Information Technology Journal 3 (3): 332-336, 2004
ISSN 1682-6027

Application of New Feature Extraction Technique to PVT Images of Composite Structures

[1]Nidal F. Shilbayeh and [2]Mahmoud Z. Iskandarani
[1]Faculty of Computer Science and Information Technology,
Applied Science University, P.O. Box 41, Amman, Jordan
[2]Faculty of Science and Information Technology, Al-Zaytoonah University,
P.O. Box 911597, Amman, Jordan

Abstract: An effective NDT (Non-destructive Testing) image analysis technique for detecting materials damage and defects existence has been developed successfully and applied to PVT images of composite structures. The developed technique is based on converting an image to its equivalent pixel values and then applying smart reconstruction algorithm to the converted image such that the presence of damage in the composite structure and its extent can be easily verified.

Key words: NDT, damage detection, PVT, image reconstruction, intelligent systems, neural networks

INTRODUCTION

The layered composites are presently the most widespread advanced materials in use. Among them, fiber reinforced composites with polymeric matrices (FRP or laminates) and polymeric sandwich materials, with thin laminate faces and foam or impregnated cores, are in real progress. The structural design and maintenance of composite structures involving these materials need comprehensive evaluation and characterization of mechanical properties and behavior under different loading conditions, in both undamaged and damaged state[1-6].

The marked inhomogeneity and anisotropy of these materials makes them vulnerable to a variety of damages. For this reason, reliable composite structures need adequate NDT/NDE methods along the maintenance activities and knowledge of residual strength/stiffness or service life estimation linked to certain damage patterns. In the end, development of damage tolerant materials may be considered a goal towards further increasing the attractiveness of composite materials in building high tech reliable products. Many NDT methods were proposed and are in use for evaluating the structural integrity of composites, from simple visual inspection to laser shearography, with various sensitivity, versatility and affordability.

In order to have a versatile NDT inspection method, ready to be used in industrial applications, not merely for laboratory research, the prime requirement is to need access on only one side using Pulse Video Thermography (PVT) assisted by computer and intelligent software specifically designed for this purpose.

In this study a new technique in detecting and analyzing the presence of damage in a car composite structure is presented. A composite component is used as a testing example to verify the validity of the technique. The composite structure is impact damaged before testing.

IRT for NDE is aimed at the discovery of subsurface features (such as subsurface thermal properties, presence of subsurface anomalies/defects), thanks to relevant temperature differences observed on the surface with an infrared (IR) camera. Figure 1 illustrates the general concept. IRT is deployed along two schemes, passive and active. The passive scheme tests materials and structures which are naturally at different (often higher) temperature than ambient while in the case of the active scheme, an external stimulus is necessary to induce relevant thermal contrasts (which are not available otherwise, e.g. specimen at uniform temperature prior to testing)[7-11].

Each NDE technique has its own strengths and weaknesses. In the case of thermography these are as follows:

(I) Fast inspection rate
(II) No contact
(III) Safety
(IV) Results relatively easy to interpret
(V) Wide range of applications

Corresponding Author: Dr. Nidal F. Shilbayeh, Faculty of Computer Science and Information Technology, Applied Science University, P.O. Box 41, Amman, Jordan E-mail: shilbayeh@yahoo.com

On the other hand, difficulties are as follow:

(I) Difficulty to deposit uniformly a large amount of energy in short period of time over a large surface.
(II) Effects of thermal losses (convective, radiative, conductive) perturbating thermal contrasts.
(III) Cost of the equipment (IR camera, thermal stimulation units for active thermography).
(IV) Capability to detect only entities (subsurface defects) resulting in a measurable change of thermal properties.
(V) Ability to inspect a limited thickness of material under the surface (thermography is a 'boundary technique).
(VI) Emissivity problems.

Pulse Video Thermography (PVT): Basically, PVT consists of briefly heat the specimen and then recording the temperature decay curve. Qualitatively, the phenomenon is as follow. The material changes rapidly after the initial thermal pulse because the thermal front propagates, by diffusion, under the surface and also because of radiation and convection losses. The presence of a defect reduces the diffusion rate so that when observing the surface temperature, defects appear as areas of different temperatures with respect to surrounding sound areas once the thermal front has reached them. Consequently, deeper defects will be observed later and with a reduced contrast.

In fact, the observation time t is function (in a first approximation) of the squared of the depth z and the loss of thermal contrast *c* is proportional to the cube of the depth:

$$t \sim \frac{z^2}{\alpha} \text{ and } c \sim \frac{1}{z^3}$$

where, α is the thermal diffusivity of the material. These relations indicate two limitations of the IRT: observable defects will generally be shallow and the thermal contrasts will be weak. An empirical rule of thumb says that the radius of the smallest detectable defect should be at least one to two times larger than its depth under the surface.

This rule is valid for homogeneous isotropic material. In case of anisotropy it is more constrained. Various deployments are possible: point inspection (example: laser or focused light beam heating), line inspection (example: heating with line lamps, heated wire, line of air jets (cool or hot), scanning laser), surface inspection (example: heating using lamps, flash lamps, scanning laser); either in reflection (thermal source and detector located on the same side of the inspected component) or in transmission (heating source and detector located on each side of the component). If the temperature of the part to inspect is already higher than ambient temperature due to the manufacturing process for instance, it might be convenient to make use of a cold thermal source such as a line of air jets. Obviously, a thermal front propagates the same way whether being hot or cold: what is important is the temperature differential between the thermal source and the specimen. Another advantage of a cold thermal source is that it does not induce spurious thermal reflections into the IR camera as in the case of a hot thermal source.

Knowledge of the evolution of thermal contrast above the defect in conjunction with equations derived from inverse heat transfer modeling allows retrieving defect parameters such as depth, diameter and thermal resistance. A common definition of the thermal contrast C is:

$$C(t) = \frac{T_j(t) - T_j(t_0)}{T_s(t) - T_s(t_0)}$$

Where, T is the temperature signal, t is the time variable, subscripts I and s refer, respectively to over a suspected defective location (that is in fact any pixel in the image) and over sound areas, respectively. C is computed with respect to before heating temperature distribution at time t_0 (to suppress the adverse contributions from the surrounding environment) and normalized by the behavior of a sound area so that a unit value is obtained over a non defect area. Such kind of analysis is common in the automotive industry. Other common applications of the active PVT scheme are in quantitative subsurface defect assessment (cracks, delaminations, impact damages, disbondings, moisture), thermophysical property evaluation; in all kind of industries[12-17].

System description: Figure 1 illustrates the system used to acquire and process the obtained thermal image. The system consists of the normal PVT system with the addition of the innovated sampling and sequence reconstruction technique which is run under smart environment that provides the overall interpretation.

After capturing of the IRT image, it is sampled, split (sliced) into sequences and statistically regrouped in comparison to intensity thresholds.

Figure 2 shows the capured images for a composite structure over intervals of time, Table 1 illustrates the reconstructed image sequences the captured image at a specific time interval.

Table 1: Pixel sequence restructuring

Pixel grouping and reconstruction				
0-49	50-100	101-150	151-200	201-250
0	1	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	1	1	0	0
0	32	27	0	0
0	10	9	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	1	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
64	13	2	0	0
4861	216	28	0	0
1887	106	2	0	0
4	24	1	0	0
0	23	0	0	0
0	13	0	0	0
0	17	0	0	0
0	11	0	0	0
0	11	0	0	0
0	49	0	0	0
144	38	8	0	0
10466	3208	143	0	0
3826	1236	78	0	0
12	3	19	0	0
0	0	12	0	0
0	0	10	0	0
0	0	7	0	0
0	0	8	0	0
0	0	5	0	0
0	0	79	0	0
4	123	0	0	0
169	7047	0	0	0
60	2525	0	0	0
0	3	0	0	0
0	0	0	1	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	10	0
4	4	0	0	0
46	94	0	0	0
16	30	0	0	0
0	1	0	0	0

Figure 2 and Table 1 deduce that using sequence reconstruction can be very effective in determining the real existence of damage. Following the increase in threshold value from column 1 through column 5 we notice that pixel levels did not return back to its initial value indicating existence of damage.

Images 1 through 4 show the PVT captured images using an IRT camera. The images clearly indicate the presence of damage within the composite structure under test as the damaged area which is a result of an impact has a slower rate of heat wave release. This heat release

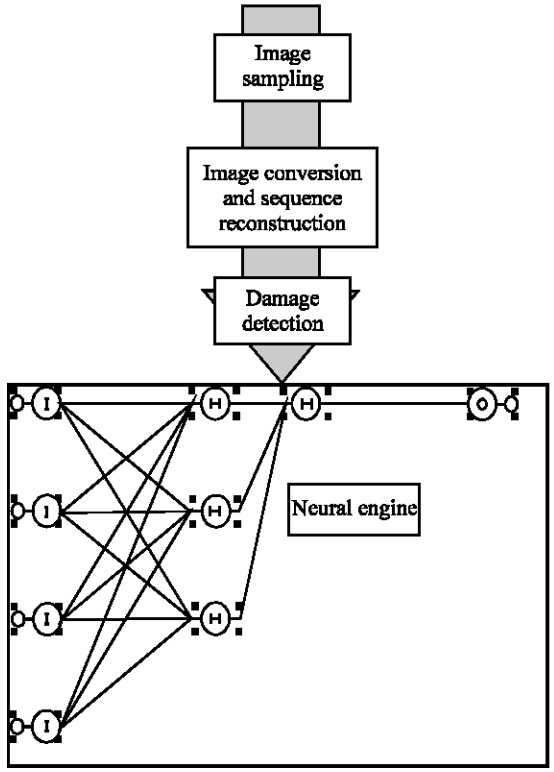

Fig. 1: Intelligent image acquisition and sequence reconstruction system

follows a power law as indicated by fading of the heat wave over time moving from image 1 to image 4. This visual information can be used effectively to predict other damage levels by converting the image into sequences and then reconstructing theses levels to not only determine the level of damage, but also to input the data into a neural engine to enable future damage predictions as a function of component type, composition, thickness and shape. Table 1 proved that the impact damage is localized as the statistical number of pixels in the high level range are negligible.

Conclusion and future work: The PVT method can be used as a viable alternative or screening procedure for the traditional NDT methods. It can detect the same type of defects but does not require two sided access, typically has a fast area scan rate and can be non-contact. A test specimen is pulsed with a powerful externally applied heat source to create a traveling steep temperature gradient within the test specimen. Flaws or irregularities alter the flow of heat, producing temperature contrasts at the surface that are video captured via computer. Thermography techniques can then be applied to the

Fig. 2: Images obtained through PVT

surface image to characterize the flaw and predict performance capability. Possible limitations of PVT include the requirement of uniform surface heating and the need for greater computational speed/memory when defects are multi-dimensional[18-22].

The development of a PVT computer workstation using off-the-shelf components would have the benefits of low cost, ease of use, portability and flexibility of application.

In this study a new algorithm and techniques is provided and validated. This innovated technique is capable of fast analysis of captured PVT images and other image formats, with smart engine based on feature extraction and Neural Networks adding the advantage of damage predication. Further development of the system is possible to improve its accuracy and widen its range of applications[23-25].

REFERENCES

1. Dillenz, A., T. Zweschper, G. Riegert and G. Busse, 2003. Progress in phase angle thermography. Rev. Sci. Inst., 74: 417-419.
2. Favro, L.D., Xiaoyan Han, Zhong Ouyang, Gang Sun, Hua Sui and R.L. Thomas, 2000. Infrared imaging of defects heated by a sonic pulse. Rev. Sci. Inst., 71: 2418-2421.
3. François, G., X. Maldague, S. Valler and J.C. Pierre, 2000. Pulsed phase thermography with the wavelet transform. AIP Conference Proceedings, 509: 609-616.
4. Maldague, X., F. Galmiche and A. Ziadi, 2002. Advances in pulsed phase thermography. Infrared Physics and Technology, 43: S. 175 - 181
5. Huang, J., P.W. Que and J.H. Jin, 2004. Adaptive dynamic focusing system for ultrasonic nondestructive testing of pipeline girth welds. Rev. Sci. Inst., 75: 1341-1346.
6. Osiander R. and J.W.M. Spicer, 1998. Time-resolved infrared radiometry with step heating. A review. Applied Physics Laboratory, 37: 680–692.
7. Spicer, J.W.M., D.W. Wilson, R. Osiander, J. Thomas and B.O. Oni, 1999. Evaluation of high thermal conductivity graphite fibers for thermal management in electronics applications. In: Thermosense XXI, Proc. SPIE, Wurzbach, R.N. and D.D. Burleigh, Eds., 3700: 40-47.
8. Busse, G., D. Wu and W. Karpen, 1992. Thermal wave imaging with phase sensitive modulated thermography. J. Appl. Phys., 71: 3962-3965.
9. Busse, G., 1994. Nondestructive evaluation of polymer materials. NDT and E. Intl., 27: 253-262.
10. Wu, D., A. Salerno, U. Malter, R. Aoki, R. Kochendrfer, P. Kchele, K. Woithe, K. Pfister and G. Busse, 1996. Inspection of aircraft structural components using lockin-thermography, QIRT-96 (Quantitative Infrared Thermography). Eurotherm Seminar 50, Balageas, D., G. Busse, C. Carlomagno (Eds.), Edizioni ETS (Pisa, Italy), pp: 251-256.

11. Balageas, D. and P. Levesque, 1998. EMIR: A photothermal tool for electromagnetic phenomena characterization. Rev. Gén. Therm., 37: 725-739.
12. Tenek, L.H. and E.G. Henneke, 1991. Flaw dynamics and vibro-thermographic thermoelastic NDE of advanced composite materials. In: Thermosense XIII, Proc. SPIE, G. S. Baird Ed., 1467: 252-263.
13. Dinwiddie, R. and P. Blau, 1999. Time-resolved Tribo-Thermography. In: Thermosense XXI, Proc. SPIE, Wurzbach, R.N. and D.D. Burleigh (Eds.), 3700: 358-368.
14. Rantala, J., D. Wu and G. Busse, 1996. Amplitude modulated lock-in vibrothermography for NDE of polymers and composites. In Research in NDE, 7: 215-228.
15. Salerno, A., D. Wu, G. Busse and J. Rantala, 1996. Thermographic Inspection with Ultrasonic Excitation. In: Proc. Rev. Progresses in Quantitat. NDE, Thompson, D.O. and D.E. Chimenti, Eds., NY: Plenum Press, 16A: 5-352.
16. Maldague, X. and S. Marinetti, 1996. Pulse phase infrared thermography. J. Appl. Phys., 79: 2694-2698.
17. Prabhu, D., P. Howell, H. Syed and W. Winfree, 1992. Application artificial neural networks to thermal detection of disbands. Proceedings of the Review of Progress in QNDE., 11: 1331-1382 .
18. Trétout, H., D. David, J. Marin and M. Dessendre, 1994. An evaluation of artificial neural networks applied to infrared thermography inspection of composite aerospace structures. Thompson, D.O. and D.E. Chimenti, Eds., Review of Progress in Quantitative NDE, 14: 827-834.
19. Hagan, H., H. Demuth and M. Beale, 1996. Neural Networks Design, PWS Publishing Company.
20. Santey, M.B. and D.P. Almond, 1997. An artificial neural network interpreter for transient thermography image data. NDT and E Intl., 30: 291-295.
21. Bison, P., S. Marinetti, G. Manduchi and E. Grinzato, 1998. Improvement of Neural Networks Performances in Thermal NDE. American Soc. of Non Destructive Testing Press, 3: 221-227.
22. Maldague, X. and Y. Largouët, 1998. Depth study in pulsed phase thermography using neural networks:Modeling, noise, experiments. Revue Générale de Thermique, 37: 704-708.
23. Foucher, B., 1999. Infrared machine vision, in thermosense XXI, Proc. SPIE, Wurzbach, R.N. and D.D. Burleigh, Eds., 3700: 210-213.
24. Ambrosio, G.d., R. Massa and M. Migliore, 1995. Microwave excitation for thermographic NDE: An experimental study and some theoretical evaluations. Materials Evaluation, 53: 502-508.
25. Sakagami, T. and S. Kubo, 1999. Proposal of a New Thermographical Nondestructive Testing Technique Using Microwave Heating. Thermosense XXI, Proc. Spie, Wurzbach, R.N. and D.D. Burleigh Eds., 3700: 99-103.