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Stéphane Bazeille, Isabelle Quidu, Luc Jaulin

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IDENTIFICATION OF UNDERWATER MAN-MADE OBJECT USING A COLOUR CRITERION

S Bazeille Laboratoire E3I2 EA-3876 ENSIETA, Brest, FRANCE stephane.bazeille@ensieta.fr
I Quidu Laboratoire E3I2 EA-3876 ENSIETA, Brest, FRANCE isabelle.quidu@ensieta.fr
L Jaulin Laboratoire E3I2 EA-3876 ENSIETA, Brest, FRANCE luc.jaulin@ensieta.fr

ABSTRACT

Keywords: Underwater, attenuation, coefficient, colour, segmentation.

With the development of autonomous underwater vehicles, the identification of underwater objects continues as a major issue. Because of specific properties of light in water particularly the absorption phenomenon, underwater imaging suffers from low contrast, from diminished colours and often from prominent green or blue colour. Today, object identification algorithms are usually based on shape, and the colour is rarely used for underwater operations contrary to terrestrial ones.
In this paper we present a new method for underwater object identification exclusively based on colour. The proposed method follows the Beer-Lambert law which describes the exponential decrease of the light intensity with the distance. According to this law, we can assume that each colour has a set of compatible colours depending of the travelling distance of the light through the water. We show that in the logarithm domain these colours belong to a line, we called “attenuation line”. Our algorithm is based on this observation. The segmentation step, splits the image into two classes: the pixels whose colours are compatible with the object and the others.
In practice we compute a PCA (principal components analysis) on pieces of pixels (of underwater images) which belong to the object in order to approximate the direction of this attenuation line. Then, each pixel is projected in the 2D plan perpendicular to this line and is labelled as a pixel of the object class or not. In this plan, for any other image of the sequence we decide if the object is present or not, given the number of its projected pixels which fall in the previous class. The remaining of the paper is organized as follows: first we will detail the theoretical principle of the approach, then the proposed algorithm and finally we will present results on object identification on real underwater videos.

1 INTRODUCTION

1.1 Colour perception of an object

The colour perception of an object depends on physical, physiological and psychological components. We will just define physical components because the latter two are properties of the visual system of the observer.
The first component is the spectral composition of the light which illuminates the coloured body. A light source can be characterised by its spectral distribution[1] and it is the spectrum of light reaching the object which determines the colour reflected. The same object will appear with different colours whether it is illuminates by the sun, an incandescent lamp, or a spot of green light for example.

[1] the energy emitted by interval of wavelength

The second component is the spectral reflectance of the object[2]. Indeed, the perception of colour depends on the special characteristics of the object itself in particular properties of its surface. Every object absorbs, transmits, reflects incident radiations with varying degrees depending on their composition. The colour is produced by the absorption of selected wavelengths of light. The object absorbs all colours except the colours of its appearance which are reflected. For example, a perfectly white object does not absorb any visible radiations.
At last, the third component is the transmission of light in the medium (e.g. air or water). In this paper we will consider in particular this last process.

1.2 Colours features

After this discussion on the colour perception, let's see how to characterise a colour. A colour can be defined by three parameters: Hue, purity, and brightness.

- The hue defines the colour type such as red, blue, or yellow which depends on the dominant wavelength i.e. the wavelength of the gravity centre of the spectrum.
- The purity defines the proportion of energy emitted at the dominant wavelength. A pure colour shows a sharpened spectrum and a impure colour constituted of a mix of wavelength shows a large spectrum. To resume the lower the purity of the colour, the more faded the colour will appear.
- The brightness of the colour also called intensity is defined by the total quantity of energy of the colour spectrum. Brighter is the colour, clearer the colour will appear.

The hue and the purity can be gathered under the term "chrominance" which defines the colour quality. On the contrary the term of "luminance" defines the colour intensity. In our algorithm we take advantage of chrominance information to identify the objects, so we have decided to dissociate it from the luminance information. To disregard the luminance we will work in normalized RGB colour space instead of working in RGB [10].

2 COLOURS IN UNDERWATER ENVIRONMENT

2.1 Underwater light propagation

Light is a form of electromagnetic radiation which travels at a speed close to $2.2 \times 10^8 ms^{-1}$ in the water. When the light is propagated through water, its intensity decreases exponentially with the distance from the source [5, 8]. The exponential loss of intensity is called attenuation and it has two main causes:

- The absorption which involves the conversion of electromagnetic energy into other forms, usually heat or chemical energy. The absorbers in seawater are:
  - Algae (phytoplankton)
  - Inorganic and organic particulate matter in suspension (other than algae).
  - Dissolved organic compounds
  - Water itself.
- The scattering which simply changes the direction of the electromagnetic energy, as a result of multiple reflections from suspended particles. Scattering by all but the very smallest particles is generally forwards at low angles. Obviously, the greater the amount of suspended matter the greater the degree of absorption and scattering.

[2] the fraction of radiant energy that is reflected from its surface

Electromagnetic radiation is characterized by its wavelength and its intensity. Scattering of light by particles is largely independent of wavelength, but absorption is not.

2.2 The Beer-Lambert Law

The Beer-Lambert law is an empirical relationship that relates the absorption of light to the properties of the material through which the light travels. It describes the exponential decrease of irradiance[3] with depth, as photons are absorbed and scattered by water and particles [8, 2]. The law is presented Eq.1:

$$I_{\lambda,z} = I_{\lambda,0}.e^{-K_\lambda.z} \tag{1}$$

where λ is the wavelength, $I_{\lambda,z}$ is the observed intensity of light at wavelength λ at the distance z from the light source, $I_{\lambda,0}$ is the intensity at the light source, K is the attenuation coefficient at wavelength λ.

2.3 The compatible colours in underwater environment

Considering a luminous underwater point which colour in RGB space is $a(a_R, a_G, a_B)$ corresponding to the three wavelengths Red, Green, Blue. According to Beer-Lambert Law, the colour of this luminous point received at a distance z is given by $b(b_R, b_G, b_B)$ with,

$$b_i = a_i.e^{-K_i.z} \tag{2}$$

This equation becomes a line in the logarithmic domain. Indeed we have

$$\ln b_i = \ln a_i - K_i.z \tag{3}$$

We can say that any colours b and c are compatible in underwater medium if the system (4) has a solution i.e. the equalities (5) or (6) are verified.

$$\begin{cases} \ln b = \ln a - z_b.K \\ \ln c = \ln a - z_c.K \end{cases} \tag{4}$$

$$\ln b - \ln c = (z_c - z_b).K \tag{5}$$

$$\frac{1}{K_R}(\ln b_R - \ln c_R) = \frac{1}{K_G}(\ln b_G - \ln c_G) = \frac{1}{K_B}(\ln b_B - \ln c_B) \tag{6}$$

From this observation and because the object we search is well known, we choose to base our identification only on this colour criterion. We test for each pixel of the image if its colour is compatible with the colour of the object and according to the number of compatible pixels and their connexity we decide if the image contain the object or not.

3 ALGORITHM DESCRIPTION

The identification algorithm proposed is based exclusively on colour. We consider the case where the object we search is known and illuminated by natural or artificial light. As we explained in the previous part, assuming the Beer Lambert law [1, 4], we can say that each colour has a set of compatible colours depending of the travelling distance of the light through the water. So, our identification step consists in classifying the pixels of the image into two classes: the pixels whose colours are compatible with the object and the others.

3.1 Calibration of identification process

The first step of our identification algorithm is to take some images of the object we search in order to calibrate the process (see Fig.1(a)). It is necessary to get some views of the searched object in

[3] Irradiance is a radiometry term for the power of electromagnetic radiation at a surface, per unit area.

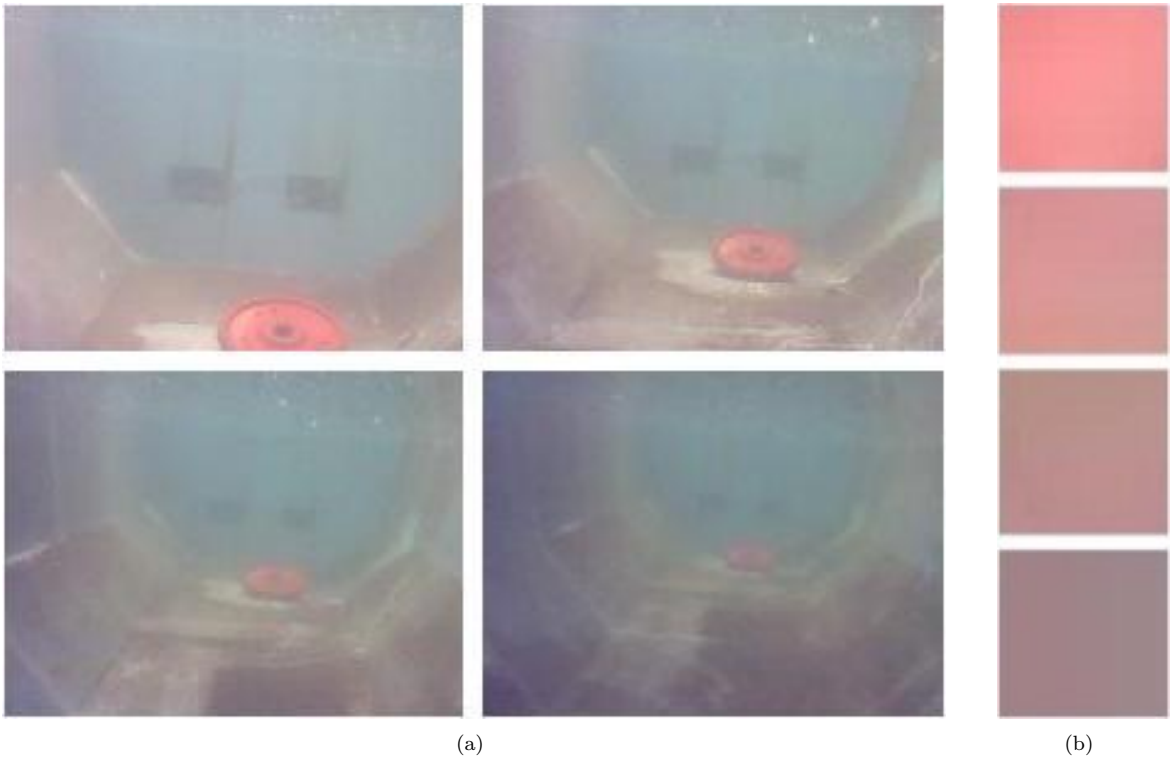


Fig. 1: (a) Calibration images. (b) Sub images of the object extracted from the calibration images. The set of pixels of those sub images constitutes the initialisation sample.

underwater conditions at different distances. Those images must be taken in conditions close to real ones in order to obtain consistent results.
From those calibration images we have at our disposal a collection of triplet RGB corresponding to the colour of the object at several distances (Fig.1(b) and Fig.2). The pixels of this initialisation sample are set together into a matrix (such as the three columns corresponds respectively to the red, green, blue values), normalized (to be more stable to intensity and lighting variations [6, 3]), and transformed to logarithm. To normalize RGB values, each red, green, and blue pixel values are divided by the sum of RGB pixel values, such as the sum equals to one. Then we compute a PCA (principal components analysis) on those data to estimate the compatibility line also called attenuation line.

The initialisation process can be summed up as follows:
- Create the matrix,
- Convert each RGB pixel to normalized RGB colour space,
- Take the log of each normalized RGB values,
- Subtract the mean from each of the data dimensions,
- Compute covariance matrix,
- Find eigen vector and eigen values,

$\Big\}\, PCA$

From the eigen vectors of the covariance matrix, we can obtain the principal axes of the set of initialisation points. The principal axis defined by the greater eigen value is the attenuation line. The plan perpendicular to this line defined by the two other eigen vectors is the projection plan or discriminated plan for the segmentation Fig.3(a).

3.2 Projection and segmentation

To classify a pixel and decide if it belongs to the object or not, we must project it orthogonally in the plan perpendicular to the attenuation line defined previously. To do this projection, we make a change of reference mark.
We have two references which are the original base $\mathscr{B}$ ($\overrightarrow{e_1}$,$\overrightarrow{e_2}$,$\overrightarrow{e_3}$) and the new base $\mathscr{U}$ ($\overrightarrow{v_1}$,$\overrightarrow{v_2}$,$\overrightarrow{v_3}$). The transformation matrix $P_{B\to U}$ from base $\mathscr{B}$ to $\mathscr{U}$, lets us, knowing the coordinates (x_1, x_2, x_3) of a pixel $\overrightarrow{w}$ in base $\mathscr{B}$, to compute its coordinates (y_1, y_2, y_3) in the base $\mathscr{U}$ by a simple matrix multiplication.

$$\begin{pmatrix} y_1 \\ y_2 \\ y_3 \end{pmatrix} = P_{B\to U} \cdot \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix}$$

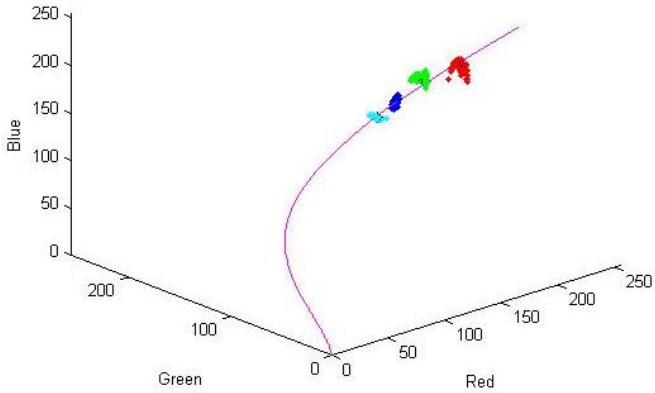
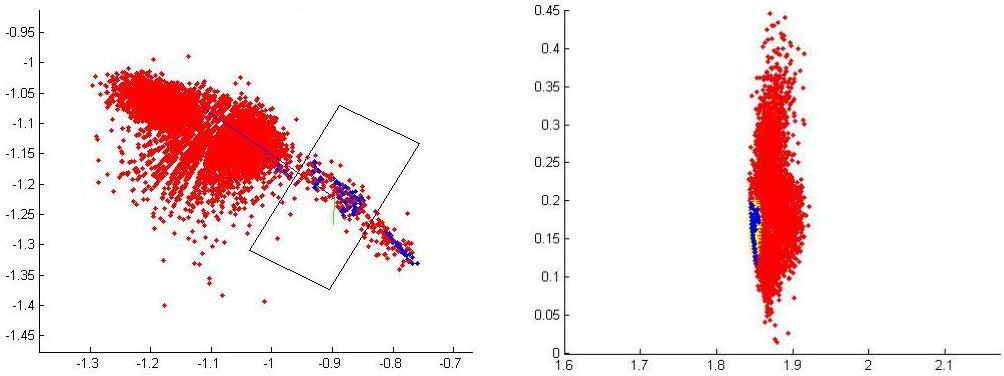


Fig. 2: Initialisation pixels at different lengths from Fig.1(b) and the approximated attenuation curve.

$P_{B\to U}$ must have as rows the coordinates of vectors of $\mathscr{U}$ expressed in the base $\mathscr{B}$, i.e. the eigen vectors. This transformation matrix is such as $(P_{B\to U})^{-1}$=$(P_{B\to U})^t$ and det$(P_{B\to U}) = 1$.
By multiplying each log RGB values by the transformation matrix we obtain coordinates of projected pixels in the discriminant plan. In this space we approximate projected of the initialization pixels to an ellipse. Then each pixel is affected to a class according to its membership to the ellipse or not. If a projected pixel belongs to the ellipse we consider it has a colour which is compatible with the object. On the contrary if it does not belong to the ellipse we consider that its colour is not the same as the object. Finally, we decide if the object is present in an image of a sequence or not, given the number of its projected pixels which fall in the class of compatibles colours.



(a) (b)

Fig. 3: (a) Initialization pixels (blue) with their eigen vectors and other pixels from images Fig.1(a) (red), (b) Projection of previous pixels in the discriminant plan. The yellow points are the projected pixels which fall in the ellipse.

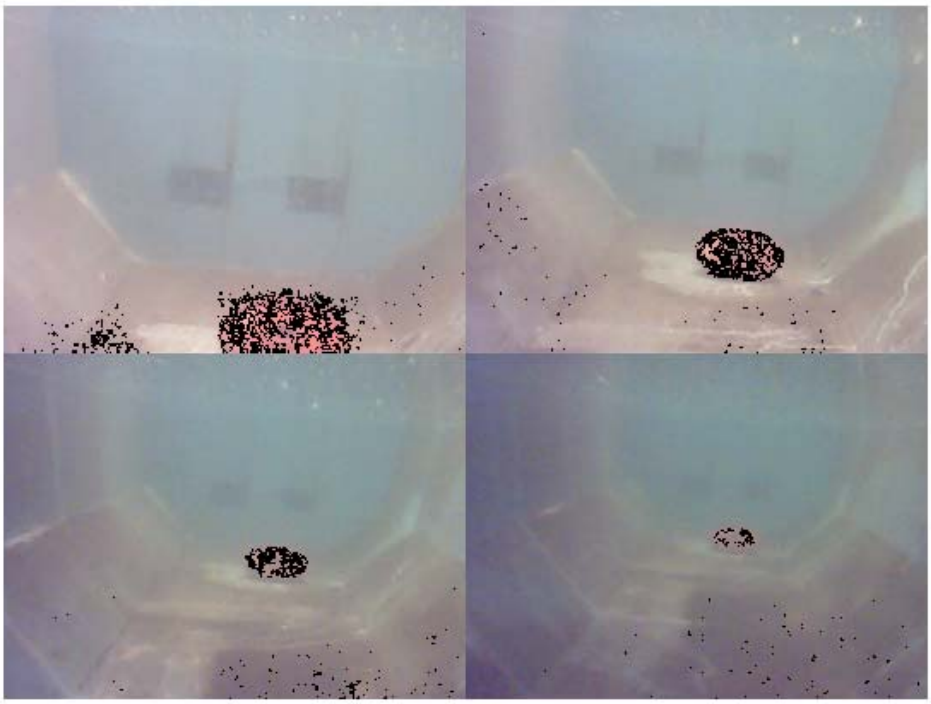


Fig. 4: Detection of compatibles pixels on initialization images

4 EXPERIMENT AND RESULTS

The proposed algorithm has been assessed on real underwater sequences recorded by a webcam in the ENSIETA's water tank under two different natural illuminations. The object to be recognized was a red round mass put on the floor. To calibrate the identification process, we have used the pictures presented Fig.1(a) taken previously with the same webcam. We have shown on Fig.4 the detection of compatible colours on those initialization images.

The recognition of compatible colours on the videos has been done frame by frame. We have shown on Fig.5 the images extracted from the two videos and the results of the recognition on those images on Fig.6. The compatibility threshold i.e. the size of the ellipse was computed such as it contains 90% of the initialization pixels selected on Fig.1(a).

At the moment, the algorithm is applied to each image succesively without taking into account the coherence of the sequence. Results show that the colours of the object are well detected when the distance is not too large (for information the distance between the camera and the object on the last image of the first sequence is about five meters). Also, the reflection of the object at the surface in the last presented image is detected has compatible colour. However on nearly all images and particularly on image close to the object, some separated pixels appear i.e. compatible colours are detected outside of the object. Those false detection are due to the global thresholding selected voluntarily large. To resume we can say results are promising, the discriminant 2D colour space is much more robust than the classical RGB colour space, but improvements and assessment on other underwater videos must be done.

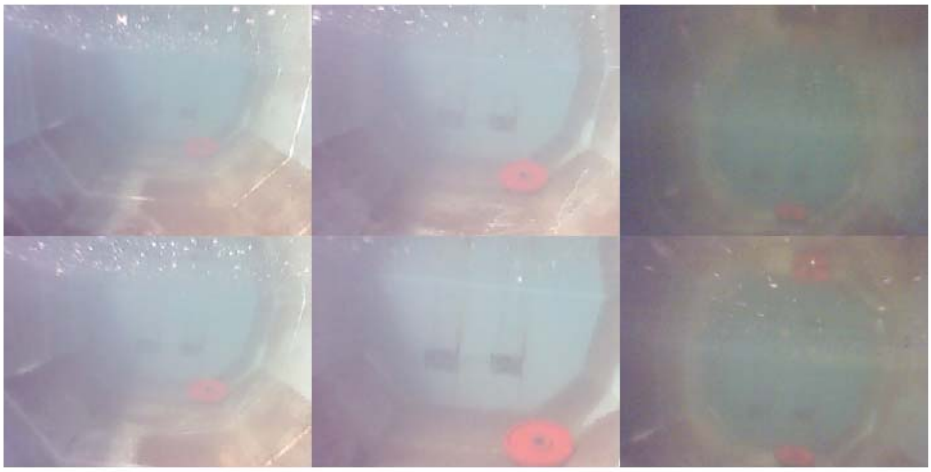


Fig. 5: Images extracted from two videos under two different illuminations

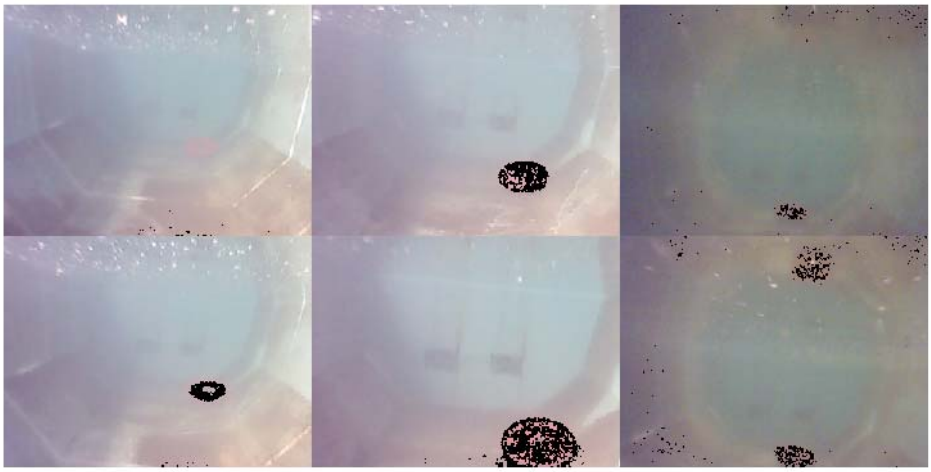


Fig. 6: Classification of colours on previous underwater videos

5 CONCLUSION AND FUTURE WORK

In many robotic applications it is necessary to identify known object by vision system. An object can generally be characterised by its shape, its colour, its size or its texture. But, under underwater conditions (contrary to aerial ones), it becomes difficult to recognize objects observing their colour or their texture because of light attenuation [11, 9, 7]. From this observation and in this operational context of research for known objects, colour is however a simple and robust criterion.

In this paper we have proposed a new method to recognize underwater object, exclusively based on its colour. This method enables to detect compatibles colours of an object considering the light attenuation. According to number of pixel which satisfies this compatibility colour criterion, we should be able to decide if the object is present or not. Without going until the identification of the object we showed that the colour is a promising feature for the discrimination step. Moreover any compact group of detected pixels can be considered as a segmentation of a potential object.
As we said, results are promising but deserve to be improved using the coherence of the sequence to refine locally the detection. Consequently our future work will be to improve robustness varying the acceptability threshold locally depending to the detection on the previous image, and to verify with the sequence the coherence of the detections to suppress false detections. The local refinement will consist for example in reducing threshold to avoid false alarms when there is no compatible colour and increasing it for the neighbourhood of a compatible pixel. We will also investigate other algorithms as mathematical morphology or optical flow in order to perfect detection results.

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