Polarization imaging with LC device for underwater vision

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The investigation of the underwater is a demanding and important issue. In this paper we present the background of this topic and recent advances in the methods. Our work was focused determining the Stokes parameters and image features using least squares method. The main goal was to obtain a better contrast of the underwater images. Results of the experiment are promising because we obtained better image contrast. Further investigation can provide even better results.

Introduction

Investigation of vision through scattering media is an important issue for scientific and technological applications as well as for everyday activities. The scattering medium can be anything which simply scatters the light (e.g. fog or turbid ocean water). This paper focuses on underwater vision. This medium is demanding because it introduces several kinds of disturbances. The major demand is to restore contrast, denoise images and correct colors. All these effects result from scattering on large suspended particles (e.g. fog or turbid ocean water) and varying degree of propagating light attenuation. There are many applications of such vision. The most common are an investigation of the deep sea, submarine military applications, and as an upgrade of diving and underwater photography equipment.

History of the design, advances and possible ways of improvement in underwater vision are present in [1, 2, 3, 6]. We can distinguish two basic groups of methods: passive and active. Passive methods utilize only ambient light which is already partially polarized. While active methods use artificial lighting. Within this group we can also divide range gated methods [7]. Underwater color restoration method based on multispectral images was proposed by [4]. Disturbances introduced by water are eliminated at first. To restore real colors in multispectral images they are processed with a real color restoration algorithm. Many underwater restoring algorithms neglect the color distortion. Scientists propose a novel method [5] based on selective color attenuation in the water which measures the sharpness of the image. Underwater target detection obtained by combining active polarization imaging with correlation based approaches is proposed by [8]. Many other polarization based methods are present in [9, 10, 11]. The method proposed in [10] allows to separate backscatter component from the signal by illumination with polarized light.

Properties of a linear polarization may give information about water column, object and background. Next to the range-gating methods for backscatter removal is a polarization technique. Here the difference between target and background characteristics of depolarization are used to restore contrast [19]. Light underwater is partially linearly polarized to the depth at which light can penetrate the water. A wide range of factors affects this polarization. In this group there are scattering and absorption caused by water and their impact depend on the light path length, water depth, direction and angle of viewing [20]. The processes which affect underwater polarization are: reflection from the water surface, single and multiple scattering, refraction of direct light component traveling from air to water, forward and backward scattering, attenuation of polarized light in water and reflection from the bottom of water tank i.e. sea floor. In the turbid media the total intensity of the measured image at each pixel x,y is composed of two elements:

$$\boldsymbol{I_{total}(x,y) = D(x,y) + B(x,y)}.$$

The direct transmission light D and the backscatter light B which increases with the increasing of object distance [21,22]. In described model forward scattering effect was left out due to relatively small impact on the image quality. The direct transmission part depends on the illumination conditions, the absorption and the scattering in the water.

$$\boldsymbol{D(x,y) = L(x,y) * T(x,y)}$$

L is the object radiance as if the image was taken in clear conditions, T is the transmittance depending on the optical depth (distance between the object and the camera) and attenuation coefficient.

The back-scattering part is partially polarized and can be described as:

$$\boldsymbol{B(x,y) = B_{infin}(1 - T(x,y))}$$

The DOP (degree of polarization) of the backscatter light is defined by:

$$\boldsymbol{p \equiv \frac{B^{max} - B^{min}}{B}}$$

where B^{max} and B^{min} its extremum values of transmittance of the backscatter light for two orthogonal orientations of the polarizer.

The gathered images corresponding to the two positions of the polarizer:

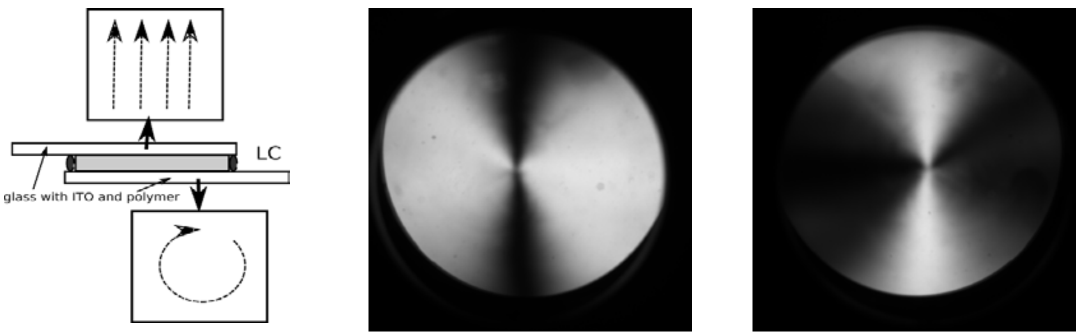
$\boldsymbol{I^{max} = \frac{D}{2} + B^{max}}$ and $\boldsymbol{I^{min} = \frac{D}{2} + B^{min}}$

In order to acquire such image, we proposed a system for polarimetric imaging based on LC filters.

Polarization camera

Despite the fact that many systems measuring stokes parameters have been developed the research is still active in this field. Areas of improvement are quite common in the machine vision: improvement of system robustness, resolution and speed to cope with real-time applications. Systems in this field can be classified as static and dynamic but here we are concentrated rather on the type of modulation than the system speed [21]. To improve the measurement frequency liquid crystal devices are used [12-18]. As an example, temporal multiplexing with two TNLC twisted nematic filters proposed by Wolff at al. or Full Stokes polarimeter based on two parallel aligned NLC nematic liquid crystal. To obtain better frequencies of acquisition bistable FLC ferromagnetic liquid crystals associated with linear polarizer are used [19].

In proposed setup we used LC filter with director of field configuration shown in *Figure 1.a*. On the one side of the liquid crystal this configuration is radial and on the second on it is linear. Analysis with exemplary usage of filter of this kind is presented in [23]



a) *b)* *c)*

Figure 1. Polarization camera with LC filter

There are several algorithms enabling image processing in the field of contrast restoration. In this paper we are proposed technique based on Saito algorithm that allow to determine DOP parameter (degree of polarization).

Test

In our experiments we performed image registration both in the air and in water. Our main goal was to verifies method for underwater image enhancement. The setup consisted of a camera connected to the PC software, linear polarizer (as analyzer), proposed liquid crystal filter, water tank filled with clear and mood water and an object. Our tested object was set of linear polarizes.

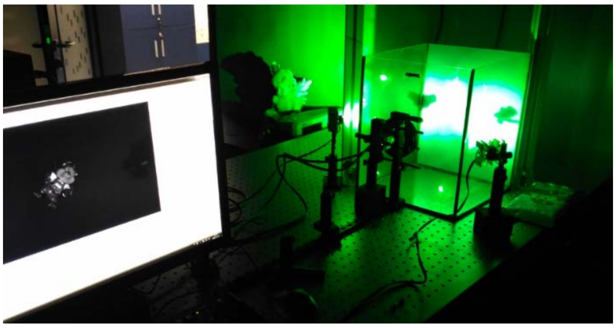
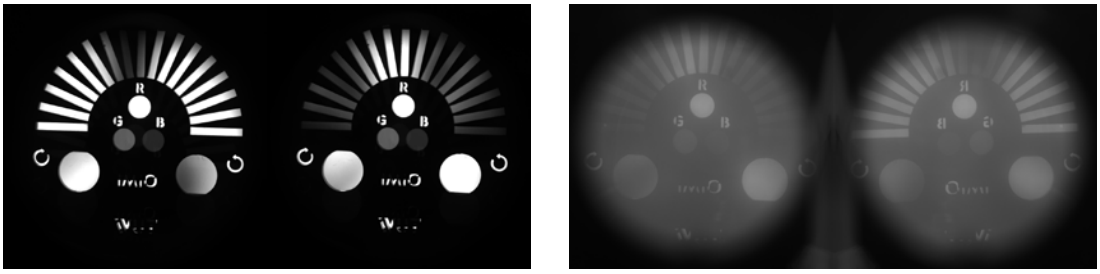


Figure 2. Experimental setup

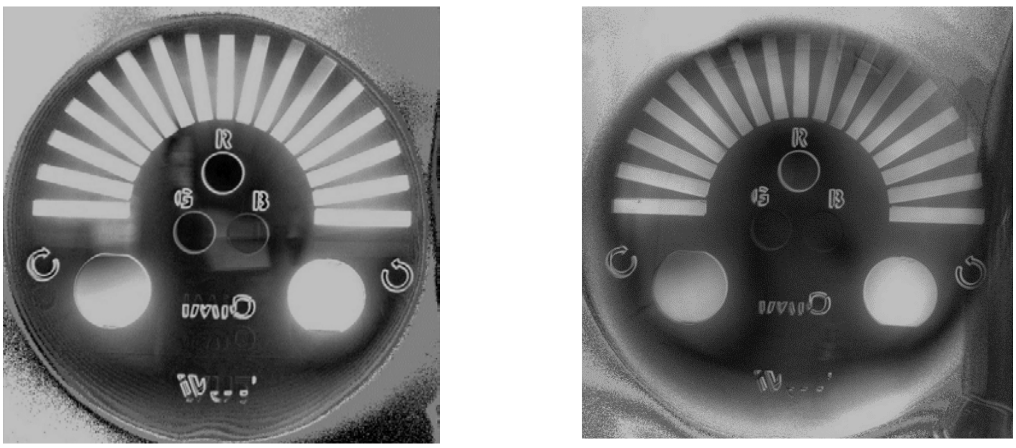
For both air and water acquisition the same step pattern was performed. We registered sets of images corresponding to the special orientation of LC filter. Below are presented exemplary images, which are part of the image set for the experiment analysis.



a) *b)*

Figure 3. Exemplary images gathered in our system: a) air b) cloudy water

The main goal of image enhancement in our experiment was contrast restoration for underwater images. The Saito method was used for degree of polarization DOP calculation. The results of image enhancement in water and cloudy water are presented in *Figure 4*.



a) *b)*

Figure 4. Result of image enhancement: a) water, and b) cloudy water

Conclusion

Imaging in underwater is demanding and has several limitations. Starting from lowering contrast and color corruption. There are many proposed methods to enhance images taken in such environment but this topic is still under development. Polarization based methods are quite simple and provide outperforming results. The use of a liquid crystal filter simplifies image processing by eliminating the need to search for optimum filter positions. It is also possible to tune the filter to obtain images with orthogonal polarization. Obtained results confirm the effectiveness of the method.

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