Laser Ultrasonic Scanning for Structural Damage Diagnosis

Creation of Ultrasonic Wavefield Images with High Spatial and Temporal Resolutions

This article presents a laser ultrasonic scanning system developed by a research team from the Korea Advanced Institute of Science and Technology (KAIST) and its applications to damage detection and impact localization using Polytec's PSV-400 Scanning Vibrometer.

Fig. 1: The ultrasonic scanning system developed by the KAIST research team.

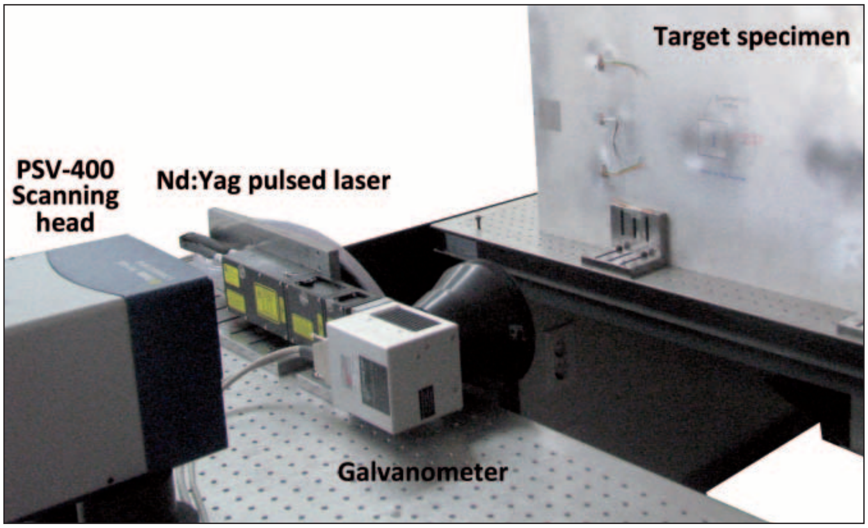


Fig. 3: Multi-layer composite panel provide by Boeing Company.

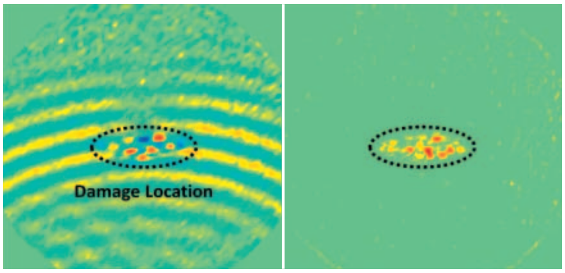


Fig. 4: Delamination detection using the measured wavefield image (left) and additional image processing (right).

The system is composed of a Nd:YAG laser for ultrasonic excitation, a laser Doppler vibrometer for ultrasonic sensing, and galvanometers for scanning. By scanning the excitation laser beam or the sensing laser beam (or both simultaneously), ultrasonic wavefield images can be generated and processed on a target surface to identify and locate defects such as delaminations in composite specimens or cracks in metallic structures. This scanning system can also be used for obtaining training data sets needed for locating impact events within a target structure. This system has a broad range of potential applications because it is able to create ultrasonic wavefield images with high spatial and temporal resolutions without the need for placing transducers on a target structure.

Development of the Laser Ultrasonic Scanning System

Fig. 1 shows the new system developed by the KAIST research group. An ultrasonic wavefield image can be produced by aiming the excitation laser at a fixed point on a target structure and scanning the sensing laser over the target area (Fig. 2a). A reciprocal wavefield image can also be also obtained by fixing the sensing laser beam on a single point and moving the excitation laser over the target scanning area (Fig. 2b). Furthermore, the scanning system can be used together with built-in ultrasonic transducers (Fig. 2c) [1].

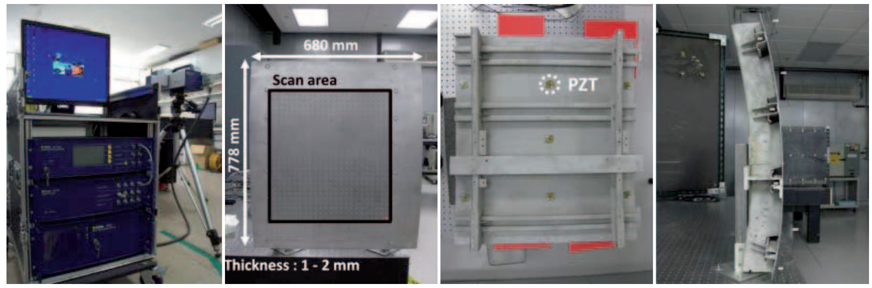
Non-Contact Delamination Detection

This laser ultrasonic scanning system is employed to detect hidden delamination in a multi-layer composite panel provided by the Boeing Company as shown in fig. 3. When propagating ultrasonic waves encounter an internal delamination, they are reflected and scattered in the vicinity of the delamination as shown in fig. 4, left. A standing wave filter was developed by the KAIST research group to further accentuate the effect of the delamination as shown in Fig. 4, right [2].

Laser Ultrasonic Training for Impact Localization

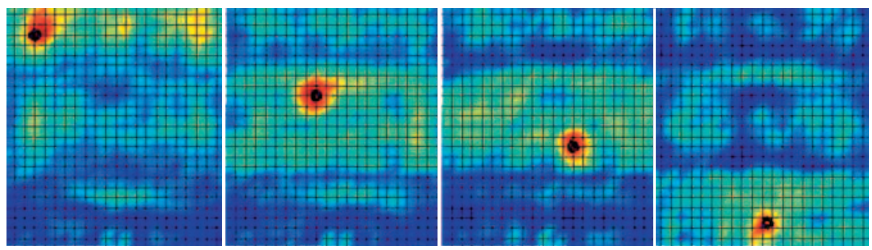
Next, the scanning system is used to pinpoint the location of an impact event within an actual aluminum aircraft fuselage segment provided by the Air Force Research Laboratory in Dayton, Ohio (fig. 5) [3]. The curved test segment has two vertical ribs and three horizontal stiffeners, adding further complexities to the specimen. Seven PZT transducers are mounted on the inside surface of the fuselage. First, an impulse response function (IRF) between an impact location and a PZT transducer is approximated by exciting the sensor and measuring the response at the impact location using the PSV-400. Then, training IRFs are assembled by repeating this process for various potential impact locations and PZT transducers.

Once an actual impact event occurs, the impact response is recorded and compared with the training IRFs. Finally, the training IRF that gives the maximum correlation is chosen from the training data set, and the impact location is identified. The correlation maps in fig. 6 demonstrate that the impact events are successfully identified in spite of the complexity of the specimen.



(a) PSV-400 (b) Front view (c) Rear view (d) Side view

Fig. 5: An aluminum fuselage for impact localization tests.



(a) Test 1 (b) Test 2 (c) Test 3 (d) Test 4

Fig. 6: Impact localization results obtained from actual impact events. Red: likely impact locations; black: actual impact locations.

Conclusion

The newly developed laser ultrasonic scanning system is advantageous for damage diagnosis because no transducers need to be placed on a target structure and damage can be automatically detected without using any baseline data. By relaxing the dependency on previous baseline data, the proposed technique can minimize false alarms due to changing temperature and loading conditions. In addition, the scanning system is used to simplify the training process often required for impact localization.

Acknowledgements

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References

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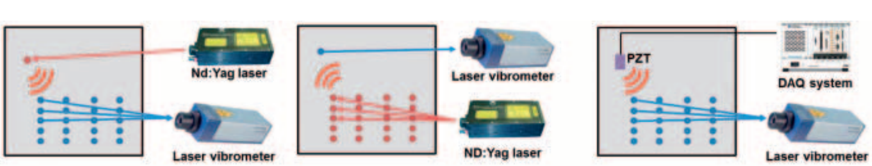

Fig. 2: Three different scanning schemes: (a) fixed-point excitation and sensing scanning, (b) fixed-point sensing and excitation scanning, and (c) surface-mounted PZT excitation and sensing scanning.

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