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Augmeting a Projector-Camera Device with Laser Pointers

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Abstract

This technical report describes augmentation of a rigidly-coupled projector-camera system with laaster pointers. A projector-camera system can be used to determine the pose of the projector relative to a display surface, so that a projection of any desired geometry can be made on the surface. There are also algorithms that are more projective in nature to generate a desired projection. This report describes how laster pointers support these computations.

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Abstract. This technical report describes augmentation of a rigidly-coupled projector-camera system with laser pointers. A projector-camera system can be used to determine the pose of the projector relative to a display surface, so that a projection of any desired geometry can be made on the surface. There are also algorithms that are more projective in nature to generate a desired projection. This report describes how laser pointers support these computations.

1 Introduction

A projector with rigidly attached camera is used as a handheld projection device in [2]. The camera views the projector-image on the display surface, as a way of inferring the pose of the projector relative to the surface. Once this is known, it is possible to create a projection with any desired geometry on the surface. For example, it is possible to do keystone correction.

In theory, nothing needs to be added to the projector-camera system to obtain the required functionality. There is, however, a shortfall in this system in practical terms. There is a requirement that the camera observes the full projector-image, to extract the four vertices of the projection boundary, before further processing[1]. This constrains the content of the projector-image, since dark areas around the boundary might make it difficult to extract the boundary seen by the camera. The problem becomes even more difficult when projecting onto a surface with some texture rather than a completely homogeneous surface.

Laser pens attached to the projector help deal with these problems. Firstly, there is no longer any constraint on the content of the projector-image, because detection of laser points from (four) laser pens attached to the projector replaces detection of the projected image boundary. Secondly, laser light is bright and sharply focussed, so that a laser point on a surface is relatively easy to detect with a camera.

This does raise another issue however. The existing processing builds on the fact that a projector is a pinhole device. But the rays generated by the laser

[1] More specifically the camera must observe four points, in general position, projecting from known location on the projector image plane - the four vertices of the projection boundary are simply the most obvious choice.

pens are in an arbitrary placement relative to the focal point of the projector, and relative to one another, and cannot be treated as a pinhole projection. This report describes how to calibrate the laser pens relative to the projector and camera, so that the laser information can be utilized straightforwardly in existing algorithms.

2 Calibration

A rigidly-coupled projector-camera system is conceptually the same as a stereo rig of two cameras, in the sense that there are two pinhole devices. Because of this, a lot of stereo calibration techniques for stereo carry over to projector-camera calibration. In fact, the projector-camera system is in some ways easier to calibrate because (a) projectors usually have negligible radial distortion so this can be ignored, (b) in place of the requirement to find corresponding feature points between stereo images, the projector projects points and the camera records them, which is easier than finding correspondence. This report omits further discussion of the well-understood techniques for stereo calibration [1] because the modifications for a projector-camera system are mostly obvious.

Now consider how to calibrate a laser pen attached to the projector-camera. We assume the ray of the laser pen is in an arbitrary location relative to the camera and projector.

First note that the ray from the laser pen projects to a line on the camera image plane, as shown in Figure 1. This line is fixed since the laser pen is rigidly-attached to the camera.

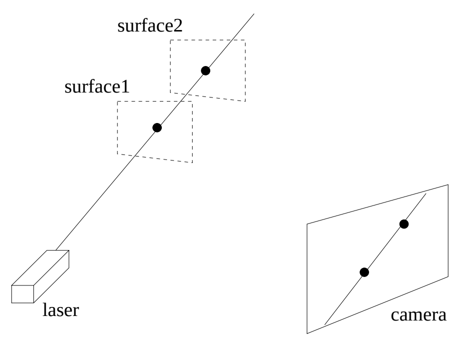

Fig. 1. The laser ray generates laser points on surfaces at different distances, and the laser points are recorded at the camera. The line through the points on the camera image plane is a projection of the laser ray.

It's easy to determine this line on the camera image plane, by -

- project the laser onto a surface,
- record the camera image p_c for the laser point

- repeat with the surface at two or more different distances, to record a set of camera image points $p_{ci}, i = 1..n$
- find the line l_c through the points

The laser ray also projects onto a line on the projector image plane. It can be determined by

- project four points $x_{pi}, i = 1..4$ from the projector onto a surface
- simultaneously project the laser onto the surface,
- record the corresponding camera image points $x_{ci}, i = 1..4$, plus p_c for the laser
- compute the camera-projector homography H_{cp} using the correspondences (x_{ci}, x_{pi})
- compute the point $p_p = H_{cp}p_c$. Point p_p is the projection of the laser point onto the projector image plane.
- repeat with the surface at two or more different distances, to record a set of projector points $p_{pi}, i = 1..n$
- find the line l_p through the points

But now the problem is reduced to two pinhole devices effectively observing a line in space. Just as two pinhole devices observing a plane are related by a homography, two pinhole devices observing a line are related by a line homography, Figure 2.

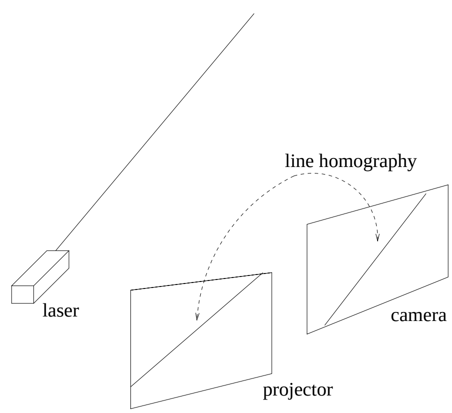

Fig. 2. The projection of the laser ray is determined on the projector image plane and the camera image plane. A line homography describes the transformation of points between these two lines.

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The line homography is determined by -

- project the laser onto a surface,
- record the camera image point p_c for the laser point. Project p_c to a point p_{c1d} on the computed line l_c, where p_{c1d} is expressed in a 1D coordinate frame on the line.
- follow the steps above for computing H_{cp} and thereby compute p_p, the projection of the laser point on the projector image plane. Project p_p to a point p_{p1d} on the computed line l_p, where p_{p1d} is expressed in a 1D coordinate frame on the line.
- repeat with the surface at three or more different distances, to record a set of corresponding points $p_{c1d}, p_{p1d}, i = 1..n$
- use the correspondences to compute a line homography G between the two lines

Given this line homography G, for any camera observation x_{c1d} of the laser point on a surface, it is possible to determine $x_{p1d} = Gx_{c1d}$, the projection of the laser point on the projector image plane. Thus, the laser point observations can be transformed so that they effectively arise from pinhole projection from the projector. And we can use this information as input to all the original algorithms for the projector-camera system, which are based on two rigidly-attached pinhole devices.

3 Other

The main reason for augmenting the projector-camera with laser pens is to avoid constraints on the form of the projected image, and to provide laser spots on the display surface that are easily detected at the camera. However there are some other advantages to using laser pens.

- Different-colored laser pens can be used on different projectors, to allow discrimination when multiple projectors are projecting to a shared projection area.
- Infra-red laser pens can be used to provide a projection that is visible to the camera but invisible to the user, and hence is unobtrusive.
- A self-setting 'laser-level' can be used in place of a laser pen to provide not just a laser spot, but a laser line indicating the world vertical - this is useful when attempting to create a projection that is correctly-aligned with the world vertical, even though the projector itself may be rotated.

4 Results

TBD

5 Conclusion

A rigidly-attached projector-camera system can determine its own pose relative to a display surface, and this is a powerful platform for a range of projection functionality. Adding laser pointers to a projector-camera is redundant in the strict sense of what information it makes available, but in practical terms, detecting projected laser points on a surface can be done much more reliably than detecting a projector-image. We described a novel technique to calibrate laser pens that are rigidly-attached to a projector-camera system, allowing projected laser light to be used as an input to existing algorithms for projector-camera systems.

References

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