Chapter 17
Bio-Inspired Polarization Vision Techniques for Robotics Applications

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ABSTRACT

Researchers have been inspired by nature to build the next generation of smart robots. Based on the mechanisms adopted by the animal kingdom, research teams have developed solutions to common problems that autonomous robots faced while performing basic tasks. Polarization-based behaviour is one of the most distinctive features of some species of the animal kingdom. Light polarization parameters significantly expand visual capabilities of autonomous robots. Polarization vision can be used for most tasks of color vision, like object recognition, contrast enhancement, camouflage breaking, and signal detection and discrimination. In this chapter, the authors briefly cover polarization-based visual behavior in the animal kingdom. Then, they go in depth with bio-inspired applications based on polarization in computer vision and robotics. The aim is to have a comprehensive survey highlighting the key principles of polarization-based techniques and how they are biologically inspired.

INTRODUCTION

From insects in your garden to creatures in the sea, inspiration can be drawn from nature to design a whole new class of smart robotic devices. These smart machines may move like living creatures, but they can do things no ordinary one can. They can be launched toward a specific target for a pre-defined task. Cameras on their heads can transmit footage back to their operators. Their length can be quickly changed by adding or removing joints. Their capabilities can be greatly enhanced for the sake of a specific mission.

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Bio-inspiration is developing to meet the needs of many challenges particularly in machine vision. Some species in the animal kingdom like cephalopods, crustaceans and insects are distinguished with their visual capabilities which are strongly improved by means of polarization. Most animal photoreceptors are able to differentially react to polarized light (Cronin et al., 2003; Horváth, 2014).

The construction of bio-inspired smart robotic systems empowered by polarization vision needs the cooperation of multiple engineering fields. Thinking leads to a unifying interdisciplinary and intelligent engineering science paradigm. Mechatronics can be seen as a natural answer as it successfully fuses mechanics, electrical, electronics, optics, biomechanics, artificial intelligence, intelligent computer control, autonomous robotic systems and more into a unified framework that enhances the design of products and manufacturing processes (Habib & Davim, 2013). Mechatronics is a multidisciplinary field of engineering. It represents an interaction of technologies in order to support new way of thinking and innovation (Habib, 2006; Habib, 2011). Hence, the smart integration of polarization vision into robotic systems is at the core of mechatronics engineering. Posing this research challenge into the hands of mechatronics engineers pushes them to unite the principles of mechanics, electronics, and computing to generate a simpler, more economical and reliable bio-inspired systems. Multi-scale polarization cameras are required for a broad range of applications in computer vision and robotics. UAV applications have an urgent call for small payload. Mechatronics engineering can greatly support a smart design of omni-polarimetric camera or a more advanced omni-pola-spectra camera which shall provide a polarimetric and spectral omnidirectional view.

This work is an update of (Shabayek, Morel, & Fofi 2013) where the most recent research in the area of bio-inspired polarization based techniques is covered. Firstly, we will briefly discuss the polarization based visual behavior in the animal kingdom, especially behaviors that can be mapped directly to the machine vision world such as orientation and navigation, water and transparent object detection, camouflage breaking, and communication. Secondly, a comprehensive cover of polarization-inspired machine vision applications will be given. Finally, the future research directions in bio-inspired machine vision applications based on polarization will be discussed.

Our objective is to give a top view of polarization applications in computer vision and robotics, especially the bio-inspired polarization dependent techniques in order to have a comprehensive coverage of such important and active area of research.

POLARIZATION BASED VISUAL BEHAVIOR IN THE ANIMAL KINGDOM

Orientation and Navigation

Sky polarization patterns are used by many insects for navigation. Honeybees use celestial polarization to move between the hive and foraging locations (Cronin et al., 2003; Horváth, 2014). Cataglyphis ants (Cronin et al., 2003) and Dung beetles (Dacke, Byrne, Baird, Scholtz, & Warrant, 2011) use the sun and moon, respectively, celestial polarization for similar tasks. At present, Dung beetles maintain travel direction by means of polarization where they are the only animal group known to use the much dimmer polarization pattern shaped around the Moon as a compass cue for orientation (Dacke et al., 2011). See Figure 1.