Plane Surface Detection and Reconstruction using Induced Stereo Symmetry

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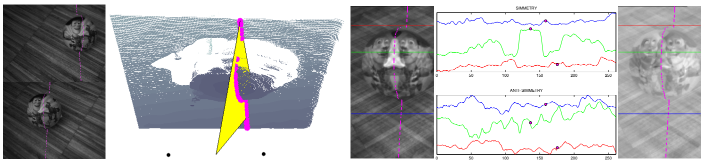
We propose an algorithm for the detection and reconstruction of plane surfaces using a new stereo approach dubbed *SymStereo* (see Fig.1). SymStereo relies in symmetry analysis for recovering the 3D curve where a virtual cut plane intersects the scene structure. The result is a profile cut that resembles the one that would be obtained by a Laser Range Finder (LRF).



(a) $\mathtt{I}$ and $\mathtt{I}'$ (b) 3D model (c) $\mathtt{I}_s$=$\mathtt{I}+\widehat{\mathtt{I}}$ (d) Epipolar Line (e) $\mathtt{I}_a$=$\mathtt{I}-\widehat{\mathtt{I}}$

Figure 1: The virtual cut plane in (b) passes between the cameras and intersects the structure in a non-continuous 3D curve (the *profile cut*). $\mathtt{I}_s$ and $\mathtt{I}_a$ are symmetric and anti-symmetric with respect to image contour of the profile cut. $\widehat{\mathtt{I}}$ is the result of warping $\mathtt{I}'$ by the plane homography.

SymStereo relates with plane-sweeping in the sense that it also samples the 3D space by virtual planes. However, there are two major differences: (i) we exclusively consider virtual planes that intersect the baseline in a point between the cameras; and (ii) instead of looking for photo-consistent regions after image warping, the data association between views is performed by detecting a mirroring contour using symmetry analysis. Works assuming multiple plane sweeping directions consider virtual planes passing between the cameras a degenerate configuration to be avoided. The reason is as follows: Let $\mathtt{I}$ be the left stereo image and $\widehat{\mathtt{I}}$ be the result of warping the right image $\mathtt{I}'$ by the plane homography mapping. If the virtual plane crosses the baseline, then $\mathtt{I}$ and $\widehat{\mathtt{I}}$, instead of being photo-consistent, are reflected one with respect to the other around the pixel location where the plane cuts the structure. The sum of $\mathtt{I}$ and $\widehat{\mathtt{I}}$ yields an image signal $\mathtt{I}_s$ that is symmetric around the image contour of the profile cut (see Fig.1(c)). In a similar manner, the subtraction of $\widehat{\mathtt{I}}$ from $\mathtt{I}$ gives rise to an image signal that is anti-symmetric at the exact same location (see Fig.1(e)). This work explores these properties and proposes SymStereo, which reconstructs the profile cut by applying log-Gabor wavelet analysis.

Algorithm for Piecewise-Planar Reconstruction

Our algorithm samples the 3D space by a discrete set of virtual cut planes and can be summarized by two main steps:

1. Processing each virtual cut plane

Let's assume a particular virtual cut plane Π. If Π intersects a planar surface, then the corresponding profile cut must contain a straight line segment.

Measuring Signal Symmetry - From each cut plane Π we render $\mathtt{I}_s$ and $\mathtt{I}_a$. A log-Gabor wavelet transform is used to quantify the signal symmetry and anti-symmetry along the epipolar lines, generating a symmetry energy $\mathtt{E}_s$ and an anti-symmetry energy $\mathtt{E}_a$ at every pixel location.

Detecting the projection of the profile cut - The projection of the profile cut is found by running standard ridge detection over $\mathtt{E} = \mathtt{E}_s \cdot \mathtt{E}_a$.

Reconstructing line cuts - The ridge points detected in $\mathtt{E}$ are used as input to a Hough transform that aims extracting line segments from the image of the profile cut.

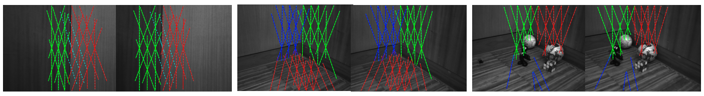
2. Plane surface detection and reconstruction

At this stage we have a set of 3D lines computed from various cut planes. In order to cluster sets of co-planar lines, the contributions of all virtual planes are used as input in a RANSAC procedure in the dual Plücker space. Each group of lines gives rise to a plane hypothesis contained in the scene.

Pose Estimation of a Single Plane Surface

In this experiment we assume that the scene is dominated by a planar surface that might, or might not, be partially occluded by non-planar objects. We estimate the relative pose between the stereo rig and the plane for the case of different textures. The results are highly accurate and, more importantly, the approach succeeds in situations where current stereo methods fail due to low and/or repetitive texture.

Detection and Reconstruction of Multiple Planes in Natural Scenes



(a) 2 Planes (b) 3 Planes (c) 3 Planes with Occlusion

Figure 2: Multiple plane detection in indoor scenes. Dashed lines correspond to the projection of the reconstructed line cuts, while solid indicates the line cuts that were assigned to one of the plane hypothesis by the RANSAC procedure (different colors signal different planes).

We also report experiments in detection and localization of multiple planar surfaces from a single stereo pair. In Fig.2, SymStereo was run using 21 cut planes, and the localization of the plane surfaces was successful in all cases. In Fig.3, after performing the detection in a manner similar to the previous experiment, each pixel in the left image was assigned to the plane hypothesis that maximizes the photo-consistency with the right image.

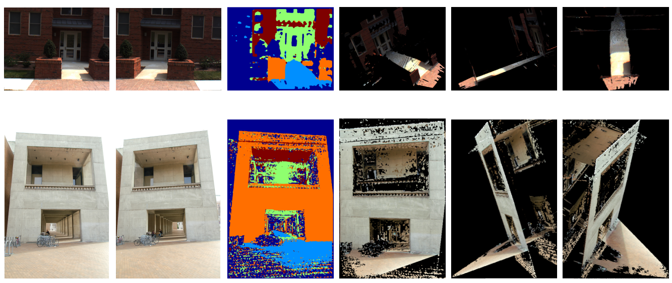


Figure 3: Wide baseline stereo of outdoor scenes. We detected and reconstructed 4 planes in each example.

SymStereo can be advantageous in many computer and robot vision tasks other than planar surface reconstruction. First, our method is designed to exclusively recover the depth along a predefined cut plane. This provides a new controlled manner for probing into the scene 3D structure. Second, our approach succeeds in reconstructing surfaces with low and repetitive texture that can not be handled by standard stereo algorithms. The explanation is that we rely in symmetry cues that have a more global character than photo-consistency metrics used for the data association in the competing methods. Third, each reconstructed profile curve is similar to the cut that would be obtained by LRF with the laser plane aligned with our virtual cut plane. Thus, this new stereo technique can potentially avoid the use of a second sensor modality in systems that combine vision and LRF, or even replace the LRF in certain applications with benefits in terms of cost and flexibility.