Extract Information of Polarization Imaging from Local Matching Stereo

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***Abstract*— Since polarization of light was used in the field of computer vision, the research of polarization vision is rapidly growing. Polarization vision has been shown to simplify some important image understanding tasks that can be more difficult to be performed with intensity vision. Furthermore, it has computational efficiency because it only needs grayscale images and can be easily applied by a simple optical setup. Nowadays, we can find various types of polarization cameras in the market. However, they are very expensive. In our work, we will study and develop a low price polarization camera setup with parallel acquisition using a stereo system. This system requires only two general cameras equipped with three types of rotator polarizer in front of them. Polarization information are obtained by taking two images. Calculations are based on stereo matching to get the angle and degree of Polarization.**

Keywords : Stereo matching, Polarization Imaging, polarization camera

I. INTRODUCTION

The main function that must exist in a polarization camera is an automatic sensing of polarization parameters and the production of polarization images. Light Polarization is a physical characteristic of light that describes the orientation of its oscillations. This can carry additional information and provide richer description of the scene which is more general than light intensity.

Polarization camera proposal started by [8],[9],[10] with two designs ; Liquid crystal Polarization camera, and a setup with two CCD cameras using a beam splitter in front of them. The application with beam splitter [6] was used for clinical mapping of skin cancer. Up to now, there are three vendors who produce polarization cameras, like Fluxdata, with integrated beam splitter for 3 CCD sensor. Samba, based on analysis and decomposition of light scattered by an object and Photonic lattice with micro polarizer array technology. All of the above systems require support of complicated expensive optical devices.

Some important issues should be addressed in order to extract polarization information from stereo matching : How to choose the best stereo matching system that can be used for polarization images without losing polarization information, and how to extract and present the polarization information ? To answer these questions, we will present the basic theory of polarization imaging and stereo systems in section 2 and 3. Section 4 will describe the imaging setup. We will also do some computation to extract polarization information, and perform some experiments to extract and visualize polarization information in section 5. In the last section, results will be presented, and the work will be concluded.

II. POLARIZATION IMAGING BACKGROUND

Polarization state or partial linear polarization of light can be measured using linear polarizing filter that resolves the electric distribution of light along a given orientation. The light radiation will be transmitted through a polarization filter according to the filter orientation [11]. Because a sinusoid can be uniquely determined by three points, we can take three transmitted radiance measurements taken between 0°-180°. Minimum requirements for these measurements are taken from image intensity measurements at polarizer angles 0°, 45° and 90° (I_0, I_{45} and I_{90}). From [11], the angle of polarization φ is

$$\varphi = 0.5 * \arctan\left((I_0 + I_{90} - 2I_{45}) / (I_{90} - I_0) \right)$$

$$\text{If } I_{90} < I_0 \; [\text{ if } (I_{45} < I_0)\; \varphi = \varphi + 90] \;\text{ else }\; \varphi = \varphi + 90 \quad (1)$$

$$\text{Intensity } I = I_{min} + I_{max} = I_0 + I_{90} \quad (2)$$

ρ is the degree of polarization, where

$$\rho = (I_{90} - I_0) / (I_{90} - I_0) \cos 2\varphi \quad (3)$$

Polarization state of light can be also measured using the Stokes parameters formulas [4],[9]. This method multiplies the Mueller matrix of a linear polarizer by a Stokes Vector to obtain:

$$I_p(\alpha) = \frac{1}{2}(S_0 + S_1 \cos 2\alpha + S_2 \sin 2\alpha) \quad (4)$$

Where α between 0° and 180°. Then, stokes parameters are computed by applying least squares method to (4). From S_0, S_1 and S_2, we can calculate the polarization state by the following equations :

$$I = S_0 \tag{5}$$

$$\rho = \frac{\sqrt{S_1^{\,2} + S_2^{\,2}}}{S_0} \tag{6}$$

$$\varphi = arctan\frac{S_2}{S_1} \tag{7}$$

III. Computational Stereo

In general, there are three important steps to solve problems in computational stereo : calibration, finding correspondences, and reconstruction [2]. Calibration is the first step to determine camera internal parameters such as focal length, optical center, and lens distortion. Calibration is also used to get the relative position of each camera (external parameters). Correspondence is how to find a correct point in the left image associated with a point in the right image. Reconstruction is the conversion into a 3D map of the objects scene based on the knowledge of the geometry of the stereo system and disparity map. Disparity is the difference between the same objects in two different stereo images.

In this work, three images are taken to extract polarization information obtained from the combination of polarizers with specific orientations in the left and right sides of the stereo system. One needs to find the correct point correspondences of features between two images. Fig. 1 will illustrates how to find correspondences between the two images.

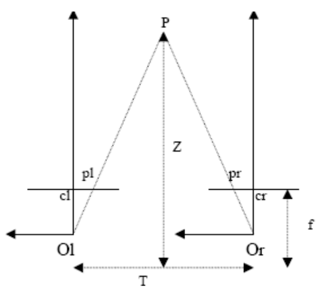

Figure 1. A Simple Stereo Setup

In fig. 1, *Ol* and *Or* are the optical centers, *T* is the baseline, *Z* is the distance between P and the baseline, and *f* is the focal length. Camera calibration provides the intrinsic parameters, to characterize the transformation mapping from an image point in camera coordinates to pixel coordinates in each camera, and the extrinsic parameters to describe the relative position of the two cameras. Epipolar geometry [13] is then used to search for corresponding points on epipolar lines.

Fig. 2, give an illustration of epipolar geometry. The triangle lies in the epipolar plane. The lower corners of the triangle (*Ol* & *Or*) are the optical centers. The intersections of the triangle's base with the planes are the epipoles. The dotted lines are the epipolar lines.

Corresponding points between two images are found by searching for the point correspondence along an epipolar line. In general, epipolar lines are not aligned with coordinate axis and are not parallel. Such searches are time consuming since one we must compare pixels on skew lines in image space. This can be overcome by rectifying the images [1],[3] to determine transformations of each image plane such that pairs of conjugate epipolar lines become collinear and parallel to one of the image axes (usually the horizontal one).

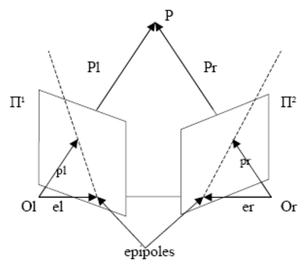

Figure 2. Epipolar geometry

Generally, correspondence problem is done in two ways: local matching and global matching. Local matching performs an evaluation of local characteristics on a small part of the image source and search for corresponding points with the same characteristics in the target image. Meanwhile, the global matching evaluates the global characteristics of the source image and then compare it with the image of the target.

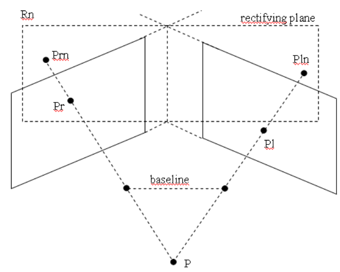

Figure 3. Ilustration of rectifying Image technique

In this work, we use local methods because while extracting polarization information, observations were made on a pixel level basis. With these methods, matching are more efficient and can provide more accurate results than the global methods.

In the local methods, the matching cost is evaluated based on similarity statistics between image neighborhood of processed pixel. To improve similarity matching, three different metrics have to be taken into consideration [2]:

- Correlation, such as NCC (Normalized Cross Correlation), this is a standard statistical method for determining similarity.
- Intensity differences such as SSD (Sum of Squared Differences) and it can be normalized as well (Normalized-SSD), and SAD (Sum of Absolute Differences).

- Rank metrics such as rank transform and census transform [13].

IV. IMAGING SETUP

Most imaging sensors are sensitive to the energy of the incoming light (intensity or color) but not to the polarization state. Therefore, polarization information can be obtained by mounting linear polarizing filter in front of a camera and capturing multiple images with different angles α (with the transmission axis) of the linear polarizer. In this work, the image acquisition setup must be able to accommodate the process for extraction of polarization information as well as for stereo matches purpose.

A. Image Acquisition

The imaging setup used is shown in fig. 4. Two units of AVT Guppy camera (F-080B monochrome camera) are installed on the baseline to get stereo images. In front of the stereo cameras, a fixed polarizer with α = 45° was set in front of the right camera. In front of the left camera, a fixed polarizer associated with an electric liquid crystal (LC) polarizer rotator, produce images with different α values 0° and 90°.

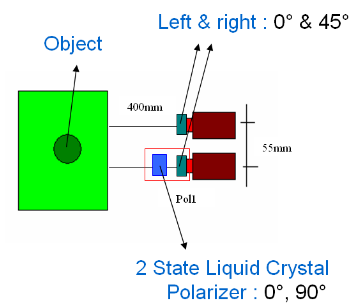

Figure 4. Image Acquisition Setup

B. Imaging System Calibration

In polarization imaging system, one must be sure that all polarization information from the scene are completely captured by the imaging system setup. Meanwhile, in the stereo imaging system, one needs to get accurate information about the camera internal and external parameters from geometry computation. A thorough calibration was performed to ensure the the two cases.

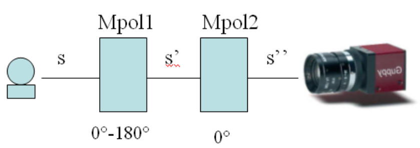

Figure 5. Photometric calibration setup, Mpol1&2 is mueller matrix from linear polarizer, s, s',s'' is incident light polarization state.

First a photometric calibration is performed. Two polarizer are set in front of each camera and the electrical polarizer rotator (in front of the left and right camera) is then allowed to be 0° and 90°. Fig. 5 shows the photometric calibration setup. Images are captured for each value for angle α from 0 to 180 with a predefined step.

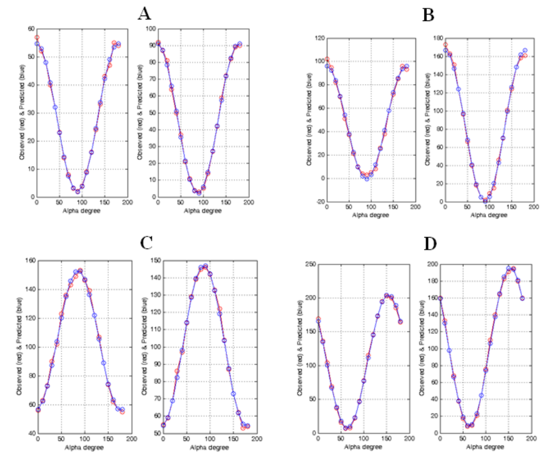

Figure 6. Photometric Calibration Result, red graphics is gray level value observed and blue is gray level value predicted.

Using the Mueller matrix of the linear polarizer and the Stokes vector (eq. (4) to (7)). The expected intensity is calculated and compared to the one measured. Ideally, the difference should be 0. But a slight difference of one or two grey levels can be tolerated (scaled of 256 grey levels), higher difference resulting in images which are too noisy.

On fig. 6, two random pixels positions were selected ((270,497) and (198,501)), A and B are left and right polarizers calibration results. C and D are liquid crystal polarizer calibration results for α degrees 0° and 90°.

The second calibration is performed to obtain the intrinsic and extrinsic stereo system parameters. In our procedure, these parameters are used to rectify images captured by our cameras. In order to perform the corresponding search on parallel lines.

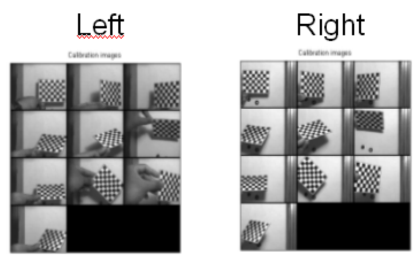

Figure 7. Calibration Pattern

Ten pairs of images for the calibration pattern were captured. The system was calibrated using the Matlab camera calibration toolbox from J.Y. Bouguet [7]. Images were rectified using the method proposed by [1].

C. Feature Extraction

To facilitate the stereo matching process between two input images, salient regions were defined to obtain clear matches and Harris corner detector in [5] was used for that purpose.

D. The Matching Cost Algorithm

The features generated by the Harris method are used as input for the stereo image matching process. Stereo matching process is done by looking for the most similar matches, based-on local image properties in predefined neighborhood / window.

To make a fair stereo image comparison, the two inputs from left image (with α degree 0° and 90°) are average ((I0°+I90°)/2). The intensity is proportional to the one of the right image (with α = 45°), which is reduced because of the polarization of incoming radiation.

Normalized SSD (Sum of Squared Differences) algorithm was used as a matching score, because this algorithm gave better matching results when applied to our polarized images, compared to other local matching algorithms (NCC, SSD, SAD, census, rank). NSSD Algorithm is computed as the following equation [2] :

$$\sum_{u,v}\left(\frac{\left(I_1(u,v)-\bar{I_1}\right)}{\sqrt{\sum_{u,v}\left(I_1(u,v)-\bar{I_1}\right)^2}}-\frac{\left(I_2(u+d,v)-\bar{I_2}\right)}{\sqrt{\sum_{u,v}\left(I_2(u+d,v)-\bar{I_2}\right)^2}}\right) \quad (8)$$

Where where I_1 and I_2 are the left and right images respectively and S(x,y,d) is the normalized sum of squared differences of the pixel (x,y) whose disparity is to be calculated using a $m \times n$ window. d is the offset in the right image with respect to the pixel *(x,y)* in the left image.

E. Reject Outliers from Matching Results

One of the common methods to reject outliers for affine or perspective models is the random sample consensus (RANSAC) [12]. RANSAC considers the features that do not fit the current geometric model as outliers and eliminate them in an iterative manner and the geometric model is estimated again on the basis of newly identified inliers. RANSAC is applied to make sure that the points found in the second image are in the correct positions.

V. EXTRACTING POLARIZATION INFORMATION

A basic but efficient technique to obtain the state of polarization of incident light is to capture three different intensity images through a set of polarization filters. If I_0, I_{45} and I_{90} are a representation of the image intensity measurements taken at an angle of polarizer of 0°, 45° and 90°, the angle of polarization, the degree of polarization and the intensity can be obtained based on equations (1) to (3).

Linear Polarization filter simplifies polarization imaging in which the ellipticity λ of the polarized component is null and the major axis of the degenerated ellipse (line) is oriented according to φ. From equation (4), one has :

$$I_\alpha = \frac{I_{tot}}{2}(1+\rho\cos(2\alpha-2\varphi)) \quad (9)$$

Intensity of polarization from three different directions of polarizer (0°, 45°, 90°) :

$$\begin{aligned} I_0 &= \frac{I_{tot}}{2}(1+\rho\cos 2\varphi) \\ I_{45} &= \frac{I_{tot}}{2}(1-\rho\sin 2\varphi) \\ I_{90} &= \frac{I_{tot}}{2}(1-\rho\cos 2\varphi) \end{aligned} \quad (10)$$

To obtain the degree of Polarization, two intensities take from equation (10) and substitute them :

$$\begin{cases} \rho\sin 2\varphi = 1-\dfrac{2I_{45}}{I_{tot}} \rightarrow (a) \\ \rho\cos 2\varphi = 1-\dfrac{2I_{90}}{I_{tot}} \rightarrow (b) \end{cases} \quad (11)$$

Leading to the angle of polarization :

$$\varphi = a\tan\left(\frac{1-\frac{2I_{45}}{I_{tot}}}{1-\frac{2I_{90}}{I_{tot}}}\right)/2 \quad (12)$$

Once the angle of polarization is obtained, one can compute the degree of polarization :

$$\rho = \frac{1-\frac{2I_{45}}{I_{tot}}}{\sin\left(a\tan\left(\frac{1-\frac{2I_{45}}{I_{tot}}}{1-\frac{2I_{90}}{I_{tot}}}\right)\right)} \quad (13)$$

In our work, polarization state computation is only performed on the pixels which were found by the matching algorithm described in the previous step.

The last step is to propose a visualization polarization information based on stereo matching result. Degree of Polarization (DoP) is visualized on the length of the line, while the Angle of Polarization (AOP) is the angle of the line to the axis x as described on fig. 8.

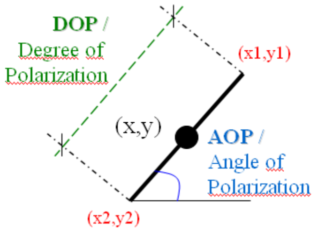

Figure 8. Illustration of the Visualization Polarization Information

VI. RESULT & EVALUATION OF POLARIZATION INFORMATION

An Effective way to ensure the calculation of the polarization state of the light is correct, is to set the polarized incident light condition with a known angle. This can easily be achived by inserting a polarizer in front of the setup system. In this work, five set conditions of incident light (0 °, 10 °, 20 °, 30°, 45°) were used and compared with the angle of Polarization obtained with our method (Table 1).

TABLE I. AVERAGE RESULTS OF POLARIZATION INFORMATION FOR EACH SCENES INCIDENT LIGHT (0°,10°,20°,30°,45°)

Incident Light angle	Total Intensity	Angle of Pol	Degree of Pol	% of Average Error
0°	0.3863	-2.1586	0.7470	0.0216
10°	0.3674	-8.7851	0.6139	0.1879
20°	0.3409	-16.0545	0.5019	0.3605
30°	0.4062	-26.6184	0.4561	0.5662
45°	0.4042	-39.7027	0.4437	0.8470

In table 1, The polarization information is an average obtained from each pixel found by mathing algorithm. By comparing polarized incident light angle with the average of angle of Polarization, we can get the average error of polarized light.

Fig. 9 illustrates the results step by step. Each source image (no.1) is processed to obtain Harris features (no.2) and then matches are found by NSSD (no.3). Outliers are rejected by RANSAC method (no.4). Finally, the polarization information is extracted from the inlier pixels and visualized (no.5). For better illustration purpose, some regions are enlarged as shown in fig. 10.

The positions selected in fig. 10, are visualized to show angle and degree of Polarization in fig. 11.

In fig. 11, the change of direction from polarization angle in every scene incident light, shows the quality of the implemented method.

VII. CONCLUSION

We presented an implementation of polarization vision system in stereo imaging. As shown in this paper, stereo polarization setup design with liquid crystal polarizer in one side and a fixed polarizer in the other side can sense partial linearly polarized light and computationally process polarization component.

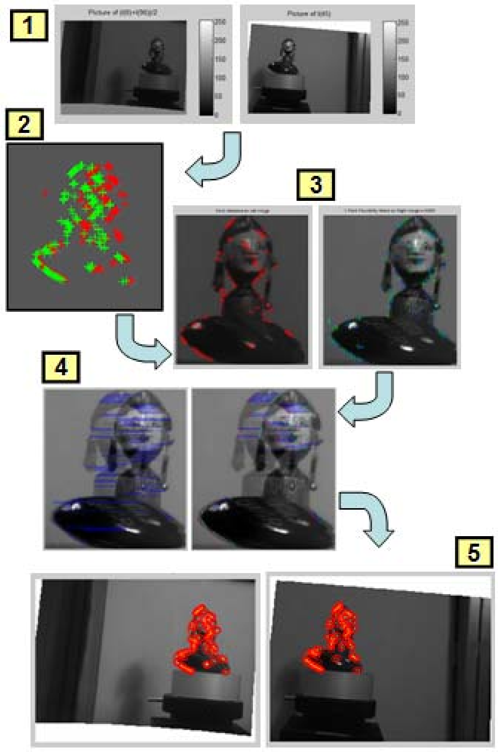

Figure 9. Results step by step visualizing Polarization Information from Stereo Matching for incident light at 10°

We also added a function to visualize polarization component in the output. Experiments show that our method exhibits good performance in complex background, especially when there is some light reflected from specular parts.

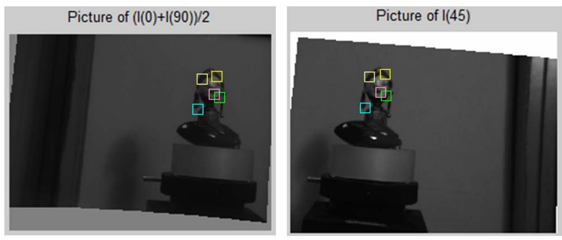

Figure 10. Selected Region Points

In our future work, we will try to obtain a dense matching method and we will use the extracted polarization component to detect either water body (lake, spillage, etc) from aerial views or metallic object from terrestrial views.

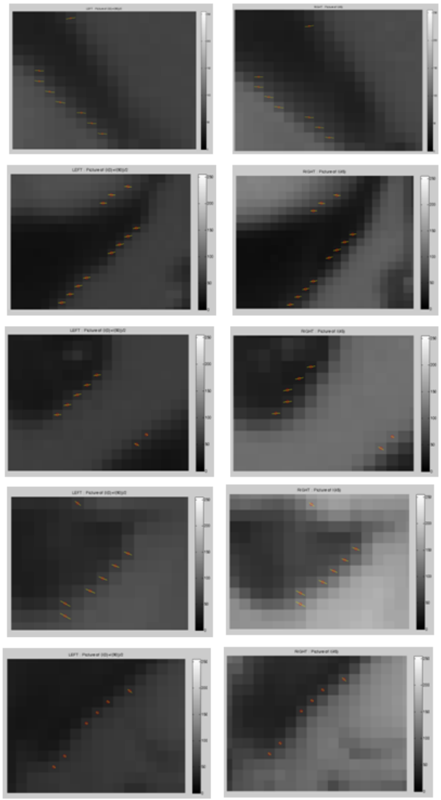

Figure 11. Visualization Polarization Information on different incident light

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