system, their rotations $R_{1,2}$, focal lengths $f_{1,2}$ and principal points c_1,c_2, we can create vectors:

$$v_1 = R_1[q_{1x} - c_{1x}, q_{1y} - c_{1y}, f_1]^T,\ v_2 = R_2[q_{2x} - c_{2x}, q_{2y} - c_{2y}, f_2]^T \qquad (2)$$

These vectors and cameras centers define lines which intersect at point Q in 3D space - coordinates of corner in scene coordinate system.

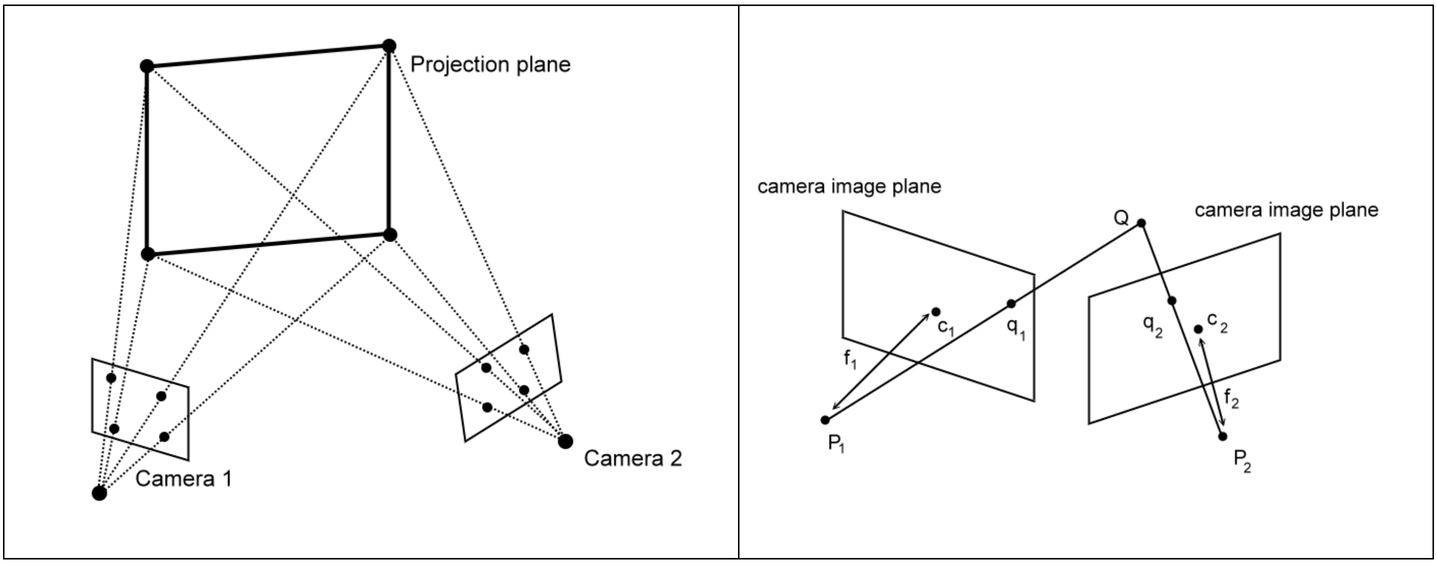

Image 2: Locating projection plane. On left, projection plane is in FOV of two cameras. Reprojected rays of corresponding points intersect at corners of projection plane. On the right is location of corner Q, with known his images q_1 and q_2. $P_{1,2}$ are camera centers, $f_{1,2}$ focal lengths and c_1,c_2 are principal points.

5. CONCLUSION

The presented calibration algorithm would provide acceptable calibration results for camera-projector systems for virtual reality. Future work will include tracking user's body parts, such as hands or head, and provide interaction with virtual worlds and view-dependent rendering.

REFERENCES

[1] Sturm, P., Triggs, B.: A factorization based algorithm for multi-image projective structure and motion. European Conf. Computer Vision, Cambridge, England, 1996

[2] Richard Hartley, Andrew Zisserman. Multiple view geometry in computer vision, CUP, Cambridge, UK, 2003