Tracking of a Laser Pointer Space Orientation by Using Single Camera.

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Abstract

The proposed tracking technique allows to realize the direct interaction and control in augmented reality. The geometry and the optical properties of the display system in Virtual and Augmented Reality (V&AR) can be used as the channel of the additional information to perform tracking and interaction with an application.

Key words: mirror symmetry, display geometry, tracking, interaction

1. Introduction

Tracking is the process of obtaining the location (position and orientation) of a real physical object in real-time. With the display systems tracking is the most important component for a virtual environment system. The majority of systems of tracking and interaction in V&AR are independent from display systems (video output). Binding to the latter is carried out during their calibration.

The basic idea of the suggested approach consists in the fact that we have an opportunity to calculate the response of the known spatial geometry of V&AR display systems on an input optical signal using for interaction performance. Thus we use various types of input signals (scalar and vector) and we use the capability of the system to receive the additional information due to the mirror symmetry of the V&AR displays.

2. Background

The interaction techniques can be broadly classified into two categories: those based on three or more degrees of freedom (DoF) input devices, and those which rely on the ubiquitous input devices coupled with a variety of schemes for mapping 2D input to 3D control. J. Peirce at al proposed interaction techniques based on interaction with 2D projection that 3D objects in the scene make on users image plane [10]. Integral 3D manipulation on a plane requires the way of switching between dimensions [1]. Efforts have been made to add more DoF :

- o   to the input device for 3D interaction;
- o   to the interaction's channel.

Many researchers consider interaction with the display at a distance with the help of the laser pointer technique [3],[6],[11],[9],[12],[8]. As distinct from a lightpen [5]

device which receives the information from the CRT monitor, the laser pointer emits a laser beam which produces a bright seen spot in the crossing point with the screen. With the help of the camera the coordinates of this spot are read out and then interpreted as the cursor coordinates in the coordinates of the application. The standard laser pointer (LP) has two DoF – movement in the x- and y- direction. It does not have an additional DoF like rotation and a mouse-button-like function and it is not enough for reconstructing the position and/or the orientation of the laser pointer.

3. Input Signals

The light from an object produces a three-dimensional distribution in an image space.
The special case of an electromagnetic wave is the spherical wave which radiates from an isotropic point
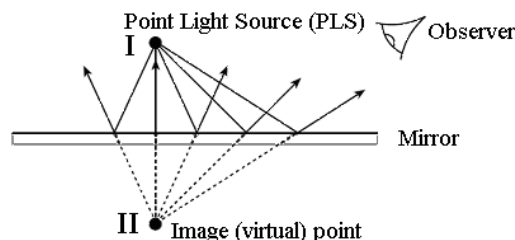

Fig. 1 : Reflection by a Plane Mirror

source.
A point light source (PLS) is a typical emitter of the spherical wave. A point light source in free space produces light rays that travel away from the source in every direction — we can locate the real source point by
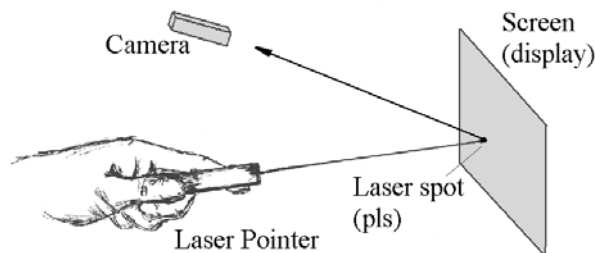

Fig. 2: Laser Pointer: vector field

observing where the rays intersect in space. If a mirror is present as well, it is possible for the rays to intersect or appear to intersect at one or more additional points in

space. Such (a) point of intersection is called an image point (see **Fig. 1**).

The second simple example of an electromagnetic wave is the plane wave. The laser is a device that amplifies light and produces a highly directional, high-intensity beam that typically has a very pure frequency or wavelength (**Fig. 2**).

4. Simplest Geometry with Mirror Symmetry

To illustrate our approach we shall consider the scheme consisting of a mirror, a virtual camera and a point light source (see **Fig. 3**).
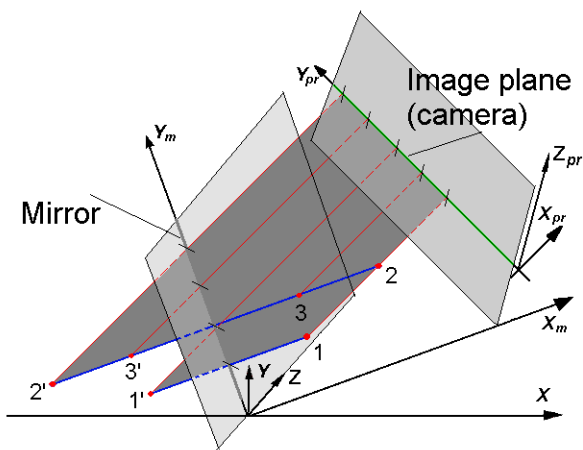

Fig. 3: Mirror as additional information channel

Here, points 1, 2, 3 correspond to different positions of the point light source, and points 1', 2', 3' are their
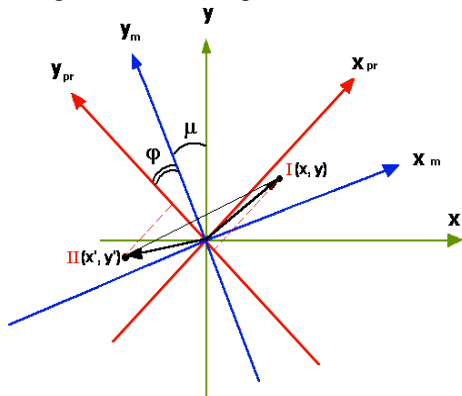

Fig. 4: World (x, y, z), mirror (x$_m$, y$_m$, z$_m$) and camera (x$_{pr}$, y$_{pr}$, z$_{pr}$) coordinate systems

mirrored reflections or image points. We use the parallel projection for the camera projective plane. The **Fig. 4** represents the three coordinate systems. For all the three the z-axis is directed from the observer.

Here I(x,y) is the point light source, and II(x',y') is its

mirrored image. Let us show that the three coordinates of the point light source could be unambiguously calculated by using only two coordinates of the point light source and its mirrored image is received from the camera.

Firstly we switch over to the mirror coordinates

$$
\begin{pmatrix} x'_m \\ y'_m \\ z'_m \end{pmatrix} = \begin{pmatrix} \cos\mu & \sin\mu & 0 \\ -\sin\mu & \cos\mu & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}
$$

and then to the camera coordinates:

$$
\begin{pmatrix} x_{pr} \\ y_{pr} \\ z_{pr} \end{pmatrix} = \begin{pmatrix} \cos\varphi & \sin\varphi & 0 \\ -\sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \pm x\cos\mu & \pm y\sin\mu & 0 \\ -x\sin\mu & +y\cos\mu & 0 \\ 0 & 0 & z \end{pmatrix}
$$

where "+" and "-" correspond to the real and the mirrored points; μ - the angle between the mirror and the world coordinate systems; φ – the angle between the projective plane and the mirror

Then after the simple transformations we have

$$
\begin{cases} y_{pr}^I = -\sin\varphi(x\cos\mu + y\sin\mu) + \cos\varphi(-x\sin\mu + y\cos\mu) \\ y_{pr}^{II} = +\sin\varphi(x\cos\mu + y\sin\mu) + \cos\varphi(-x\sin\mu + y\cos\mu) \end{cases}
$$

$$
\begin{cases} y_{pr}^I + y_{pr}^{II} = 2\cos\varphi(-x\sin\mu + y\cos\mu) \\ y_{pr}^{II} - y_{pr}^I = 2\sin\varphi(x\cos\mu + y\sin\mu) \end{cases} .
$$

And the coordinates of the point light source are

$$
x = \frac{-D\sin\mu}{2\cos\varphi} + \frac{d\cos\mu}{2\sin\varphi} \ ,
$$

$$
y = \frac{D\cos\mu}{2\cos\varphi} + \frac{d\sin\mu}{2\sin\varphi} ,
$$

$$
z = z_{pr} ,
$$

where

$$
y_{pr}^I + y_{pr}^{II} = D
$$
$$
y_{pr}^{II} - y_{pr}^I = d \quad .
$$

Thus all the three coordinates of the point light source are unambiguously reconstructed according to the 2D projection received from a single camera.

4. Virtual Showcase

Showcase (VS) is a projection-based Augmented-Reality display that allows multiple users to observe and interact with an augmented physical content which is presented inside the display [2].
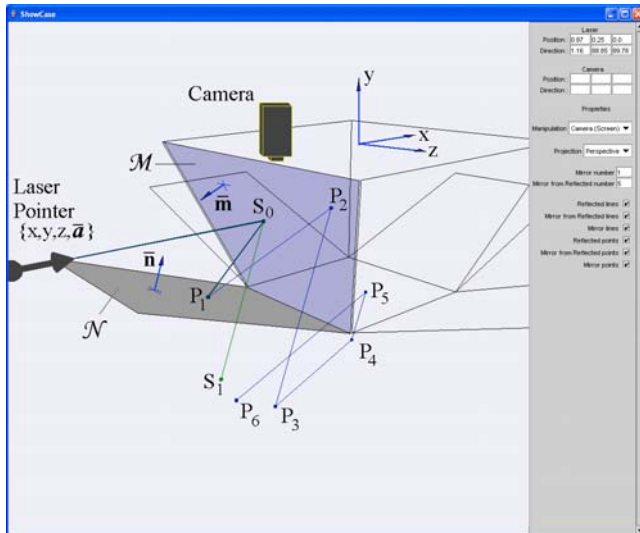
Fig. 5: VS response simulation.
P_1 – reflected point; S_1, P_2-P_6 – mirrored points; M – screen plane; N – monitor plane

As **Fig. 5** shows, the Virtual Showcase consists of two main parts a convex assembly of four semi-transparent mirrors assembled as a truncated pyramid and graphics displays. Users can see real objects inside the showcase through the half-silvered mirrors merged with the stereo graphics displayed on the projection screen.

Our analysis of the opportunity to realize the interaction in the Virtual Showcase is based on the mirror symmetry of the VS display and on the fact that the 3D geometry and the optical properties of the showcase are known and do not vary during the presentation.

The half-silvered screen and the display in the VS is the more complex optical scheme than the single mirror scheme discussed above. The both types of input signals (the point light source and laser beam) are presented in the VS display geometry response scheme. In this case the laser beam will not only be reflected from the surface, but will also have the numerous mirrored points. For the analysis of the received points the java applet modeling of the VS response to a laser beam is written (see **Fig. 5**). It allows us to investigate different variants of the camera location and to simulate the response of the system to the optical input signal for various LP positions.

The method of the work consists in restriction of the number of points due to the choice of the camera's position. So the camera which is located as it is shown in **Fig. 5** will receive the information from five or seven points depending on a vector determining the LP position in space (on the number of laser beam reflections from the mirrors N and M).

To restore the orientations of the LP (the LP vector in space), the information on two points only (**Fig. 6**) is enough. These points are the first spot S_0 on the screen and its reflection P_1 on the monitor. Having their coordinates in planes XZ (camera image plane) and knowing the VS geometry we can calculate the three-dimensional coordinates of these points. Thus we calculate the vector specifying the straight line in space

on which LP is located:

$$\mathbf{a} = -2\mathbf{m} + \frac{\mathbf{P_1} - \mathbf{S_0}}{|\mathbf{P_1} - \mathbf{S_0}|}$$

where

$$\frac{\mathbf{P_1} - \mathbf{S_0}}{|\mathbf{P_1} - \mathbf{S_0}|} = \mathbf{b}$$

is a unit vector corresponding to the reflected laser beam, **m** - is an unit normal vector of the surface M.

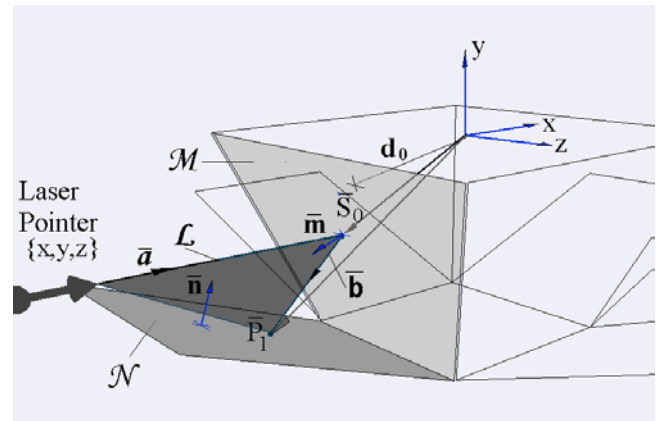If the light from a spot $P_1(x_{p1} , y_{p1}, z_{p1})$ is mirrored by a

Fig. 6 Scheme of the LP vector calculation;
a – laser pointer vector; b – reflected laser beam.

plane mirror M which distance from the coordinate origin is d_0 (see **Fig. 6**), and which surface normal has direction $\mathbf{m}=(m_x , m_y , m_z)$, the image point coordinates $P_2(x_{p2}, y_{p2}, z_{p2})$ are given by

$$P_2^T = M_m P_1^T ,$$

where

$$M_m = \begin{pmatrix} 1-2m_x^2 & -2m_x m_y & -2m_x m_z & 2m_x d_0 \\ -2m_x m_y & 1-2m_y^2 & -2m_y m_z & 2m_y d_0 \\ -2m_x m_z & -2m_y m_z & 1-2m_z^2 & 2m_z d_0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

- the reflection matrix for plane $M.$ (see [2])

Then we can calculate coordinates for next mirrored point $P_3^T = M_n P_2^T = M_m M_n P_1^T$, and so on for other points.

Therefore the coordinates of the points S_1, P_3, and P_6 (see **Fig. 5**) are related to the coordinate of the point P_1. This relation can be used for more accurate calculation of the coordinate the P_1, which is used for tracking the position of the LP.

The result of simulation and the real data are presented on **Fig. 7**.

The VS consists of a semi-transparent mirror (screen) and a mirror (display) that are located on the acute angle one to another. That is the reason why we will get a plenty of the reflected and mirrored points. That makes the use of the visible laser pointer impossible in the VS.
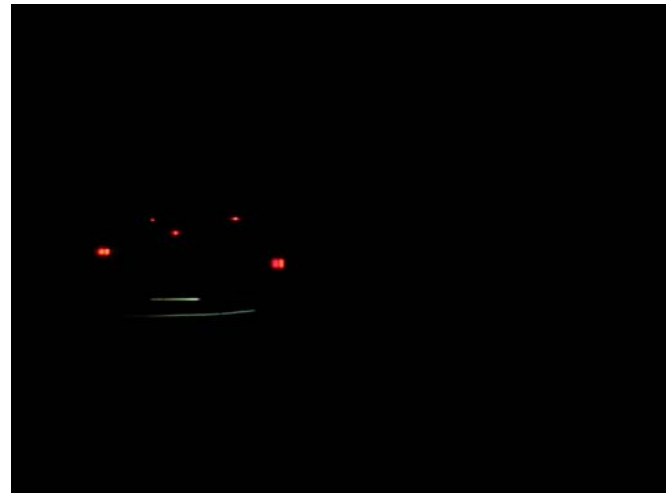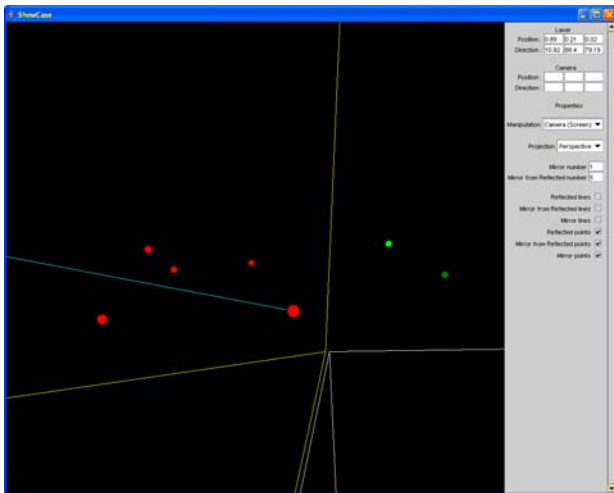
Fig. 7: Simulation of the VS response on input signal (left) ; Real data for red color laser pointer (right)

The device for interaction can be constructed on the basis of an infra-red (IR) laser which is invisible to the human eye and therefore does not interfere with the visible channels of presentation [7].

The coordinates of the laser spots received from the IR camera are interpreted as the position of the pointer (often represented on the screen by a cursor). Interaction is implemented not with the laser spots on the screen directly but with their mathematical model..

4. Conclusion

In this paper we have presented a method for optical tracking based on the additional information channel. The key idea is the use of mirror symmetry and space geometry of display systems in V&AR.

The method is based on the fact that we have an opportunity to calculate the response of the known spatial geometry of V&AR display systems on an input optical signal using for tracking and interaction performance.

4. Acknowledgments

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