*Proceedings of The nineteenth National Seminar on Aerospace Structures, Feb 23-25, 2017, VIT –Vellore.*

# Adaptive background removal for fringe profilometry based surface inspection of aircraft structures

Augustin M.J, Archana M.R, Yashvi Jalan, Priyanka Singh, Nithin Joy, Amit Kumar Gupta, Nitesh Gupta

*Advanced Composites Division, National Aerospace Laboratory, Kodihalli,560017,India*

**Abstract**

Visual inspection is one of the main processes to ensure the structural integrity of the aircraft structure adopted by the aircraft industry. This inspection scheme is highly skill based and raises safety issues to the inspector along with human errors. A lot of research is going on in this area to find an efficient alternative or as an aid for visual inspectors. Reconstructing and presenting the aircraft surface status in the 3D model from the images of the aircraft surface captured through a movable probe around the aircraft and presenting to the inspector can make the inspection faster effective and reliable. Among the recent advances in the 3D scanning methodology Fringe Projection based Profilometry (FPP) is an efficient method due to its ease of implementation and fast processing capability. FPP does is project a pattern on the surface under study and capture the images using a camera and create a 3D reconstruction of the surface. This paper explores the use of FPP for detecting the surface damage detection, also suggest a method which removes the background automatically for the surfaces thereby making the process faster and accurate Studies were carried out using different surface colors and lighting conditions and found be effective

*Keywords:* Non-destructive Inspection; Fringe Projection based profilometry

## 1. Introduction

One of the widely used methods to ensure the aircraft structural integrity is visual inspection. It involves a human inspector who visually examines the surface of the aircraft for surface defects such as dents, cracks, corrosion, etc. This practice raises safety issues to the inspector and it also has a number of disadvantages: it is time-consuming, some damages may not be noticed, sometimes ineffective due to inspector fatigue or boredom and also, does not provide any standard record for future reference.

The research on automating visual inspection dates back to 1990s. The Carnegie Mellon University developed a prototype, Automatic Non-Destructive Inspector (ANDI) [1] that creeps or holds onto the aircraft surface with vacuum assisted suction cups, scans an eddy current sensor and traverses around the surface using linear actuators. Colour CCD video cameras were used to align the robots with rivets. In this method, the inspector could see the surface on TV monitors. This had several disadvantages because the ANDI crawls over the surface, which might cause cracks or scratches on the aircraft surface. Later on, the Carnegie Mellon University developed Crown Inspection Mobile Platform (CIMP)[1] in which they designed an interim robot whose inspection was limited to the crown and was equipped with a 3D-stereoscopic video system that gives the inspectors remote binocular inspection capability.

The technological developments in cameras and electronics open up an alternative of using image processing based approach to aid the remote visual inspection. The inspector can capture high-quality images of the surface at the inspection console, and then use image-processing algorithms, he can easily identify the surface for dents, cracks or corrosion, etc. Use of 2D image processing is not good enough for the detection of dents as dents deform the surface into the third dimension. Two-dimensional image processing also poses the limitation that it detects surface features along with the surface defects. Examining the surface in a 3 D reconstructed model can eliminate this issue. Recent developments in 3D scanning provide an easy way to achieve this in a cost-effective way. Various methods are discussed in literature to reconstruct the surface profiles using optical profilometry, such as time of flight [6,7,8], laser scanning [9,10,11], digital hologram interferometry [12,13], structured light projection [14,15,16,17], etc. This paper explores the use of digital fringe projection technique [2,3,4,5] this has advantages like high accuracy, fast acquisition speed, can obtain a full frame of the 3D profile with one or several images, No damage or contamination of the structures.

## 2. Fringe Projection Profilometry (FPP)

The basic idea of FPP approach is that phase of the pattern projected will be get modulated according to the surface profile. The retrieval of the phase of the pattern projected onto the surface and converting to the height is the basic step of fringe profilometry. A 3-step phase shifting method is used in this paper. The implementation may be divided into the following steps - (a) Pattern Generation and Projection, (b) Image Acquisition, (c) Fringe Analysis, (d) Phase-to-Height Mapping, and (e) Calibration. Sinusoidal fringe patterns with three different phases are projected onto the target surface, the images captured are processed to give a 3D reconstruction of the surface, which can be examined for surface defects. The performance of FPP depends on the phase retrieval from the captured image.This paper explores the use of fringe profilometry for the surface dent detection on the aircraft structures.It also proposes a methodology to remove the background which can make the process faster, accurate and efficient.

### *2.1. Pattern Generation and Projection*

Sinusoidal fringe patterns generated using the equation

$$Image(x, y) = Asin(2\pi f(\cos(\theta)\, x + \sin(\theta) y)) \tag{1}$$

Here, the phase (phi) is represented by (cos(θ)x + sin(θ)y), where x and y are the coordinate positions on the 2D surface. In the present study, only vertical patterns are used. So, θ = 90° (or π/2 rad). Figure 1 shows the three $\frac{2\pi}{3}$ vertical phase-shifted fringe patterns generated on the system.

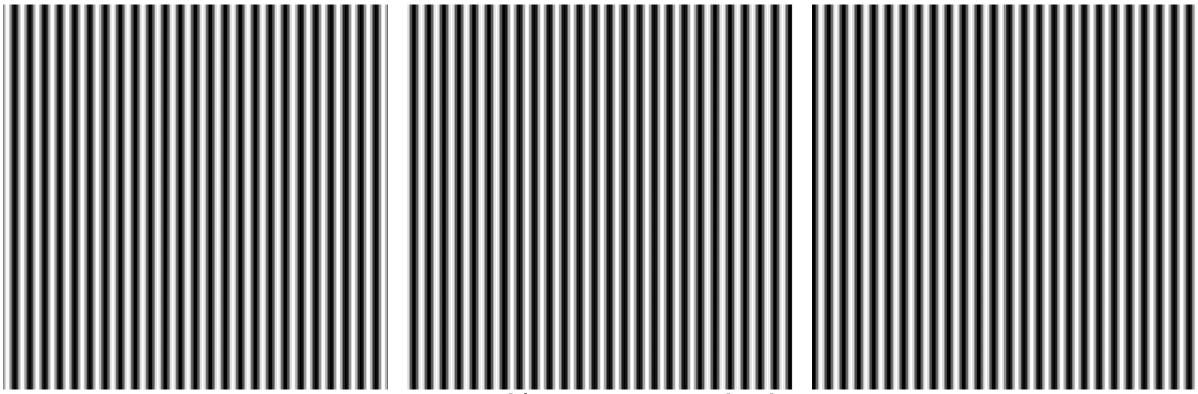


Figure 1 Vertical fringe patterns generated on the system

### *2.2. Image Acquisition*

The camera and projector are both connected to the system. Three patterns are projected onto the reference and object surface separately with phase shifts in steps of $\frac{2\pi}{3}$ and the images are captured. Figure 2 depicts the schematic lay**o**ut of the FPP system.

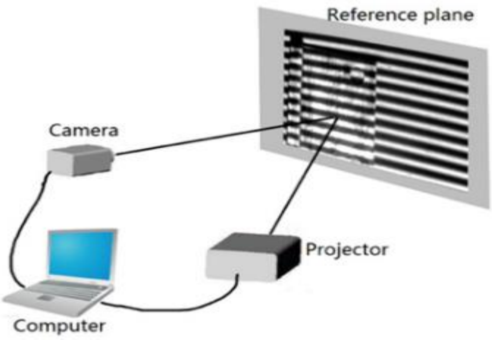



Figure 2. System Layout of fringe projection

*2.3 Fringe Analysis*

Fringe analysis mainly involves two steps: (a) Phase Wrapping and (b) Phase Unwrapping.

(a) Phase Wrapping – Basically, this step is phase detection. Phase detection on 3-step fringe projection is carried out using the following equation:

$$\phi(x,y) = tan^{-1}\left(\sqrt{3}\,\frac{I_1 - I_3}{2I_2 - I_1 - I_3}\right) \quad (2)$$

where $\phi$ represents the wrapped phase, $I_1$, $I_2$ and $I_3$ represent the grayscale intensity values of the three phase-shifted images. The use of inverse tangent function constraints the phase values in the range [$-\pi$,$+\pi$]. Hence, we need to unwrap this phase to retrieve the original phase information. Figure 3a shows the result of wrapping

(b) Phase Unwrapping – Phase unwrapping is performed to recover the absolute phase from the phase wrapped map. The modulo-$2\pi$ discontinuities are removed and the unwrapped phase map is obtained. Unwrapping follows the Itoh condition [18]. There are advanced algorithms for phase unwrapping such as Goldstein, Constantini, PUMA, etc. which works efficiently in real-world scenario. Figure 3b shows the result of unwrapping

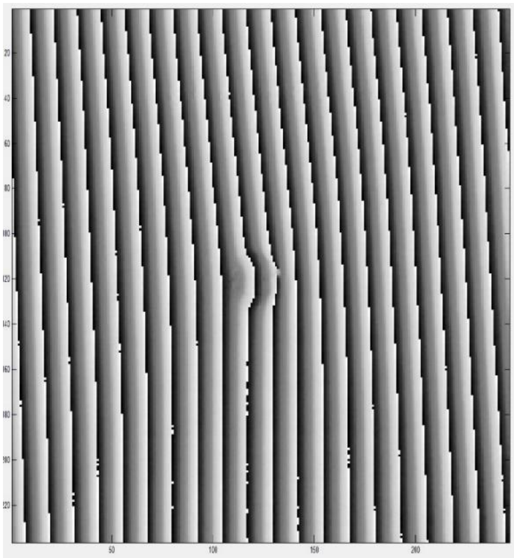


Figure 3a


Figure 3b

*2.3. Phase-to-Height Mapping*

Phase values need to be converted to height map to convey some meaningful representation. 3D surface map is obtained from absolute phase map of the object and the reference plane. The height values are obtained with respect to the reference plane.

*2.4. Calibration*

Calibration is done to obtain correspondence of the data with the world coordinates. The result depends on extrinsic and intrinsic parameters of the projector and camera.

## 3. Background Removal

One of the problems in using the phase reconstruction is that the background also take will also get processed, which don't have any proper information. In addition to making, it slower in processing lot of noisy information gets reconstructed. As the dent sizes are very small, information about this will be merged in the background variation. As nature of background is arbitrary for the application, it is required to have a method, which will adapt automatically. Here, background refers to all the unnecessary elements in the images. Ideally, only the surfaces containing the projected patterns should remain. This algorithm takes images with fringe pattern projected on the object. Since the pattern is projected on the foreground only, all the area where the fringe is not present/very low in intensity is detected as a background. This algorithm works on the idea of constant background with fringe movement in the foreground in a different set of images. The main idea is eliminating common region in all the 3 set of images. The formula used for background detection is given below:

$$bw = (bw1\&{\sim}bw2)|({\sim}bw1\&bw3)|(bw2\&{\sim}bw3) \quad (3)$$

Here, bw1, bw2, and bw3 are thresholded grayscale copies of the captured images. Local adaptive thresholding functions in MATLAB is used for the thresholding [3]. Morphological operations [4-6] were carried out for eliminating noise. Figure.4 shows the flowchart for background removal module.

## 4. **Experimental Setup**

The experimental setup consists of a projection system using SHARP PG-D-3050W projector, the image acquisition is done using Basler pilot camera, piA2400-17gc, through GigE frame grabber card, NI PXIe-8234, Dual GigE vison board on NI PXIE 1082. The PXIe-8840 Quad-Core with express card programmed through LabVIEW was used for controlling the projection and image acquisition. The algorithms are implemented n LabVIEW for the real-time operation. The experimental setup is shown in Figure.

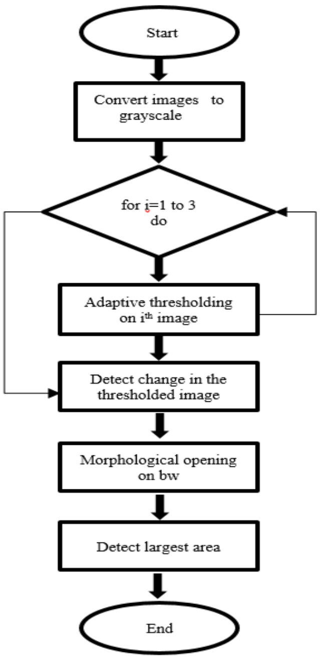
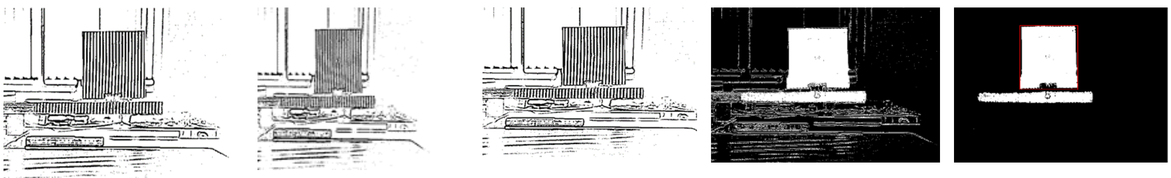



Figure 4. Flowchart for Background Removal

Figure 5.Experimental setup

## 4. Experimental studies

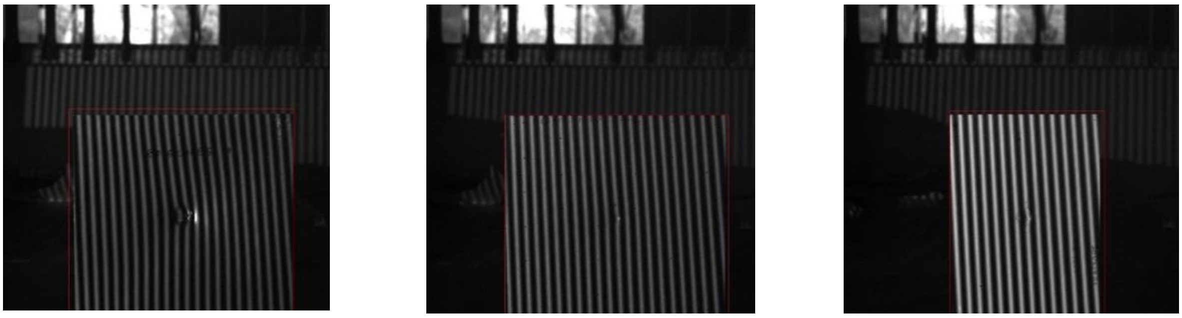
Studies were carried out for validating the algorithms using the experimental setup described in section 4. Three types of surfaces at three different distances from camera-projector plane including 80cm, 100cm and 120cm.Studies were carried out with different background conditions. The background removal process is shown in Figure 6. The object detected will be marked with red boxes.



Phase shifted image A | Phase shifted image B | Phase shifted image C | Separating foreground and background | Morphological operations and selecting foreground

Figure 6. Background removal process

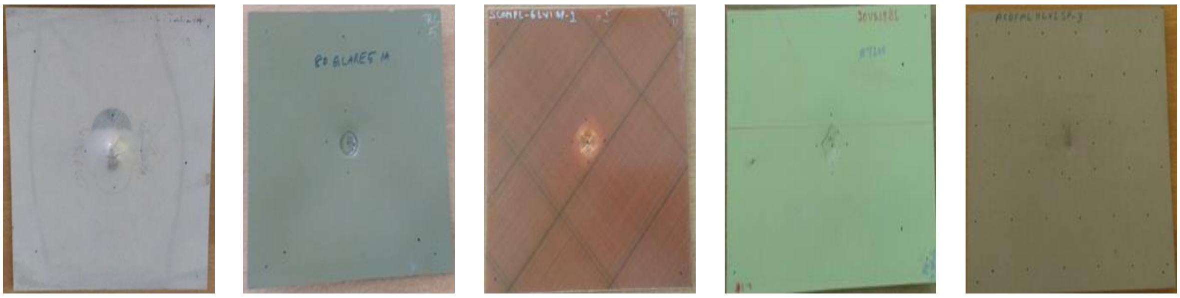
The results of the validation studies on three different surfaces at 80 cm distance is presented in Figure 7



Painted Metallic surface | Non-Painted metallic surface | Painted Composite surface

Figure 7. Automatic back foreground selection on different surface

Studies were also carried out at different distances and under different background conditions. Some cases it was noticed that very close backgrounds are being picked up, which can be further cleared manually by setting the threshold. Studies are under progress to make the process fully automatic. The automatic selection algorithm was further used along with the detection of the dents on different surfaces. The objects under study are shown in Figure 8. The results are presented in Table 1 and Figure.9.



Object 1 | Object 2 | Object 3 | Object 4 | Object 5

Figure 8. Objects under study

Table 1 Experimental Results

| **Sample** | **Actual Dent Depth (mm)** | **Calculated Dent Depth (mm)** | | | |
|---|---|---|---|---|---|
| | | **At 700 mm** | **Error** | **At 1000 mm** | **Error** |
| Object 1 | 4.80 | 4.596 | 0.204 | 4.388 | 0.412 |
| Object 2 | 6.15 | 6.26 | -0.105 | 5.0982 | 1.0568 |
| Object 3 | 0.84 | 0.71 | 0.135 | 0.781 | 0.064 |
| Object 4 | 1.64 | 1.654 | -0.014 | 1.11 | 0.53 |
| Object 5 | 1.39 | 1.3727 | -0.0173 | 1.0194 | 0.3706 |

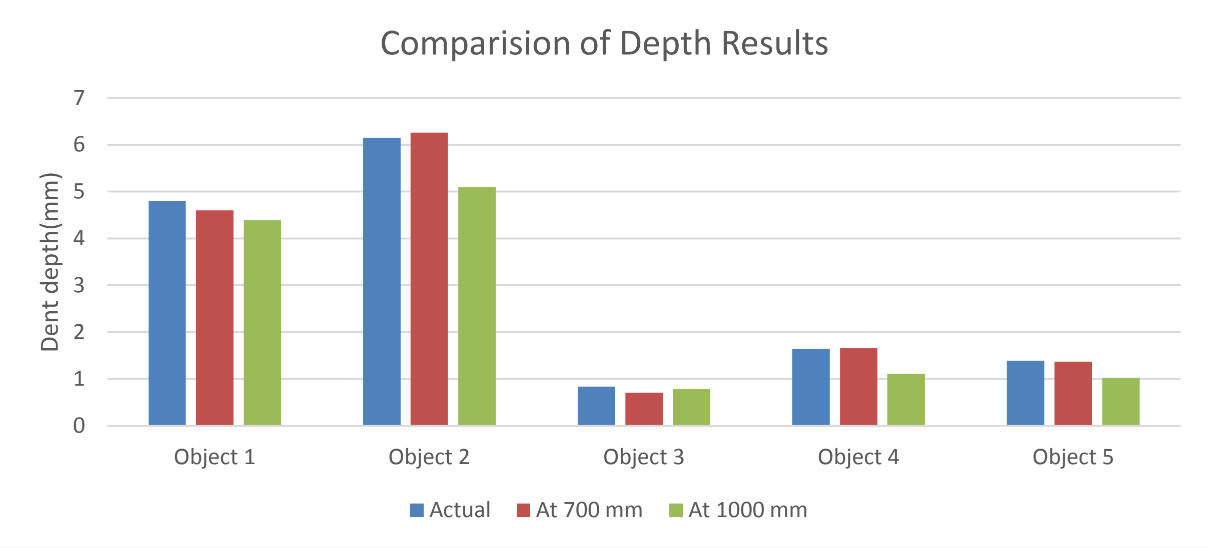



Figure 9. Comparison of depth results

## 5. Conclusion

The studies indicate that Fringe Projection based Profilometry (FPP) can be used for the detection of the surface damages like dents on aircraft surfaces. It is also found that the background removal algorithm Static Background Removal with Fringe Shift is found to be working well, for different surface and different background environments. The studies showed that this method is able to detect and measure dents of size greater than 0.7mm. Studies are under progress for optimizing the local threshold for fully automatic background removal. Correction of the non-linearity of the projector, more robust calibration of the projector and camera, use of different pattern projection can also result in improvement in accuracy. Studies are under progress in these directions.

## References

[1] Davis IL, Siegel M. Automated Nondestructive Inspector of Aging Aircraft. InMeasurement Technology and Intelligent Instruments 1993 Sep 22 (pp. 190-201). International Society for Optics and Photonics.
[2] Nguyen H, Wang Z, Kieu H, Le M. Fast-Speed, High-Accuracy and Real-Time 3D Imaging with Fringe Projection Technique. InAdvancement of Optical Methods in Experimental Mechanics, Volume 3 2015 (pp. 363-369). Springer International Publishing.
[3] Wang Z, Nguyen DA, Barnes J. Recent advances in 3D shape measurement and imaging using fringe projection technique.
[4] Talebi R, Abdel-Dayem A, Johnson J. 3-D reconstruction of objects using digital fringe projection: survey and experimental study. InProceedings of World Academy of Science, Engineering and Technology 2013 Jan 1 (No. 78, p. 720). World Academy of Science, Engineering and Technology (WASET).
[5] Liu Y. Accuracy improvement of 3D measurement using digital fringe projection.
[6] Massa JS, Buller GS, Walker AC, Cova S, Umasuthan M, Wallace AM. Time-of-flight optical ranging system based on time-correlated single-photon counting. Applied optics. 1998 Nov 1;37(31):7298-304.
[7] Hagebeuker DI, Marketing P. A 3D time of flight camera for object detection.
[8] Cui Y, Schuon S, Chan D, Thrun S, Theobalt C. 3D shape scanning with a time-of-flight camera. InComputer Vision and Pattern Recognition (CVPR), 2010 IEEE Conference on 2010 Jun 13 (pp. 1173-1180). IEEE.
[9] França JG, Gazziro MA, Ide AN, Saito JH. A 3D scanning system based on laser triangulation and variable field of view. InIEEE International Conference on Image Processing 2005 2005 Sep 11 (Vol. 1, pp. I-425). IEEE.
[10] Wulf O, Wagner B. Fast 3D scanning methods for laser measurement systems. InInternational conference on control systems and computer science (CSCS14) 2003 Jul 2 (pp. 2-5).
[11] Monserrat, Oriol, and Michele Crosetto. "Deformation measurement using terrestrial laser scanning data and least squares 3D surface matching." *ISPRS Journal of Photogrammetry and Remote Sensing* 63.1 (2008): 142-154.
[12] Schnars U, Jüptner W. Direct recording of holograms by a CCD target and numerical reconstruction. Applied optics. 1994 Jan 10;33(2):179-81.
[13] Schnars U, Jüptner WP. Digital recording and reconstruction of holograms in hologram interferometry and shearography. Applied optics. 1994 Jul 10;33(20):4373-7.
[14] Klette R, Schlüns K, Koschan A. Computer vision: three-dimensional data from images. Singapore: Springer; 1998 Sep 1.
[15] Chen F, Brown GM, Song M. Overview of three-dimensional shape measurement using optical methods. Optical Engineering. 2000 Jan 1;39(1):10-22.
[16] Scharstein D, Szeliski R. High-accuracy stereo depth maps using structured light. InComputer Vision and Pattern Recognition, 2003. Proceedings. 2003 IEEE Computer Society Conference on 2003 Jun 18 (Vol. 1, pp. I-195). IEEE.
[17] Valkenburg RJ, McIvor AM. Accurate 3D measurement using a structured light system. Image and Vision Computing. 1998 Feb 20;16(2):99-110.
[18] Ying L. Phase unwrapping. Wiley Encyclopedia of Biomedical Engineering. 2006.