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AIR-COUPLED ULTRASONIC SYSTEM FOR NON-DESTRUCTIVE EVALUATION OF WOODEN PANEL PAINTINGS

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Abstract

Nondestructive and non-intrusive methods are being developed to detect voids, hidden cracks, and fine fractures in wooden art objects. Such anomalies are often the cause of premature failure. The transportation of panel paintings (paintings on wood) is an area where new techniques are needed. In particular, determining the physical integrity and baseline characteristics of art objects is critical to deciding whether they can be transported to exhibitions.

Air-coupled ultrasonics is a nondestructive evaluation technique that may be useful for establishing the structural integrity of panel paintings. Traditional ultrasonic methods require the use of coupling liquids such as water, oil, and grease. The advantages of using other, non-contact ultrasonic methods in the art conservation field are obvious. The method has advantages over radiography for finding cracks at certain angles in the wood and delaminations between layers of a painting. Also, unlike radiographic techniques, ultrasonics does not present a health hazard.

The air-coupled system currently under development at the Johns Hopkins University, is especially configured to allow investigations of wooden panels. The system is capable of producing two-dimensional representations (C-scans) of a panel painting. Special signal processing methods are used to inspect inhomogeneous materials such as wood. In particular, methods are being developed to enable the system to distinguish potentially harmful anomalies from inhomogeneities natural to wood, including growth rings.

1 INTRODUCTION

The presence of cracks, voids, and delaminations in art objects poses many transportation difficulties. Unfortunately, many of these internal anomalies are not visible externally. Consequently, assessment of the transportation risks to art works is difficult Ultrasound is a technique which can potentially find delaminations and cracks which radiography techniques cannot. Traditional ultrasound has used couplants such as water, oil, and grease, all of which are inappropriate for art objects. The need for a non-contact ultrasonic method for use in the art conservation field has been discussed before /1/. Research in air-coupled ultrasound has been pursued to further refine the air-coupled inspection technology, which was initially developed for aerospace applications. Aircoupled ultrasound will permit monitoring the internal condition of art objects in a nonintrusive manner.

In this paper, the features of an air-coupled ultrasonic system are described. The system is being especially adapted for the art conservation field. In particular, the special problems presented by the grain of the wood are being addressed.

In the past, air has not been generally used as a coupling medium because of low signalto-noise ratios. This was caused primarily by the high acoustic mismatches between solid materials and air. Significant improvements have been made with the current air-coupled inspection systems. The progress has been primarily in the area of transducers and support electronics.

There is a considerable body of literature on the subject of air-coupled ultrasound /2-10/. Historically, the main obstacle to the use of air-coupled transducers was the misconception that the attenuation in air is very high. It is actually only 20 dB/m at 600 kHz and 20-C. There is still a substantial signal strength loss between a solid sample and the air, as the acoustic impedance of the material is five orders of magnitude larger. This is one of the major limitations of the air-coupled ultrasound technique. This limitation can now be overcome through the judicious selection of the critical components, including transducers, transmitting and receiving electronics, and appropriate signal processing methods.

The use of ultrasound in art conservation is not a new idea. Conservation scientists have performed ultrasonic tests on a variety of materials. For instance, ancient masonry buildings /11/ have been tested before and after repairs to determine the penetration and diffusion of grout, and to measure the degree of strengthening effected in masonries through repair. In this work, correlations were found between the sound transmission data, aging tests, changes in the mechanical properties, and flaws.

The calcerous stone monument "St. George and the Dragon" was examined with ultrasound by Yakhont and Pimenov to determine the lithogical composition and other characteristics of the stone, as well as the existing damage /12/. The possibility of using ultrasound to test metal castings in order to show their condition and thickness has been discussed /13/. Measurements taken on wetted archaeological woods have shown the homogenization and strength of waterlogged wood /14/. Ultrasound was also used in conjunction with thermography to investigate whether Leonardo da Vinci's lost painting "The Battle of Anghiari" could be present beneath six large murals by Georgio Vasari /15-16/.

Previous work with air-coupled ultrasound has been limited to one-dimensional line scans of various specimens containing both real and ardficial flaws. The specimens included wooden panels 3.5 cm thick with voids and cracks /17-18/, and hardboard samples covered with gesso, with delaminations between the two materials /19/. This paper describes the operadon of an air-coupled ultrasound system that is capable of execudng two-dimensional scans.

2 INSPECTION CONCEPT

Large scale areas of the wooden panel need to be mapped nondestrucdvely in order to determine the extent of internal anomalies. The results should be displayed so as to give a clear representadon of the internal condidon of the panel.

The physical configuration of an air-coupled system is shown in Figure 1. When the ultrasonic signal direction is at right angles to the planar crack or delamination, the anomalies are easy to detect. On the other hand, when the flaws are normal, radiography can more easily detect them.

Figure 2 shows the inspection configuration used at the Johns Hopkins University and the National Institute for Standards and Technology to inspect wooden panels and plates. During the analysis, a transducer is positioned on either side of the sample. One of the transducers is used as a transmitter and the other as a receiver. In an unflawed sample, the signal has a condnuous path along which to travel; however, the signal is stopped when it encounters actual air-pockets, indicadve of cracks, delaminations, or voids. This loss of signal is used as a discriminant of internal anomalies.

Changes in the ultrasonic wave that passes through the material are representative of inhomogeneides. Variations have been reported in the intensity of the ultrasonic signal because of the changing grain orientation in wooden samples /20-21/. The tesdng method must recognize variations in the ultrasonic signal which are due to natural and non-harmful anomalies such as the density differences due to growth rings. Special experimental arrangements which overcome this problem by using discriminant algorithms have been described by McDonald /22/. In that case, the transducers were water-coupled. It is believed, however, that the methodology developed by McDonald will be applicable to the system using air-coupled transducers.

3 EXPERIMENTS

Figure 3 shows a block diagram of a digitally controlled ultrasonic measurement system which can operate between 50 kHz and 5 MHz. The measurement system contains a broadband receiver, gated radio frequency (RF) amplifier, RF synthesizer, dming circuitry, mixer, gated superheterodyne receiver, gated integrators, and a 12 bit analog to digital converter (A/D converter). The ultrasonic measurement system is linked with a commercial C-scanning system which controls the posidon of the transducers in the XY-plane.

The experimental configuradon is shown in Figure 2. The transducers are mounted on rods that have 360- rotadon around the verdcal axis. The rods can be positioned at any distance from each other, within 20 cm, and may be locked into posidon along a horizontal beam. The beam can also be rotated 360-. This configuradon will allow for investigations of the wood, with the transducers at different distances from each other and at many angles with respect to each other. The entire transducer-holding fixture is attached to the motorized C-scanning system.

Initially, the appropriate frequency range and experimental set-up for wood and wood products of different densities and thicknesses are determined. Similar tests are then performed on wood layered with materials typical of panel paintings, for example paint and gesso, an animal hide glue and chalk. After this, various flaws can be introduced into the sample and appropriate frequencies for finding them are determined. This work provides the basis for examining actual paintings on wood.

4 SUMMARY AND RECOMMENDATIONS

An air-coupled ultrasonic system has been integrated at the Johns Hopkins University for inspecting wooden panels. The system was designed to map flaws in wooden panel paintings, which could not be detected by other techniques such as radiography. Examples of such flaws include delaminations and planar cracks.

The ability to penetrate solid wooden panels with a sufficient signal to noise ratio has been demonstrated in previous work. Emphasis needs to be placed on overcoming unpredictable signal amplitude variadons caused by the presence of growth rings and other inhomogeneities. The algorithm that will be used is based on methods developed earlier by Kent A. McDonald who used water-coupled transducers. Further work, therefore, is needed in the area of algorithm design to improve the resolution and the flaw detection reliability of the system.

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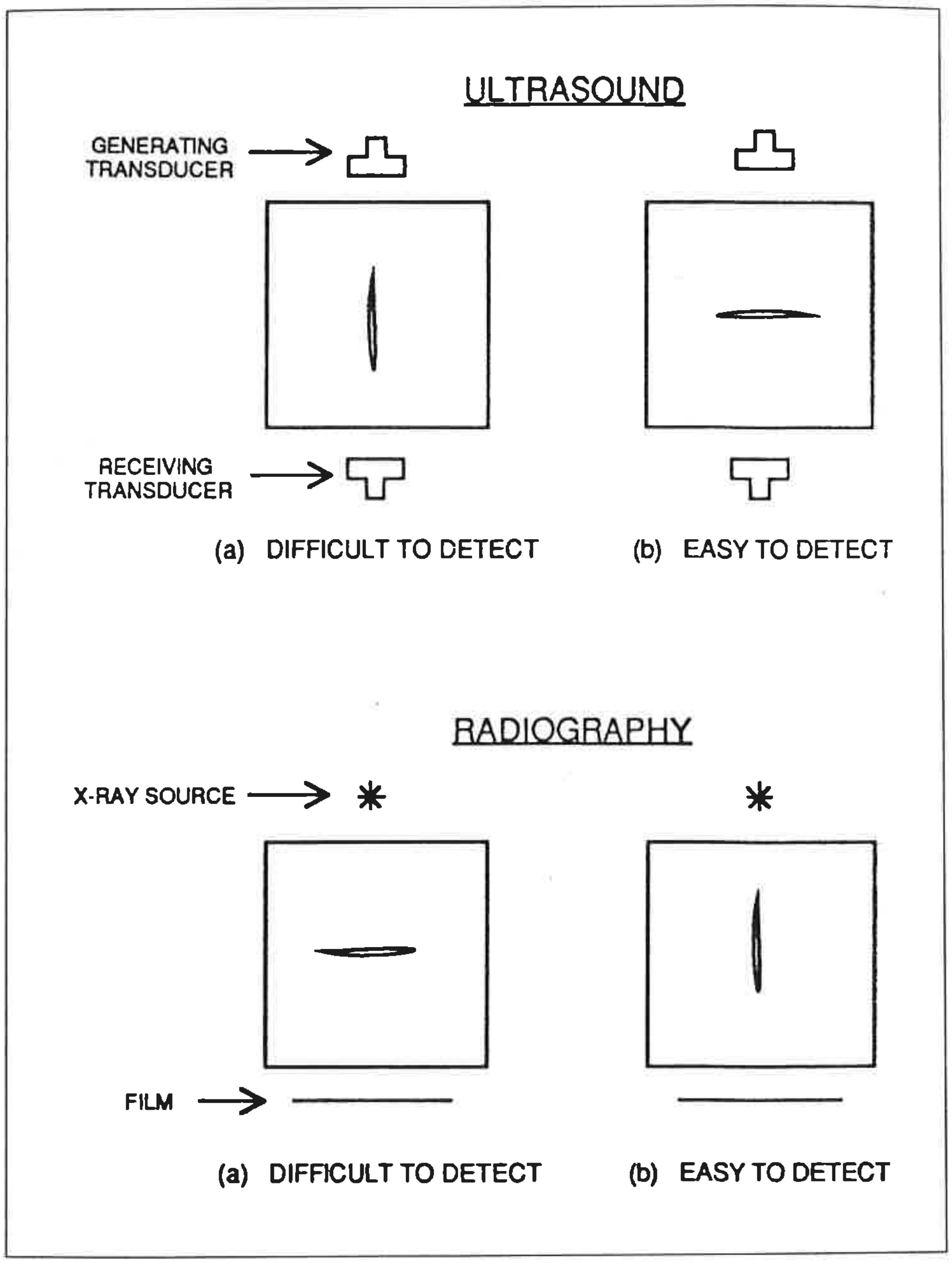

Fig. 1 - Principles of flaw detection using ultrasonics and radiography.

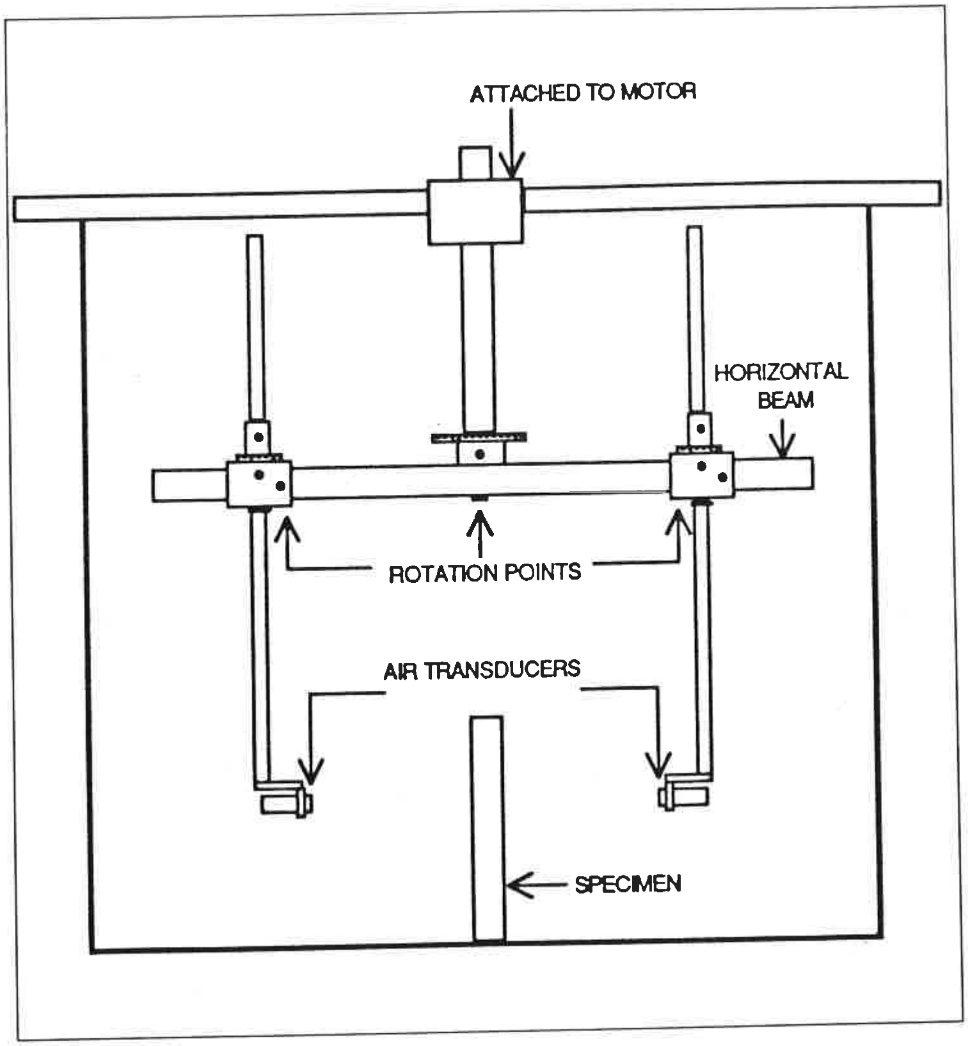

Fig. 2 - Physical configuration for air-coupled ultrasonic inspection system used to detect flaws in wooden panels

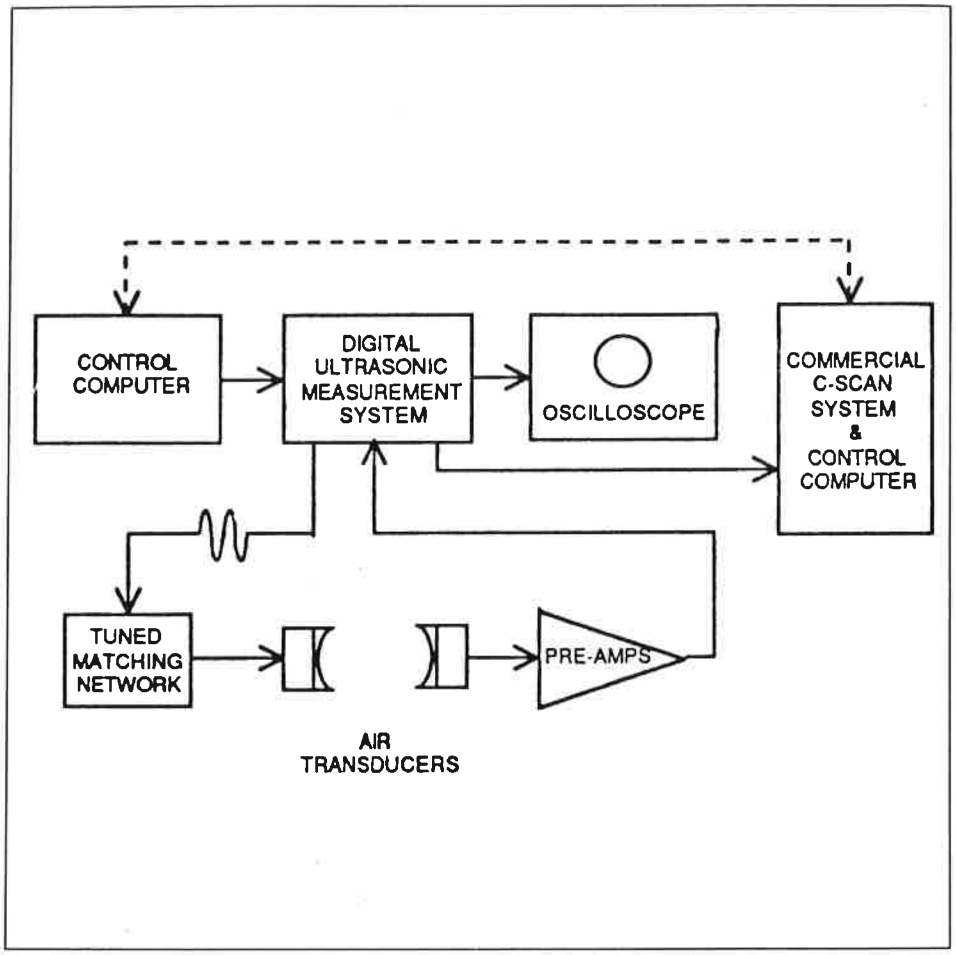

Fig. 3 - Block diagram for air-coupled ultrasonic system