

# 3D SURFACE RECONSTRUCTION FROM HORIZONS\*

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## ABSTRACT

*In this paper we present a general solution to the problem of 3D reconstruction from the analysis of luminance edges, which takes into account possible viewer-dependent characteristics of such contours. The method first proceeds by matching contours in a loose fashion, so that both sharp edges and horizons are included. Classical stereometric methods allow us to detect sharp edges and rule out all matches that include any such edges. Among the remaining matches we then identify those that can be classified as horizon contours and estimate the 3D coordinates of the three visible rims through an entirely geometrical procedure.*

## INTRODUCTION

All 3D scene reconstruction methods from stereo-correspondence of luminance contours are based on the fundamental assumption that homologous points are generated by the same detail of the scene and, therefore, they are back-projected onto the same 3D coordinates. This corresponds to assuming that the luminance edges are generated by object's details that do not change with the viewer's position. If this hypothesis is correct, then the quality of 3D reconstruction can be very accurate, provided that a certain quality in the calibration of the camera system is guaranteed and that no matching errors have been made.

Among the 3D features that give rise to luminance edges, those that are caused by a discontinuity of the surface and/or of its tangent plane (borders, edges and ridges) or of its radiometric properties (texture, illumination, shadows), are viewer-independent (*sharp*). Not all image contours, however, are viewer-independent. Not infrequent, in fact, is the case of edges that are associated to the extremal boundary (*rim*) of a smooth surface. In that case, a portion of the surface is hidden behind the non-zero curvature of the surface itself.

Surface rims are characterized by the fact their tangent plane passes through the optical center of the considered viewpoint. In this paper, rims of this type are called "horizons" and their projections on the image plane are called "horizon contours".

Horizons are a precious source of information as their views provide us with enough information for extracting surface's differential properties of order zero (3D coordinates), one (tangent planes) and two (local curvature), while sharp edges only allow us to extract 3D coordinates. In this paper we present a rather general solution to the problem of 3D reconstruction from the analysis of the luminance edges extracted from a calibrated triplet of cameras. The method takes into account possible viewer-dependent characteristics of such contours. In order to do so, it begins by matching contours in a loose fashion, so that both sharp edges and horizons are included. Classical stereometric methods [1] allow us to detect sharp edges and rule out all matches that include any such edges. Among the remaining matches we then identify those that can be classified as *horizon contours* and estimate the 3D coordinates of the three visible rims by following a fully geometrical approach.

The method is based on the geometrical approach proposed in [2] but it represents an extension of it as, besides removing the hypothesis of local cylindricity of the imaged surface, it also performs a coherence test along the rim for validating it.

The technique proposed in this paper has been implemented with a set of three standard TV-resolution CCD cameras and tested over real scenes of a certain complexity.

## HORIZON'S DETECTION AND ESTIMATION

The minimum number of cameras that can be used for extracting information from horizon contours is three. When using a trinocular acquisition system, in fact, the information on rims can be extracted

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either by analyzing cylindrical portions of the surface or planar sections of it.

As we cannot assume the surface to be cylindrical, we need to choose a family of planes with which to section the surface over which to perform rim analysis. A good choice is shown in Fig. 1, where the surface is cut through by the so-called *radial planes* [1]. Radial planes are defined with reference to a specific camera (*reference camera*) as those planes that pass through the reference optical center and that intersect the reference image plane perpendicularly to the extremal boundary. This choice leads to a local parametrization on the surface, which is made of *radial curves* (intersection between surface and radial planes) and rims (see Fig. 1).

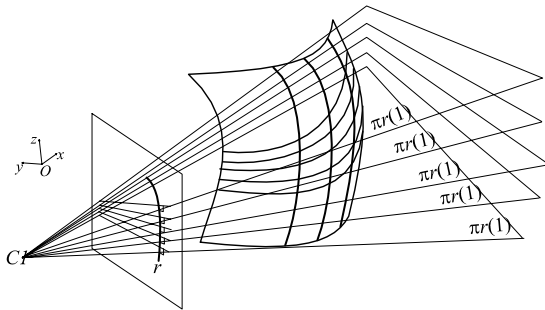


Fig. 1: local surface parametrization induced by the radial planes.

Let camera 1 be used as a reference camera. In order to perform 3D reconstruction from horizons, we need to reconstruct the radial curve on each one of the radial planes. In order to do so, we proceed, as shown in Fig. 2, by determining three coplanar

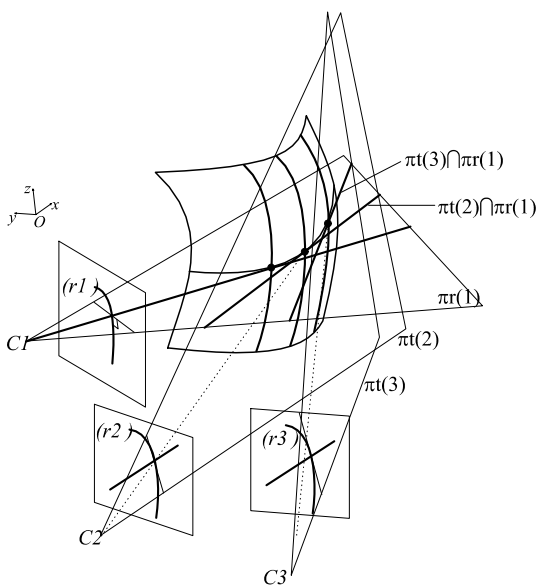


Fig. 2: radial curve reconstruction from three tangent lines.

lines on the radial plane  $\pi_r^{(1)}$  that the radial curve is bound to be tangent to, and find the osculating circle to such lines. Being such a circle tangent to the three lines, it can be taken as an approximation of the radial curve.

The three lines that we start from (on the radial plane  $\pi_r^{(1)}$ ) are:

- the reference optical ray  $l_1$
- the two intersections  $l_2 = \pi_t^{(2)} \cap \pi_r^{(1)}$  and  $l_3 = \pi_t^{(3)} \cap \pi_r^{(1)}$  between the radial plane  $\pi_r^{(1)}$  and the tangent planes  $\pi_t^{(2)}$  and  $\pi_t^{(3)}$ , where  $\pi_t^{(i)}$  is defined as the plane that passes through the optical centers of camera  $i$  and is tangent to the occluding contour at the intersection with the epipolar line associated to the reference optical ray.

The fact that we are using the intersections between radial plane and tangent planes is equivalent to assuming the surface to be *locally conical*. This hypothesis is quite reasonable and allow us to exploit not just the information on the image coordinates of the rims [2] but also on their orientation.

The osculating circle is determined as one of the four possible solutions shown in Fig. 3. We assume that the correct solution is given by the only circle that lies on the same side of the three lines. Also the other solutions, however, carry significant information. For example, the circle which is inscribed in the triangle formed by the three lines (*internal circle*) is the one that we use for deciding (through thresholding) whether a triplet of edges corresponds to a sharp edge or not. Furthermore, an *a-posteriori* check on the coherence of the radius of such a circle over different radial planes allows us to decide whether the triplet of contours is, in fact, a horizon.

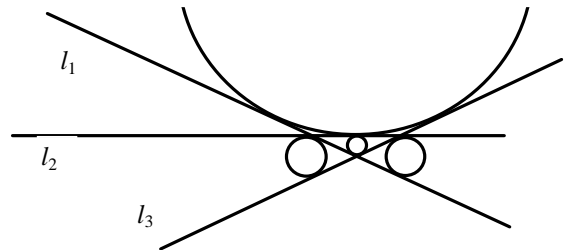


Fig. 3: among the four possible osculating circles, only the one that lies at the same side of the three lines is assumed as correct.



Fig. 4: original view of the test object.

#### EXAMPLES OF APPLICATION

As an example of application of the proposed technique, we considered the analysis of the luminance edges associated to a trinocular view of the vase of Fig. 4. As we can expect, classical stereometric principles can only provide us with 3D reconstruction results such as those of Fig. 5. As we can see, this reconstruction is not even sufficient for recognizing the object as a vase. In fact, the radius of curvature of the extremal



Fig. 5: *sharp* stereo correspondences.

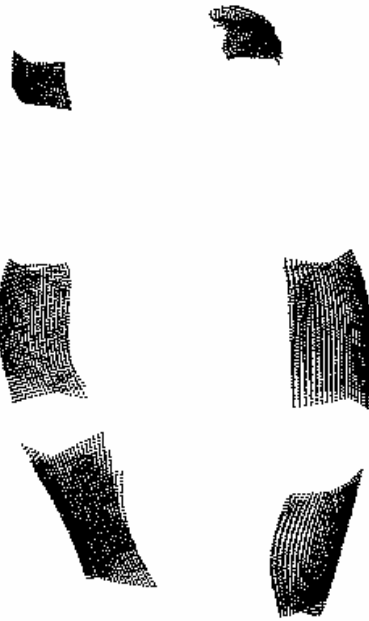


Fig. 6: radial curves reconstructed from the horizons

boundaries of the vase is rather large, therefore classical stereo matching cannot be used for extracting information from it.

In Fig. 6 we can see the radial curves as reconstructed by using the method proposed in this paper. In Figs. 7 (top view) and 8 (side view) area matching and horizon analysis are combined to show the coherence of the results in the two cases. Fig. 9 shows the final reconstruction after surface interpolation and texture mapping.

#### CONCLUSIONS

In this paper we presented a general solution to the problem of 3D reconstruction from the analysis of

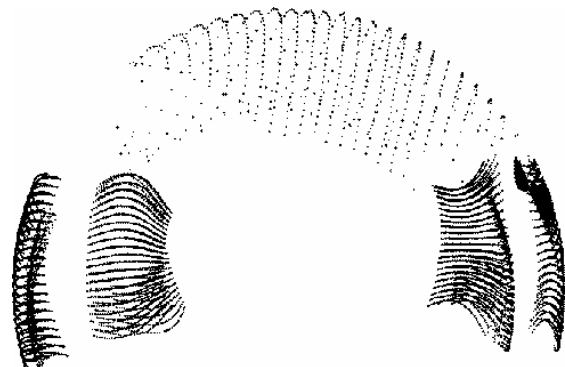


Fig. 7: comparison between 3D reconstruction from horizons and from area matching: top view.

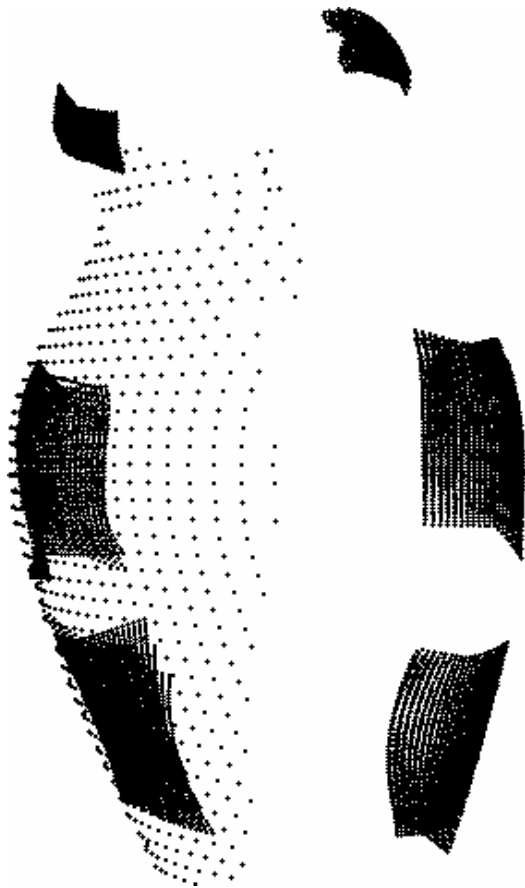


Fig. 8: comparison between 3D reconstruction from horizons and from area matching: front view and surface interpolation with texture mapping.



Fig. 9: surface interpolation with texture mapping.

luminance edges, which takes into account possible viewer-dependent characteristics of such contours. The method has been integrated with classical stereometric method in order to perform a classification between sharp edges and horizons and extract as much information as possible from them. Examples of application to real triplets of images have been presented, proving the effectiveness of the proposed reconstruction strategy.

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