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UNDERWATER POLE INSPECTION USING TWO MICRO AUVS

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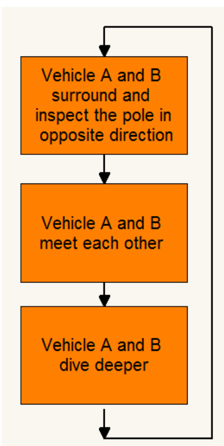
Graphical abstract



Abstract

This article describes the strategy to use two Autonomous Underwater Vehicles (AUVs) in underwater pole inspection work. They are called vehicle A and vehicle B. Vehicle A will surround the pole in counter clockwise direction whereas vehicle B will surround the pole in clockwise direction until the two vehicles meet. Then they will dive a certain distance and continuous surrounding the pole in opposite direction. The mechanical design of both vehicle A and vehicle B are exactly the same. The only different between them is vehicle A will make use of higher capability of underwater navigation and tracking system. Therefore, vehicle A is functioning as lead vehicle. Vehicle A and vehicle B will communicate with each other periodically for control signal dissemination and positioning error. This article also mention about the prototype design of vehicle A And vehicle B. Some preliminary result of proposed pole inspection system is also included in this article.

Keywords: Underwater pole inspection, cooperative AUV

Abstrak

Artikel ini menerangkan strategi untuk menggunakan dua kenderaan autonomi dalam air (AUVs) dalam kerja pemeriksaan tiang . Mereka dipanggil kenderaan A dan B. Kenderaan A akan mengelilingi tiang mengikut arah lawan jam manakala kenderaan B akan mengelilingi tiang dalam arah mengikut arah jam sehingga dua kenderaan bertemu. Selepas itu, kedua-dua kenderaan akan menyelam jarak tertentu dan berterus mengelilingi tiang dalam arah bertentangan. Reka bentuk mekanikal kenderaan A dan kenderaan B adalah sama. Satu-satunya perbezaan di antara mereka adalah kenderaan A akan menggunakan sistem pengesanan lokasi yang lebih tinggi keupayaannya. Oleh itu, kenderaan A berfungsi sebagai kenderaan memimpin. Kenderaan A dan B akan berkomunikasi antara satu sama lain untuk penyebaran isyarat kawalan dan pembetulan kesilapan kedudukan. Artikel ini juga menyebut tentang reka bentuk prototaip kenderaan A dan kenderaan B. Beberapa hasil awal sistem pemeriksaan tiang yang dicadangkan juga dimasukkan dalam artikel ini .

Kata kunci: Pemeriksaan tiang dalam air, AUV koperasi

1.0 INTRODUCTION

Oil and gas industry brings a lot of economic benefit. However, oil and gas off shore platforms faces unwanted marine growth problem on their jacket legs. Marne growth will increase the mass of jacket leg and reduce its natural frequency. Therefore, underwater pole visual inspection system is required to measure the marine growth rate on the surface of the jacket leg. This information is very important to schedule the maintenance on the marine growth strategically.

There are many ways to complete a visual inspection on an underwater pole. The conventional way is using human diver. However, this method of pole inspection is not effective and having high life risk.

K. Izman *et al.* have proposed a pole inspection system using pole climbing robot [14]. However, installation of this system on the pole is difficult and time consuming. Furthermore, marine growth on the surface of underwater pole has increased the difficulty for climbing robot to move in smooth motion.

The other way to inspect underwater pole is using a remotely operated vehicle (ROV). However, ROV faces serious limitations due to the connecting cable between the vehicle and control station. The ROV cannot go far from the control station without a long connecting cable. Furthermore, a long connecting cable which can get stuck has increased the operational difficulties. This means that the ROV's operator has to be well trained and occupied a practiced skill. High cost will be involved in hiring and training a ROV operator.

This article proposes an approach to improve the ROV's pole inspection system by eliminating the needs of the connecting cable and operator. These can be done by simply made the ROV completely autonomous. This means that instead of using ROV, this article suggests of using autonomous underwater vehicle (AUV) in underwater pole inspection.

Due to the limitations of state-of-the-art embedded systems, AUV is still limited in both its autonomy and capabilities. By using multiple vehicles, there is potential to complete the pole inspection operation more effectively, quickly, and robustly than with a single vehicle. Therefore, this article also studies the possibility of underwater pole inspection using two AUVs. The pole to be inspected is assumed vertical and without branch.

This article is organized as follows: the cooperative strategy of the two AUVs to inspect the pole is presented in Section 2. The design of the two AUVs used is shown in Section 3. The preliminary result of proposed pole inspection strategy and buoyancy test is discussed in Section 4. Finally, conclusion of this article is given in Section 5.

2.0 COOPERATIVE STRATEGY OF TWO AUVS IN UNDERWATER POLE INSPECTION

There are two AUVs involved in the proposed pole inspection operation. The two AUVs will be called vehicle A and vehicle B in the remaining of this article. They work together to complete the pole inspection operation. Their cooperative strategy will be discussed in this section.

2.1 Underwater Pole Specification

This article focuses on vertical pole inspection. The pole to be inspected is assumed vertical and without any branch. The proposed pole inspection strategy is targeted to inspect vertical pole which has diameter, D between 1.5 meters and 3 meters and height, H between 30 meters and 80 meters.

2.2 Inspection Path

Figure 1 shows the isometric view of the inspection path of vehicle A and vehicle B whereas Figure 2 shows the front view of the inspection path of vehicle A. Note that the inspection path of vehicle B cannot shown in Figure 2 because it is exactly behind the inspection path of vehicle A. This means that vehicle A will cover the front part of the pole whereas vehicle B will cover the part behind the pole. Both the two vehicles are equipped with underwater camera. They will record video of the pole's surface along the whole path.

First, vehicle A and vehicle B will dive together at same point from surface. After reach one meter depth, both the vehicles will surround the pole while maintain their depth at same level. Vehicle A will surround the pole in counter clockwise direction whereas vehicle B will surround the pole in clockwise direction until the two vehicles meet. Then they will dive a distance, h and continuous surrounding the pole in opposite direction. The two vehicles will keep repeating the path until they reach the predefined depth.

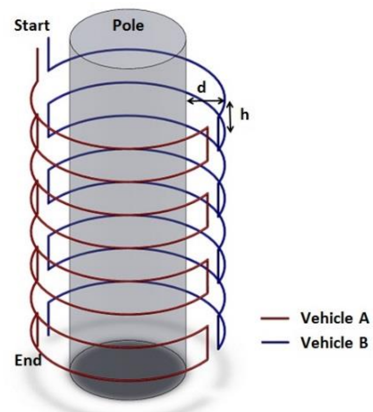


Figure 1 Isometric view of inspection path of vehicle A and B

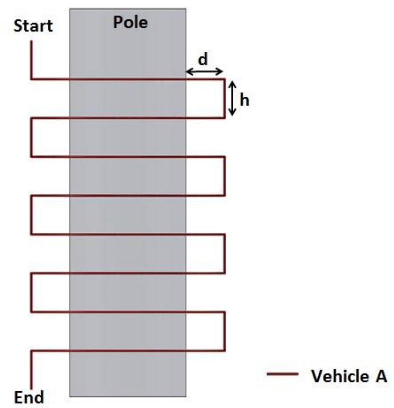


Figure 2 Front view of inspection path of vehicle A

2.3 Distance between Two Surrounding Path, h

As explained before, vehicle A and vehicle B will dive a fixed distance h after surrounding the pole 180 degree. The distance h is depending on the vertical field of view (vFOV) of the underwater camera. As shown in Figure 3, distance h should be equal or less than the vFOV of the camera so that the camera will not miss out any part of the pole during the inspection.

On the other hand, according to Figure 4, when the value of h is less than the vFOV of the camera, some part of the pole is inspected twice by the underwater camera. Therefore, this will decrease the efficiency of the pole inspection system.

Figure 5 shows the most ideal value of h, which is equal to the value of vFOV. In this situation, the camera able to capture all the part of the pole without any repetition. However, this will required a very precise control system and nearly impossible to achieve it.

Therefore, value of h which is slightly less than the value of vFOV should be used. In the proposed pole inspection system, the value of h is fixed at one meter.

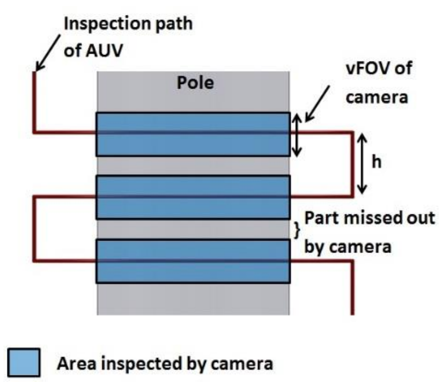


Figure 3 Inspected part of pole when h is more than vFOV

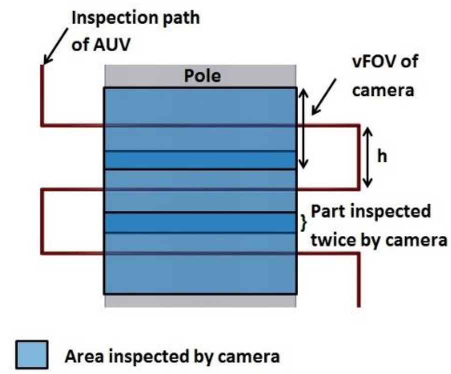


Figure 4 Inspected part of pole when h is less than vFOV

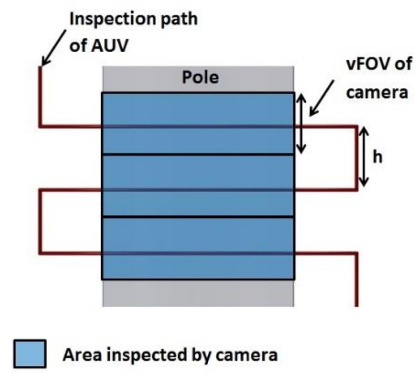


Figure 5 Inspected part of pole when h is equal to vFOV

2.4 Distance between AUV and Pole, d

Visibility underwater is always poor. Therefore, the two vehicles must maintain at the short fixed distance, d from the pole while inspecting the pole. Laser pointer is used to measure the distance between the pole and the vehicle. K. Muljowidodo *et al.* had proved that the product of the actual distance between camera and obstacle, d and the number of pixels between laser spot and the image center, R is a constant [1]. Figure 6 gives a clearer picture about d and R. An experiment is needed to find a reference value of d and R so that distance between the camera and pole, d can be calculated using Equation (1):

$$dR = dref\ Rref \qquad (1)$$

where

d = distance between the camera and pole

R = the number of pixels between laser spot and image center

dref = reference distance between the camera and pole

Rref = the pixels number between laser spot and image center when distance between the camera and pole is dref

As shown in Figure 6, the camera is placed at a known distance, dref, and then the number of pixels between laser spot and the image center, Rref is measured using image processing software.

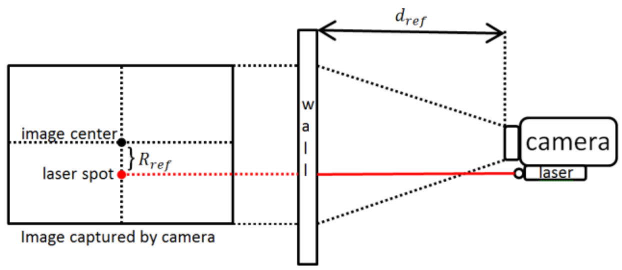


Figure 6 Experiment to verify the value of product of d and R

2.5 Synchronization between AUVs

Seokhoon Yoon and Chunming Qiao had proposed a cooperative rendezvous scheme named synchronization-based survey (SBS) to facilitate cooperation between AUVs [2]. This SBS is developed for large number of AUVs which surveying large area. However, its concept is used to synchronize vehicle A and vehicle B in this article. Vehicle A and vehicle B will periodically communicate with each other for control signal dissemination and positioning error correction.

In the proposed pole inspection system, vehicle A will perform synchronization with vehicle B using acoustic communication device. Vehicle A is chosen as lead AUV. Vehicle A is equipped with underwater acoustic modem which enables the communication between control station and vehicle A. Vehicle A will pass control signal or instructions from control station to vehicle B at synchronization section. For example, if control station wants to terminate the pole inspection operation in sudden, it will send a resurface command to vehicle A, and then vehicle A will share the command with vehicle B. Finally the two vehicles will resurface together.

Gao Rui and Mandar suggest that vehicle with higher positioning accuracy can give a more accurate position estimates to AUVs with poorer navigational capabilities [3]. In this article, vehicle A as the lead AUV will make use of higher capability of underwater navigation and tracking system. When these two vehicles meet at synchronization section, they will exchange their positioning information in order to compare and recalculate to give a higher accuracy and reliability of navigation system.

3.0 AUV DESIGN

This article design a high manoeuvrability box-shaped micro size AUV which is suitable for the proposed underwater pole inspection system. Both vehicle A and vehicle B will use the same design. In this section, mechanical system design, buoyant system design, propulsion system design, electronic system design of the AUV will be discussed.

3.1 Mechanical system design

The typical shape of AUV is torpedo shape, i.e. Bluefin-21 [4], Hugin 4500 [5], Slocum [6], Taipan [11], and Girona 500 [12]. However, torpedo shape is only suitable for long distance low manoeuvre travel. It is not suitable in this case. In the other hand, the typical box shape of ROV, i.e. Falcon [7], Tiger ROV [8], Spectrum ROV [9], and Millennium Plus ROV [10] is suitable for the operation. This means that we have to build an AUV with typical ROV's shape. Therefore, micro size box shaped AUV is designed. As shown in Figure 7, the AUV designed is 0.9 meters long by 0.8 meters wide, and height 0.6 meters. The AUV's frame is formed by aluminium plates. All the actuators, sensor, and buoyant system are attached to these aluminium plates using screw and nuts.

There is a water tight cylinder hull which centred in the frame. It is used to protect the electronic system and power system from sea water. The material of the cylinder hull body is polymer whereas the material of the cylinder hull door is aluminium. O-ring is used to seal the gap between the cylinder door and body.

The weight distributed for AUV is shown in Table 1. Its total weight is 60 kg. The aluminium frame is only contribute 20% of the total weight. This is because square holes have been designed on the aluminium plates to decrease their weight.

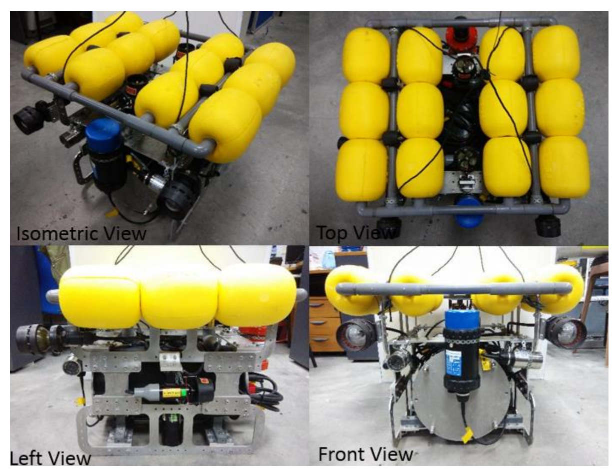


Figure 7 Mechanical design of box-shaped AUV

Table 1 Weight distribution of AUV prototype

Parts	Mass (kg)
Aluminium Frame	12
Electronic Hull	16
Thruster x 4	4
Underwater Spot Light x 2	1
24Vdc Li-Po Battery	13
Electronic Component	1
Underwater Acoustic Modem	4
Sonar	4
Underwater Camera x 2	1
Altimeter	2
GyroCompass	2
Total Mass (kg)	60

3.2 Buoyant System Design

The AUV is designed to be neutral buoyant. As shown in Figure 8, its buoyancy force is provided by twelve seine float with hard shell and the cylinder hull. The weight which can be supported by a cylinder shape buoyant system is calculated using Equation (2) as shown below. As shown in Table 2, the total weight that can be supported by the design buoyant system is 63 kg. This means that the designed AUV is slightly positive buoyant. Its net buoyancy force is 3 kg.

$$W=\rho V \quad (2)$$

where

W=weight that can be supported
ρ=density of sea water
V=volume of buoyant system

Table 2 Supported weight by buoyant system

Parts	Mass that can be supported
Seine floats	$W = 12(\rho\pi r^2 l) = 12(1027 \times \pi \times 0.07^2 \times 0.19) = 36kg$
Cylinder Hull	$W = \rho\pi r^2 l = 1027 \times \pi \times 0.13^2 \times 0.5 = 27kg$
Total	$63kg$

3.3 Propulsion System Design

As mentioned in [13], the most important manoeuvre for the AUV is depth control and heading control. Therefore, the AUV is designed to have two surge thrusters, two heave thrusters, and one sway thruster. Figure 8 shows the overview of the position of five thrusters on the body frame. This propulsion system will give 5 DOF to the vehicle motion. There is no thruster to provide motion in rolling angle for the AUV. Motion in rolling angle direction is not important because the AUV is able to maintain its stability in rolling angle direction.

The two heave thrusters are used for station keeping purpose. They will maintain the vehicle at desired depth.

On the other hand, the two surge thrusters are used to move forward and turning in yaw direction.

Last but not least, the sway thruster will correct the position error of AUV in the sway direction when there is wave disturbance acting on the AUV.

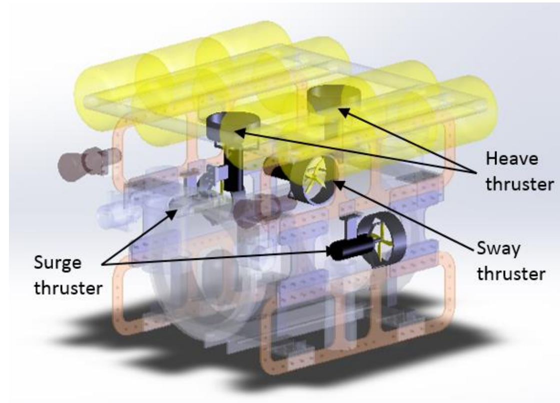


Figure 8 Propulsion system design

3.4 Electronic System Design

Figure 9 shows the overall electronic system design. PC 104 is used as central processing unit. It reads the data from all the sensors and give instruction to the five thrusters. Few Arduino control boards are used as slave controller to process the input and output of the sensors before send to PC 104.

The AUV is equipped with underwater camera. With it, the AUV will be able to complete underwater task which required visual inspection. Lighting system is developed to increases the brightness of the image taken by camera.

Besides, gyrocompass, altimeter, and pressure transducer are used to measure the orientation and position of the AUV. These sensors will enable the AUV glide following a preprogramed path.

Water sensor, temperature sensor and current sensor are used as security system of the AUV. They will terminate the underwater mission of the AUV and bring it to the surface of water if there are water leakage, over heat or short circuit.

Besides, the AUV is able to communicate with surface control station using acoustic modem. The control station can give command to the AUV during its underwater mission.

The electronic system is power up by a 24Vdc lithium-polymer battery. Its capacity is 50 Ah. Few DC-DC converters are used to scale down the voltage of the battery into suitable voltage for other electronic devices.

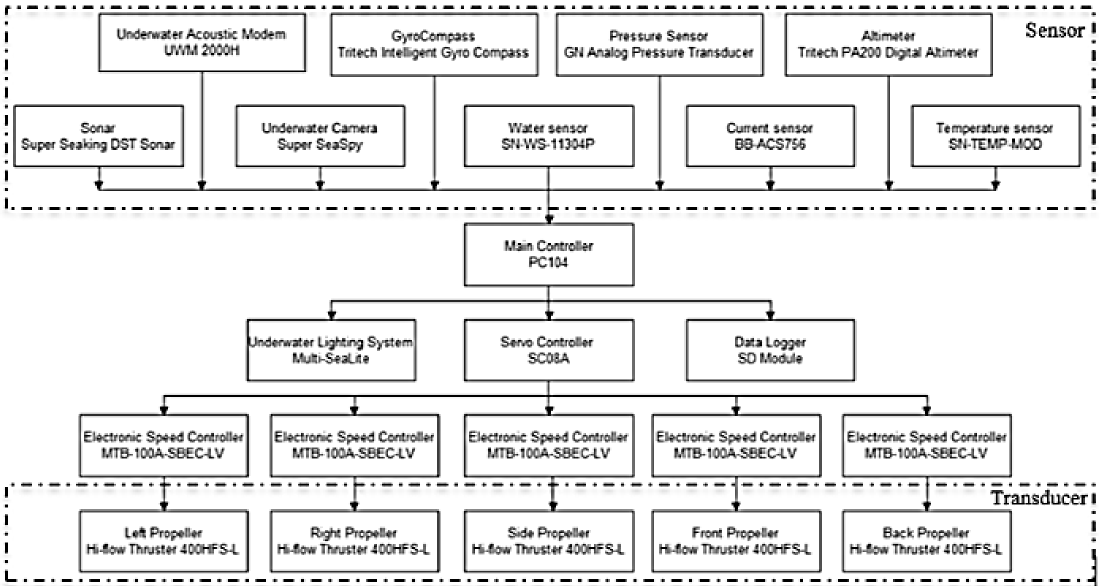


Figure 9 Electronic system design

4.0 RESULT

Preliminary result of proposed underwater pole inspection system and buoyancy test result is shown in this section.

4.1 Preliminary Result of Proposed Underwater Pole Inspection System

Distance travelled by the AUV, s can be calculated using Equation (3) whereas time needed for the AUVs to complete the pole inspection, t can be calculated using Equation (4).

$$s = [\pi H(D/2+d)]/h + H \quad (3)$$
$$t = s/v \quad (4)$$

where

- s = distance travelled by the AUV
- H = height of the underwater pole
- D = diameter of the underwater pole
- h = distance between two surrounding path
- t = time needed for the AUV to complete the pole inspection

In order to estimate the time needed for the AUVs to complete the pole inspection, both the distance between AUV and pole, d and the distance between two surrounding path, h are fixed at 1 meter. High moving speed will affect the quality of image taken by the camera. Therefore, the speed of the vehicle, v is assumed to be a low speed of 0.5 m/s. By using Equation (3) and Equation (4), the time needed for vehicle A and vehicle B to inspect a pole with diameter 3 meters and height 80 meters is 23.6 minutes. The calculation is shown by Equation (5).

$$t = \{[\pi H(D/2+d)]/h + H\}/v \quad (5)$$
$$= \{[\pi 80(3/2+1)]/1 + 80\}/0.5$$
$$= 1417 \text{ seconds}$$
$$= 23.6 \text{ minutes}$$

4.2 Buoyancy Test of Buoyant System

Buoyancy test is important to make sure the constructed AUV has nearly zero buoyancy force of its initial state. Buoyancy test is done by simply throw the vehicle into the water and observes whether the vehicle is sinking or floating. Additional weight is added to the frame until the whole body of AUV is submerged into the water. Figure 10 shows the picture of buoyancy testing of the AUV at swimming pool. The vehicle is slightly positive buoyancy and float in the way that the whole body is submersed into water. The weight distributed evenly on the body of the vehicle without making it incline to any direction.

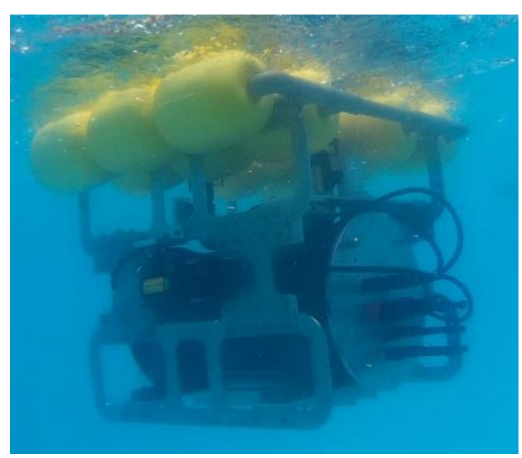


Figure 10 Buoyancy test of AUV prototype

5.0 CONCLUSION

One of the advantages of the proposed pole inspection strategy is its capability to inspection underwater pole without the need to know the diameter and height of the pole before the operation. The two AUVs will automatically surrounding the pole at fixed distance from the pole's surface until reach seabed.

Micro AUV always has great limitations on its battery capacity. Micro AUV has not enough space to install big capacity battery. Therefore, micro AUV only can operate within a short range of time. The AUV designed in this article only can operate for one hour. The time limitation problem is solved by using two micro AUVs. The time needed to complete the pole inspection is only 23.6 minutes, which is less than one hour. If only one AUV used, the time taken will be doubled (45.2 minutes).

Performance of this pole inspection strategy will be tested at sea using two AUV prototypes. Furthermore, a robust control system will be developed to guide the AUVs so that they can complete this pole inspection strategy.

Acknowledgement

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