REGISTRATION OF A 3D MODEL ON A SINGLE IMAGE IN WIDE ANGLE AUGMENTED REALITY

Youngmin Lee
5th R&D center, ADD, Korea

Kwangyun Wohn
Computer Science Department, KAIST, Korea

ABSTRACT

This paper presents a new design of a wide angle augmented reality (AR) system and an effective registration method using a single image. The AR system is designed to meet three requirements: (1) the field of view (FOV) of the AR system must be wide enough to view reference constructions in outdoor scenes; (2) the precise registration of virtual objects should be guaranteed at any position of the image; and (3) the registration should be valid after motion of the camera.

We use camera calibration and calibration-free methodologies in our approach. The internal parameters of the camera are determined roughly by the camera calibration and how the distortion coefficient of the camera lens is refined. The external parameters are determined by the calibration-free approach. At least four coplanar points forming a projected parallelogram are needed to construct the affine coordinates that are used for the registration. The only presumed condition is that the user specifies some projected parallelogram lines of the reference object interactively.

The experimental results demonstrate the display prototype of the wide angle AR system with the distorted images removed and registration of 3D virtual models in static and dynamic camera environments.

1. Introduction

Augmented reality (AR) is a rapidly growing research area of virtual reality. After publication of the concept [1] and definition [2] of AR, many research results have been published recently with many applications. However, registration remains a major problem, and it is closely related to the components of the AR system.

At the component level of AR systems, several kinds of 3D sensors (magnetic sensors, mechanical sensors, optical sensors, and hybrid styles) are used to increase the precision of registration [3]. Another important component of an AR system is a display device. Previous researchers have used two kinds of display systems: the see-through head mounted display (HMD) and the video see-through HMD [4]. The field of view (FOV) of a single eye covers 75.3 degrees and the overlapped region of both eyes is over 60 degrees [5]. However, the FOV of the camera could not achieve these angles. In the case of the see-through HMD with a camera sensor, the location gap between the camera and the eye is a critical

problem [6]. In the case of the video see-through HMD, the HMD's FOV is limited to the camera's FOV.

Camera calibration has been developing as a major issue for several decades. Most previous research into camera calibration has employed a narrow angle lens, necessitating auxiliary equipment to achieve precise camera parameters [7].

In calibration-free approaches a registration method using projection invariant properties has been introduced [8], [9]. Kutulakos presented a registration method that used reprojection and reconstruction properties with four non-coplanar points in affine space from two reference images [10]. The approaches showed the feasibility of registration, but overlooked the internal parameters of the camera. Accordingly, the results are not applicable to our wide angle AR system, and that registration process is not suitable for our dynamic camera environment. The reason is that the affine coordinates cannot be constructed from one image.

In this paper we propose an AR system with a new concept of dual purpose video see-through HMD. The system has a wide angle CCD camera, and the FOV is wide enough to view building structures in our campus. We have developed a method to solve the distortion recovery problem of the wide angle AR system and the registration problem using a single reference image. The only presumed condition is that the user specifies some projected lines forming a parallelogram on the known reference object interactively. We can register the virtual object at any position of the affine coordinates from the reference image.

Section 2 of the paper contains the overall system configuration and the functional description. In Section 3 we formulate the distortion removal problem for wide angle lenses and describe our solution. Section 4 describes the construct of the affine coordinates from a single image and the registration procedure for virtual objects. Section 5 describes the prototype display system, distortion removal results, and registration results for static and dynamic camera environments. In Section 6, we give our conclusions and present possibilities for future research.

2. Proposed AR System

In this section we describe our AR system configuration and propose a new concept for the display system.

2.1 FUNCTIONAL STRUCTURE AND PROCEDURE

The overall AR system is shown in Figure 1. The CCD camera photographs objects in the real world and sends the image to the AR subsystem and display device.
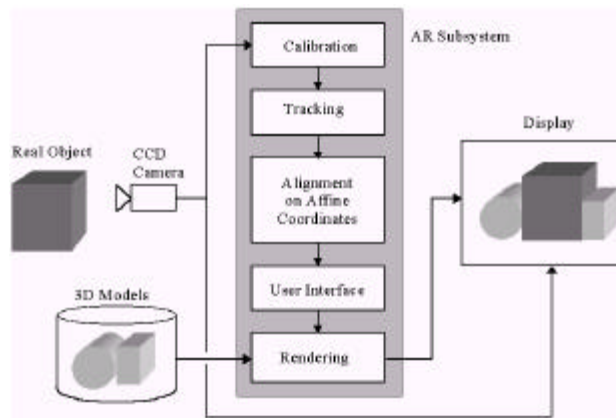
Figure 1: Configuration of the AR system

In the AR subsystem the camera calibration is processed to determine internal parameters of the camera. The internal parameters are lens center, focal length, uncertainty factor, and distortion coefficients. The internal parameters remain valid until the focal length of the camera is changed. The distorted input image is recentered to the lens center and distortion is removed at this stage.

For tracking we interactively specify some projected parallel lines of a known reference object. After the tracking process we construct the affine coordinates of the input single image in an alignment process. Then we determine the external parameters of the reference object using calibration-free methods. Next we select positions, orientations, and sizes of virtual objects that will be rendered. The selection is done only once, and the virtual objects will be registered on the affine coordinates precisely. The registrations of virtual objects remain valid even after movement of the camera. In the rendering step the virtual objects are rendered with real objects in the image. Finally, the virtual object is projected on the display along with the real background image.

2.2 DUAL-PURPOSE DISPLAY SYSTEM
USING A WIDE ANGLE LENS

The see-through HMD and the video see-through HMD represent traditional display systems. We propose a concept of a dual purpose video see-through HMD in Figure 2. This device can be a video see-through HMD if it employs a full mirror or a see-through HMD if it employs a half mirror. One advantage of the HMD is that the FOV of the camera and that of the eyes are geometrically equivalent.

In AR systems a narrow angle lens can avoid the distortion problem between the real object and the virtual objects that need to be overlaid. However, the narrow FOV is uncomfortable. That is why we adopt a wideangle lens in our AR system.
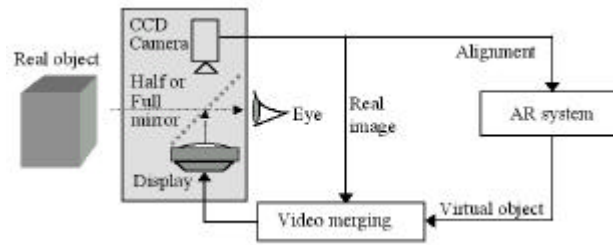
Figure 2: Dual-purpose video see-through HMD

3. Distortion Removal for Wide-angle Lens

We use Tsai's non-coplanar camera calibration method for internal parameters [11], and we refine the distortion coefficient using an iterative algorithm. In this section we describe the distortion removal process.

3.1 CAMERA CALIBRATION

Camera calibration is a nonlinear minimization problem with a known procedure that calculates the parameters of camera rotation and translation with respect to the world coordinates.

Using Tsai's noncoplanar calibration method for a single camera [11], we determine the internal parameters: lens center (C_X, C_Y), focal length f, uncertainty factor s_x, and distortion coefficient k_l.

3.2 REMOVAL OF DISTORTION
BY ITERATIVE LEAST SQUARES

Most camera systems have radial and tangential distortion. Distortion models of lenses are well known [12]; we consider radial distortion only.

We use the Hough transform to handle a line. A property is that a line in the XY plane must be a point in the rq plane. r is the shortest distance from the origin of the XY plane to the line and q is a counterclockwise angle between the x-axis and the closest point. The line equation is $r = x\cos q + y\sin q$, which can be defined for all kinds of lines.

We measure the longest line image with k in the XY plane. The line is selected from the edge image. If there is a line in the XY plane then the line is matched with a point in the rq plane of Hough space. Measured points with distortion coefficient d in the XY plane are defined by

$$p^{d}{}_{i} = (x^{d}{}_{i}, y^{d}{}_{i}), \quad i = 1, 2, \cdots, n$$

The sinusoidal equation for p_i in the rq plane is

$$r_{i} = x_{i}\cos q + y_{i}\sin q, \qquad -p \leq q \leq p$$

From the two sinusoidal curves, there is one intersection point, because two points in the XY plane make two sinusoidal curves and the curves intersect at a point in the **rq** plane. Hence, these intersection points are measured. Measured points in the **rq** plane are

$$m_i^* = (r_i^*, q_i^*),\ i = 1, 2, \cdots, M,\ \text{where } M = \lfloor n/2 \rfloor$$

Errors at each point and total errors at stage j are defined by

$$E_j = s^2 = \frac{1}{M} \sum_{i=1}^{M} (e_i)^2$$

where

$$e_i = \sqrt{(r_i^* - r_0)^2 + (q_i^* - q_0)^2}$$

The minimum variance of the Hough space is represented and verified to a line in the XY plane. The initial k_1 value is from the result of Tsai's internal calibration. Next, the k_1 value is selected using a divide-and-conquer algorithm. Hence, the problem is to find the distortion coefficient that minimizes E.

4. Registration of a Virtual Object

The first step of registration is to construct the affine coordinates from a reference object volume. We can generally view many parallelogram points on the construction, using these parallelograms with an interactive method for recognition and correspondence problems. The second step is to register a virtual object in the affine coordinates of the reference object.

4.1 FORMULATION

We use camera coordinates for the registration process in Figure 3. We have 3D models that we want to superimpose, and we assume that the length, the height, and the depth of the reference object are already known.

We can therefore measure the vertices of the reference object $(x_R, y_R, z_R)^T$ in world coordinates. The virtual object's points $(x_V, y_V, z_V)^T$ are given in the 3D models, and the projected points $(x', y', 0)^T$ of objects are tracked in the camera image. We also have the projection information P as a result of the camera calibration process.
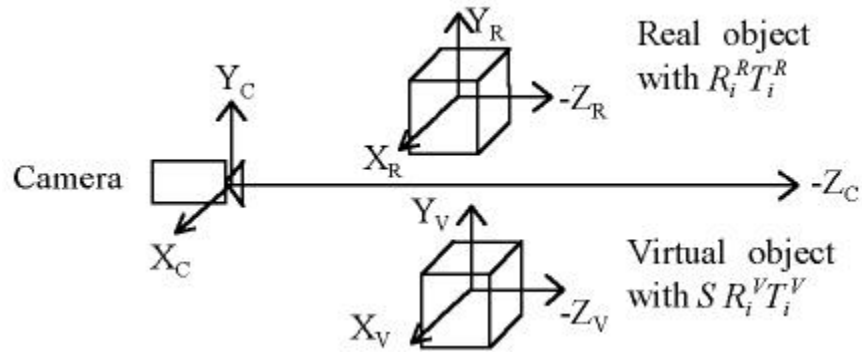
Figure 3: Formulation of registration

If the real object is registered in rotation R_i^R and translation T_i^R with respect to the camera, then we can determine the values by the calibration-free method. Next, we register the virtual object in $R_i^V T_i^V$ with the interactively given scale S of the virtual object. The first registration step of the virtual object at $R_i^V T_i^V$ in the affine coordinates with respect to the real object should be done interactively once. The remaining problem is to determine $R_i^R T_i^R$ from the single input image in the camera coordinates.

$$S(x_V, \ y_V, \ z_V)^T \xrightarrow[R_i^V T_i^V]{} (x_R, \ y_R, \ z_R)^T$$

$$\xrightarrow[R_i^R T_i^R]{} (x_C, \ y_C, \ z_C)^T \xrightarrow[P]{} (x', \ y', \ 0)^T$$

$$(x' \ \ y' \ \ 0)^T = h^{-1} P R_i^R T_i^R R_i^V T_i^V h S (x_V \ \ y_V \ \ z_V)^T,$$

where i = frame number

Known: $(x_R, \ y_R, \ z_R)^T$, $(x_R', \ y_R', \ 0)^T$, P Unknown: R_i^R, T_i^R

Given: S, $(x_V, \ y_V, \ z_V)^T$, R_i^V, T_i^V

4.2 MEASUREMENT

We can select one, two or three orthonormal parallelograms of the known reference object according to the viewing direction in Figure 4. There are four cases of parallelograms of a reference according to camera position. The four cases can be regrouped according to the number of faces. We can generate the affine coordinates for each case.
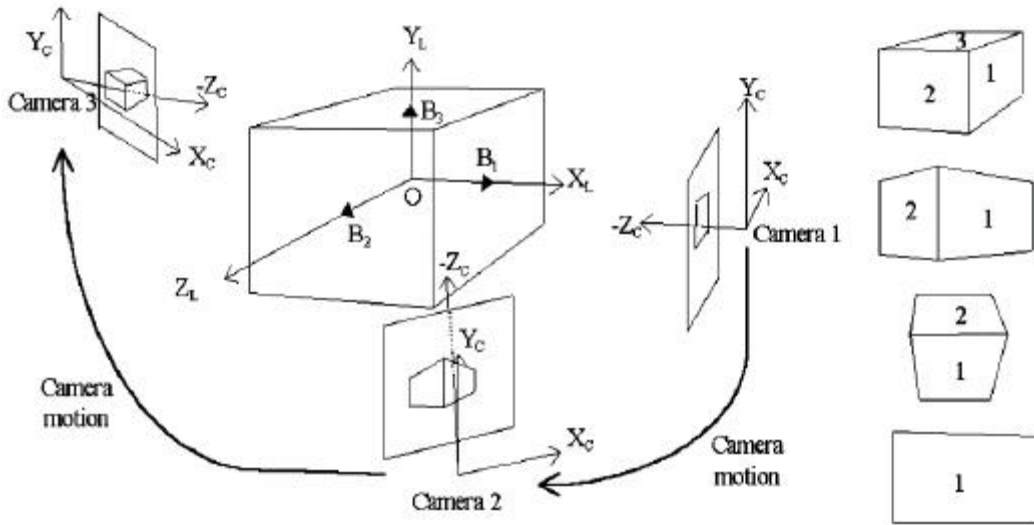
Figure 4: Measurement during camera motion

4.3 CONSTRUCTION OF THE AFFINE COORDINATES

A 3D line *L* and its projected 2D line *L¢*are represented in parametric form [13]. We know the size of the reference object from our assumptions. Let the half-length along the x-axis be width l_x, y-axis be height l_y, and z-axis be depth l_z.

4.3.1 Three measured faces

Three parallelograms can be measured according to the camera position. The affine coordinates consist of three base vectors (B_1, B_2, B_3). The directions of the vectors are measured from the center (O_R) of the reference volume to each normal direction of the surfaces in Figure 5(a).
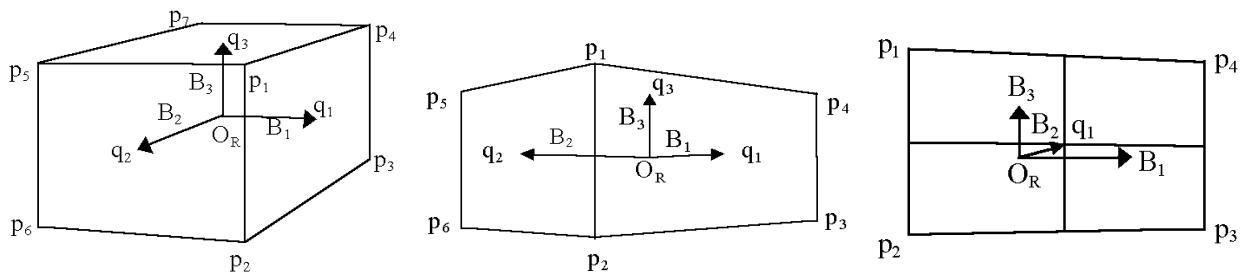
(a) Three faces case   *(b) Two faces case*   *(c) One face case*

Figure 5: Three measured faces and the base vectors

A parallelogram consists of four planar points. Let the projected points of each face be counterclockwise

$$(u_i, \ v_i), \ i = 1, 2, 3, 4$$

The 2D center position (u_c, v_c) is generally determined from the cross point of the two diagonal lines.

$$u_c = \frac{v_2 - v_1}{\left(\dfrac{v_3 - v_1}{u_3 - u_1} - \dfrac{v_4 - v_2}{u_4 - u_2}\right)}, \quad v_c = \frac{v_4 - v_2}{u_4 - u_2} u_c + v_2 \tag{1}$$

Let q_1, q_2, q_3 be the three center positions of the measured faces. The three projected points are determined simply by equation (1) from the three measured surfaces. Also, the 2D center position O_R of the object volume is obtained from parallelogram points p_5, p_6, p_3, p_4 by equation (1). We now know all 2D positions of the base vectors including the center position and their 2D lengths.

The direction cosines are determined from two projected parallel lines. Let L'_1, L'_2 be the two lines.

$$L'_n = \left\{ \begin{pmatrix} u \\ v \end{pmatrix} \left| \begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} c_n \\ d_n \end{pmatrix} + \boldsymbol{h} \begin{pmatrix} g_n \\ h_n \end{pmatrix} \right. \right\}, n = 1, 2$$

Let $(b_1, \ b_2, \ b_3)^T$ be the direction cosines of the projected lines L'_1 and L'_2. Then the direction cosines [13] are

$$\begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix} = \pm \frac{\begin{pmatrix} h_1 f \\ -g_1 f \\ d_1 g_1 - c_1 h_1 \end{pmatrix} \times \begin{pmatrix} h_2 f \\ -g_2 f \\ d_2 g_2 - c_2 h_2 \end{pmatrix}}{\left\| \begin{pmatrix} h_1 f \\ -g_1 f \\ d_1 g_1 - c_1 h_1 \end{pmatrix} \times \begin{pmatrix} h_2 f \\ -g_2 f \\ d_2 g_2 - c_2 h_2 \end{pmatrix} \right\|} \tag{2}$$

The 3D position of the center point O_R is determined from three base vectors. Let the starting position of the vector B_1 along the x-axis be $(a_{11}, a_{12}, a_{13})^T$ in 3D and the destination position of the vector is

$$(a_{11}, a_{12}, a_{13})^T + \boldsymbol{1}_x (b_{11}, b_{12}, b_{13})^T \ .$$

The direction cosines $(b_{11}, b_{12}, b_{13})^T$ of B_1 are determined with three parallel pairs of lines by equation (2). The half size of the x-axis length of the reference object is the length of B_1, which is known from the given condition. If the two projected points are observed at $(u_1, v_1)^T, (u_2, v_2)^T$, the point $(a_{11}, a_{12}, a_{13})^T$ is given by the perspective projection equations.

$$a_{13} = \frac{\mathbf{1}_x \left[(u_2 - u_1)(fb_{11} - u_2 b_{13}) + (v_2 - v_1)(fb_{12} - v_2 b_{13}) \right]}{(u_2 - u_1)^2 + (v_1 - v_2)^2}$$

$$a_{11} = \frac{u_1}{f} a_{13}, \quad a_{12} = \frac{v_1}{f} a_{13}$$

(3)

The starting positions $(a_{21}, a_{22}, a_{23})^T$ and $(a_{31}, a_{32}, a_{33})^T$ of vectors B_2 and B_3 can be determined by the same method.

The 3D position of the reference object center O_R can be determined with the starting positions of vectors B_1, B_2 and B_3 using the weighted average method. The weight is related to the angle between the viewing direction and the measured surface normal. The sum of the weights is 1.0. Hence the translation T_i^R is determined by the 3D position of O_R.

$$T_i^R = O_R = \begin{pmatrix} O_1 \\ O_2 \\ O_3 \end{pmatrix} = \begin{pmatrix} w_1 a_{11} + w_2 a_{21} + w_3 a_{31} \\ w_1 a_{12} + w_2 a_{22} + w_3 a_{32} \\ w_1 a_{13} + w_2 a_{23} + w_3 a_{33} \end{pmatrix}$$

(4)

Direction cosines represent the orientation of the reference object directly. Let the angles between the x, y, z-axis of camera coordinates and B_1, B_3, B_2 be $\mathbf{g}$, $\mathbf{b}$, $\mathbf{a}$ respectively in Figure 6. We can use the model's bases to represent the orientation. Hence, we can represent the orientation of the reference object with fixed angles in the camera coordinates. The rotation of the reference object with respect to the camera coordinates is defined by

$$R_i^R = R_{i,XYZ}^R(\mathbf{gba}) = R_{i,z}^R(\mathbf{a}) R_{i,y}^R(\mathbf{b}) R_{i,x}^R(\mathbf{g}) =$$

$$\begin{bmatrix} \cos\mathbf{a}\cos\mathbf{b} & \cos\mathbf{a}\sin\mathbf{b}\sin\mathbf{g} - \sin\mathbf{a}\cos\mathbf{g} & \cos\mathbf{a}\sin\mathbf{b}\cos\mathbf{g} + \sin\mathbf{a}\sin\mathbf{g} \\ \sin\mathbf{a}\cos\mathbf{b} & \sin\mathbf{a}\sin\mathbf{b}\sin\mathbf{g} + \cos\mathbf{a}\cos\mathbf{g} & \sin\mathbf{a}\sin\mathbf{b}\cos\mathbf{g} - \cos\mathbf{a}\sin\mathbf{g} \\ -\sin\mathbf{b} & \cos\mathbf{b}\sin\mathbf{g} & \cos\mathbf{b}\sin\mathbf{g} \end{bmatrix}$$

(5)

$$\text{where} \quad \mathbf{a} = \cos^{-1}\left(\frac{k \cdot B_2}{\|B_2\|}\right), \quad \mathbf{b} = \cos^{-1}\left(\frac{j \cdot B_3}{\|B_3\|}\right), \quad \mathbf{g} = \cos^{-1}\left(\frac{i \cdot B_1}{\|B_1\|}\right)$$
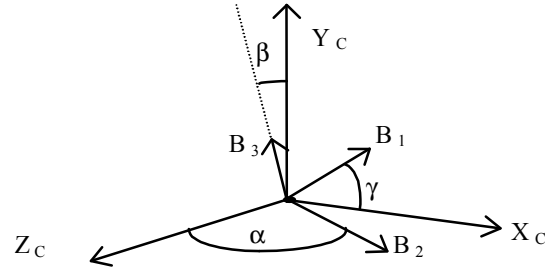
Figure 6: Local coordinates of an object
on camera coordinates

4.3.2 Two measured faces

Let q_1, q_2 be the two center positions of the measured faces in Figure 5(b). The two projected points of q_1, q_2 and the projected center position O'$_R$ of the object are determined in the same manner as in the three faces cases by equation (1). We can solve for the direction cosines of B_1, B_2 and the 3D position of O_R by equation (2) and equation (3).

Let q_3 be the end position of the base vector B_3. The direction cosines $(b_1, b_2, b_3)^T$ of B_3 are determined from the parallels of the two faces by equation (2). The starting position of q_3 is the position $(a_1, a_2, a_3)^T$. q_3 is defined by

$$q_3 = (a_1 \ a_2 \ a_3)^T + \boldsymbol{l}_Y (b_1 \ b_2 \ b_3)^T$$

Hence, the projected position of the point q_3 is

$$u_{q_3} = f \frac{a_1 + \boldsymbol{l}_Y b_1}{a_3 + \boldsymbol{l}_Y b_3}, \quad v_{q_3} = f \frac{a_2 + \boldsymbol{l}_Y b_2}{a_3 + \boldsymbol{l}_Y b_3} \tag{6}$$

The translation T_i^R and the rotation R_i^R of the reference object can be determined by the same method as for three measured faces case, except for the weights in the calculation of T_i^R. The translation T_i^R is defined by equation (4) with $w_3=0$.

4.3.3 One measured face

One parallelogram can be measured by camera position. A vanishing point of the parallelogram is always inside the parallelogram in this case (Figure 5(c)). The direction cosines of B_1, B_2, and B_3 can be determined with one projected parallelogram. Four corner points of a parallelogram are defined by

$$p_1 = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix}, \quad p_3 = \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix}, \quad p_4 = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} + \mathbf{1}_X \begin{pmatrix} m_1 \\ m_2 \\ m_3 \end{pmatrix}, \quad p_2 = \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix} - \mathbf{1}_X \begin{pmatrix} m_1 \\ m_2 \\ m_3 \end{pmatrix}$$

We know the sizes $\mathbf{1}_x, \mathbf{1}_y, \mathbf{1}_z$ from the half-length of the reference object. We can infer the direction cosines $(m_1,m_2,m_3)^T$ of the base vector B_1 and $(n_1,n_2,n_3)^T$ of the base vector B_3 by equation (2). Let the normal direction cosines of B_2 be $(A,B,C)^T$ [13]. The 2D position $(u_{q1}, v_{q1})^T$ of q_1 is obtained by equation (1). The 3D positions of the four points are defined by equation (3). Finally, the 3D position $(q_{11}, q_{12}, q_{13})^T$ of the point q_1 is determined from the four corner positions. The position of the center O_R can be defined by

$$O_R = \begin{pmatrix} o_1 \\ o_2 \\ o_3 \end{pmatrix} = \begin{pmatrix} q_{11} \\ q_{12} \\ q_{13} \end{pmatrix} - \mathbf{1}_z \begin{pmatrix} A \\ B \\ C \end{pmatrix}, \quad \begin{pmatrix} A \\ B \\ C \end{pmatrix} = \frac{\begin{pmatrix} m_1 \\ m_2 \\ m_3 \end{pmatrix} \times \begin{pmatrix} n_1 \\ n_2 \\ n_3 \end{pmatrix}}{\left\| \begin{pmatrix} m_1 \\ m_2 \\ m_3 \end{pmatrix} \times \begin{pmatrix} n_1 \\ n_2 \\ n_3 \end{pmatrix} \right\|} \tag{7}$$

The projected position $(o_1', o_2', 0)^T$ of the O_R is determined with equation (6), and the base vectors can be determined with equation (7). Therefore the three bases of the affine coordinates from a reference image can be constructed:

$$B_2 = \begin{pmatrix} o_1 \\ o_2 \\ o_3 \end{pmatrix} + \mathbf{1}_X \begin{pmatrix} m_1 \\ m_2 \\ m_3 \end{pmatrix}$$

$$B_3 = \begin{pmatrix} o_1 \\ o_2 \\ o_3 \end{pmatrix} + \mathbf{1}_Y \begin{pmatrix} n_1 \\ n_2 \\ n_3 \end{pmatrix}$$

$$B_1 = \begin{pmatrix} o_1 \\ o_2 \\ o_3 \end{pmatrix} + \mathbf{1}_Z \begin{pmatrix} A \\ B \\ C \end{pmatrix}$$

4.4 REGISTRATION OF A VIRTUAL OBJECT

After constructing the affine coordinates, a virtual object can be registered with given scale *S*, given translation T_i^V, and given rotation R_i^V in the affine coordinates of the reference object at first frame once. The virtual object is matched with the real object in the affine coordinates. The scale, the position and the orientation of the virtual object are invariant with respect to the real object after the motion of the camera.

Figure 7: Proposed system and distortion recovery

Let the position that we want to register in the affine coordinates be $(a_1, a_2, a_3)^T$ and the translation be T_i^V.

$$T_i^V = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} = \begin{pmatrix} o_1 \\ o_2 \\ o_3 \end{pmatrix} + r \begin{pmatrix} m_1 + n_1 + A \\ m_2 + n_2 + B \\ m_3 + n_3 + C \end{pmatrix} \qquad (8)$$

where

$$r = \sqrt{a_1^2 + a_2^2 + a_3^2}$$

The rotation R_i^V of the virtual object can be assigned in the same manner as in equation (5). The R_i^V is defined with respect to the affine coordinates of the reference object.

$$R_i^V = R_{i,XYZ}^V (\boldsymbol{gba})$$

In occlusion problems, the depth order of virtual objects can be determined by the 2D size of the base vector B_3 at any position of the affine coordinates. A point on the affine coordinates can be translated to a point in the image coordinates and the projected position of T_i^V is determined by equation (6).

We suppose that the y-axis base vector B_3 has invariant size for this construction. The 2D size of B_3 at position E in the affine coordinates is the difference between the position $E(a_1, a_2, a_3)$ and the other position $F(a_1, a_2, a_3+1)$. Let the projected positions of E, F be $(u_E, v_E)^T$, $(u_F, v_F)^T$ respectively. Then the 2D size of B_3 at E is defined by

$$h_{B_3} = \left\| \begin{pmatrix} u_F \\ v_F \end{pmatrix} - \begin{pmatrix} u_E \\ v_E \end{pmatrix} \right\|$$

The 2D size of B_3 can be determined at any position in the affine coordinates. Therefore, distances of the virtual objects from the camera can be comparable with the length in Equation (8). Also, the equation can be applied to the reference object for occlusion problems.

5. Experimental Results

The overall AR system was implemented on a Pentium PC, and the rendering part was also implemented on a SGI workstation to obtain the best rendering. All programs were developed using C and C++. The 3DS and SEG formats were used for virtual models. We used a Meteor board in the PC and a Kukje NTSC color camera that has 4-mm focal length and 45 horizontal degrees FOV after the distortion removal process. We constructed a prototype of the dual-purpose video see-through HMD (Figure 7(a)). An input image from the camera has 640×480 resolution and 24-bit RGB color.
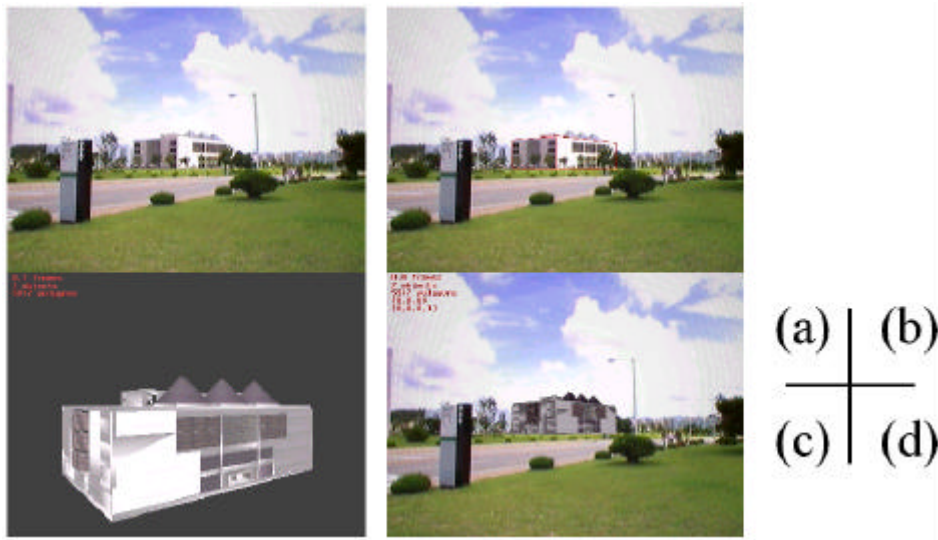

Figure 8: Static registration process

The distorted image from a 4-mm wide-angle lens is used for the input image (Figure 7(b)). The re-centered image with distortion removed (c) is reconstructed after the 12th iteration of the recovery

process with total error $E_{12} < 0.03$. The linearity of the longest line on the right hand side of the image can be clearly observed.

We apply the static registration process to a library scene on KAIST campus to supply an outdoor image. The library is far away from the camera in Figure 8 (a). We drew several lines (b) and performed the construction process for the affine coordinates. Then we selected a virtual library model (c) and registered it at (0,0,0) in the affine coordinates. The static registration results are shown in (d).

For dynamic registration in Figure 9, from the first input image (a), we registered a virtual model (b) at (3, 0.5, -1) using the same process as the static registration example. We registered the 'Dabotop' model, which is a famous pagoda in Korea. The registration position (3, 0.5, -1) of the virtual object was invariant in the coordinates after the camera was moved. Accordingly, we could keep the same position in the new input images (c), (d). The registrations yielded good results and are applicable to many other applications.

Figure 9: Dynamic registration

6. Conclusions

We have described a precise registration method for the wide-angle AR system, and proposed a new prototype of the dual-purpose video see-through HMD of the AR system. The AR system was employed to view building structures in our campus and it was verified the feasibility of the dual-purpose video see-through HMD.

In the static registration results, the re-centered input image with distortion removed was in good agreement with the computer-generated graphical object. The static registration results were precise and the virtual object was registered at any position we want in the affine coordinates.

We needed only one image for the construction of the affine coordinates in the registration process, which was applied to the dynamic camera environment. Furthermore, the affine coordinates were constructed from at least four coplanar points of a parallelogram. This was suitable for dynamic camera environments. As a result, the registration of virtual objects at any position of the affine coordinates could be realized.

Currently, we are attempting to estimate the quantitative precision of registration in the results. For further work, we are interested in the occlusion problems in dynamic environments, and in research in related areas.

REFERENCES

[1] M. Weiser, "Some Computer Science Issues in Ubiquitous Computing", Communications of ACM, vol.36, No.7, July 1993, pp. 75-85.

[2] S. Feiner, "Augmented Reality : The Future", in ACM SIGGRAPH 94 Course note for Developing advanced VR Applications, Jul. 26, 1994, pp.7.1-7.11.

[3] A. State, G. Hota, D. T. Chen, W.F. Garrett, and M. A. Livingston, "Superior Augmented Reality Registration by Integrating Landmark Tracking and Magnetic Tracking", in Proceedings of SIGGRAPH 96, New Orleans, Louisiana, Aug 1996, pp. 429-438.

[4] J. P. Rolland and F. A. Biocca, "Quantification of Adaptation to Virtual-Eye Location in See-Thru Head-Mounted Displays", Virtual Reality Annual International Symposium, Mar. 1995, pp. 56-66.

[5] W. Robinett and J. P. Rolland, "A Computational Model for the Stereoscopic Optics of a Head-Mounted Display", Presence, Vol. 1, No. 1, Winter 1992, pp. 45-62.

[6] M. Bajura, and U. Neumann, "Dynamic Registration Correction in Video-Based Augmented-Reality Systems", Proc. IEEE Computer Graphics and Applications, Sep 1995, pp. 52-60.

[7] R. Azuma, and G. Bishop, "Improving Static and Dynamic Registration in an Optical See-through HMD", in Proceedings of SIGGRAPH 94, Orlando, Florida, 1994, pp. 197-204.

[8] J. P. Mellor, "Realtime Camera Calibration for Enhanced Reality Visualization", Proc. of CVRMED '95, 1995, pp. 471-475.

[9] M. Uenohara and T. Kanade, "Vision-Based Object Registration for Real-Time Image Overlay", Proc. of CVRMED '95, 1995, pp. 471-475.

[10] K. N. Kutulakos and J. Vallino, "Affine Object Representations for Calibration-Free Augmented Reality", Proc. of VRAIS '96, 1996, pp. 25-36.

[11] R. Y. Tsai, "An Efficient and Accurate Camera Calibration Technique for 3D Machine Vision", Proceedings of IEEE Conference on Computer Vision and Pattern Recognition, 1986, pp. 364-374.

[12] C. C. Slama, C. Theurer, and S. W. Henriksen, *Manual of Photogrammetry*, Fourth Edition, American Society of Photogrammetry (1980) Chapter 3.

[13] R. M. Haralick and L. G. Shapiro, *Computer and Robot Vision*, Volume II, Addison-Wesley Publishing Company (1993) Chapter 13, 14.

BIOGRAPHIES

Youngmin Lee is a senior researcher in 5th R&D Center at Agency for Defense Development (ADD) and a Ph.D. candidate in computer science department at KAIST. He received the B.S. and M.S. degrees in computer science from Soongsil University, Seoul, Korea in 1984 and 1986. From 1986 to now, he has been researched at ADD. His technical interests include augmented reality, virtual reality, and simulation.

Contact information:

Youngmin Lee
5th R&D Center, Agency for Defense Development (ADD),
Yu-song P.O. Box 35-5
Taejon 305-600, Korea
Email: ymlee@vr.kaist.ac.kr (or click on mailto:ymlee@vr.kaist.ac.kr while online)

Kwangyun Wohn received the B.S. degree in applied physics from Seoul National University in 1974, and the M.S. and Ph.D. degrees in computer science from the University of Wisconsin in 1981, and the University of Maryland in 1984, respectively. From 1984 to 1986, he was with the Division of Applied Sciences, Harvard University, from 1986 to 1990, with the Department of Computer and Information Science, University of Pennsylvania. He is currently with the Computer Science Department, Korea Advanced Institute of Science and Technology (KAIST). His interests are computational vision, computational reality, and computer graphics.

Contact information:

Kwangyun Wohn
Computer Science Department, Korea Advanced Institute of Science and Technology (KAIST)
373-1 Ku-song dong, Yu-song ku
Taejon 306-701, Korea
Email: wohn@vr.kaist.ac.kr (or click on mailto:wohn@vr.kaist.ac.kr while online)