Lab 1 - Polarization Imaging

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Chapter 1

Introduction

1.1 Background of Study

This is a report based on laboratory course in Polarization imaging for our course module Sensors and Digitization. We were given certain tasks to perform based on a follow up form our class tutorial on polarization. You will find in this report findings in which we made and ways in which we took to perform the tasks given.

Polarization is a property that is common to all types of vector waves. In classical physics, light is modeled as a sinusoidal electromagnetic wave in which an oscillating electric field and an oscillating magnetic field propagate through space. Since the magnetic field is always perpendicular to the electric field, we usually sketch just the electric field when visualizing the optical waves oscillations. Polarization is defined in terms of the pattern traced out in the transverse plane by the electric field vector as a function of time. Light is called natural or unpolarized if its plane of polarization fluctuates randomly around the direction of light beam propagation, so that, on average, no direction is favored. For example, most naturally produced light (sunlight, firelight) is unpolarized. In any other case, the light beam can be considered to consist of partially polarized or fully polarized light.The polarization of a light beam can be represented by its electric field vector. Its optical power is a scalar quantity that is proportional to the mean square of the electric field amplitude.

Consider z be the direction of propagation. Then, the polarization vector is in the x-y plane. By superposition of the x- and y-vector components at time t at any location, the polarization vector can be expressed:

$$\vec{E}(t) = \vec{E}_x(t) + \vec{E}_y(t) = E_x cos(\omega_t + \sigma_x)\vec{e}_x + E_x cos(\omega_t + \sigma_y)\vec{e}_y$$

where E_x and E_y are the amplitudes of the x and y components of the electric field,e_x, e_y are the unit vectors of the x-y orthogonal reference system,ω is the angular frequency, and σ_x and $\sigma_y$are the phases of the electric field in the x and y directions, respectively. The phase difference is $\sigma = \sigma_x - \sigma_y$.

We will use this to solve the tasks asked and we will perform several experimental set ups.

1.2 Objectives

The main goal for this laboratory course we are to understand how a simple camera can be transformed into a polarization state measurement system. Two different systems where implemented:

1. A simplified polarization imaging set-up that consists of a manually rotating placed in front of the sensor.
2. A contrast polarization measurement system that uses a Twisted Nematic Liquid Crystal.

In order to achieve the goal given we took time to revise our lectures which made us to be well equipped for the necessary tasks given. we performed tas using the Wolff's method and also the least mean square method.

Chapter 2

Hardware and Software Specifications

2.1 Hardware Specifications

In order to perform the necessary tasks given we used the following hardware components:

1. PC Computer
2. Frame Grabber - IEEE 1394
3. Camera- Allied Vision Technologies Guppy with One lens and video Cable
4. Arcoptix switchable polarization rotator0-90 degrees and Arcoptix USB LC driver
5. Two linear Polarizers
6. Four mounting pots and four post holders
7. Lighting Device And Polarized ring

2.1.1 PC Computer

Our PC computer with a basic windows operating system which had the software which will be used to perform the tasks installed on it. This will be useful in monitoring and controls of the activities during the practical session.

Figure 2.1: PC Computer

2.1.2 Frame Grabber - IEEE 1394

The Frame Grabber Device used is designed for machine vision and scientific applications requiring high-resolution and high-speed digital imagining. They offer a range of features including on-board programmable region of interest, pixel decimation, image scaling, and lookup tables. Hubs connected to ports allow acquisition from additional cameras.

2.1.3 Camera- Allied Vision Technologies Guppy with lens

This camera is an ultra-compact, inexpensive VGA machine vision camera with a sensitive CCD sensor (Sony ICX424). At full resolution, it runs up to 58 frames per second. Higher frame rates can be reached by a smaller area of interest (AOI).

Features :

- Look-up table (LUT)
- Area of interest (AOI), separate AOI for auto features
- Auto gain (0 to 24 dB)
- Auto exposure (129 μs to 67 s)
- Auto white balance
- Store-able user sets

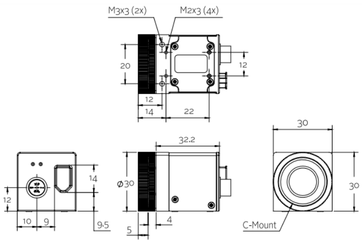


Figure 2.2: Dimensions of Camera

Figure 2.3: Camera with lens (8mm) and video cable

Specifications:

- Interface : IEEE 1394 - 400 Mb/s, 1 port
- Sensor : Sony ICX-424
- Sensor type : CCD Progressive
- Cell size : 7.4 μm x 7.4 μm
- Lens mount : C-Mount, CS-Mount
- Max frame rate at full resolution : 58 fps
- ADC : 10 bit
- Operating temperature : +5 °C to +45 °C
- Power requirements (DC) : 8 V to 36 V
- Mass : 50g

2.1.4 Arcoptix switchable polarization rotator0-90 degrees and Arcoptix USB LC driver

This Liquid Crystal twisted nematic polarization rotator (TN cell) is very useful when one wants to rotate the orientation of a linear polarization by a fix amount of typically 45° or 90°. When light is traversing LC twisted nematic cell its polarization follows the rotation of the molecules (see figure below). The screens of any laptop computer are based on the same effect. In optical systems the polarization is often rotated by quartz retardation plates (?/2 or ?/4 plates). Quartz plates shows high quality and good transmission performances especially in the UV region. The polarization converter needs to be connected to an alternative (AC) power supply producing a square wave signal with change of polarity (oscillating between positive and negative bias).

Features :

- Cost effective
- industrial quality
- compact
- some wavefront distortion
- spacers distributed over the aperture

Figure 2.4: Liquid Crystal and USB LC Driver

Specifications:

- Twist : 45° or 90°
- Twist accuracy : ±1°
- Output ellipticity : Between 0.1 and 10% (depending of the model and the wavelength)
- wavelength range : 350-1800 nm
- Active area : 10 mm or 20mm (diam.)
- Substrates : Glass

2.1.5 Two linear Polarizers

Linear Polarizers are Polarizers designed to linearly polarize incoming light. Passing white light through a Linear Polarizer blocks half of the incident light, causing the electric field component to displace so that it oscillates in only one plane with respect to the direction of propagation. Linear Polarizers are ideal for a range of industrial, imaging, or laboratory applications.

Figure 2.5: Linear Polarizers Used

2.1.6 Four Mounting Posts and Four Post Holder

These where the optical mounting post and holder in performing the tasks asked during the laboratory course.

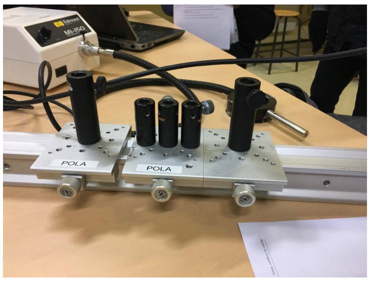


Figure 2.6: Four Mounting Posts and Four Post Holder

2.1.7 Lighthing Device and Polarized Ring

The lighhting device used was the Dolan-Jenner MI-150 Fiber Optic Illuminator. MI-150 series illuminator has been re-designed to feature an optional iris and 5 times longer lamp life. 150W EKE bulb lifetime is typically 1000-10,000 hours depending on intensity. The MI-150 features a low-profile top handle and side door for easy lamp changes. Additional features include: on/off rocker switch, intensity control via adjustment knob, and 25mm filter holder with the standard IR filter. Dolan Jenner SX Fiber Optic adapters needed to mate with fiber optic light guides. Replacement Bulb sold separately.

Figure 2.7: Lighting Devic

Figure 2.8: Polarized Ring

2.2 Software Specificaions

The following where the softwares used during the laboratory course:

1. Arcoptix USB LC Software
2. Matlab
3. Vimba Driver Viewer

2.2.1 Arcoptix USB LC software

The Arcoptix LC (Liquid Crystal) driver is a USB computer controlled electrical power supply optimized for driving liquid crystal cells such as the LC Variable phase retarder, the TN cell or the polarization converter. This was what we used in controlling the USB LC driver.

Figure 2.9: Software Interface

2.2.2 Matlab

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. The name MATLAB stands for matrix laboratory. The matrix-based MATLAB language is the world?s most natural way to express computational mathematics. Built-in graphics make it easy to visualize and gain insights from data. The desktop environment invites experimentation, exploration, and discovery. These MATLAB tools and capabilities are all rigorously tested and designed to work together.

We used this software to compute the polarization parameters and also a color image of the three parameter on a single image.

Figure 2.10: Matlab Software

2.2.3 Vimba Driver Viwer

Vimba is Allied Vision's future-proof and platform-independent SDK for GigE Vision, IEEE1394, USB3 Vision, and Camera Link cameras.

Features:

- Operating system independent
- Linux ARM support
- APIs for C, C++, and .NET
- Based on the GenICam standard
- GenICam-based third-party software automatically connects with Vimba's TLs (transport layers).
- Integrated viewer

Chapter 3

Simplified polarization imaging

In this first part, we want to study the evolution of the image light intensity by changing the polarization degree using a polarizer which is an optical filter that lets light waves of a specific polarization pass and blocks light waves of other polarizations.
To start with, design the following imaging set-up:

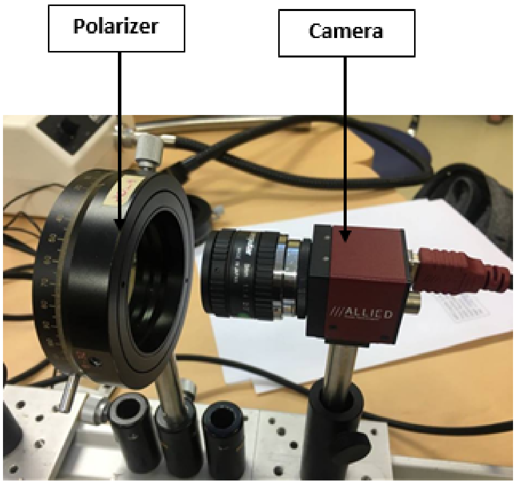


Figure 3.1: First set-up

- Connect the camera cables.
- Start the "Vimba Priver Viewer" software on the laptop.
- Grab a part of the computer screen and rotate the polarizer to see what happens.

Results : By changing the angle of polarization from 0 to 360, we get the following results.

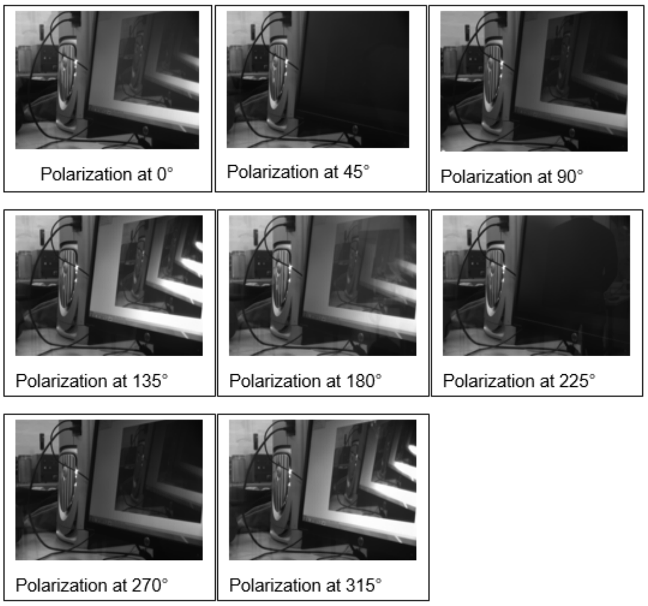


Figure 3.2: Grabbing images at different degrees of polarization

Observation: When we set the polarizer at 0 , we observe that the polarization direction is vertical because we get a vertically and linearly polarized light as output. We can also see that the more we increase the polarization degree the more the light intensity of the computer screen increased just after 45 to 180 and decrease from 0 to 45.

3.1 Wolff's method

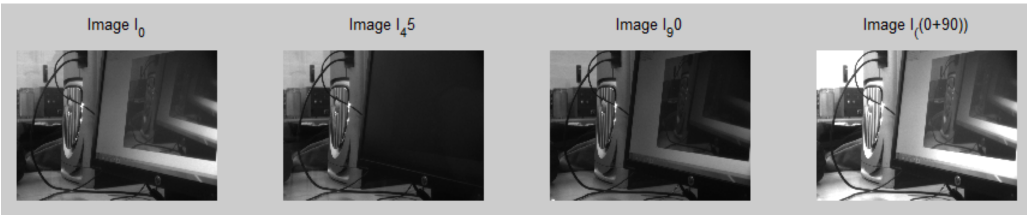
To study the Wolff'sethod, we snap and store 3 images of a scene made of a part of the computer screen with the polarizer at orientation of 0 , 45 and 90.
Then with Matlab, compute and show the polarization parameters given by:
$I = I0 + I90$
$\tan 2\varphi = \frac{I-2*I45}{I+2*I45}$
$\rho = \frac{\sqrt{(I-2*I45)^2+(I-2*I90)^2}}{I}$
And get the images from φ and ρ.

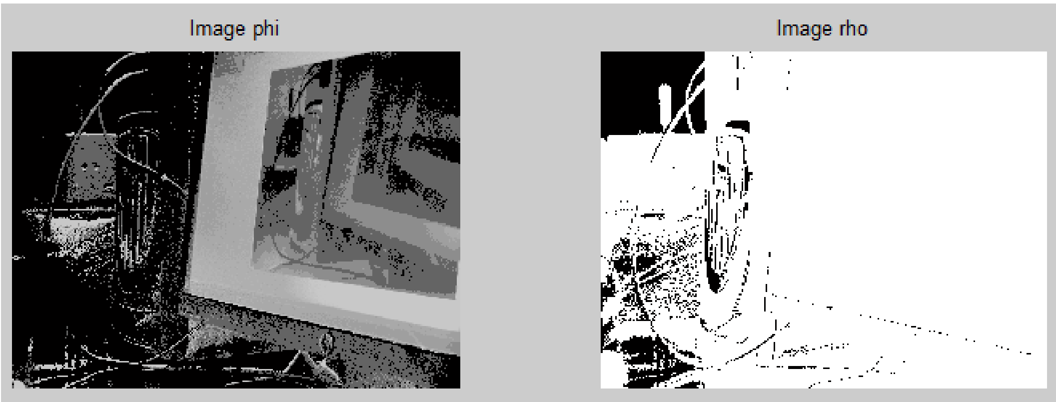
3.1.1 Getting images from φ and ρ using Matlab

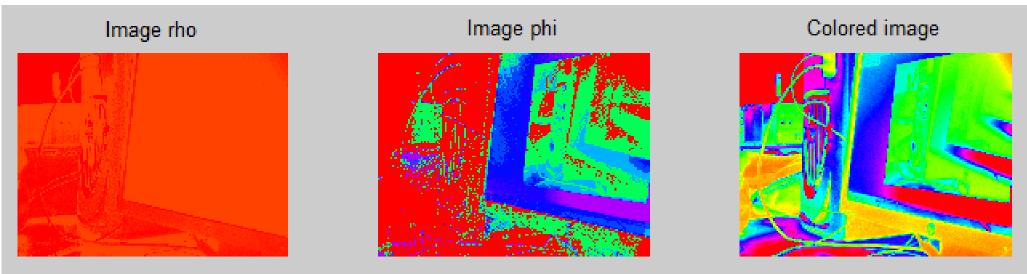
```
clear all;
close all;
clc;

%% Wolff's method
%Reading the image where thw polarizer is at 0
I0 = imread('screenchot_pola0.bmp');
%Reading the image where thw polarizer is at 45
I45 = imread('screechot_sreen45.bmp')
%Reading the image where thw polarizer is at 90
I90 = imread('screenchot_screen90.bmp');
%Get a new image which is the sum of the image at polarizer eqqual to 0 and
%90
I = I0 + I90;
%Calculate the angle of linear polirazat
tan2phi =  (I-2*I45)./(I-2*I90) ;
phi= (atan(double(tan2phi)))/2 ;
% Getting rho, the degree of polirazation
x =  (((I-2*I45).^2)+((I-2*I90).^2))/2;
rho = (sqrt(double(x)));
```

```
%% Plotting all figures
figure()
subplot(1,4,1); imshow(I0) ; title('Image I_0');
subplot(1,4,2); imshow (I45) ;  title('Image I_45');
subplot(1,4,3); imshow (I90) ;  title('Image I_90');
subplot(1,4,4); imshow (I) ;  title('Image I_((0+90))');
figure()
subplot(1,2,1); imshow (phi) ;  title('Image phi');
subplot(1,2,2); imshow (rho) ;  title('Image rho');
%%
figure()
subplot(1,3,1);imshow(uint8(rho));colormap(hsv);  title('Image rho');
subplot(1,3,2);imshow(phi);colormap(hsv);  title('Image phi');
Iadd = uint8 (phi)+ uint8(rho) + uint8(I);
subplot(1,3,3);imshow(Iadd);colormap(hsv);   title('Colored image');
```

Wolffmethod.m







Chapter 4

Contrast polarization

This method consist in taking two different images with two orthogonal directions of a linear polarizer.If an additional polarized lightning according one of these directions is used it enables to estimate the depolarization properties of the object and to remove specular reflections.A liquid crystal is used here to programmatically change the orientation of the polarizer.

4.1 Getting started

- Design the following imaging set-up with two polarizers oriented at0.

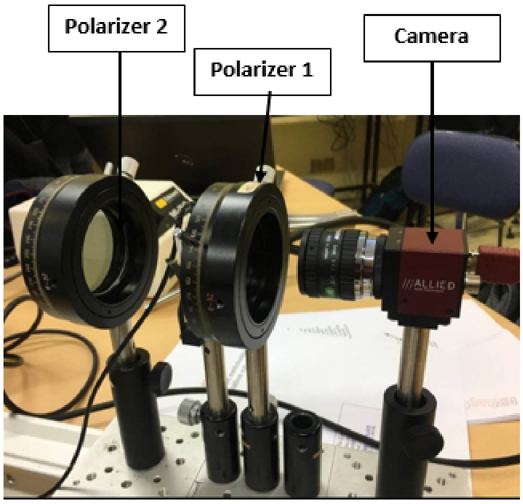


Figure 4.1: Grabbing images with two polarizers

- Connect Acroptix usb LC Driver to the computer. Modifythe parameter and observe what happens .

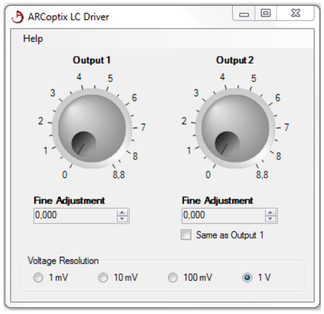


Figure 4.2: Acroptix parameter

Figure 4.3: Influence of the Acroptix

We can see that the more we increase the output1 from the LC driver the more light intensity increases and it stabilizes at from 4.

4.2 Diffuse specular reflection

To remove specular reflections, and additional polarized lightning source is used. Put the polarizer in front of the light which is in front of the camera as shown the following set-up.

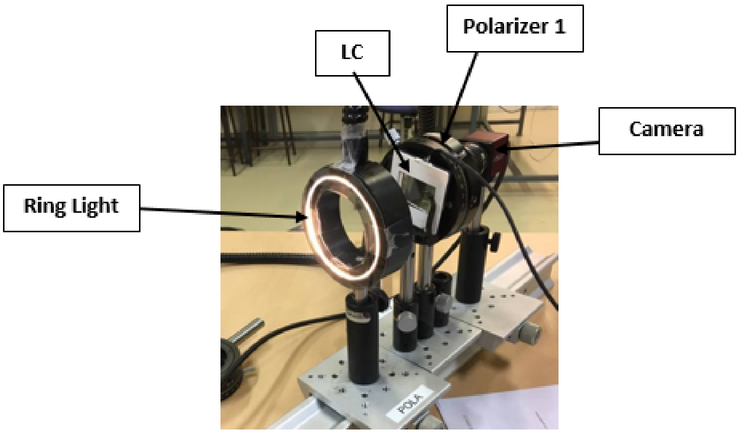


Figure 4.4: Setting up the light

Then snap two images of your hand and store it as I0 (polarization at 0) and I90 (polarization at 90)

Hand image at polarization at 0

Hand image at polarization at 90

4.3 Showing parameters by using Matlab

```
clear all;
close all;
clc;
%% Lab1 - Polarization Imaging
% Diffuse Specular reflection

%Reading the image where the polarizer is at 0
I0 = imread('hand0.bmp');

%Reading the image where thw polarizer is at 90
I90 = imread('hand90.bmp');

Total_light_intensity = I0 + I90;
Polarization_contrast = I0 - I90;
Polarization_contrast_ratio = Polarization_contrast ./ Total_light_intensity  ;

figure()
subplot(121);imshow(I0 );title('I0');
subplot(122);imshow(I90 );title('I90');
figure()
subplot(131);imshow(Total_light_intensity );title(' Total light intensity ');
```

```
subplot(132);imshow(Polarization_contrast );title('Polarization contrast');
subplot(133);imshow(Polarization_contrast_ratio);title('Polarization contrast ratio'
    );
```

Diffusespecularreflection.m

Figure 4.5: Results

We can see that when we add the two images, the light intensity is high. It decrease when we subtract the image at 0 of polarization by the image at 90.

Chapter 5

Conclusion

This lab course was for us an opportunity to get familiar on the field of polarization. We did the theoretical part in class and during this lab we saw the practical aspect of it. We observed linear and vertical light polarization using polarizer. Using two polarizers we were also able to estimate the depolarizations properties of the object which was the screen of the computer here and to remove specular reflections, a polarized lightning source was also used to remove those reflections. We were able to modify the orientation of the polarizers manually and also pro-grammatically using the liquid crystal.

We've seen only a few part of the polarization . There is still things to learn so we will do further studies on it to make us ready for another projects that we will fid ourselves in .

References

1. **Lecture Notes on Sensors and Digitization**
2. **Arcoptix**
   http://www.arcoptix.com/pdf/arcoptix%20Polarization%20Rotator%20Description.pdf