Color Characteristics for the Evaluation of Suspended Sediments

Konstantia Moirogiorgou*, Sofia Nerantzaki†, Giorgos Livanos*, Marios Antonakakis*, Nikolaos P. Nikolaidis†, Euripides G.M. Petrakis*, Andreas E. Savakis‡, George Giakos§, Michalis Zervakis* and Katerina Mania*
*TUC/School of Electronic and Computer Engineering, University Campus, 73100 Chania, Crete, Greece
† TUC/ School of Environmental Engineering, University Campus, 73100 Chania, Crete, Greece
‡Department of Computer Engineering, Rochester Institute of Technology, 83 Lomb Memorial Dr. Rochester, New York, 14623, USA
§ Department of Electrical and Computer Engineering, Science and Technology Integration Research Laboratory, Manhattan College, Riverdale, NY

***Abstract*—This study focuses on a significant issue of the environmental monitoring application area, which is the suspended sediment concentration estimation. More specifically, the purpose of the current work is to provide a new non-intrusive way to estimate the suspended sediment (SS) distribution. The proposed methodology uses the color characteristics of river flow images and provides a high correlation factor with the suspended sediment measurements. In our opinion, the importance of the current work derives from the fact that it provides an alternative and effective way of estimating SS distribution rather as opposed to the conventional method that requires human presence, especially if we consider the difficulty of taking measurements of the river pollution during flush flood events when the sediment distribution is increased and is directly related to water quality.**

Keywords— environmental monitoring; river suspended sediment distribution; hue and saturation analysis;

I. INTRODUCTION

Water quality and protection of water resources is one of the cornerstones of environmental protection. So the need to efficiently monitor water quality parameters is crucial.

Sediment transport in rivers and streams is directly associated with river pollution. For example, during flush flood events, the concentration of suspended sediments is increased with increased discharge, especially in temporary rivers where there is no flow continuity over both space and time. It is clear that the measurement of the suspended sediment distribution in rivers, in both 'dry' and 'wet' periods, is important for understanding the elemental life cycling of these kind of environments and, moreover, for issuing the combined effects of various land-use patterns that affect the sediment transportation [1], [2].

The conventional ways to measure sediment concentration in a river, either requires human presence through grab sampling or, for continuous measurements, the use of turbidity sensors which are expensive and require frequent recalibrations in the field. Although grab sampling is considered to provide more accurate measurements, since the analysis is done at the lab, it is not always easy to implement. Especially in cases which is mostly needed like flush flood events in temporary rives, it is difficult to take measurements because the event may last only a few hours and, sometimes, the water lever may increase in such a degree making it impossible for someone to get in the river [3], [4]. The use of camera sensors and image processing techniques provides a new non-intrusive way for estimating SS concentrations which eliminates the need of human presence as long as the methodology results in the same conclusions with those that are provided using the conventional ways of measurements.

We propose an image processing methodology that makes use of images of the river surface captured during measurements and results in high correlation between the image color characteristics and the suspended sediments concentration measurements. Related conventional ways for sediment concentration measurement are briefly reviewed in Section II and the proposed methodological modules are presented in Section III. The results are discussed in Section IV and the paper concludes with the conclusion.

II. RELATED WORK

The study of aquatic environments may help environmental scientists predict the impacts of hazardous environmental events such as flush flood events. As mentioned before, one of the factors that are crucial for estimating water quality during these events is the sediment load transport.

The conventional ways used to measure the suspended sediment distribution involve turbidity sensors that are positioned in the river in order to take the measurements. Also, a variety of in situ measurements systems have been developed using other kind of technologies. Most of them are based on optical or acoustic scattering or, even more, on infrared or visible light optical backscatter [5], [6].

The current work proposes image analysis in order to correlate the color characteristics of the river surface images with the suspended sediment concentration measurements. The study is focused on introducing a valid way to evaluate the sediment distribution in cases of extreme events, avoiding the need for human presence during these events.

III. Proposed Methodology

Our methodology is based on the analysis of the color characteristics of the images and, moreover, on the analysis of the Hue and the Saturation color coefficient. The captured images of the river surface are converted in the HSI color space that provides compact color information. In that way, we aid the effective and reliable analysis of the optical measurements. The HSI color model describes the color characteristics of an image through three components, the Hue, the Saturation and the Intensity component. Hue is related with the pure color of an image, while Saturation derives the amount of white is mixed with the Hue. The advantage of converting images to the HSI color space is that it is easy to select a desired hue, that is a desired pure color band and then select the range values of saturation that are suitable for the case study we examine. As shown in Fig. 1, Hue values appear in the form of an angle between [0,360] degrees, while saturation range of values is [0,1].

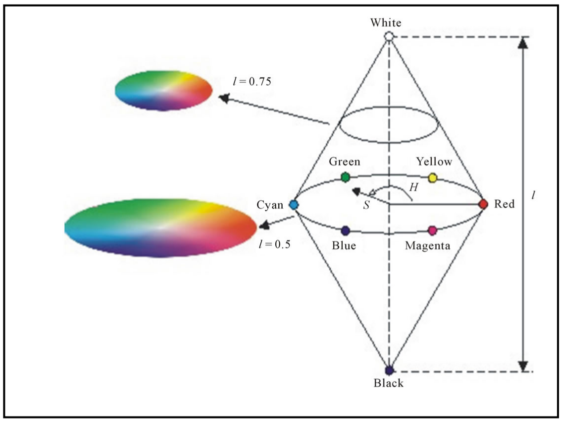


Fig. 1. HSI color space representation [7]

In the current research, we want to isolate the sediment information and correlate it with the sediment distribution measurement we have for each image. As a case study, we took real data from a river gorge, the Keramianos – Katochori gorge which is located in Chania, Crete, Greece. The stream that passes though the gorge has an episodic nature in flow and sediment transport. It is dry most of the year except after heavy rainfalls where there is an abrupt change in flow and SS concentration. During these flood events, significant quantities of suspended solids and pollutants are transported through the gorge and one of the crucial issues for the environmental scientists is to have a measurement of the sediment concentration during the event. The difficulty lies in the fact that these flood events only last a few hours, so it is almost impossible to be there during a flood event in order to take the necessary measurements. So, the purpose of our research is to offer a non-intrusive method for estimating SS concentration with the use of the color characteristics of river images along with the respective field measurements in order to characterize the sediment load transport.

We chose to process data that were taken during flood events with and without high sediment concentration, as it is shown in Fig. 2.

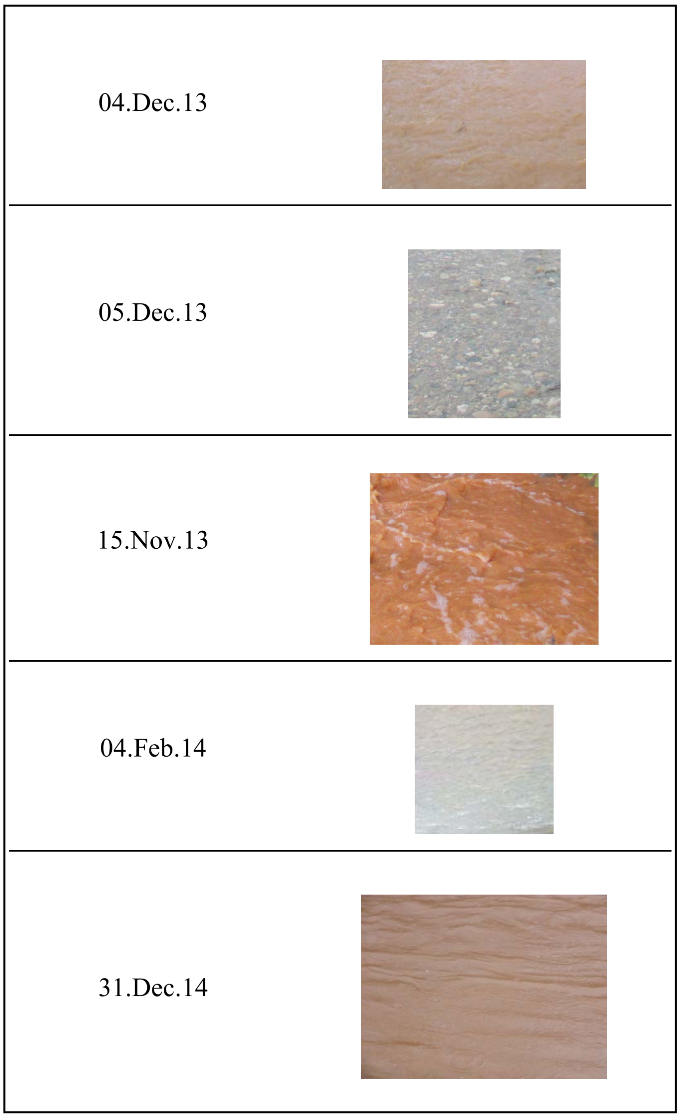


Fig. 2. Input images of river surface

The different images were captured under different weather and shooting conditions and that is the reason for having image resolution and image size dissimilarities between different dates. The corresponding suspended sediment concentrations are [273, 5, 1205, 25, 250] (mg/L).

Through this image dataset we want to prove that our methodology can detect the sediment presence. Finally, it is important to clarify that input data are extended in time, so they are characterized by temporal correlation.

The first step in our methodology is to convert our images in the HSI color model and isolate the Hue and the Saturation channel for each image. Since we want to identify the sediments, we have to locate the pixels with Hue related to brown-scale colors (Fig. 3). To do so, we process only the pixels that have values at the range [0.0, 0.2], that is a combination of yellow and red color bands. We reached this limits by considering the Brown color on the Hue scale normalizing it to a maximum value of 1.

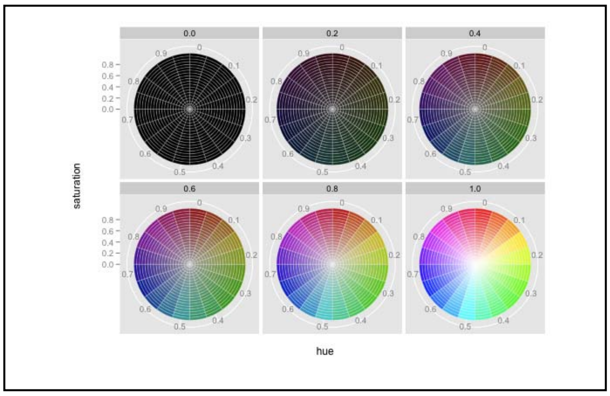


Fig. 3. Hue & Saturation Color Space [8]

The reason for taking into account the saturation values is mainly due to the different weather conditions the pictures where taken at each date (Fig. 2). In order to clarify the desired saturation values and confirm the hue values of interest that we take into account as sediment information, we calculated the Hue and Saturation histograms for each image. The hue histograms helped us to limit the range to [0.02, 0.1], while the saturation histograms helped us to conclude with the values of interest, so we continued with the pixels that have saturation values in the range [0.25, 1]. Fig. 4 shows the Hue and Saturation histograms of each image.

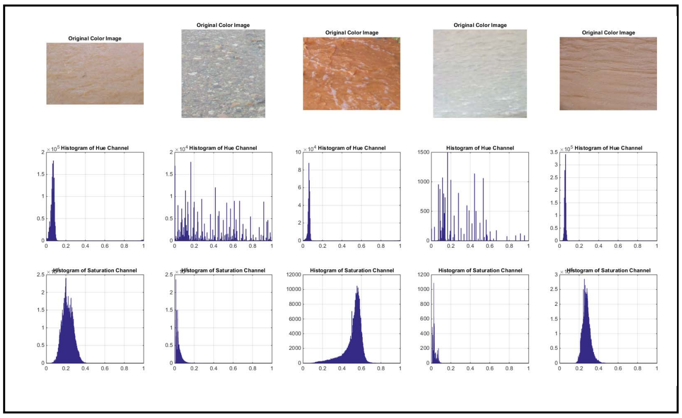


Fig. 4. All cases with their Hue & Saturation histograms

The next thing to do was to isolate the pixels with hue and saturation values out of our area of interest. First, we colored green the pixels with undesirable hue values and, on those pixels that remained, we changed the color to blue in order to indicate the undesirable saturation values. We show that the remaining pixels on each image indicate sediment concentrations leaving out foam, water ripples and illumination issues (Fig. 5).

The final step in our methodology was to correlate the color characteristics of the images with the related sediment concentration values. We performed a set of quantitative calculations only on the images' areas that are not filtered out (as explained earlier) and have concluded on a specific way to associate them. In the next Section, this final step will be presented in details.

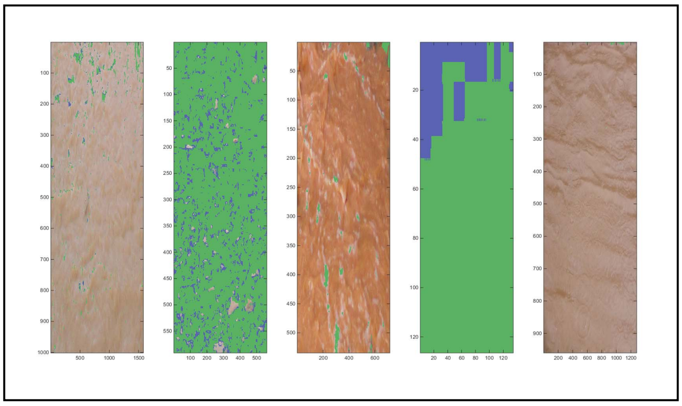


Fig. 5. All cases where Green & Blue pixels represent Hue & Saturation values out of the area of interest

IV. RESULTS

In our case study of Keramianos for which we have a temporal extend of images and of corresponding suspended sediment concentrations, we calculated a series of quantities based on Hue and Saturation values of interest in order to see which quantity can give us a high correlation coefficient with the measured concentrations. The quantities that were calculated were the average value of all the Hue values of each image, the average value of the Hue values of interest of each image, the average value of the joint of the hue and saturation values of interest of each image and, finally, the percent of the pixels that have hue and saturation values of interest of each image. Results are shown at Table I.

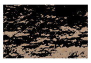
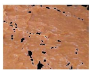
TABLE I. CORRELATION COEFFICIENT FOR 4 DIFFERENT IMAGE QUANTITATIVE CHARACTERISTICS

Quantity that was correlated with the measured concentrations	**Correlation Coefficient**
Average value of all the Hue values	-0.6058
Average value of the Hue values of interest	-0.3680
Average value of the joint of the Hue and Saturation values of interest	0.2840
Percent of the pixels that have Hue and Saturation values of interest	0.8383

The above results show that if we consider the percentage of pixels that have the desired range values of Hue and Saturation, for each image (that is, for each discrete date) along with the measurements, we can reach a high correlation factor of 0.8383.

Finally, in Table II, in order to summarize, we present the input images, the output images where black color represents the pixels that are out of the area of interest and the corresponding percent of the non-black pixels, the measured concentrations and the resulting correlation coefficient.

TABLE II. FINAL RESULTS OF KERAMIANOS CASE STUDY

Image before processing					
Image after processing					
Date	04.12.13	05.12.13	15.11.13	04.02.14	31.12.14
% of Pixels that contribute to determining sediment presence	0.1012	9.250e-05	0.3223	0	0.2489
Sediment Concentration Measurement (mg/L)	273	5	1205	25	250
Correlation Coefficient	0.8383				

It is clear that the resulting images after the process of the 'hue-intensity of interest' image steps, provide us with a special indication to isolate view of the areas, with high suspended sediment concentration, along with the results of high correlation factor between the images and the measurements.

In order to validate our methodology, we also processed images depicting SS concentration from another river in Chania, Koiliaris river. The processed image from Koiliaris river presents an interesting case study since it was taken at a specific location where there is the junction of two flows (Fig. 6).

Fig. 6. Image of Koiliaris river case study

One from a karstic spring that has negligible SS concentration and the other is from Keramianos gorge which, as we explained earlier, is responsible for high sediment concentration during flood events. Fig. 7a presents the Koiliaris case study during a flush flood event along with the Hue and Saturation histogram of the image. Although we do not have a temporal extend of this case, we processed an image of a flood event at Koiliaris river in order to prove our methodology in terms of a right selection of Hue and Saturation values of interest. As it is shown in Fig. 7b, the stream with the pure sediment load is isolated form the rest of the image.

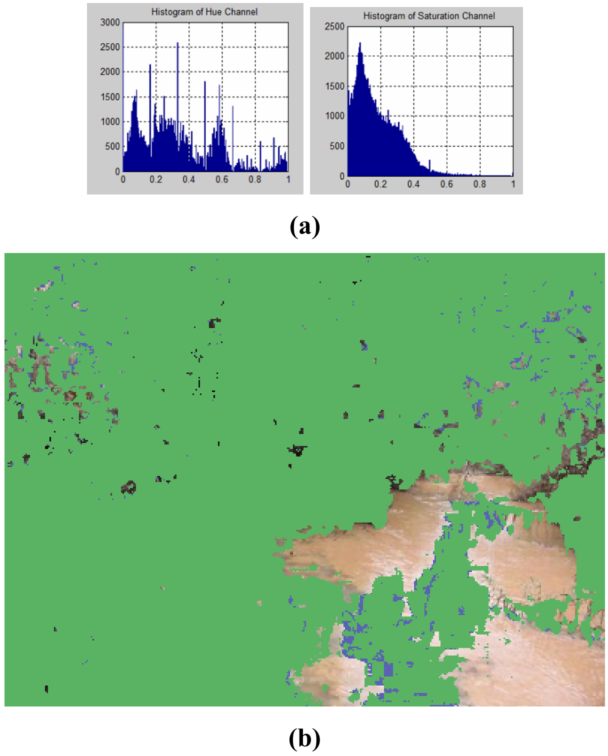


Fig. 7. (a) Hue & Saturation histograms of Koiliaris river case study, (b) Koiliaris river image where Green & Blue pixels represent Hue & Saturation values out of the area of interest

V. CONCLUSIONS

This study focuses on identifying sediments in images of river flow and proposes a complementary way to make conclusions on the sediment concentration. The study can be very useful when applied in temporary rivers where flood events with high of suspended sediments concentration occur. Our work emphasizes on hue and saturation image analysis along with statistical analysis techniques. We have concluded that there is a high correlation factor between the measured sediment concentration and the color characteristics of the river surface images, showing that we can use image quality characteristics for the determination of sediment transport.

The contribution of this work is that it offers a new robust and accurate methodology in assessing crucial water quality parameters like SS concentration, especially during extreme conditions like flush flood events in temporary rivers without the drawbacks of the conventional methodologies. Especially, considering the fact that the presence of temporary rivers are likely to further increase due to the combined effects of intense agricultural practices, land-use change, climate change, and increased water use for human activities [9], [10]. So, the study presented here may be a useful tool for observing and understanding their behavior and, probably, help in the prediction of flood events impacts.

As for future work, we intend to examine various other locations of temporary rivers and extract the common base features of each location in order to proceed with a more generic scheme of correlation between chemical measurements and images. In that way, we will be able to conclude with a robust and flexible algorithmic approach.

Acknowledgments

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