because the debonding damage makes the force experienced by the material much larger by the designated force [1]. Although this defect can cause a prone problem on the structure, the detection of adhesive debonding is challenging because it often occurs between laminates and invisible from external surfaces. To overcome this problem, several non-destructive testing (NDT) has been developed. The common available NDT techniques for debonding damage include optical fiber [6-8], piezoelectric [9-12], and laser ultrasonic [13-16]. Among these techniques, the laser ultrasonic technique uses ultrasonic waves of short wavelength and high frequency on detecting debonding damage. It also popular since laser ultrasonic is couplant free, non-contact, and allow long range sensing from the target structure. The visualization of debonding damage also possible to be done without using any baseline data from pristine condition [16]. One issue of a full non-contact laser ultrasonic technique is that the power level, laser duration and laser beam size need to be carefully tailored because high laser power density above a certain threshold will cause damage to the target structure, such as surface melting, vaporization, ablation and plasma phenomena [17]. Due to the restricted laser power, the ultrasonic response can remain detectable only within a limited distance for most of the target structures. In laser ultrasonic scanning techniques, limited laser power level also limits the size of the scanning area as well.

This study develops a new synchronized laser scanning technique and uses this technique for detecting hidden debonding damage. In the scanning area, this new technique synchronously moves the two laser beams used for ultrasonic wave generation and detection, and the distance between the excitation and sensing points can be adjusted for different target structures. The proposed technique offers the following advantages: (1) since the distance between the excitation and sensing points is kept to be short and constant, the proposed technique is less affected by the limitation of the laser power level and can cover a much larger scanning area; (2) because of the improved signal to noise ratio achieved by the short and constant distance between the excitation and sensing points, the total scanning time can be reduced by less time averaging; (3) through spatial comparison, damage can be detected and visualized without relying on baseline data obtained from the pristine condition of the target structure; (4) the proposed technique is validated for hidden debonding damage detection in bonded aluminum sheets.

Synchronized Laser Ultrasonic Scanning System

This section develops a full noncontact laser ultrasonic scanning system to identify the debonding problem on the specimen. The main system of the laser ultrasonic devices can be split into two systems: an ultrasonic wave generation system and a sensing system. A pulse laser and laser Doppler vibrometer are used to generate and sense the ultrasonic wave. A complete noncontact laser ultrasonic scanning system is developed and adopted in this study [18]. The system is mainly composed of a Q-switched Nd:YAG pulse laser, an LDV and a control unit. The ultrasonic waves are created through the thermal expansion of an infinitesimal area heated by the pulse laser. Then, LDV measures the generated ultrasonic responses based on the Doppler effect of light. This system set-up has been widely used with two scanning strategies: (1) fixed laser excitation and scanning laser sensing and (2) fixed laser sensing and scanning laser excitation as illustrated on the Figure 1.

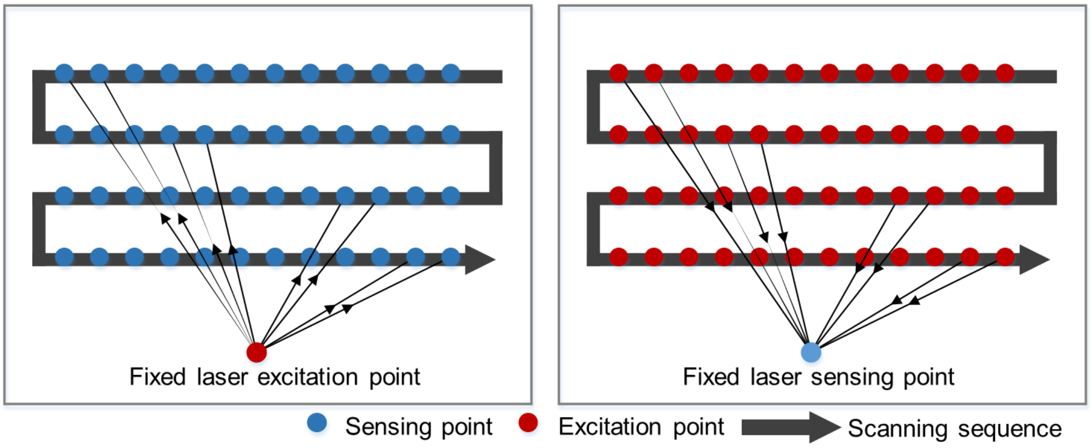

Figure 1. Conventional laser ultrasonic scanning strategies, fixed laser excitation and scanning laser sensing (left), scanning laser excitation and fixed laser sensing (right).

As an example, An et al adopted the second strategy to visualize a crack. The overall working principle are like [18]: First, virtual grid points for excitation on the target structure are created, and the sequences of excitation points are predetermined. Then, the control unit transmits a trigger signal to the Nd:YAG pulse laser to shoot the excitation laser beam to the first determined excitation point. Simultaneously, the same trigger signal also transmitted to the LDV to activate the data acquisition. Then, the control unit sends a signal to the galvanometer so then the laser excitation point moves to the next predetermined point. By repeating the ultrasonic excitation and sensing to all the determined scanning points, an ultrasonic wavefield image can be reconstructed over the target surface and processed for damage detection.

As the goal of the system is to visualize a clear ultrasonic wave propagation, a good signal to noise ratio is needed. Hence, higher power lasers for both ultrasonic wave generation and detection are usually being used to improve the signal to noise ratio. But, if the laser power exceeds a certain threshold determined by the material characteristics of the target structure, it will form a damage on the specimen surface [17]. The distance between laser excitation point and laser sensing point also need to be controlled to obtain a good signal to noise ratio. This distance limitation between those points lead to a limited size of the scanning area. Another way to improve the signal to noise ratio is by utilizing a great number of time averaging of the response signals. But, as the number of time averaging get greater and greater, the data acquisition process will take much more time.