Automatic quality inspection with Liquid Penetration Test using robots

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***Abstract*—By performing the Liquid Penetration testing using few numbers of robots, we can completely automate the quality control process. By using certain algorithms, we can easily make the robot to perform the required operations that are carried out in the liquid penetration test and determine whether there are cracks in the part. With Machine Vision and OpenCV, we can find if the part is defective or non-defective. A camera will be fixed to the robot's end-effector and it will take a picture of the part surface and then the backend algorithm of the OpenCV will find whether the part has external cracks. Then using some segregation algorithm, we can sort the parts that are defective. By implementing this system along with the use of conveyors, the quality inspection can be completely automated and can be done more efficiently.**

Keywords—quality, inspection, liquid, penetration, non-destructive, OpenCV, machine, vision

I. INTRODUCTION

Quality control is one of the most important tasks in manufacturing. It indirectly leads to the goodness of the product in the market and determines the brand value of it. Because by supplying a defective item to the market, the customer satisfaction will drastically diminish and the trust they have on the brand will be gone. So, to avoid all those things, a separate department for quality control will be available in most of the manufacturing facilities. They employ manual labour to verify whether a manufactured part is defective or non-defective. They are basically two ways to check the product, destructive method and non-destructive method. Destructive methods are used to find the properties of a part by breaking the material or damaging it. But won't be able to find surface finish defects like cracks and so on. So, the other method is used. Non-destructive method doesn't destroy materials since it uses advanced methods like liquid penetrant testing, ultrasonic testing and radioactive testing. By using these non-destructive methods, we can detect the cracks in the manufactured part without breaking or destroying it. In industries only manual labours are used to do these quality checking. Errors may arise due to poor human checking because of fatigue, or there may be errors in the steps. So to avoid all these and avoid to make the process more efficient, we use robots and image processing methods to automate the quality checking process. There will be a group of robots to perform the required steps for liquid penetrant testing (LPT) and an automated conveyor to move the parts to the required robot at the required instant. This will make the whole process quick. Also, the data can be collected about the parts fairly easily and quickly. As the final robot is equipped with a high-definition camera, the verification stage is completed based on the computer vision. We be taking a picture of the part after all steps before inspection and analysing that image to check whether there is defect or not. As the time progresses, we will be having a ton of data on our hand about the process, so we will be able to use them for AI concepts such as machine learning and Deep learning. By doing so, we can make the process even more fast and can make the accuracy even higher than done by humans. Liquid Penetration Testing, abbreviated as LPT, is one of the most popular NDT (Non-Destructive Testing) methods used in quality inspection. Non-Destructive Tests are tests performed to verify whether the parts have internal or cracks. They do not damage the part in any way, will only check whether the parts are defective are not. The cracks may appear on the surface due to a variety of reasons including defective welds, high amounts of vibration during machining, even there may be internal cracks during casting. These cracks reduce the vital aspects of the part like surface finish and smoothness. So, to find these types of cracks, NDT is widely used in the industries. They differ from Destructive testing in a way that NDT will never damage or deform or degrade the part in any way, while Destructive testing does so. Destructive testing techniques are used to find the properties of the part rather than quality inspection. There are many types of NDT that are available in the industry like magnetic particle testing, ultrasonic testing, radiography testing, etc... other than LDT. These four techniques are the most commonly used NDT methods. LPT is comparatively cheaper than the other three methods and main observation done to find the crack is illumination of liquid in the crack. Because of this, Machine vision can be used to find the color change in the surface of the part with just a camera.

II. LPT PROCESS

Liquid Penetration Testing is also called as dye penetrant testing (DPT), uses the capillary principle to inspect the part i.e., a liquid can flow into narrow space, even if it is restricted by external forces, without help.

A. Pre-Cleaning

This is the first stage of the LPT process. In this stage, the part is cleaned thoroughly to remove all the dirt and foreign matters present on the surface. If not cleaned properly, the inspection will become complicated and there will be loss of time. This is usually done by applying some water or any cleaning liquid on the surface and then wiping the surface with a cloth or sponge.

B. Apply Penetrant

The next step is to apply the penetrant on the surface of the part, once the part surface is completely cleaned. The penetrant is usually kind of a fluorescent gel. The penetrant is sprayed or applied on the surface using a brush. There should be a dwell time of approximately 3 minutes.

C. Remove Penetrant

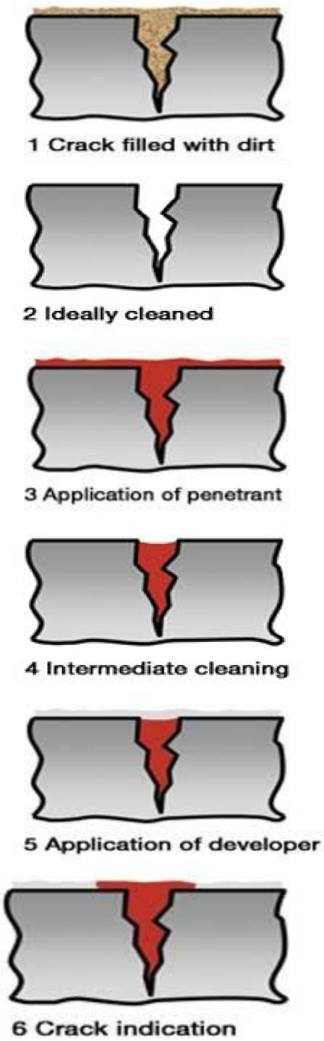
The next step is to remove the penetrant, so that the penetrant will be only present inside the cracks and completely wiped off the surface. This done by using a cloth or sponge. This is similar to cleaning but instead only the penetrant present on the surface is removed.

D. Apply Developer

The next step is to apply the developer on the surface of the part. It is applied using a cloth or a sponge. There should be a dwell time of approximately 5 minutes. This will penetrate the crack and makes the fluorescent gel to come out of the crack.

E. Inspection

The final step is inspecting the part. If there is any crack present, then the fluorescent gel will be present there. If the part has any cracks, it is taken out. If there is no crack on the part surface, there will be no penetrant left, so the surface will be clear. Otherwise, the part is cleaned and sent for further processing.



III. MERITS AND DEMERITS OF LPT

A. Merits

- Complex shapes can also be inspected using LPT.
- The apparatus required for LPT are also very compact.
- LPT can even find very small cracks.
- LPT can be used to inspect mostly all the materials including ferrous, non-ferrous, conductive, non-conductive, metals and non-metals.
- This is a cost-effective method comparatively.
- It is non-hazardous, unlike radioactive testing.
- This produces visual results.

B. Demerits

- Internal cracks cannot be detected, only external cracks are detected.
- LPT will not consider anything about the depth of the crack.
- Pre-cleaning and post-cleaning are mandatory.
- LPT is a multi-stage process, so it takes a quite a bit of time.
- Porous materials cannot be inspected using LPT.
- Disposing the chemicals is mandatory and also, they should be handled cautiously.

IV. PROPOSED SYSTEM

In our proposed system, there will be five robots, one robot for each process of the LPT. All the robots are of Cartesian type. Robot1, Robot2 and Robot4 will have a small pipe with them to apply the required liquid on the surface. Robot5 will have a camera on its end-effector to take pictures. There will be holding devices to hold the part near each robot. The parts to be inspected will be coming in a conveyor. When they reach the first robot, the conveyor will stop for a preset amount of time, the pneumatic cylinder extends and holds the part so that the cleaner is applied on the part. Then the cylinder retracts and then the conveyor restarts and the part goes to the next robot. It is held there for the preset amount of time so that the penetrant can be applied and then the conveyor restarts. While this happens in the Robot2, the next part will be in the Robot1. Then the part will move to the Robot3 where it is held for the preset amount of time so that the penetrant is removed. Now the next part will be in Robot2. Then the part moves towards Robot4 where it is held for the preset amount of time so that the developer is applied on the part. Then the part goes to the Robot5 and is held there for a preset amount of time so that the camera can take a picture of the surface and check whether it is defective. Then the conveyor again runs, if the part is detective, a pneumatic cylinder pushes the part in the basket. If it is non-defective, the cylinder will not extend and the cycle continues. Before the parts reach the Robot1, they are timed and released through the conveyor. This will help to precisely co-ordinate the control of all the elements of the system. Also, an extra robot can be used for post-cleaning process if required. This will also be a cartesian robot with a sponge or cloth on its end-effector.

A. Cartesian Robot

The cartesian robots used are of 3DoF type, means that they can move in x, y and z axes linearly. The axes are mutually perpendicular means that they are at 90° to each other. These types of robots operate on cartesian coordinates. Their advantages include moving heavy payloads, accuracy, repeatability, quick, etc… And the main thing is that multiple cartesian robots can be controlled using a single motion controller. These cartesian robots are primarily used in industrial automations applications such as picking and placing, material handling, packaging, loading, and unloading, etc... They are preferred where speed and precision are the most important requirements. Except for the final robot, all the robots will have the required tool on the end-effector. The last robot on the line will have a camera to take picture on its end-effector. Based on the signal from the Robot5, the operation of the final pneumatic cylinder is decided.

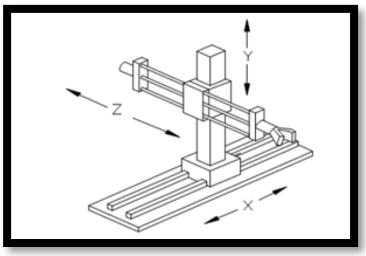


Figure 1 - Cartesian Robot

B. *Pneumatic Cylinders*

Pneumatic cylinders are used to convert compressed air power into mechanical energy. These act as an actuator in a pneumatic system. They are operated at a maximum pressure of 6 bar. All the pneumatic cylinders used are flanged-type double acting cylinders and they are actuated by a solenoid operated 5/2 DCV. The cylinders are cushioned, so that they are quitter in operation and they will not wear out quick. The DCV operates depending on the electric signals given to it by the controller. The compressor and the FRL (Filter Regulator & Lubricator) unit are same for all the cylinders in the cylinder. There will be a total of 6 pneumatic cylinders used, out of the 6, the first 5 will operate without a condition. Only the 6^{th} cylinder operates on the condition that the part is defective. All the cylinders get supply from a single air compressor. The amount of extension required is controlled by moving the cylinder accordingly.

Figure 2 - Pneumatic Cylinder

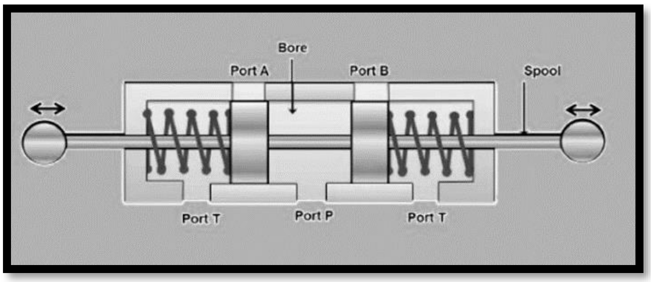


Figure 3 - 5/2 DCV

C. *Controller*

The controller controls all the necessary components in the system like robot movement, conveyor movement, pneumatic cylinder extension and retraction, coordinating the robots and cylinders, etc. The accuracy of the controller decides the efficiency of the system. Every element of the system is connected to the controller with the use of wires. This system uses as Raspberry Pi as the main controller. The Raspberry Pi is an inexpensive credit card-sized computer that plugs into a computer monitor or television and uses a standard keyboard and mouse. It's a capable little device that allows people of all ages to explore computing and learn to program in languages like Scratch and Python. It's capable of doing everything you'd expect from a desktop computer, from browsing the web and playing high-definition video to creating spreadsheets, word processing and playing games.

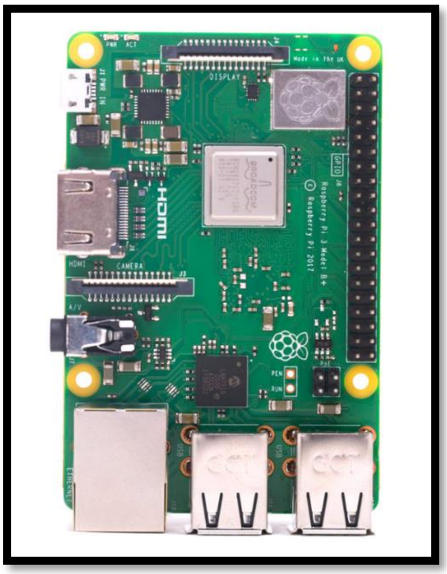


Figure 4 - Raspberry Pi

D. *OPENCV*

OpenCV is mainly used for computer vision, machine learning and image processing. It is an open-source library. Now-a-days, it is also used for real time analysis. They are used AI too. More than 2500 algorithms are present in this library. These algorithms are used for face detection and recognition, object identification, object tracking, movement tracking, extracting 3D models, etc…

Various companies which are well-established namely Microsoft, Google, IBM, Sony, Yahoo, Intel, Toyota, Honda use this library (OpenCV) for their products. Also, start-ups like VideoSurf, Applied Minds and Zeit era use this library primarily for their products. Stitching Streetview images together, detecting intrusion from surveillance in Israel, monitoring mining equipment in China, helping robots to navigate and pick the objects from one place to another at Willow Garage, detecting the drowning accidents in a swimming pool in Europe, running interactive art in Spain and New York, checking runways for debris in Turkey, checking product labels in factories around the world, to rapid facial detection in Japan.

V. ALGORITHAM

A. *Image Processing*

Various image processing algorithms:

- Morphological Image Processing
- Gaussian Image Processing
- Fourier Transform in Image Processing
- Edge Detection in Image Processing
- Wavelet Image Processing

Morphological Image Processing

Morphological picture processing attempts to cast off imperfections from binary photographs because binary areas created by easy thresholding can be distorted by means of noise. It also enables in smoothing the photo the usage of opening and ultimate operations. Morphological operations may be prolonged to grayscale photos. It consists of non-linear operations associated with the photograph feature structure. It relies upon on the relative ordering of the pixels, but on their numerical values. This technique analyzes an picture using a small template known as a texture detail, that is located at numerous viable locations in the photograph and as compared to the corresponding neighboring pixels. The structuring element is a small matrix with values of zero and Ones.

B. *Algorithm For Image Processing*

- Dilation and erosion are the two main operations carried in the morphological image processing method.
- The dilation produces the pixels at the boundaries of the objects in the photo.
- The erosion operation removes the pixels from the object barriers.
- The total number of pixels removed or delivered by this technique in the real picture depends on the dimensions of the structuring element.

The structuring element is a matrix of convenient zeros and ones that can be of arbitrary shape and size. It is far away for all valid locations in the photo and compared to the corresponding pixel neighborhood.

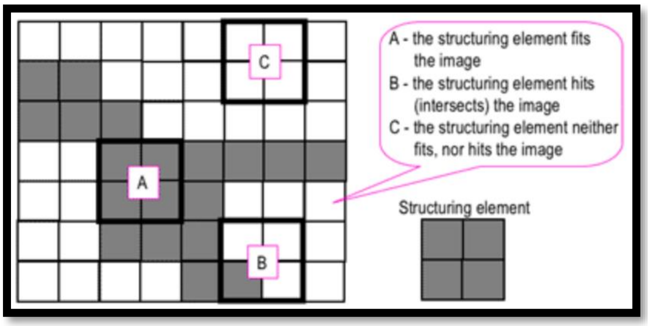


Figure 5 - Structuring element

The elements in box 'A' fits in the object we want to select, the elements in box 'B' has an intersection with the object in the picture and the elements in the box 'c' does not intersect with the object. The binary pattern defines the element structure's configuration. It is in such a way that the shape of the object we needed to inspect. The centre box of the element's structure identifies the pixel being processed.

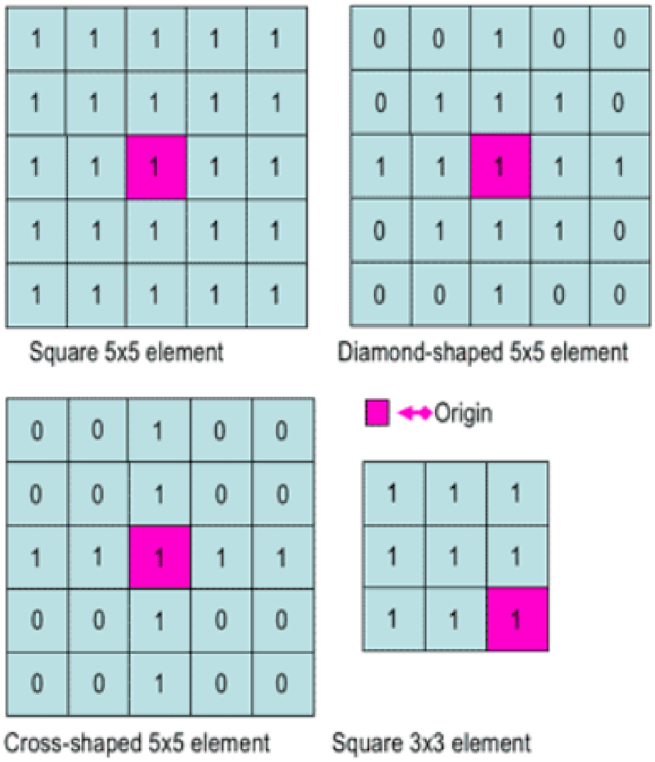


Figure 6 - Structuring element configuration

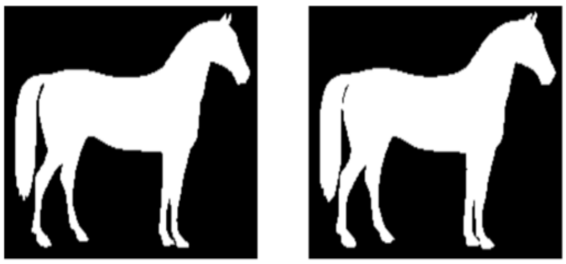


Figure 7 - Dilation

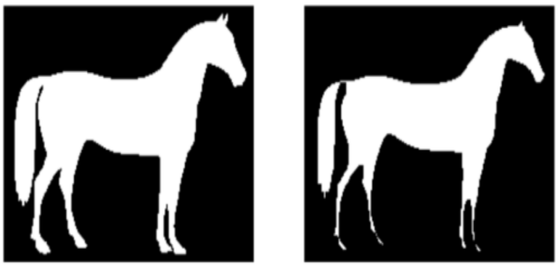


Figure 8 - Erosion

C. Algorithm For Colour Detection

- Importing the libraries (OpenCV and NumPy)
- Reading the image by the function called 'cv2.imread()' with mentioning the image path and storing this function in a variable.
- Converting the input image from BGR image to HSV image (hue, saturation, value). We can also convert the input image to grayscale image. Conversion is made with the function 'cv2.cvtcolor()' with two parameters (input image, type of conversion).
- The most important step is masking of the image. Here, it will show only the desired colour or the colour which has been given as an input from the user. The others colours will not be visible.
- The image can be outputted or showed to the user with the function 'cv2.imshow()'with the parameters (window name, variable holding image

VI. PROCESS DIAGRAM

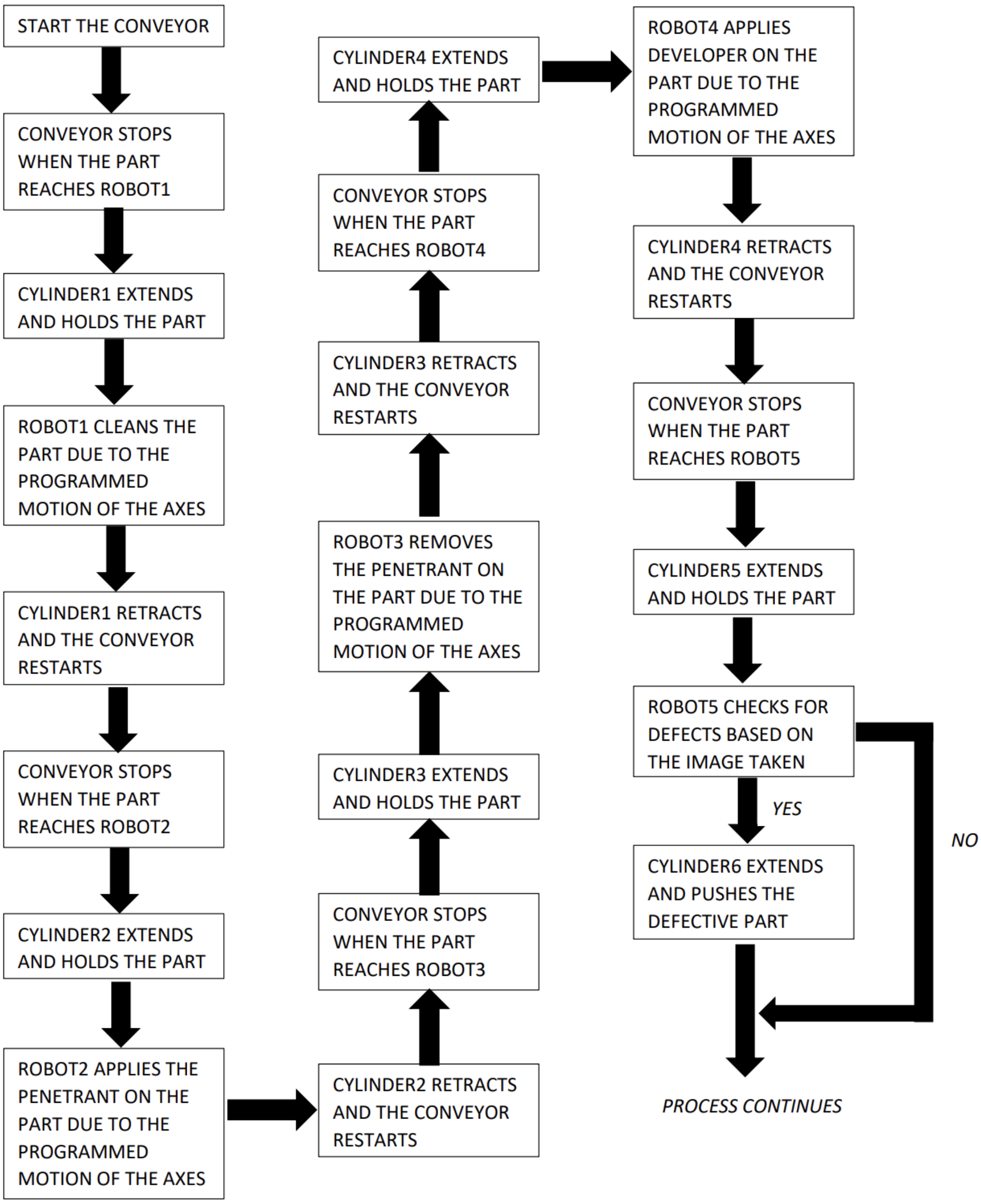


Figure 9 - Process diagram

The parts are initially placed in the conveyor-the transmission line. The part is moved through the conveyor to the Robot-1. When the component reaches the Robot-1 it stops. A pneumatically operated cylinder-1 is extended to hold the component for cleaning. Robot-1 cleans the part in-order to make the part free from dust dissipation and to make the liquid to penetrate. The cleaning is done in the programmed motion of axis. After cleaning, the cylinder-1 retracts and the conveyor starts to move. When the part reaches the Robot-2, it stops for applying penetrant. Once the conveyor stops, the Cylinder-2 retracts and holds the part. Robot-2 applies the penetrant on the programmed motion of the axis for the inspection. After applying the penetrant, the cylinder-2 retracts and the conveyor moves to the next station. The conveyor stops when the part reaches the Robot-3. The cylinder-3 extends and hold the part. Now the Robot-3 removes the penetrant on the part based on the programmed motion of axis. After removing, cylinder-3 retracts and the conveyor starts to move. Again, it stops when the conveyor reaches the Robot-4 it stops and the Cylinder-4 extends to hold the part. Robot-4 applies the developer on the part after removing the penetrant by robot-3 due to the programmed motion of axis. Cylinder-4 retracts after applying the developer and the conveyor starts to move. The conveyor stops when reaches the next robots and the various images are captured for inspection. Based on the captures images the robots check for the defects. If the robot finds any defects in the part, the cylinder extends and remove the part. If there is no defects in the part after the inspection carried out by the robot, the part is moved to the next process by the conveyor.

VII. CONCLUSION

With automation hitting every industry, the quality control sector will not be a surprise. The penetration testing market was valued at USD 580 million in 2020 and anticipated to register a CAGR of 24.3% during the forecast period (2021 - 2026). As it is the one of the most common and affordable solution, it is more feasible for the inspection. Also, by automating the LPT process, the efficiency of the process is increased. This proposed system can be expanded to accommodate other NDT tests too like ultrasonic testing and magnetic testing.

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