Autonomous boat for underwater surveillance

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Abstract--- ***Generally, an autonomous boat with vision ability faces difficulties in navigation and data processing. In this work, implementation on image processing in underwater environment is implemented using autonomous for surveillance purposes. In this endeavor, the focus will be on analyzing the use of single vision cameras in providing data for research on environmental front underwater and also detecting depth and obstacles for better navigation. The system is able to detect solid objects in underwater and it can provide different information of marine environment using correct algorithm and technique. The result is accurate enough to detect obstacles or objects above and beneath the water taking into account the diffraction of light needed for perfect vision. In this research, OpenCV library is used for digital image processing and color feature analysis rather than MATLAB due to the complexity for real time process. The design structure is mainly based on Pontoon style because it is more stable and reliable especially on the river wave condition. Moreover, additional sensors and actuators are implemented in this project to monitor underwater information for navigation purposes.***

Keywords: Autonomous boat; OpenCV; Surveillance; Pontoon style

1. INTRODUCTION

Image is defining as a representation of an optical counterpart or an object's appearance, produced by reflection from a mirror, the passage of luminous rays through a small aperture, reception on a surface and the refraction of light through a lens. The spatial coordinate of an image is two-dimensional and each position holds information on intensity [1].

Autonomous Underwater Vehicles (AUV) and Remotely Operated Vehicles (ROV) are one of the actively researched fields nowadays by many fields with many different purposes such as environmental pollutions, biological studies, and historical discoveries and also surveillance purposes. The data such as underwater mines, shipwrecks, coral reefs, pipelines and telecommunication cables from the underwater environment are the usual suspects collected for their investigations [2].

Underwater images are essentially characterized by their poor visibility because light is exponentially attenuated as it travels in the water, and the scenes result poorly contrasted and hazy. Light attenuation limits the visibility distance at about twenty meters in clear water and five meters or less in turbid water. The light attenuation process is caused by absorption and scattering, which influence the overall performance of underwater imaging systems. Forward scattering generally leads to blur of the image features. On the other hand, backscattering generally limits the contrast of the images, generating a characteristic veil that superimposes itself on the image and hides the scene. Absorption and scattering effects are not only due to the water itself but also due to the components such as a dissolved organic matter.

Moreover, the visibility range can be increased with artificial illumination of light on the object, but it produces non-uniform of light on the surface of the object and producing a bright spot in the center of the image with poorly illuminated area surrounding it. The amount of light is reduced when we go more in depth; colors drop off depending on their wavelengths. The blue color travels across the longest in the water due to its shortest wavelength.

Underwater image suffers from limited range visibility, low contrast, non-uniform lighting, blurring, bright artifacts, color diminished and noise [3]**.** Higher accuracy imaging equates to increased pixel resolution requiring much greater bandwidth and storage capability. High definition (HD) and ultra-high definition video (UHD or super hi-vision) produce images having 1920 x 1080 and 7,680 x 4,320 pixels, respectively. Image compression formats such as HDV, MPEG-4 AVC/H.264 and VC-1 reduce data rate and memory demands by up to a factor of nearly 50.

Although these reductions help make requirements more manageable, losing data is incomprehensible for users. A primary goal of extended range underwater imaging is to improve image contrast and resolution at greater distances than what is possible with a conventional camera and underwater lighting.

2. IMAGE PROCESSING ALGORITHMS

The key difficulties in processing underwater images are identified as follows.

i. Obscuration of objects of interest by living things/ coral / algae in the water
ii. insufficient contrast between different components of the image
iii. difference of illumination due to refraction at the surface
iv. change of shading balance with profundity because of absorption in water and its substance

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v. change of scale of the fish images because of the large range of distances of observation and different sizes of fish
vi. large range of types of marking on the fish and contrast with the background partial obscuration of one fish by another
vii. flexing of fish as they swim and presentation in a wide range of poses, problems with long term immersion of instruments in the sea changing window properties over the field of view.

The Image processing can be divided into two parts, which are image restoration and image enhancement. Image restoration is to recover back original image after properties of the image is degraded by certain effects. Whereas, image enhancement is to enhance the quality of an image or to focus particular aspect on the image to produce images that are better from the previous one. For image processing, it does not reduce the amount of data present but rearranges it. Image processing needs to undergo steps of analysis to restore or enhance images. Some of analysis steps are discussed in this sub-topic.

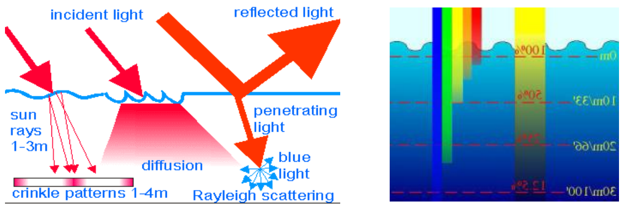

Fig.1: Refraction of Light Underwater and Underwater Wavelength [3]

2.1. Spatial filtering

A spatial filter is an image operation where every pixel is changed by a capacity of the intensities. An image could be filtered to eliminate a band of spatial frequencies. High frequencies exist in the presence of rapid brightness transitions while low frequencies exist in the presence of slowly changing brightness. High pass, low pass and edge detection filters are operations in spatial filtering. Each of this operation affect images that are analyzed. In every image processing, this step will be carried out to enhance or to restore back images**.** In [4] they used this method to calibrate and to align image of molding products. The alignment procedure is based on pattern matching and uses a cross correlation algorithm. This method is often used in applications where there is need to measure the similarity between images or parts of images. Other method that can be used is convolution spatial filtering. However, the mask is first flipped both horizontally and vertically before image is compared.

2.2. Sharpening

Images can be enhanced by sharpening method. By sharpening, fine detail of the image can be highlighted. Blurry images due to noise or other effects are reduced in this process. Sharpening emphasizes edges in the image and makes them easier to see and recognize. No new details are actually created in creating a sharpened image. The nature of sharpening is influenced by the blurring radius used. In addition to that, differences between each pixel and its neighbors too, can influence the sharpening effect

2.3. Edge detection

Edges in image are defined as local changes of intensity in an image. Edges occur on the boundary between two different regions in an image. Purpose of edge detection is to produce a line drawing from an image that is analyzed. Some important features that can be extracted from the edges of an image are corners, lines and curves. In [5] this edge detection method is used. In this paper, the edge detection method used Vertical Sobel Operator to suit the application. The edge detection result is being used for analyzing and determining size of the object. Other operator such as Robert operator, Prewitt operator, Canny operator and Krish operator are also often used as edge detectors. Some of disadvantages in edge detection is it filters information that may be regarded as less relevant. It only preserves the important structural properties of an image. From this statement, still small part of information in that image is missing due to the filtering process.

2.4. Colour detection

In color detection, there are a few distinct choices that can be defined such as RGB color pixel and histogram extraction, wavelength detection and many more. These methods can be carried out using special sensors and tools that are designed for color detection.

2.5. Pixel extraction

For pixel extraction of an image, the colour of an object can be extracted through analyzing the pixel value. For example, by extracting the RGB value, the colour of a single pixel can be identified.

2.6. Colour histogram

Colour histogram is a representation of colour distribution in an image. The number of pixels that each colours have are represented in the colour histogram. Each colour have a fixed list of ranges that span the colour space of an image. The colour histogram of an image is constructed by the count of pixels of each colour. In image processing, colour histogram consists of three components respecting to the RGB colour space. It is fast to manipulate, store, compare, and insensitive to rotation and scale [6].

2.7. Wavelength

Colours most predominantly define through wavelength of light spectrum that shines down on the surface of this earth. The progression of the colour spectrum wavelength is from the long wavelength as red to short wavelength as violet, or from low to high frequency. A colour spectrum wavelength is commonly expressed in terms of nanometer unit (1 nm=10^-9m). Figure 5 shows the wavelength of visible light ranging from 380nm to 780nm [7].

3. SYSTEM DEVELOPMENT

3.1. Overview

The autonomous boat is designed for remote operation and image processing development on the boat to image of object below and above water and also to detect obstacles

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and the depth of a lake or river. The development of the image processing is designed using OpenCV Library rather than Matlab due to real time based process.

This project dedicated on image formation and image processing methods, extended range imaging techniques, imaging using spatial coherency and multiple-dimensional image acquisition and image processing.

An autonomous boat works independently as it is programmed automatically to do its job efficiently, but constant supervision is needed in case of any malfunction or deviation from the set point. Hence, navigation system is in place to allow manual control mode. This safety feature is necessary to preserve the boat and the expensive component, which are mounted on the boat.

Adding of proper sensors and actuators make the boat run smoothly and boat serves surveillance jobs effectively.

Knowledge of several areas of engineering such as mechanical, electronics, communication, material and software engineering were utilized. Precision, reliability and stability were maintained in the process of designing this project. In addition, the design process was also considering the economic value of the boat.

Lastly the boat must be able to maintain its data collections and store on board data storage and transmit the data through wireless communications to main data base center. In a nutshell, to reiterate, image processing and water quality probe systems are added as an upgrade to the systems.

Photos must be crystal clear with such resolution to allow fine details visibility. The elements from any photo must be explained using numbers, letters, etc. The text within a figure or photo must have the same style, shape and height as the caption has.

Any table, figure or picture must have a caption (**Fig.1**, Table1, etc.) followed by a proper description. All similar graphics must be generated using the same software product (Excel, Origin, Mathematica, etc.). Importing graphics into the article as images (JPG, BMP, PNG, etc.) should be avoided. All similar electronic schematics, charts, program flow, simulated characteristics, etc. from the article should be generated using the same software product. Importing images from other articles or books it's totally forbidden unless they are cited.

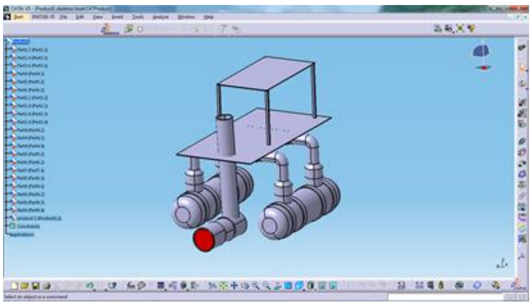

Fig. 2: Autonomous Boat Design using Catia V5R17

3.2 Blurring

This situation is also known as smoothing. It occurs because the visual effect of a low pass filter. The sharp brightness transitions had been reduced to small brightness transitions. Thus, it looks blurry. Purpose of blurring image is to reduce the effects of camera noise and missing pixel values. For blurring effect, two techniques are used which are neighborhood averaging (Gaussian filters) and edge preserving (median filters).

3.3. HSV color space

To track the object of interest using color based methods, the color of the object of interest and the background should have a significant color differences. The representation of color information is performed by hue and saturation values in the HSV system. The HSV (hue-saturation-value) system is a color space that is more suitable for color based segmentation compared to the RGB color space as it has the capability of representing the color of human perception and simplicity of computation. HSV color space consists of three matrices; the hue, saturation and value in which it represents the color, saturation represents the color depth and value represents the color brightness [8].

Given that human are much more sensitive to brightness than saturation and hue, saturation and value components of HSV color space have been adopted to define color saliency. **Fig. 3** shows the original image in RGB color space on the left and the saliency map computed using value and saturation components on the right image. From Figure 2, saliency map computed using value and saturation results in more saliency in the red-colored area while background outcomes in less salient value. Hence, value and saturation components of HSV color space are proven to be suitable to compute saliency map. Besides, these components help to reduce the complexity of saliency computation [8].

3.4. Stereo matching

Computing saliency map by static monocular image are mostly expensive as the correlated processes are significantly complex. Therefore, binocular image is chosen to compute color contrast and texture contrast of each region. Left and right image of stereo vision system are used as the source image to compute saliency map. Subtraction process in the left and right images is estimated to find the difference of the binocular image. This process is essential to eliminate background of the images and results in the less saliency map for low color contrast parts and more saliency for high color contrast parts. After overlapping the left image and the right image of the stereo pair during image subtraction, information in terms of color contrast and disparity can be obtained. Figure 6 shows the left and right image with saturation and value components of HSV color space respectively. The original image can be seen in Figure 3[8]**.**

Fig. 3: Left and Right Images of Stereo Vision System [8]. Left and right images of stereo vision system [Image].

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The subtraction image in Figure 7 highlights the objects or areas from **Fig. 6** with high color contrast as background with low color contrast have been eliminated. This provides better results compared to the saliency map computed using monocular image in Figure 3 [8].

Fig.4: The subtraction image between left and right images [8]. The subtraction image between left and right images [Image]. [8] Regions of Interest Extraction Based on HSV Color Space

3.5. Colour detection device

For colour detection device, there are many sensors or tools that can be used as vision sensor. Each one of them has their own specification that can even directly detect and differentiate between colours. For example, camera or webcam sensor, colour sensor and spectrometer are the commonly used.

3.6. Camera/Webcam sensor

The general working idea of a camera is that it uses an electronic sensor to transform images into digital data. The most common sensors used are Complementary Metal-Oxide Semiconductor (CMOS) and Charge-Coupled Device (CCD).

The working principle of a CMOS image sensor uses the Bayer pattern as arrangements of colour filters that are placed over the photosites. For the arrangement of photosites, the row at the top and bottom are blue and green filter respectively. While green and red filters are placed on the opposite side of photosites. The CMOS imaging chip has slightly better performance than the CCD. The image produced has a system with moderate noise. In addition, the applications of the chip is inferred in Logitech Webcam.

Moreover, the limit colour of a light are predefined frequency to pass through the filter, and be recorded as luminance data. In addition, the yellow and green frequencies are sensitive to human eyes, hence the ratio of digital image are the same as how human see colours. The green filter has a high number of neighbouring red and blue filter.

4. METHODS FOR IMAGE PROCESSING UNDERWATER

In this part, the general view of some of the most recent methods that address the topic of underwater image processing providing an introduction of the problem and enumerating the difficulties found. The indications of the available methods focusing on the imaging conditions for which it is developed (lighting conditions, depth, environment where the approach was tested, quality evaluation of the results) and considering the model characteristics and assumptions of the approach itself [9].

Furthermore, this section will review Jaffe-McGlamery's model of the optical properties of the light propagation in water and the image formation. Then, followed with a report of the image restoration methods that take into account this image model. Next, works that addressed image enhancement and color correction in underwater environment are presented plus brief description of some of the most recent methods. Lastly, this section will consider the lighting problems and focuses on image quality metrics and quality control of image.

4.1. Autonomous navigation boat

An autonomous boat is a self-navigating aquatic vehicle above water that is predefined with instruction codes. Several methods could be used to navigate a vehicle such as Behavior based navigation. It can manage complexity tasks and easy to program and debug behaviors[10]. Some of the navigation system use the GPS module and Compass sensor to navigate from one point to the other points based on the latitude and longitude[11]. Some of the Unmanned ground vehicle (UGV) also due equip with the autonomous navigation system but the navigation system that they use may vary with each other. Navigation method must be divided into two part which is the first part include the direction of the UGV and steering angle to desired way, and the other part is that the UGV goes through a target as named way point (WP). During the operation, the way point should be updated to the next target

The UGV can be classified into about five parts. The UGV system is composed of vehicle system that is controlled vehicle, remote control system that is steered and monitored of vehicle from afar, obstacle system that is sensed obstacle, vision system that is sensed obstacle and gained information of configuration of the ground, and at the end, navigation system that is setting up the information of position and path [12]. Each system data is transmitted to integration system, and each data gain the priority. So integration systems give order to vehicle system about the movement, avoidance and stop [12]. The application of unmanned ground vehicle has applied to the design of the autonomous boat also but the boat is move by using the thruster.

The movement from one point to the other can be calculated based on triangular method since the compass sensor is always pointing toward the north therefore the vector angle to the next point can be calculated and give signal to the microcontroller to start the thrust in order to align the boat toward that next point. The boat will move toward the next point within the direction and will maintain that position until it reaches the position. Whenever the boat face some of the obstacle on the surface of the river the boat will try to avoid that obstacle by turning only one thrust and the boat will slightly turn and come back to the original direction toward the point.

The design of the autonomous navigation system must implement the closed loop system therefore there must be a feedback from the sensors that used to the main controller

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[13]. The closed loop system will provide the entire system about the current position of the boat and where the boat should head to. Microcontroller is widely used for the purpose of integration of the sensors and actuators. It also will determine in which way or behavior they will function to.

4.2. GPS and compass navigation system

This system is basically combined the two modules which are GPS receiver and compass to get the heading point and movement target of the device. GPS (Global positioning system) is a module that capable to receive the position in term of latitude and longitude coordinates whereas the compass sensor is a module that capable to output the heading angle from the earth magnetic north and the value is collected by computing the raw data from the magnetometer. Basically, magnetometer comes with X, Y and Z earth magnetic dipole values. By implementing the triangle calculation and appropriate equation, the heading angle could be calculated and output value between 0 and 360 degree.

The GPS and Compass module is a closed loop transfer function. The input is in term of coordinate point which is latitude and longitude and this point will be predefined in the programming code and store it inside the internal memory of microcontroller. The output of this close loop control system will issue the four thrusters to run and will turn the boat either left or right and will run all four of the thrusters when the boat is already heading toward the desired point.

The microcontroller used in this project is Arduino Mega 2560 and the program language used is basic C language. The sensors which are GPS and Compass will feed the current position of the boat to the microcontroller and then the microcontroller will calculate the angle required to turn the head of the boat so that it will face the desired point. Basically the output of the GPS module is a standard output called as NMEA 0183 (National Marine Electronics Association) and in the form of ASCII value. The output type that is usually used to get the coordinate point is in the form RMC (Recommended Minimum Specific GNSS Data) for instance $GPRMC,111636.932,A,2447.0949,N,12100.5223,E,000.0, 000.0,030407,,,A*61<CR><LF> and to decode these output the RMC output table is required.

The output of the compass sensor is in the form of raw data magnetometer and some of the compass sensor has been tilt compensated and the wave of the water would not affect the accuracy of sensor. A magnetometer is a measuring instrument used to measure the strength and perhaps the direction of magnetic fields.

5. RESULTS & DISCUSSION

This section discusses the results obtained from experiments regarding in image processing. The experiments are conducted using Microsoft Visual Studio 2010 and OpenCV as its libraries of processing the image.

5.1 Read & display image from file

The first step to image processing is learning to understand the software that is going to be used to manipulate the images that will be taken. Then, learning to capture and load the image to the following software needs to be done in order to further develop the images. The main objective of the project the project is to capture underwater image sample as video image and the program will process the video as an image by image. Program that capture video image underwater from the camera setup will be compiled and run using the coding that will be predefined. As OpenCV is used, a constructor to view image from the webcam is introduced. And a series of tests will be done on this program.

Any digital image consists of pixels that contains some value. Every pixel has a fixed number of bits allocated in it. When the value of the pixel is increased, the intensity of that pixel is also increased. The minimum value for a pixel is 0 and it represents black. Then, the maximum number that a pixel can have is 255 (11111111 in binary).

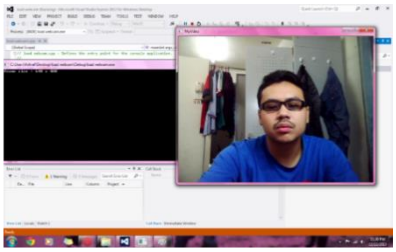

Fig. 5: My Image Displayed

Following image is an image taken through a personal webcam to detect and display colored images through video constructor. This constructor opens the camera indexed by the argument of this constructor and initializes the Video Capture object for reading the video stream from the specified camera. Here the '0' means the index of the camera to be used. Instead of 0, no 1,2,3 also can be used if your computer is attached to more than one camera.Color image should consist of at least 3 planes; Red, Green and Blue. Any color can be created using a particular combination of these 3 colors. Any pixel is a combination of three 3 values. (255, 0, 0) represent pure red. (0, 255, 0) represent pure green. (255, 0, 255) represents pure violet.

5.2 Color detection

One of the most fundamental methods to detect and segment an object from an image is the color based methods. There should be a significant color difference colors in the object and the background in order to segment objects successfully using color based methods.

This software (OpenCV) captures images and videos in 8-bit, unsigned integer, BGR format. A normal working function is used to convert the color space of the original image of the video from BGR to HSV image. HSV color space consists of 3 matrices, 'hue', 'saturation' and 'value'. Meaning that, a captured images can be considered as 3 matrices, BLUE, RED and GREEN with integer values ranges from 0 to 255. Almost exclusively, BGR color space is more suitable for color based segmentation but HSV color space is the most suitable color space for color based image segmentation.

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In OpenCV, value range of 'hue', 'saturation' and 'value' are respectively 0-179, 0-255 and 0-255. 'Hue' represents the color, 'saturation' represents the amount to which that respective color is mixed with white and 'value' represents the amount to which that respective color is mixed with black.

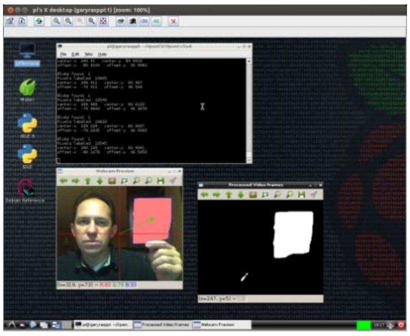

Fig. 6: Red Color Detection

5.3 Shape detection

In this part, the objective is to track the shape of the desired object. The shape and position of object is detected using color contours with OpenCV. Using color contours, a sequence of points of vertices of each white patch that are considered as polygons. For a shape like triangle and quadrilaterals, each will have three and four edges respectively. Therefore, any polygon can be identified by the number of vertices. Polygons such as convexity, concavity and also equilateral can be recognized by calculating and comparing distances between vertices.

The image is converted from the original image into gray scale. It is because this method works only with gray scale image with single channel. To get better results, the gray-scale image is threshold using 'cvThreshold' function. Then, almost all contours (triangles, quadrilaterals and heptagons) in the threshold image can be identified and tracked using this technique.

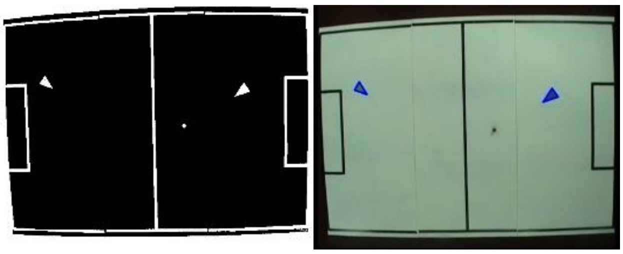

Fig. 7: Triangle Shape Detection

6. CONCLUSION

This section will discuss on the achievements of this research, limitations and challenges of this project and also recommendations for future developments of this research. The limitations and solutions of the problems should be identified, as it will help to rectify and improvise the current design and produce a better and efficient result

In conclusion, the autonomous boat will have many functions and mechanisms that will satisfy the user for various purposes. This project consists of many subsystems such as underwater imaging, navigation system, depth measurement system, PH measuring system and also wireless data transmission and storage system. Although this research focuses more on the image processing and PH measurement system. Nevertheless, other developed subsystems worked well hand in hand with the current system.

This research has presented numerous ways of constructing an autonomous boat with an imaging system implemented in it. Moreover, this research has discussed about various types of sensory and probes that can be integrated in the autonomous boat to develop a multi-functional mechanism. Algorithms and calculations for image enhancement underwater are presented and some preliminary results are shown.

The mechanical part of this autonomous boat is designed using the Catia V5 Edition. Meanwhile, the image processing experiments tested are using the Visual Studio software with OpenCV library. The process of detecting image has been performed by carrying experiment with the webcam in the laptop using various types of image processing techniques. From this experiment, the RGB and HSV range has been determined for a few colors of the object of interest. Among techniques used are Edge Detection Method and Template Matching and the most suitable techniques used underwater are color enhancement using edge detection method due to the complexity and also accuracy on image enhancement.

There are a few limitations in this research. The first one is the testing on the electronic gadgets was done in a small scale using a webcam above water. Therefore, the results will not be similar underwater. This is due to research time needed to understand the algorithms and finding the right instruments to conduct it underwater. Understanding the template coding and algorithms from other sources and research was a challenge.

To conclude, this research has theoretically met some of its objectives. Furthermore, this paper has successfully managed to answer the best method to get the best image and algorithms underwater as well as to integrate new sensors with current system. Also, improving the current design of the boat that fits well with the new system that will be implemented.

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