Multimodal Stereo Vision For Reconstruction In The Presence Of Reflection

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Figure 1: The four camera system

Traditional stereo approaches assume a lambertian scene, an assumption which is violated in the presence of specular reflections. A variety of techniques have been developed to detect and reconstruct these surfaces [1, 4] using a variety of constraints, however in this work we attempt to reconstruct a reflecting surface and a reflected scene using different imaging modalities. Using a four camera system shown in Fig. 1, operating as two stereo pairs we reconstruct a reflecting surface as well as a reflected scene. The camera system consists of a pair of visible band cameras and a pair of Long Wave InfraRed (LWIR) cameras. We leverage these different imaging modalities by taking advantage of the fact that reflectivity is wavelength dependent and reflective materials in one modality can appear non reflective in complementing modalities.

We calibrate the system by extending the work of [3] to handle cross modality calibration. This gives us a common coordinate system. To reconstruct a reflected scene we first extract the reflecting surface. This is done by adding texture to the surface in only one modality, and reconstructing correspondences, and fitting a plane to these points using principle component analysis. The implicit representation of this plane

$$P \cdot n + d = 0 \tag{1}$$

can be used to intersect rays for reconstruction. Where P is the origin, n is the plane normal and d is a constant.

Reconstructing the scene is accomplished by stereo matching the reflected images using uncalibrated rectification and disparity matching using [2]. Each point in the disparity map can be viewed as a ray going from the camera center through the image plane defined by,

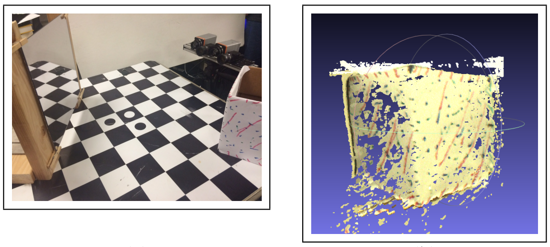
$$V_i = C_0 + t \cdot \frac{\beta}{norm(\beta)} \tag{2}$$

where C_0 is the camera center, and

$$\beta = R' \cdot A^{-1} \cdot [x_i, y_i, 1] \tag{3}$$

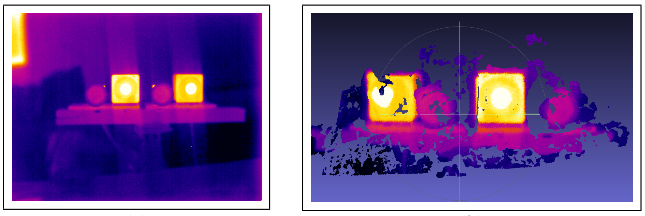
where A is the camera matrix, and R is the camera rotation matrix, and $[x_i, y_i]$ is the pixel location. We intersect these rays with the reflecting surface by substituting P from equation 1 with V_i from equation 2, and the reflected ray direction is defined as,

$$V_{reflected} = V_i + (2 \cdot n \cdot C_i) \tag{4}$$



(a) (b)

Figure 2: Results from reconstructing a cube: (a) The experimental setup; (b) The reconstructed model.



(a) (b)

Figure 3: Results from reconstructing a self portrait of our camera system: (a) The camera system reflected in LWIR; (b) The reconstructed model.

where

$$C_i = -(n \cdot V_i) \tag{5}$$

$V_{reflected}$ is the direction of the reflected ray. The reflected ray is defined as $I_i + t_i * V_{reflected}$. For each set of corresponding rays the closest point of intersection is calculated using least squares method resulting in a dense 3D point cloud.

We test our approach with a reflection setup that allows us to swap materials in place relative to the camera system. Using this setup we demonstrate texture can be added to the surfaces that is visible in just one imaging modality, and that the reflecting surface can be accurately modeled. Furthermore we show our reconstruction technique can be applied in both directions, by reconstructing a visible scene using the LWIR cameras to extract the reflecting surface, and reconstructing a LWIR scene by extracting the reflecting surface using the visible band cameras as shown in figures 2 and 3 respectively.

[1] Thomas Bonfort, Peter Sturm, and Pau Gargallo. General specular surface triangulation. In *Asian Conference on Computer Vision 2006*, 2006.

[2] Heiko Hirschmuller. Accurate and efficient stereo processing by semi-global matching and mutual information. In *CVPR (2)*, pages 807–814. IEEE Computer Society, 2005. ISBN 0-7695-2372-2. URL `http://dblp.uni-trier.de/db/conf/cvpr/cvpr2005-2.html#Hirschmuller05`.

[3] Philip Saponaro, Scott Sorensen, Abhishek Kolagunda, Stephen Rhein, and Chandra Kambhamettu. Material classification with thermal imagery. In *CVPR*, 2015.

[4] Silvio Savarese and Pietro Perona. Local analysis for 3d reconstruction of specular surfaces. In *CVPR (2)*, pages 738–745. IEEE Computer Society, 2001. ISBN 0-7695-1272-0. URL `http://dblp.uni-trier.de/db/conf/cvpr/cvpr2001-2.html#SavareseP01`.