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ULTRASONIC THICKNESS MEASUREMENTS USING MACHINE LEARNING

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ABSTRACT

Thickness measurements using ultrasonic contact test is a well know nondestructive evaluation technique. However, its implementation in a robotic system with closed-loop feedback control for artificial intelligent measurements requires precise information of positioning and force of the ultrasonic probe. In this work, we describe an ultrasonic probe developed in our lab that uses a semispherical soft membrane made from an elastomer. The aim is to develop a methodology for positioning and force control based on ultrasonic signal information process using sparse matrix optimization and Fourier analysis techniques. The results show that the proposed methodology allows a fine tuning of the probe pose with high sensitivity to load and misalignment to get accurate thickness measurements.

Keywords: ultrasonic signals, basis pursuit, thickness measurements

1. INTRODUCTION

The implementation of a dexterous robotic arm to perform an ultrasonic inspection has still important challenges that need to be addressed. Autonomous thickness measurements and defect detection involves an adequate probe positioning and signal conditioning. Correct ultrasound transmission can only be achieved by controlling the real contact area and applied pressure between the probe and the test object. However, surface roughness, non-uniform contact pressure distribution and nonlinear mechanical behavior of the materials makes difficult to get good contact conditions.

In robotics, hemispherical end-effector with soft contact instead of a rigid one has been studied for manipulation and grasping tasks [1]-[4]. A soft end-effector offers advantages such as, distributed contact forces, better control of gripping forces, and a large friction coefficient. Thus, the use of a hemispherical soft probe in dry contact equipped with an ultrasonic sensor could provide an efficient mean for transmission of ultrasonic energy into the test object and improve manipulation and exploration tasks. To accurate assess the thickness or location of a discontinuity using time of flight (TOF) many techniques such as filtering, wavelet transform1 and_ analytical methods have been reported [5],[6].

The objective of this work is twofold: first, to study the relation between spectral signature of the reflected energy from contact interface as a function of force and misalignment; and second, to develop a methodology for signal conditioning based sparse matrix and basis pursuit optimization for accurate thickness measurements.

2. MATERIALS AND METHODS

The experimental platform consists of a '6 DOF robotic arm (FIGURE 1). It is used to control the applied force. The system's end effector incorporates a wrist force/toque sensor (ATI, Mini40), and an ultrasonic transducer hosted by a solid hemispherical probe made of a soft elastomer (dry couplant silicone manufactured by Sonemat Inc.); a depiction of the probe is shown in Figure 1 b. The hemispherical soft silicone used as end effector has a radius of curvature (*R*) of 16 *mm* with a Young modulus (*E*) of 0.173 MPa, acoustic longitudinal velocity c_l=1.03 *mm/*µsec. A piezoelectric transducer with a frequency of 5 MHz is attached to the soft semispherical probe coupled by a water column (length=17.5mm) which generates the ultrasonic signal that interacts at the interface between the soft probe and the surface of the object under inspection (Figure 4b). The transducer is connected to a pulser/receiver device; and 100 *Mega samples/sec* digital oscilloscope gathers and transmits the data obtained from the piezoelectric to the PC through USB port. The force sensor reads and sends the force data to the PC through a National Instruments data acquisition card. The robotic arm is a by a 6-DoF robot KUKA KRC1 manipulator. a costumed made ultrasonic probe attached to a force sensor ATI Mini-40 FT connected to a National Instrument NI DAQ PCI-6221 board were used.

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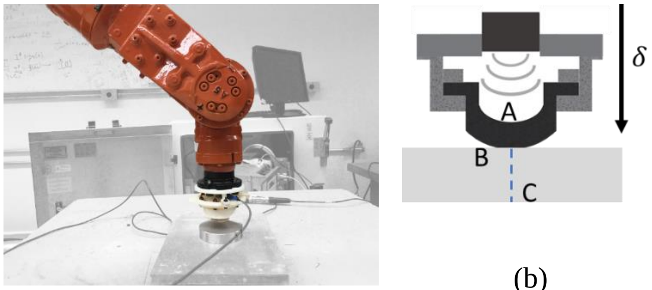
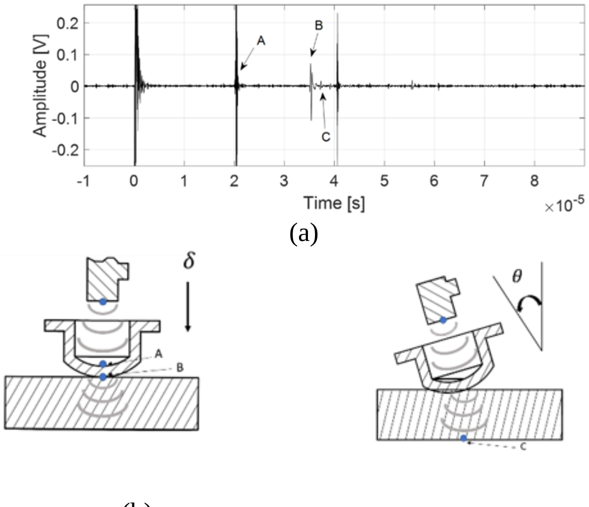


(a) (b)

FIGURE 1: (a) ROBOTIC ARM EQUIPPED WITH THE SOFT CONTACT PROBE; (b) SCHEMATIC DESCRIPTION OF ULTRASONIC INTERACTION WITH A TEST OBJECT.

3. RESULTS AND DISCUSSION

A typical time trace of a pulse-echo recorded signal from the ultrasonic probe is shown in figure l. The echo signals were identified as: echo from the interior face of the elastomer hemispherical shell (A), echo from the exterior of the elastomer (B) and signals from the bottom wall of the object under test (C) (see Figure l b,c).



(a)

(b) (c)

FIGURE 2: a) TYPICAL TIME RECORD AFTER SIGNAL GETS INTO CONTACT WITH A TEST OBJECT. SCHEMATICS OF THE PROBE END-EFFECTOR; WITH a) NORMAL ; b) OBLIQUE ORIENTATION WITH RESPECT TO THE OBJECT'S SURFACE.

In order to study the effect of load and pose of the end effector on the frequency distribution of the signals (spectrum) of the reflected signal from the contact interface (B) (see Figure 5), experiments were carried out at a range of 0-2N and orientation angles in the range of 0-2degrees. The results of reflected spectral amplitude of signals from the contact interface (B) at normal incidence and oblique incidence are given in Figure 6a and b respectively.

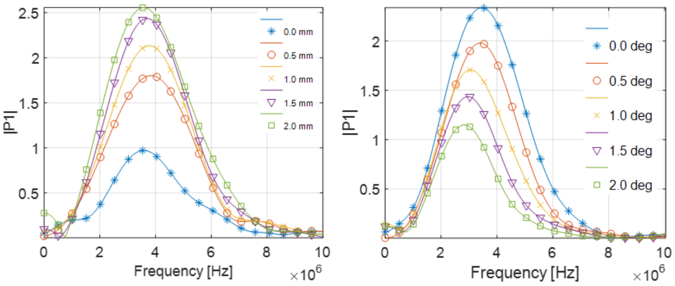


FIGURE 3: RESULTS OF FOURIER TRANSFORM ON THE SIGNALS FROM B FOR A) NORMAL AND B) OBLIQUE SENSOR'S POSE.

A comparison between the observed frequency shift is given in FIGURE 3. For a small misalignment, the maximum value of frequency shift decreases consistently with the angle of the probe. This behavior could be explained by a shifting of main energy location due to misalignment aiming to the like-crack gap form between the elastomer probe and the object surface as a change in the interfacial stiffness of contact interface [7].

The steps of the methodology for the robotic thickness measurements were: 1) Detection of the onset of contact based on the ultrasonic signal amplitude; 2) Denoising of the signal with basis pursuit (BP); 3) finding correct orientation based on spectral analysis; 4) Increase load; 5) finally, to measure TOF on denoised signal and find thickness. The process is carried out in line using the robotic arm.

Thickness measurements on the test sample with varying step thickness were carried out. An example of the results for a thickness is given in FIGURE 4.

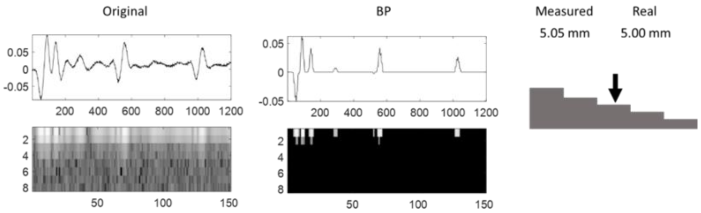


FIGURE 2: a) EXAMPLE OF RESULT OF BASIS PURSUIT (BP) DENOISING FOR THICKNESS MEASUREMENTS OF THE TEST SAMPLE (RIGHT SIDE). THE PLOTS ON THE TOP ARE THE ORIGINAL AND RECONSTRUCTED TIME DOMAIN SIGNAL. THE BOTTOM PLOTS ARE THE CORRESPONDING SPECTROGRAM TRANSFORMATION OF THE SIGNALS.

In Table 1, the results of thickness measurements show that the implemented signal processing using denoising and basis pursuit allow to have an accurate measurement of the thickness.

TABLE 1: RESULTS OF THICKNESS MEASUREMENTS

Calibration step	Estimated	Direct	Difference
1	7.11	7.06	0.05
2	5.62	5.50	0.12
3	5.08	5.00	0.08
4	3.46	3.40	0.06
5	2.51	2.50	0.01

4. CONCLUSION

A position and force control methodology for an ultrasonic probe equipped with a soft contact probe to carry out dry contact thickness measurements was discussed. It was found that a semispherical probe with soft contact allows a controlled increase of the contact force and energy transmission. Alignment and contact force were controlled based on time frequency analysis and basis pursuit denoising allowing signal representation with only relevant feature to perform thickness measurements.

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