General solution for calculating geometric & illumination

Augmented Reality is used for a wide range of applications in computer vision such as computer-aided surgery, repair of complex machines, establishment modifications, interior or structural design. In Augmented Reality applications the user's view of the real world is enhanced by virtual information. This additional information is created by a computer which has a model of the real world and the model of some real world objects in which the user is located. These real objects are tracked, so the computer knows the location and rotation of them. The Augmented Reality system imagines a virtual camera in the virtual world which can see a range of virtual objects corresponding to real world objects. The additional virtual data is superimposed over these real objects. This visual enhancement can either have the form of labels, 3D rendered models, or even shading modifications. With the help of optical see through displays the user can see both the virtual computer-generated world on the screenand the real world behind it. In general these are displayed on an see through head mounted display (HMD) to get an Augmented Reality view.

These optical see through devices present a special challenge because the system has no access to the real world image data as at a video see through device. So the HMD represents avirtual camera for which several parameters must be accurately specified as well.

Necessary tasks needed for calibrating virtual cameras

- A virtual camera defines a projection of the virtual 3D world to the 2D image plane.
- As shown in figure 4.3 the user sees the computer generated 2D image appearing inhis HMD about one meter in front of his face.
- The virtual world objects are registered in 3D.
- In order to see the right objects at the desired positions the virtual camera must provide the correct projection.
- Finding this projection is called camera calibration.
- Once the projection is found the viewing component of the Augmented Realitysystem uses it to represent the virtual world.

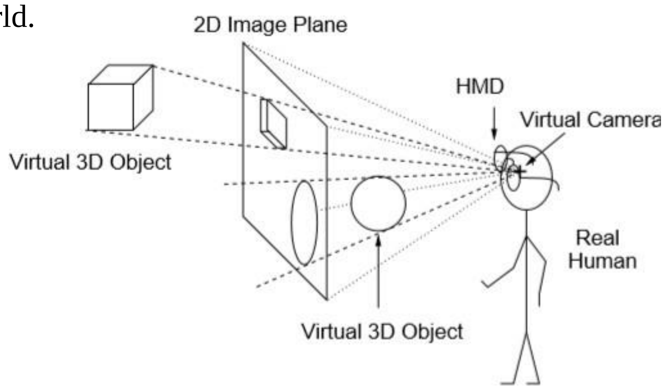


Fig. 4.3 The 3D virtual world is mapped to the 2D image planeVirtual Camera / Camera Model

A camera maps the 3D virtual world to a 2D image. This mapping can be represented bya 3×4 projection matrix P. Each point gets mapped from the homogeneous coordinates of the 3D virtual world model to homogeneous coordinates of its image point on the image plane. In general this matrix has 11 degrees of freedom (3 degrees of freedom for the rotation, 3 more for the translation, and 5 from the calibration matrix K) and can be split up into two matrices P = KT. Whereas the matrix K holds the internal camera parameters, such as the focal length and aspect ratio. T is a simple transformations matrix which holds the external camera parameters that are the rotation and the translation. A finite camera is a camera whose center is not at infinity. Let e.g. the center be the origin of an Euclidean coordinate system, and the projection plane z = f. It is also called the image plane or focal plane. The distance f is called the focal length. The line from the optical camera center vertical to the image plane is called the principal axis or principal ray of the camera. The point where this line intersects the image plane is called the principal point or the image center. Furthermore the plane through the camera center parallel to the image plane is called the principal plane. Assume that the Augmented Reality system already knows the position Tmarker and the orientation Rmarker of the tracked HMD marker represented as the transformation F in figure 4.5.

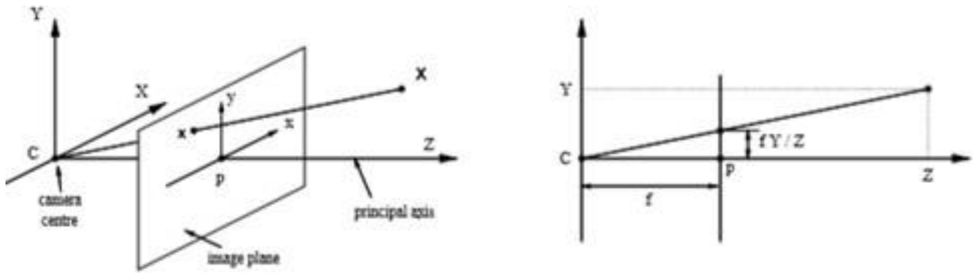
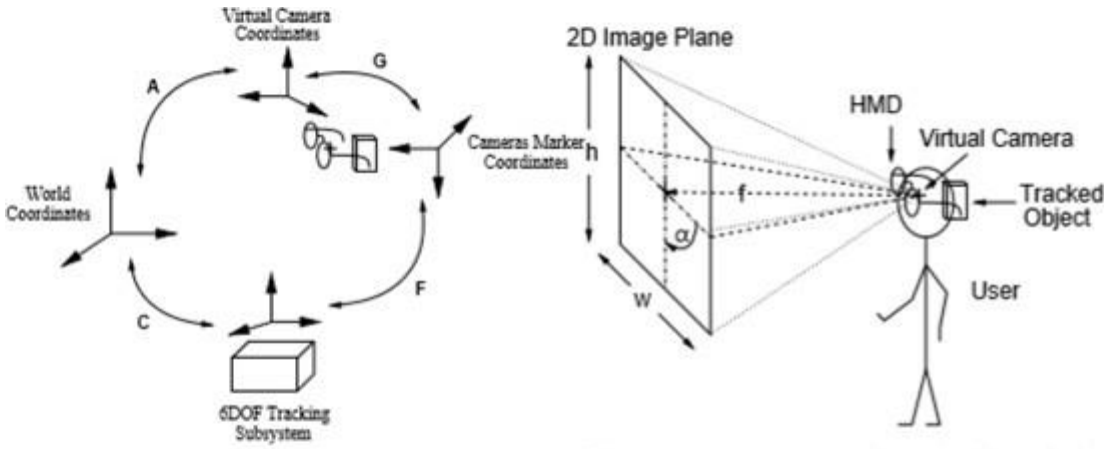


Fig. 4.4 Camera Geometry



(a) Extrinsic parameters and the relevant coordinate system transformations

(b) intrinsic parameters such as focal length f, aspect ratio w/h, and the skew represented as the angle α

Fig. 4.5 The Camera Calibration Parameters

In order to get the position and orientation of the virtual camera center the additional transformation G should be found. The position Tcamera2marker can be found by measuring with a ruler the distances in all three directions X,Y, and Z of the cameras bodies coordinate system to the virtual cameras center which should be approximately between the user's eyes. And the orientation Rcamera2marker can be found by measuring the angles χ, ρ, and σ between the X-, Y-, and Z-axis of the camera marker and the corresponding axis of the virtualcamera coordinate systems. Constituting these angles, the desired transformation is G =

Rcamera2marker [I|−Tcamera2marker]

Now the viewing subsystem of the Augmented Reality system knows the pose of the virtual camera relative to the tracking subsystem's coordinate system. As the transformationC is also constant, because the tracking subsystem is rigidly fixed in the laboratory, it can be measured the same way as well. Thus the overall transformation matrix A that maps the virtual camera center to the world coordinate system is

$$A = GFC$$

where A is a 3 × 4 projection matrix that transforms world coordinates to camera coordinates.C is a 4×4 homogeneous transformation matrix that maps world to tracker coordinates. During the implementation phase it is assumed that the world and the tracker coordinate systems are equal, e.g. C = I. Furthermore F is also a 4 × 4 homogeneous transformation matrix that maps the coordinate system of the camera marker to the tracker coordinate system. At last G is the 3×4 projection matrix that defines the camera transformation relative to the coordinates of the camera marker. The matrix G is the desired projection matrix, as F isknown to the Augmented Reality system by the tracking subsystem.

Calibration needed for -

In order to get an effective augmentation of the real world, the real and virtual objects must be accurately positioned relative to each other. The computer system contains in its virtual world a virtual camera which can see a range of several virtual objects. These are usually displayed on a head mounted display (HMD) to get an AR view. So the HMD represents a virtual camera for which several parameters must be accurately specified as well.If these parameters do not fit properly, the virtual picture might have a different size than the real one or even be distorted. Once all the parameters are found and adjusted correctly, the user can use the AR system to augment the reality. But may be some other user wants to use the same AR system as well. And maybe he has another interocular distance or he wears the HMDs lightly different than the person who first adjusted all the parameters. Even if this person puts on the HMD for another session again, the primarily adjusted parameters will not fit as good any more. So the procedure of calibrating the virtual camera has to be kept simple,in order to make it possible for users who know nothing about the mathematical background of calibration to adjust the HMD anytime fast and precise. Another problem has always been the accurate adjustment of different displays because different algorithms are necessary.

Calibration is the process of instantiating parameter values for mathematical modelswhich map the physical environment to internal representations, so that the computer'svirtual world matches the real world. These parameters include information about optical characteristics and pose of the real world camera, as well as informations about the environment, such as the tracking systems origin and pose of tracked objects.

Functional Requirements of the calibration service- describe the interactions between the system and its environment.

1. Accurate Alignment
   The main goal of a successful calibration is an Augmented Reality system in which all virtual objects are optimal adjusted. The HMD user should see the real objects and the corresponding superimposed virtual objects accurate aligned. So the distance, size, and form of them should fit to their real counterparts. Even when the user moves through the tracked space the visual enhancement shall keep correctly aligned.

2. Easy to Use

In order to get a practical solution for the calibration of see through devices, the parameters need to get estimated in a user-friendly procedure. Thus the user interaction wherethe calibration points are measured shall be intuitive and not impose a great burden on the user.

Nonfunctional Requirements – describe the user visible aspects of the system that are not directly related with the functional behavior of the system

1. Performance

The performance of the calibration procedure primarily depends on the performance of the middleware. As the calibration service depends on DWARF the desired components can be executed distributed on different computers. Thus the system latency (delay) should be kept at a minimum. It is vitally to receive the relevant measurement data in real time as the user is allowed to move. Thus the measured parameters change in real time, too. The actual calculation of the calibration parameters does not need to be in real time as it will be donejust once. But the updating of the viewing component should be completed within a few seconds.

2. Accurate Tracking

For an accurate alignment the Augmented Reality system needs to know the exact pose ofthe virtual camera respectively the tracked 6DOF (freedom of movement of a rigid body in three-dimensional space) marker of the HMD in real time. The pose of other objects, such as the position of the 3DOF calibration points, must be known, too. As the real world location of these objects may change by moving these, the virtual objects need the same pose change. This is solved by the ART track1 tracking subsystem which updates the virtualmodel of the Augmented Reality system in real time.

3. Reliability

The system should guide the user in a way that it is guaranteed to obtain good results. Additionally it should provide hints on how good the accuracy is at the moment.

4. Quality of Service

The goal is to find the optimal solution where the measurement deviation is minimized. Furthermore error estimates should be provided to other DWARF components in order to be able to reduce error accumulation.

Pseudo Requirements

Pseudo requirements are imposed by the client that restricts the implementation of the system. The only pseudo requirement that occurred for the calibration method is that the prototypical implementation has to be done in context with ARCHIE. So the main focus has been a good aligned ARCHIE application rather than a perfect calibration method.

Consequently the user interface controller of the calibration method needed to be written in Java depending on the object-oriented Petri net simulation framework called JFern .

NOTE: DWARF stands for Distributed Wearable Augmented Reality Framework. The name is an acronym representing the guidelines for the general system architecture. ARCHIE is the latest application. The acronym stands for Augmented Reality Collaborative Home Improvement

Environment. The completion of the ARCHIE project provides new functionality to DWARF thereby making it more mature. Advanced Realtime Tracking (ART). For accurate position and orientation tracking, the infrared (IR)-optical Advanced Realtime Tracking subsystem ART track 1 is used with four cameras. Single Point Active Alignment Method (SPAAM) is a simple method to calibrate virtual cameras