POLARIZATION VISION IN THE EYE OF A CATADIOPTRIC SENSOR

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Abstract Humans have marginal sensitivity to polarized light, however many animals are sensitive to it. This extra dimension of reality remains mostly invisible to us without the aid of instruments. Combining polarization with catadioptric sensors provides a natural compass for autonomous robots. Light in nature is mostly partially linearly polarized. After being reflected on a metallic mirror, its polarization state is changed. By redesigning the catadioptric sensor, we proved that we can measure the polarization state of the incident light after being reflected from a metallic surface.

Introduction

Polarization vision has been associated with behavioral tasks like orientation, navigation, and communication through polarizing reflections. However, only recently have we become aware that it can be incorporated into a high-level visual perception akin to color vision, permitting segmentation of a viewed scene into regions that differ in their polarization. Polarization information can be used for object identification, contrast enhancement, navigation, camouflage breaking, signal detection and discrimination, and communication. This biological inspired feature can be perfectly used in autonomous robots after combining it with catadioptric sensors.

Mathematical background

Stokes Vectors

UP	Linear		Linear ±45°		Circularly			
	Horizontal	Vertical	+45°	−45°	Right	Left	PLP	EP
$\begin{pmatrix} S_0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$	$S_0 \begin{pmatrix} 1 \\ 1 \\ 0 \\ 0 \end{pmatrix}$	$S_0 \begin{pmatrix} 1 \\ -1 \\ 0 \\ 0 \end{pmatrix}$	$S_0 \begin{pmatrix} 1 \\ 0 \\ 1 \\ 0 \end{pmatrix}$	$S_0 \begin{pmatrix} 1 \\ 0 \\ -1 \\ 0 \end{pmatrix}$	$S_0 \begin{pmatrix} 1 \\ 0 \\ 0 \\ 1 \end{pmatrix}$	$S_0 \begin{pmatrix} 1 \\ 0 \\ 0 \\ -1 \end{pmatrix}$	$\begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ 0 \end{pmatrix}$	$\begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix}$

Examples of Stokes vectors representing polarized light. UP: UnPolarized, PLP: Partially Linearly Polarized, EP: Elliptically Polarized.

Mueller Matrices

The incident beam is characterized by its Stokes vector. The incident beam interacts with the polarizing medium M, and the emerging beam is characterized by a new Stokes vector which can be expressed as a linear combination of the four Stokes parameters of the incident beam. The 4x4 matrix M is known as the Mueller matrix for the polarizing medium.

$$S^{out} = M.S_i = \begin{pmatrix} S_0^{out} \\ S_1^{out} \\ S_2^{out} \\ S_3^{out} \end{pmatrix} = \begin{pmatrix} m_{00} & m_{01} & m_{02} & m_{03} \\ m_{10} & m_{11} & m_{12} & m_{13} \\ m_{20} & m_{21} & m_{22} & m_{23} \\ m_{30} & m_{31} & m_{32} & m_{33} \end{pmatrix} \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix}$$

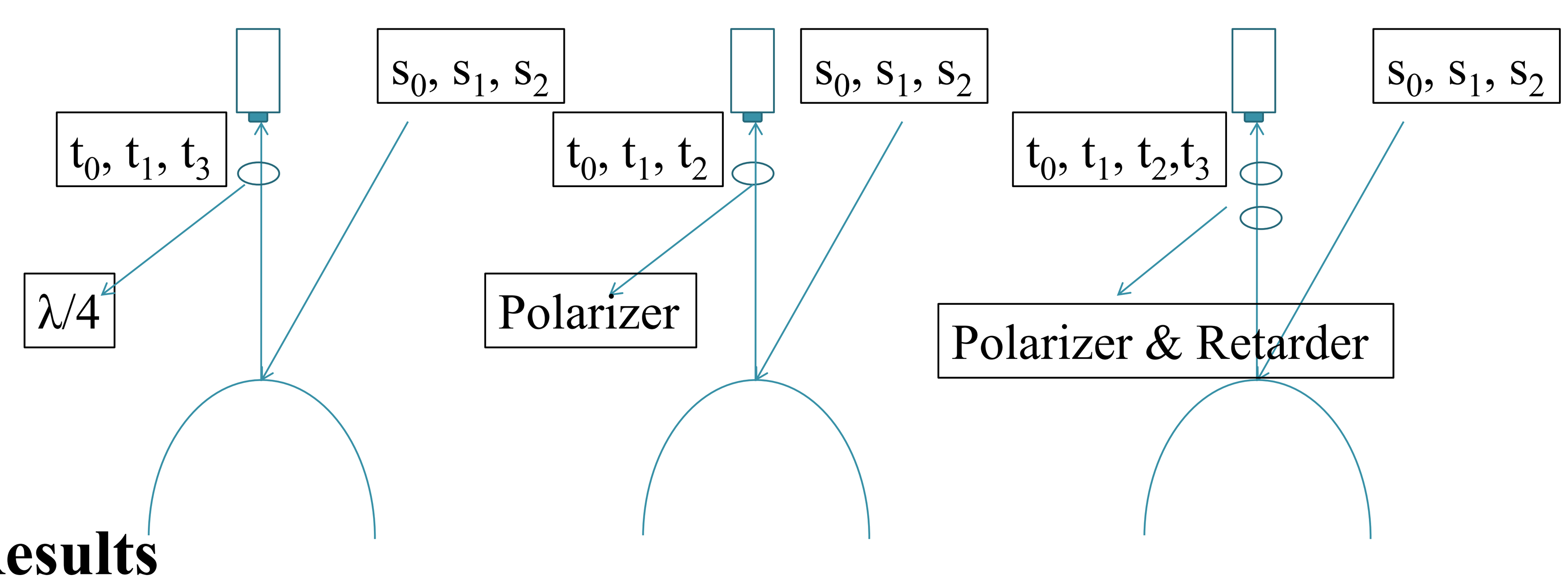
Light interaction with a catadioptric sensor

We have: $\mathbf{S^{out} = M^{catadioptric}.S^{incident}}$

$$\begin{bmatrix} \frac{(Fs-Fp)\,s1}{2} + \frac{(Fs+Fp)\,s0}{2} \\ -\cos(delta)\sqrt{Fp\,Fs}\,\sin(2\,Phi)\,s2 + \frac{(Fs+Fp)\cos(2\,Phi)\,s1}{2} + \frac{(Fs-Fp)\cos(2\,Phi)\,s0}{2} \\ \cos(delta)\sqrt{Fp\,Fs}\,\cos(2\,Phi)\,s2 + \frac{(Fs+Fp)\sin(2\,Phi)\,s1}{2} + \frac{(Fs-Fp)\sin(2\,Phi)\,s0}{2} \\ -\sin(delta)\sqrt{Fp\,Fs}\,s2 \end{bmatrix} = \begin{matrix} t0 \\ t1 \\ t2 \\ t3 \end{matrix}$$

where *Fs* is the perpendicular polarized reflected component, *Fp* is the parallel polarized reflected component, *delta* is the phase shift, and *phi* is the rotation angle. In order to compute the incident light polarization parameters S_0,S_1, and S_2, we need to make a calibration step. We note that the reflected light becomes elliptically polarized as the last parameter is non-zero.

PolaCatadioptric design



Results

It is intended to be used for UAV to orient themselves to correctly navigate in open environments. The computed polarization parameters are represented in HSV.

References

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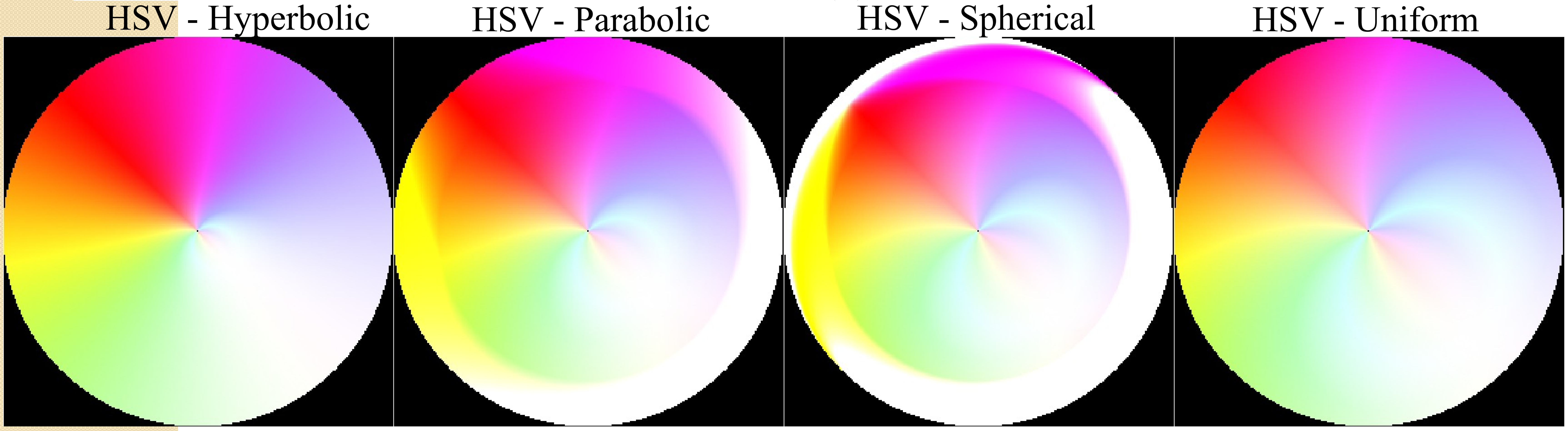
HSV - Hyperbolic HSV - Parabolic HSV - Spherical HSV - Uniform



Hue: Polarization Angle,

Saturation: Polarization Degree

Value: Intensity