# 3D SURFACE RECONSTRUCTION AND COMPARISON SYSTEM USED FOR MARKING LOCAL DEFECTS OF TESTED OBJECTS

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**Abstract: Nowadays automatic 3D acquisition systems allow building accurate models of real 3D objects in a cost- and time-effective manner. This technology was used in a particular application context: shape defects detection. Specific needs of this domain are: medium-high accuracy, reliability, and a short acquisition time. A low-cost 3D reconstruction and testing prototype system was designed, based on structured light which compares the reconstructed shape of the tested objects with the reconstructed shape of a reference object. The scanner architecture and the first results obtained by implementing a prototype used to mark local defects of tested objects are presented.**

***Key words:*** *3D reconstruction, quality testing, structured light, defects marking.*

## I. INTRODUCTION

The requirement on the quality of items produced industrially is growing because of the producers, but also because of a so-called professional consumer current (prosumer). Testing the quality of parts and detecting faults before they are incorporated into a finished product, or before they reach the market, is a requirement that no longer can be neglected, as solving this problem can bring financial benefits and notoriety. Until a few years ago, a review of each produced item was regarded as impossible, especially for products manufactured in large quantities. Along with the developments in technology, especially in the field of computers and various acquisition equipments, different testing techniques have been implemented which allowed the verification of each product without intervention in the manufacturing technology, by simply placing a test system on the production line.

If the first quality testing applications were based on simple 2D images analysis, currently due to increased computing power, different new quality testing systems are proposed, systems that allow the comparison between the 3D image of the tested object and the 3D image of a reference object, or a predefined shape.

There are a lot of solutions that were proposed in order to reconstruct the 3D shape of a sampled object, starting from contact methods, such as Coordinate Measuring Machines, or transmissive methods, such as the 3D Industrial Computer Tomograph, to reflection methods, such as 3D radar, 3D sonar, or optical 3D reconstruction methods, such as stereo techniques or structured light techniques [4].

An acquisition technique based on structured light, also called Fringe Pattern Profilometry, was used for the implementation of our prototype system. Fringe Pattern Profilometry is being used more frequently in recent time studies as a cost effective optical acquisition technique and measuring tool for real three-dimensional surfaces.

The prototype system has been designed around two very common devices: a video projector and a digital still camera. A video projector is used to project structured light patterns on the object to be scanned. The digital still camera is used to acquire images of the object covered with the structured lighting. Both devices are driven by a software tool running on a standard PC, which produces a series of patterns, projected by the emitter, and drives the camera. Photos are taken, to acquire images of the distorted patterns (from which the 3D geometry is reconstructed).

A limitation of this system, that is common to all methods which project a series of patterns, is that the scene should be static during the acquisition time.

This paper is organized as follows. The first part of the paper briefly describes the theory on which the fringe pattern reconstruction techniques are based; this is followed by a presentation of the testing system which was designed using a phase shifting fringe patterns technique. The paper contains also experimental results and conclusions.

## II. 3D SHAPE RECONSTRUCTION TECHNIQUES BASED ON STRUCTURED LIGHT

Fringe Pattern Profilometry (FPP) starts by projecting a light pattern (in this case vertical bars) on the surfaces of the object that is subjected to the acquisition process. The shape of the object deforms the fringe patterns. The image of the deformed fringe pattern is acquired and used along with an image of the fringe pattern projected on a reference plane (virtual plane) that is parallel with the acquisition plane

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(formed by camera-projector line and a line parallel with the fringes and perpendicular to the camera-projector line). The shape of the object can be determined by analysing the distorted and original fringe patterns.

There are various methods to reconstruct the 3D surface information of the original object, the ones that are most commonly used are: Phase Shifting Profilometry (PSP) [5][6][7], Fourier Transform Profilometry (FTP) [8][9], and other methods such as Spatial Phase Detection (SPD) [10], Phase Locked Loop (PLL) [11].

The reconstruction technique that was used no longer needs the acquisition of an image containing the fringe pattern projected on a reference plane. The phase difference induced by the shape of the object is instead computed starting from a set of six images of the scene taken in such a way that the fringe pattern is moved from one frame to another, or better said the signal that generates the fringe pattern is phase shifted from one frame to another. This reconstruction techniques, described in [1][2][3], implies the use of a set of 6 sample images in order to compute the phase difference image. The generator signal is phase shifted from one image to another by $\pi/3$.

The output of this algorithm is an image representing the phase difference introduced by the shape of the object, phase difference which is wrapped in the $[-\pi,\pi]$ interval.

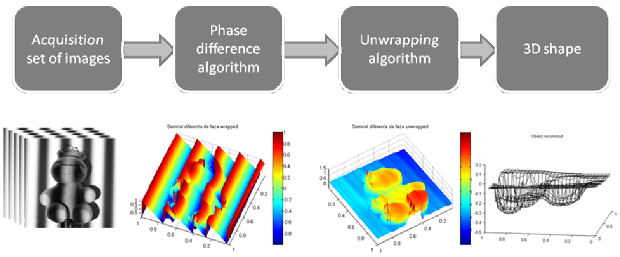


*Figure 1. 3D shape reconstruction steps followed by the proposed method.*

There are various methods used to unwrapped bi-dimensional signals. As we tested different unwrapping methods, Figure 2. and Figure 3., we found that they don't work as well on images as on bi-dimensional signals.

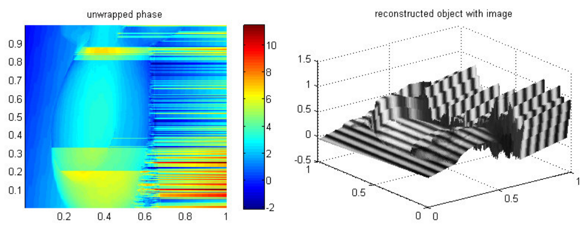


*Figure 2. Unwrapped phase using Matlab unwrapping.*

The proposed defect detection system uses a novel phase difference unwrapping method. This method, presented in [2], follows three simple steps:

- creates a new image by mirroring the original phase difference image;
- computes the second order derivative for the mirror image;
- low pass filters the image in frequency domain, with the help of an Laplace filter.

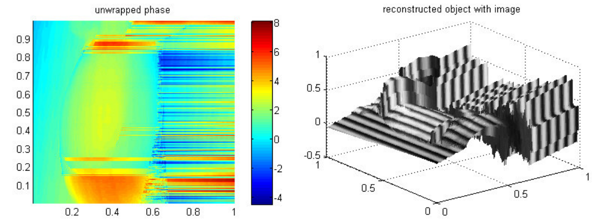


*Figure 3. Unwrapped phase using $2\pi$ unwrapping.*

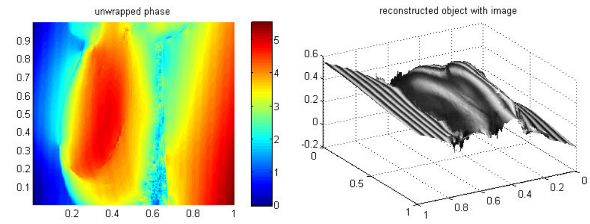


*Figure 4. Unwrapped phase using proposed algorithm.*

The last method, Figure 4., gives better results on unwrapping three-dimensional signals, as one can see there are no jumps from one line to another as in the case of using one of the other unwrapping methods, Figure 2. and 3.

## III. SYSTEM ARCHITECTURE

Shape error detection has a large field of interest. Systems that detect defects of objects are used on production lines but can also be used in testing lines (e.g. testing for components deformation).

Our main objective was to prove that 3D reconstruction and defects detection may have a common future.

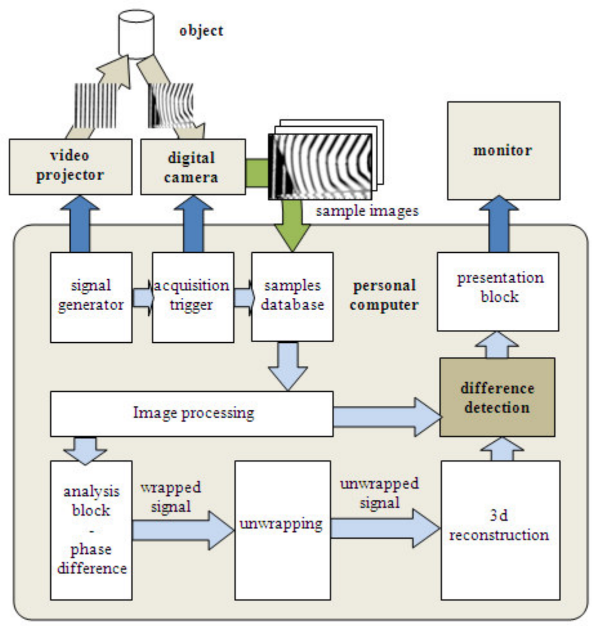


*Figure 5. System architecture.*

For the design of our low-cost testing system, Figure 5., we chose to implement the light source unit using a standard video projector. We used a video projector because of the flexibility of this device (which allows to experiment any type of light patterns), but also because of its wide availability. A similar choice was also used in [1][2].

The sensor can be either a custom device, either a standard digital camera or a video digital camera.

In our project the requirements for the sensor device were:

• the resolution of the image should be as high as possible (at least, not less than the resolution of the video projector);

• the images provided by the sensor should not be compressed, or the compression process used on the images should not interfere with their quality;

• it should be driven by a computer, possibly by giving access to the exposure, and aperture time parameters.

We chose to use a DSLR digital photo camera, because it fulfilled all the above requirements.

## IV. RESULTS

In order to use this prototype system one must first acquire the 3D shape of the reference object. After this the system will acquire the 3D shape of each of the tested objects, and it will compare those shapes with the one for the reference object.

One can see that we may determine if the tested object is deformed by comparing its wrapped signals with the wrapped signal of the reference object. Another way of detecting if the object is deformed is by comparing each sample image of the reference object with the corresponding sample image of the tested object. We decided to detect the deformed objects based on the reconstructed surface because we wanted to be able to compute the deformation degree and to detect the exact deformed area.

The reconstruction process starts by first acquiring a set of six sample images of the scene illuminated with a phase shifting structured light. Using the image analysis algorithm presented in [1] the system computes a phase difference image. In Figure 6. one can see the phase difference image for the reference object as well as for the tested object. The phase difference signal is wrapped in [-π,π].

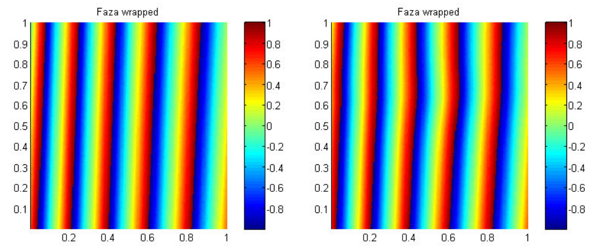


*Figure 6. Wrapped phase: (left) reference object, and (right) tested object.*

Figure 7. shows the unwrapped phase difference signal for the reference object, as well as for the tested object.

Starting from the unwrapped phase difference signal, the system computes, by means of triangulation, the shape of the reconstructed object. In Figure 8. one can see the reconstructed shape for the reference object and for the tested object. The representation is made using a polygon mesh structure even if the actual structure containing the reconstructed surface is a range image.

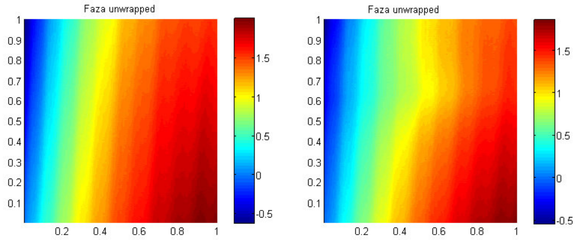


*Figure 7. Unwrapped phase: (left) reference object, and (right) tested object.*

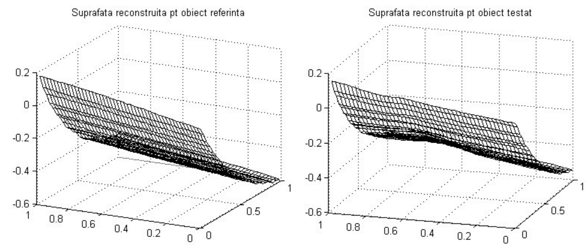


*Figure 8. 3D reconstructed surface: (left) reference object, and (right) tested object.*

In order to get a better visual perspective of the two reconstructed surface, the reference and tested object, we covered the reconstructed surfaces of each object with a gray texture and then we illuminated the newly formed objects from an arbitrary point. The result of this process can be seen in Figure 9; the image on the left represents the reference object, while the image on the right represents the tested object.

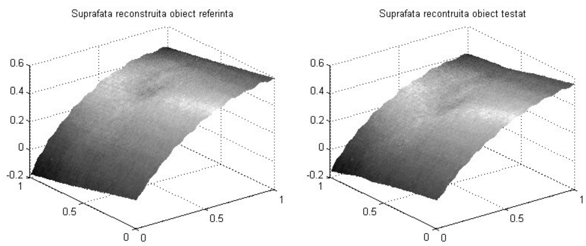


*Figure 9. 3D reconstructed surface with texture under illumination: (left) reference object, and (right) tested object.*

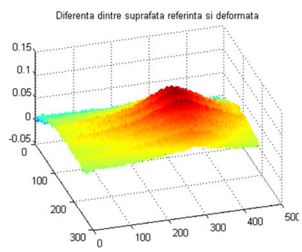


*Figure 10. Difference between reference surface and tested surface.*

Figure 10. shows the difference between the reconstructed surfaces of the reference object and that of the tested object. By applying a threshold on the difference image the application is able to detect the part of the reconstructed surface that is deformed when compared to the reference surface, Figure 11.

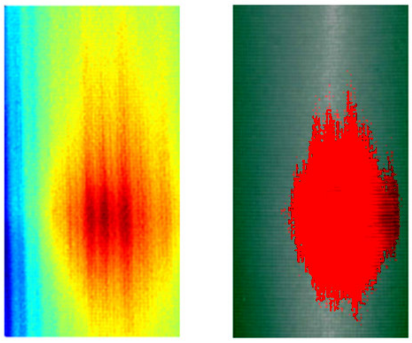

*Figure 11. (left )Difference image, and (right) area of tested object that has been marked as being deformed.*

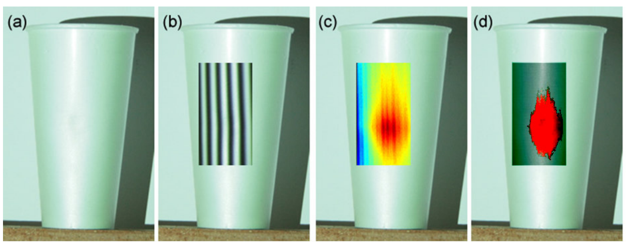


*Figure 12. Different steps during the defects marking process.*

Figure 12. shows: (a) the tested object, (b) the part of the sample images that is used to detect the deformation, (c) the difference between the reconstructed surfaces of the reference object and that of the tested object, and (d) the area marked as being deformed.

One of the drawbacks of this technique is that it has to acquire the sample images of a static object. The result obtained with the prototype system proves that this solution can be applied on an industrial scale as long as we will be able to decrease the acquisition time. In order to put this system into practice we have to be able to make the tested object stationary during the acquisition process.

The equipments used for this experiment were a laptop with 1MB of RAM and an Intel DualCore Processor, a 1024/768pixels Epson video projector, and a Canon D400 digital camera with a standard EF 18-55mm objective. The experiments were conducted using ambient light, that is, a combination of natural light and light from tungsten light bulbs. At this moment we were not concerned with the influence of lighting conditions on the final result, but further research may be done concerning this matter.

## V. CONCLUSIONS

This article presents a 3D testing system based on structured light that can be implemented using only consumer technology (a personal computer, a video projector, and a digital camera).

We want to conclude by saying that in the future this can lead to the development of a versatile and portable optical profilometer used for testing of 3-D objects.

As a future development, we can mention the implementation of a module capable of determining the volume of the deformation starting from the deformation image.

This system may also be used for medical purposes, for instance in computing the volume that was removed by means of an abdominal liposuction intervention.

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