Visual Behavior Based Bio-inspired Polarization Techniques in Computer Vision and Robotics

Sistem Pencitraan Non konvensional terinspirasi dari Alam

Disajikan dalam seminar:
“Further image processing Applications: in the natural sciences and medicine”
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Agenda

- Introduction Polarization
- Bio-inspired polarization vision :
  - Pola-Stereo Vision
  - Omnidirectional Vision and more Applications
    - Camera calibration (Polarization + caustics) and shape from polarization
    - Robot navigation (Skylight polarization patterns)
    - UAV attitude estimation (Polarimetric segmentation)
- Multiple Spectral, UV and IR
- Measurement and Calibration
- Reference
Introduction

Intensity

Wave length – color

Polarization

The fact of light in Nature

THE ELECTROMAGNETIC SPECTRUM

non-ionizing

ionizing

radio frequency spectrum

infrared

ultra violet

gamma

cosmic

rays

EMF Sources

geomagnetic

sources

radio frequency spectrum

microwaves

emford
e

subways

AC power

CRT monitors

cell phones

microwave & satellite

sunlight

medical

x-rays

radioactive

sources
Polarization

- Polarization is the phenomenon that describes the oscillations orientation of the light (or other radiation) waves which are restricted in direction.

- Humans need the help of polarizing optics to visualize most invisible polarization effects.
Polarization

- Light can be polarized by several processes:
  - Selective Absorption – Dichroism
  - Reflection
  - Scattering
  - Birefringent
Bio-inspired polarization vision

- Many fish, cephalopods, crustaceans, insects, and other animals are capable of perceiving polarized light.

- Polarization vision can be used for most tasks of color vision like: object recognition, contrast enhancement, camouflage breaking, and signal detection and discrimination.

From top left to bottom right: a) Bee b) Ant c) Nocturnal d) Salmonid

From left to right (aquatic insects): a) Dragonfly b) Mayfly c) Backswimmer
Bio-inspired polarization vision

- Useful for navigation tasks:
  - Self Localization
  - Orientation
  - Detection of water, food, prey or obstacle

- Bio-inspired examples:
  - terrestrial animal
    - visual ability to analyze light pattern in the sky or in the reflected surfaces.
  - marine animals
    - Camouflage or communication
    - Enhance the visibility of the scenes

From left to right: a) Butterfly b) Mantis shrimp
Bio-inspired polarization vision

• Terrestrial Animal

*Bee Visual Ability: Self Localization and Orientation info to find a food*

In addition to their ability to sense Earth's magnetic field, the bees also have Polarization sensitive ability. This can be understood from the fact that bees have a unique behaviour based-on the position of the sun and the earth's gravity called *the swaggle waggle dance of bees* [Srinivasan (2011)]

Based-on review of [Andreou and Kalayjian (2002)], other terrestrial animals such as dragonflies and waterstrides use the polarization of reflected light to detect water. The insec alike beetles, flies, and also some reptile such as salamanders and lizards are able to sense and use polarization in their environments.

- dragonflies
- waterstrides
- beetles
- salamander
- Catagylips ant desert
Bio-inspired polarization vision

• Marine Animal

The cephalopods (one kind of squid) have more unique capability to sense polarization of light. They can respond and reflect the patterns of polarized light at once. The interesting fact is, the cephalopods are colorblind, but their eyes have photoreceptors and corresponding hair-like microvilli which expand their surface area, and can enhanced ability to selectively perceive linearly polarized light [Shashar and Cronin (1996)].

Cuttlefish (one species of cephalopod) have ability to manipulate the reflected pattern of polarization in their skin. They can use its ability for camouflage and also for enhancing the visibility of their prey. They also induced polarization patterns in their skin for communication between male and female during copulation time [Shashar et al. (2000)].

The Octopus used polarization information to increase visual contrast [Shashar and Cronin (1996)]. they have a unique colour-vision system that is able to register a change, located in the mid-band region of the eye. The mid-band may therefore be involved in communication in both colour and polarization space [Marshall and Shashar (1999)].

The mantis shrimp have a hyperspectral eyes with crystalline structure of their microvilli which perceive from the infra-red, visible to UV range. They can also perceive linearly and circularly polarized light [Chiou et al. (2009)].
Bio-inspired Stereo vision

Most of animal (also human) have a stereo capabilities to aware scene around.

Human eyes are horizontally separated by about 50–75 mm (interpupillary distance) depending on each individual.

**Human eyes have an overlapping field of view of about 120°.** It is only in this field that we have stereoscopic vision. Beyond this 3-D area out to 160-180°, we see things only in two dimensions (2-D)–i.e., flat without depth.

- **Interpupillary distance (IPD)** is the distance between the center of the pupils of the two eyes.
- Based on Anthropometric databases in
  - *Military Handbook 743A*

Interpupillary distance (IPD) is the distance between the center of the pupils of the two eyes.
Pola-Stereo Vision

- **Polarization Imaging**: The images are ‘darker’ than intensity images, need at least three different images.
- **Stereo vision**: matching point problem, need clear images, different view, need more geometric approach.

HOW TO GET A WIN-WIN COMBINATION?
Pola-Stereo Vision

- To build a prototype of stereo vision system with polarization sensitivity:
  - Can measure DoP and AoP for every angle of incident light.
  - Can reconstruct 3D point of stereo images
- To develop a simple and fast polarization imaging algorithm based-on stereo vision
- Simple and Efficient in setup and algorithm
- Easy to Use
- Not expensive
# Pola-Stereo Vision

## Learning from Previous Researches

<table>
<thead>
<tr>
<th>BeamSplitter</th>
<th><strong>Polarization Parameters Estimation</strong></th>
<th><strong>No 3D Information</strong></th>
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</thead>
<tbody>
<tr>
<td>Wolff</td>
<td>• Increase the polarization parameters estimation</td>
<td>• No 3D information</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Mizera et al 2001</th>
<th><strong>Stereo Video Polarimetry System</strong></th>
<th><strong>Displacement of the Camera</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 camera</td>
<td>• Stereo video polarimetry system to visualize the polarization patterns in stereovision</td>
<td>• Displacement of the camera</td>
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</table>

<table>
<thead>
<tr>
<th>Sarafranz 2009</th>
<th><strong>Polarization Filter Settings</strong></th>
<th><strong>No 3D Reconstruction</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi camera</td>
<td>• Two images are taken simultaneously with different polarization filter settings</td>
<td>• No 3D reconstruction</td>
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</table>
Pola-Stereo Vision
Principle of Design

- **Stereovision** => 2 cameras
- **Measurement of partially linearly polarized light** => at least need 3 images
- **Automatic acquisition** => Liquid crystal components

Based on work: Mohammad Iqbal with supervision Prof Fabrice Mériaudeau and Dr. Olivier Morel
Pola-Stereo Vision
Polarization-Stereo Imaging System Schema

Main Capabilities

Calibration

Polarization Calibration
Stereo Geometric Calibration

Image Acquisition
Rectifying Image
Feature Detection
Stereo Matching
Remove Outlier
Extract Polarization Information

3D Reconstruction

Stereo Evaluation
Pola-Stereo Vision
Evaluation of System Capabilities

Heterogeneous Scene
In nature, the light reflected from real objects would have many variations in orientations.

3D Reconstruction

(a) (b) (c) (d)
Omnidirectional Vision

Introduction

- Blue sky contains a skylight polarization pattern.
- Some insects (e.g., Bee, Cricket, and Desert ant Cataglyphis) have ability to utilize the polarization pattern of the sky for navigation purpose.
- **Estimating** a polarization pattern can be applied for navigation robot by following the strategies of those insects.
Omnidirectional Vision
Learning from Previous Researches

- Implementing a polarization pattern as additional way in navigation robot. [Lambrinos et al., 2000]
- The polarization pattern has the same pattern between simulation model and the real experiment results, it has been shown by Pomozi. [Pomozi et al., 2001]:

Some insects have ability to utilize polarization pattern for navigation.

1. **Desert ant Cataglyphis** is able to explore its desert habitat for hundreds of meters while foraging and return back to its nest precisely on a straight line by taking skylight polarization pattern. [Kesson et al., 2002]

2. **Cricket** is able to use skylight polarization under low degree of polarization for orientation even under unfavorable meteorological conditions. [Labhart, 1996]

The insect’s selected region based on degree of polarized skylight (≥ 10%)
Omnidirectional Vision
Sensor and Optical System

- The system uses Polarimetric camera and mirror of catadioptric.
- Catadioptric has an omnidirectional view
Omnidirectional Vision
Pola-Catadioptric Schema

The combination of rotation system

Rotation system in polar celestial coordinate

Determine Sun location

Selecting a mirror for a camera sensor

Hyperbolic
Parabolic
Spherical

Rotating a camera sensor by using Roll and Yaw rotations system

X-axis rotation (Roll)

Z-axis rotation (Yaw)

Combination Yaw + Roll rotations

Estimation of Polarization

DoLP
AoP

Based on work: Puja Riwaldi, 2010
Omnidirectional Vision
Evaluation of System Capabilities

Using analysis of combination Yaw + Roll rotations we can estimate the polarization pattern (DoP and AoP) from the incident light from the ground.
Omnidirectional Vision

More Application…

• Camera calibration

3D Reconstruction by means of polarization imaging

• Shape from Polarization

Based on work: Olivier Morel, Ferraton, Abd-El-Rahman Shabayek
Omnidirectional Vision
More Application…

- Robot navigation


Simulation of the sky angle of polarization pattern in Le Creusot, France at 16:00 on 15-Mar-2011 using a polycatadioptric sensor.

Based on work: Abd-el-rahman Shabyek
Omnidirectional Vision

More Application...

- **UAV** (*unmanned aerial vehicle*) attitude estimation

Based on work: Abd-el-rahman Shabayek
Multiple Spectral, UV and IR

- Multiple Spectral

**Multi-spectral (Multi = more than one, Spectral = plural of spectrum)**

Spectrum = A band of colors, as seen in a rainbow, produced by separation of the components of light using prism by their different degrees of refraction according to wavelength.

**Asclepios system**

- Multi-spectral Camera
- Artificial Neural Network
- Reflectance Cube

**Shape from Shading**

- Surface
- Photo
- Retrieve the surface(s) which gives the same photo

**Shape from Polarization**

- Find using normal, The relationship between:
  - the angle of polarization $\phi$ and azimuth angle $\phi$
  - the degree of polarization $\rho$ and zenith angle $\theta$

Based on work: Egi Wisnu Moyo and Fitria Handayani S.
Multiple Spectral, UV and IR

- **Multiple Spectral**

**Shape from Shading**

- normal surface
- reflectance result
- surface recovery

**Shape from Polarization**

- intensity image
- degree of polarization
- angle of polarization
- surface recovery

Based on work: Egi Wisnu Moyo and Fitria Handayani S.
Multiple Spectral, UV and IR

- **UV** (ultraViolet) — *Shape from UV*

*Based on work: Rindra Rantoson, 2009*
Multiple Spectral, UV and IR

- IR (Infra Red) – Scanning From Heating

Based on work: Gonen Eren, 2009
Measurement and Calibration

• Stokes Polarimeter Design

Calibration Step:

Two measurement of pol states of the scenes:

• He-Ne Laser beam with output a single wavelength at 632.8 nm (Main Focus),
• An observed real scene made of a monitor display and a single polarizer oriented at 0°.

Measurement Result:

<table>
<thead>
<tr>
<th></th>
<th>Peak-to-Valley P-V (%)</th>
<th>Standard Deviation STDV (%)</th>
<th>Root Mean Square Error RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>18</td>
<td>3.89</td>
<td>0.09</td>
</tr>
<tr>
<td>S2</td>
<td>33.4</td>
<td>6.8</td>
<td>0.16</td>
</tr>
<tr>
<td>S3</td>
<td>22.7</td>
<td>5.05</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Stokes Vector:

S0 : Total intensity ( \( I_0 + I_{90} \) )
S1 : Difference between horizontal and vertical linear polarization ( \( I_0 - I_{90} \) )
S2 : Difference between linear polarization at 45° and – 45° ( \( I_{45} - I_{-45} \) )
S3 : Difference between right and left circular polarization ( IRCP – ILCP )

Based on work: Aristyo Sudhartanto
Conclusion

Bio Inspired of Polarization Light Research can be classified into:

- Based-on Combine the two systems:
  1. Stereo + Polarization vision (iqbal, 2010)
  2. Omnidirection (Wide area Lens system) + Polarization vision (Puja, 2010)

- Based-on result:
  1. 3D reconstruction (iqbal, 2010)
  2. Navigation
  3. Shape or scene estimation

- Based-on light Spectrum:
  1. Visible light
  2. Multiple spectral system (Egi, 2011) and (Fitria, 2011)
  3. UV or IR
Publication

- Abd El Rahman SHABAYEK, Cédric DEMONCEAUX, Olivier MOREL, David FOFI, "Vision Based UAV Attitude Estimation: Progress and Insights", Accepted for publication in the International Conference on Unmanned Aircraft Systems (ICUAS’11), Denver, CO USA, May 2011.
Thanks 😊