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Enhancement of Underwater Images Using FPGA

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ABSTRACT:
Due to low illumination and changing environmental circumstances, underwater photography is difficult. The obtained weak images must be upgraded due to limited light offered by the Automated Underwater Vehicles (AUV). In order to employ AUVs, image enhancing algorithms must be created in hardware. Because of their intrinsic parallelism, Field Programmable Gate Arrays (FPGA) have shown to be a superior solution for image processing approaches. Power law transform, contrast stretching, Histogram Equalization, Histogram Stretching, and Negative transformation are among the spatial domain procedures used to preprocess an underwater picture. A comparison of the above-mentioned picture enhancement technique implemented in FPGA is conducted in this work.

FPGA, Image Enhancement, Histogram, and Power Law Transform are all terms used in this research.

I. Introduction

There is a rich history of undersea culture in the subaquatic environment. Underwater archaeology is the study of this rich cultural past under the surface of the oceans. Underwater photography has captured coral reefs, oil pipelines, telephone cables, and shipwrecks. [1] As a result, deep-sea research is currently being carried out. In ancient times, the sea was the primary route of transportation. They have had an enormous impact on trade. Shipwrecks were widespread in those days because of the ever-changing and unpredictable weather patterns in these areas. As a result, shipwrecks provide archaeologists with a window into the past. As time capsules, shipwrecks may reveal a lot about the people and culture of the period. Archaeological practises, even those based on science, may lead to the destruction of valuable artefacts.

Due to the absence of light, underwater photography is challenging. Suspended particles and molecules in water scatter and absorb light rays as they move through the water's surface. As the depth of the water grows, the quality of the images improves. Artificial lighting is necessary because of the dispersion of light in the aquatic environment. As a result, the region is illuminated unevenly by this artificial light. Any sensor that generates electromagnetic radiation with spatially scattered intensity values that can be processed and stored in RAM may create pictures. [2] Each application requires a different approach for obtaining images, such as how quickly they can be taken and how precise they can be, as well as a wide variety of other factors.

If you want your images to be as precise as possible, you'll need additional software and patience. FPGAs and ASICs are more beneficial to designers (Field Programmable Gate Arrays and Application Specific Integrated Circuits). The cost of the tool, as well as its design flexibility and performance, are important considerations. FPGAs are preferred over ASICs because of their field programmability, reusability, faster design cycle, and cheaper cost. Performance may be boosted by using FPGAs' specific hardware features like as high-speed I/O and block RAM.

Multilevel contrast stretching for picture enhancement was suggested by the authors of Xu et al [3]. Divides the picture into its individual components, then improves contrast at both the inter-object and intra-object levels. Artefacts like ringing and blocking may be prevented from being introduced. Image sequence contrast may be improved using a block-overlapped histogram equalisation technique, as described by Tae et al. (1998)[4]. Real-time implementations of the classic histogram-based contrast enhancement approach are hampered by the high processing and storage needs and the possible loss of seldom distributed pixel intensities, which might result in catastrophic data loss. It is clear that Jiang Duan [5], the protagonist of Jiang Duan, is a fictitious figure. An example of how a local tone mapping approach may be utilised to generate high dynamic range pictures on a common display is shown in this article. In order to mimic local contrast prior to contrast stretching, it uses bilateral filtering to smooth out the picture and adaptively stretch the contrast in local locations. Neighbourhood-based equalisation of histograms According to Eramian et al. [6,7], the histogram equalisation approach suggested by Eramian and his colleagues is unique in that the histogram is further categorised using local visual features. The sort of measure to use is influenced by how the bins are split and whether or not contrast enhancement is provided.

A brief introduction to different image processing algorithms is provided in the following sections before a more in-depth look at the hardware implementation, results, and debate. The histogram equalisation method produces a superior outcome by evaluating the quality measurement factors.

Preliminary Details

Colorometric and generic picture perspectives are two topics of image processing that have lately received a lot of attention. Each point in the image has a different intensity based on its location in space and is stored as a numerical value indicating its memory strength. Grayscale pictures need less storage space than colour photos.

T is used to transform f(x, y) into g by applying it to an image f(x,y) (x, y). As seen in this equation, the values of the two pixels are linked by the following equation: g(x, y) = Assuming that T is an operator on the pixel values (x,y) defined around point (g(x,y)), this equation connects the two values (f(x,y)) (x, y). [7]

$$g(x, y) = T[f(x, y)] \tag{1}$$

1.1. Image Inverting: Each byte in a grayscale picture has an intensity value ranging from 0 to 255, with 0 being the brightest shade and 255 being the darkest shade. Simply subtract 255 from the current pixel value to invert the picture. It may be expressed numerically as:

$$g(x, y) = L - 1 - f(x, y) \tag{2}$$

Where g(x,y) is the transformed pixel. L is the maximum intensity level [7].

2.2 Thresholding: Thresholding is a basic picture segmentation technique. Different threshold values may be set to each RGB plane to threshold a colour picture, and the threshold image can then be combined.

2.3. Power law transform: Image intensity values may be changed by multiplying current intensity values by nth power and nth root.

This may be stated numerically as:

$$g(x, y) = cf(x, y)^{\gamma} \tag{3}$$

Where c and □ are positive constants.

This equation can be modified as:

$$g(x, y) = c(f(x, y) + e)^{\gamma} \tag{4}$$

Although the range of dark input values may be restricted, gamma-fractional power law curves may transform this into a wider range of output values.

2.4 When it comes to stretching, things are rather different: The histogram's spread is the simplest way to think about contrast. The dynamic range of a photograph encompasses all of the image's brightness variations. Contrast is weaker when several pixels are in the low-intensity zone. This is one of the simplest methods for gathering data in low-intensity regions. The only way to boost contrast is to transmit the pixels from the input to the output in a straight line. A and B are the lower and upper bounds of the expanded intensity values, respectively. Unprocessed versions of the image are represented by the c and d swatches. It is possible to linearly stretch the input pixels to span the whole range if their range is constrained. [8] This may be expressed numerically as follows:

$$g(x, y) = (f(x, y) - c)[(b - a)/(d - c)] + a \tag{5}$$

2.5 Histogram Equalization: The histogram of a digital image with gray level in the range [0, L-1] is a discrete function of the form:

$$H(r_k) = n_k \tag{6}$$

Where r_k is the kth is gray level and n_k is the number of pixels in the image having the level r_k. A normalized histogram is given by:

$$P(r_k) = n_k / n \tag{7}$$

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Probability P(rk) of occurrence of rk grey levels.

In a normalised histogram, the total of all components equals one.

The histogram's components are more concentrated at the bottom end of the grey scale in the dark picture.

It is standard practise to use histogram equalisation to improve the look of photographs. Using equalisation of histograms, an image's intensity may be altered. At f(x,y), the picture's intensity is at its highest (x,y). From 0 to L-1, the total number of intensity levels accessible, the intensity levels range from 0 to L-1.

For each pixel with an intensity of n, divide its total number of pixels by the value of Pn. g(x,y) is an equalised histogram picture with the definition given below.

$$g(x, y) = (L-1)\sum P_n \quad (8)$$

We can transform the histogram to produce a new enhanced image The transformation follows:

$$g(x, y) = T(f(x, y)) \qquad 0 \le r \le 1 \quad (9)$$

This maps a level in g(x, y) for every pixel in f(x, y).

2.6. Median Filtering: In order to reduce unwanted pixel intensities, pictures must be preprocessed. Pixel by pixel, the median of the pixels around it is used to replace each individual pixel value in the image. Because there are no beginning and ending pixel values, each of these pixels must be repeated. As a result, median filtering has a number of important downsides, including these. Median filtering preserves edges while greatly reducing noise.

This technique, also known as averaging filtering, uses the average intensity of neighbouring pixels to replace each pixel's intensity. F(x,y) is the intensity of the input picture at (x,y), and g(x,y) is the modified image. The following is a numerical representation of average filtering:

$$g(x, y) = \sum_{k=-m}^{m} \sum_{l=-m}^{m} W_{kl}\, f(x_{i+k}, y_{j+l}) \qquad \text{for } i,j = (m+1),\ldots,(n-m) \quad (10)$$

II. Design and Hardware Implementation

Xilinx is the best choice for image processing, according to the study [10]. Since the Altium Designer software and Xilinx Spartan 3 AN are used, the hardware design is done on the Altium Nano board 3000 as a development platform. Customized hardware is built for the application.

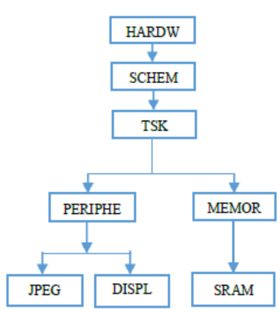

Fig 1: Hardware Design

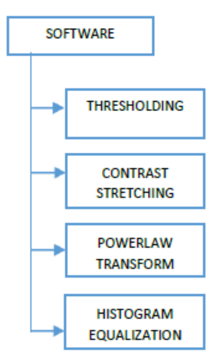

Fig 2: Software Design

III. Result and Discussion

Underwater imaging study has shown that extra lighting is required due to water molecules absorption of light wavelengths. Blue and green images are created when light waves penetrate deeper in the open ocean, while green images are created when light waves penetrate deeper in coastal seas. The colour qualities of photos are affected by the extra light given by imaging equipment. Colorful photos make up most of the collection. As a result, one of the RGB channels in the picture has become more saturated. For each pixel in this study, each colour component is extracted, and the process is repeated for each one. It is possible to do per-pixel processes using this approach, which limits the gain of saturated pixels. The FPGA has also been used to develop image processing methods like inversion and thresholding. Numerous methods for improving performance were tested. Various underwater photograph-enhancing approaches are examined in Tables 1 and 2 based on their Peak Signal to Noise Ratio and Structure Similarity Index Matrix (SSIM). The Histogram equalisation technique is outperformed by other alternatives in terms of performance.

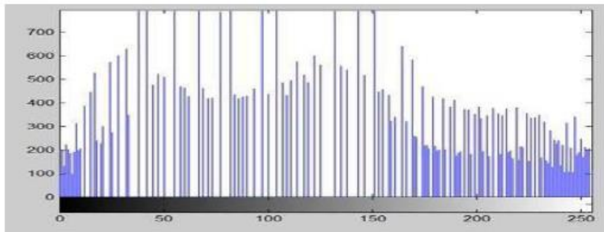

Fig 3: Histogram Equalized Image on Altium NB3000TFT

Fig 4: Original Image

Fig 5: Inverted Image

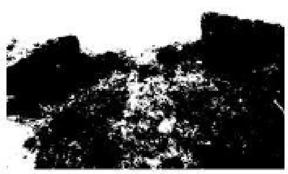

Fig 6: Threshold

Fig 7: Power law transform gamma=0.5

Fig 8: Power law transform gamma =2

Fig 9: Histogram Equalization

Fig 10: Contrast Stretching high

Fig 11: Contrast Stretching low

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Table 1: PSNR Value

Method	Image1	Image 2	Image 3
Contrast High	47.557	21.744	42.67
Contrast Low	25.458	30.028	33.53
Histogram Equalization	32.827	40.764	46.54
Power law low	18.753	16.53	18.75
Power law high	28.15	21.160	26.64

Table 2: SSIM value

Method	Image 1	Image 2	Image 3
Contrast High	0.9248	0.4397	0.8330
Contrast Low	0.8166	0.7534	0.7912
Histogram Equalization	0.7494	0.9466	0.8873
Power law low	0.7405	0.6740	0.7578
Power law high	0.7148	0.3470	0.1170

Table 3: Device Utilization

Number of slices	6044
Number of slice flip-flops	5296
Number of 4 input LUTs	8634
Number of	8340
Number used as RAM	270
Number used as ROMs:	24

IV. Conclusion

One of the colour channels in underwater photos is more saturated than the other two. Because of the non-uniform illumination and light propagation qualities, the green and blue channels are saturated in the tested photos. The algorithm's resilience has been evaluated on a large data set to ensure that it is reliable. There are no unappealing artefacts when using the power law conversion with varied gamma values. FPGAs have a huge number of memory blocks that may be accessed in parallel. As a result, the time it takes to process each pixel is significantly reduced. The FPGA is a superior option for image processing applications because of its cheap cost and high performance. The goal of this project was to successfully incorporate fundamental image processing algorithms for underwater photographs on the Altium Nano board 3000. As a consequence of the foregoing results on evaluated photos, the FPGA is required in the area of image processing.

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