Using Ultrasonic Tactile Sensor for Materials Recognition On Thin Wall Objects in Assembly Lines

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Abstract

One of the important tasks of robots is object recognition without human intervention. The main aim of this study is developing an ultrasonic sensor to recognize the materials of thin wall objects. This study is based on the physics rules in ultrasonic that ultrasonic velocities, longitudinal and transverse velocities, are altered in different materials because of differences in their elastic modulus. Obviously applying forces by robot to an object walls should be in harmony with their elastic modules and kind of materials, especially thin wall objects. The novelty of this research is related to using an especial probe for omitting the effect of near field by using a delay line made of a column of water in plastic membrane. The ultrasonic sensors with delay lines make it possible to detect the material of thin wall objects. The measured ultrasonic velocities are compared with standard ones to detect objects materials. The results of experiments are very promising and confirm that it is possible to detect plates made of St 11, copper, with 1 m thickness.

Keywords: Ultrasonic velocities, longitudinal velocities, transverse velocities, object recognition

1. Introdoction

1.1 object recognition

Industrial automation and robotics are at a high demand in the different industries. The robots have been used in many different industries because of their high accuracy and repeatability. In 1891s robots were used for general tasks such as machine tending, material transfer, painting, welding which does not require high accuracy. In 1881s market analysts predicted that industrial robots will become increasingly vital in applications which require high precision and accuracy [1]. It is predicted that in the close future that robots will increasingly integrate themselves with human beings and their environments. To achieve this aim, robots need to acquire information about the environment and its objects [1]. In many industries, object recognition is widely used for inspections, assembly lines and manipulation tasks [3, 4]. So robots for different purposes, such as navigation and assembly lines should be able to recognize different objects from each other [5, 6] and the current state of technology provides different ways to achieve this task. Researchers have tried to use image processing to detect objects.

Robots are program to distinguish the different objects according to differences in colors and forms. However, there are a number of difficulties, not only cannot robots distinguish and separate objects with same colors and forms but also, the lightning conditions of the environment can greatly affect the object recognition ability [7].

Besides, algorithms for object recognition by image processing have many limitations because of the changes in illumination, occlusion, scales and positions [5]. Therefore several sensors have been developed to suit those purposes. Tactile sensors [9] are commonly defined as a device that can measure a given property of an object. Researchers develop a robot with haptic sensors for discrimination of material properties. The hand of robot is covered with a set of haptic sensors on the palm and the fingertips tactile sensors have been used in the past to explore the 3D shape of objects [8]. In terms of robotic manipulation, a fully integrated force/tactile sensor has been developed by Hetzel Leibe Levi & Schiele [11]. Micro Tactile Sensor (MTS) has been fabricated to determine the physical properties, Young's Modulus, of living tissue [11]. Meanwhile different mechatronic principles have been explored in the past, such as pressure-sensitive conductive polymers [11], piezo-resistive sensors [13], piezo-electric vibration sensors and temperature [14]

Ultrasonic sensors have often been used in the development of sensory systems for robotics applications [15]. Ultrasonic-based measurements are extensively used both in research and production field, spanning in endless applications such as environment sensing of autonomous mobile robots, high definition imaging of biomedical devices, precise location of micro-flaws in materials, accurate estimation of the level of flammable fluids or dangerous rivers, and so on [16]. In most cases, these sensory systems are based on the determination of times of flight (TOF) for signals from every transducer and ultrasonic sensors are used for the measurement of distances in the range of a few millimeters to a few meters for different tasks [17] estimating the form of objects is possible by using this sort of sensors. Another sort of ultrasonic sensors that are well known as ultrasonic transducers are frequently used in nondestructive testing. Ultrasonic transducers are able not only detect the defects such as crack in objects, but also they have a potential to measure the mechanical properties of materials. Studies show that measuring elastic modules and estimating tension strength and even hardness, is possible by using ultrasonic transducers [16]. It is clear that ultrasonic sensors are promising technology in robotics qua not only can they recognize different materials from each other's, but also they can estimate the mechanical properties of objects.

However, robotic industries face some difficulties in using ultrasonic sensors especially in some applications one of which is in thin wall objects. On the one hand robots should be enable to recognize the material of thin wall objects to estimate the safe amount of exerting force to the thin walls, on the other hand, identification of kinds of materials in thin wall objects by using ordinary ultrasonic sensors is difficult. And the difficulty is related to dead zone. Ultrasonic wave in dead zone can not reflect any valuable data. One the one hand, high frequency probe should be used for testing thin wall objects and another hand, ultrasonic wave with high frequency lead to creating a zone that is called dead zone.

It is logical that there should be a harmony between the amounts of applying force by robots and the elastic module of materials when the robot arms exert a force on the object walls, especially thin wall objects. So identifying the elastic modules of objects will be helpful for determining the amount of forces that should be exerted to the objects. So that developing ultrasonic sensors in robotics with the potential of testing thin wall objects would be useful.

The main aim of this study is developing an ultrasonic sensor to recognize the materials of thin wall objects. As ultrasonic sensors determine the materials of object according to ultrasonic velocities, firstly, the correlation between ultrasonic velocities and elastic modulus is discussed and then the limitation of using ultrasonic sensors in thin walls and the structure of developing ultrasonic sensor will be explained.

1.2 correlations between ultrasonic wave and elastic module

As a sub category of acoustics, ultrasonic deals with the acoustics above the human hearing range (the audio frequency limit) of 11 kHz [17]. So, Ultrasonic is defined as that band above 11 kHz [16]. The ultrasonic wave (UW) can be generated with the mechanical, electrostatic, electrodynamics, electromagnetic, magnetostrictive effect, piezoelectric effect, and laser methods [11]. On the basis of propagation mode, there are four types of ultrasonic velocities, as longitudinal, transverse, surface and lamb wave velocity.

Ultrasonic velocity is related to the elastic constants and density of material. Different materials have different elastic constants, so that objects made of different materials can be distinguished from one another by measuring elastics constants. And also, the elastic constants in the materials can be determined by measuring the velocity of longitude and transverse waves [19].

The elastic constants of material are related with the fundamental solid state phenomenon such as specific heat interatomic forces, co-ordination changes etc., and also with the impact shock, fracture, porosity, crystal growth and micro structural factors (grain shape, grain boundaries, texture and precipitates etc.).

Therefore, studying the propagation of ultrasonic waves in materials is a canny tool for determination of elastic constants, which provides data to distinguish different materials from each other. The determination of longitudinal and transverse wave velocities in an isotropic material makes it possible to approximately calculate the elastic constants using the following formulate (ASTM E484-85 1885) [18]:

$$\sigma = \frac{(1-2(V_s/V_l)^2)}{2\times(1-(V_s/V_l)^2)} \tag{1}$$

$$E = \frac{\rho V_s(3{V_l}^2 - 4{V_s}^2)}{{V_l}^2 - {V_s}^2} \tag{2}$$

$$G = \rho {V_s}^2 \tag{3}$$

$$K = \rho({V_l}^2 - 4/3({V_s}^2) \tag{4}$$

Where are the Poisson's ratio and E, G, and K, are the Young's, transverse, and bulk module, respectively. Vl and Vs. are the ultrasonic longitudinal and transverse wave velocities, respectively. The above equations are usually used for material characterization by ultrasonic wave velocity measurements as well as for studying the effect of metallurgical parameters such as precipitation on metals in isotropic materials (ASTM E484-85 1885) [18].

Measuring the ultrasonic velocity involves determination of time of travel between the first and the second back surface reflection and dividing it by the distance traveled by ultrasound as shown in the figure 1. The accuracy of these measurements depends on the accuracy with which time of travel and the thickness of the components are measured [11].

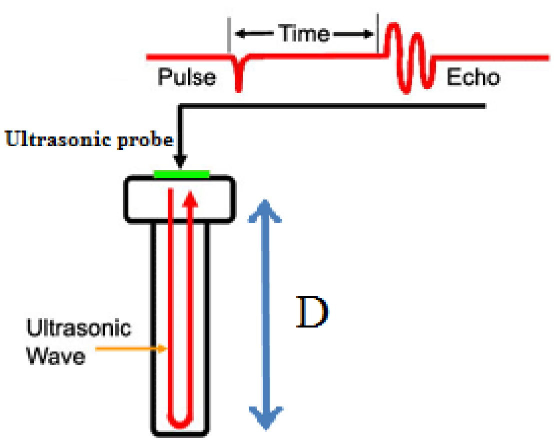

Fig.1. Ultrasonic Pulse-echo technique

Longitudinal wave normal beam probe should be used for measuring longitudinal velocity .The value of unknown longitudinal velocity in the test specimen shall be calculated as follows:

$$V = \frac{(A_k n_1 t_1 v_k)}{(A_1 n_k t_k)} \quad (5)$$

Ak = distance from first to Nth back echo on the known material, m (in.), measured along the baseline of
the A-scan display
nl = number of round trips, unknown material t l= thickness of unknown material, m (in.)
vk = velocity in known material, m/s (in./s),
Al= distance from the first to the Nth back echo on then known material, m (in.), measured along the baseline of the A-scan display,
nk= number of round trips, known material, and tk= thickness, known material, m (in.).

In similar way the unknown transverse velocity (Vs) may be determined by comparing transit time of transverse wave in an unknown material to the transit-time in a material of known (V). The measurements shall be carried out in same way as described for longitudinal wave. The normal beam transverse wave probe shall be used for this.

Any material whose ultrasonic velocity is known and which can be penetrated by acoustical wave maybe used. The velocity of standard block shall be counter checked with some other technique of higher accuracy. The probe is coupled with suitable couplant on the reference standard and then on the test piece [19].

1.3 Near field

One of the significant challenges in using ultrasonic wave in thin wall objects is the phenomenon called near field. Ultrasonic sensors typically have a dead zone immediately in front of them in which objects cannot be detected because they deflect the wave back before the receiver is operational. In ultrasonic testing, the interval following the initial pulse where the transducer ring down prevents detection or interpretation of reflected energy (echoes). In contact ultrasonic testing, the areas just below the surface of a test object that cannot be inspected because of the transducer is still ringing down and not yet ready to receive signals. This region is known as the Near Field and the extent of the near field, known as the near field distance can be calculated from:

$$NF = \frac{D^2}{4\lambda} \quad (6)$$

Where:

NF=Near field distance

D = Crystal diameter

λ= Wavelength

or example for calculate the Near field distance for a 10 mm-diameter 20 MHz crystal transmitting into steel (Velocity 5960 m/s) therefore

λ= 0.298 mm

NF= 83.89 mm

So that ultrasonic sensors cannot sense objects in the near field. However, one of the best strategies to cope this phenomenon is doing test in water (immersion test) or using delay line. In this study a column of water that surrounded by a plastic membrane is used as a delay line.

2. Materials and Methods

2.1 Martial

Some plates made of different materials including Aluminum, Bronze, Copper, Lead, Tin, Zinc, and low carbon steel (st 12) are selected for experiments. The samples have flat parallel surfaces with thickness tolerance of 0.02mm. A commercial robot (figure 1) is used and the ultrasonic probes are mounted on the grasp of the robot. The robot grasp touch two surfaces of the plates. The probes should be compacted to the surfaces, so, the springs are mounted in the grasp to provide essential forces. And also, the robot grasp attached to a micrometer which enables the robot to measure the dimensions of the object.

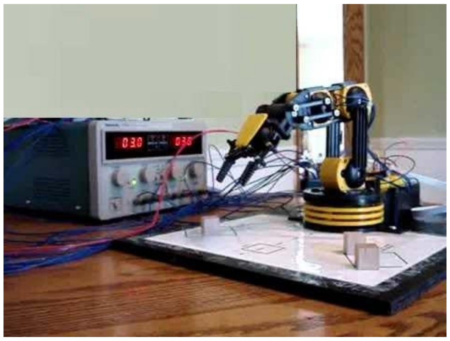

Fig.2. A commercial robot that Separate of objects with different plates

2.2 Ultrasonic equipment

The longitudinal wave velocity was measured by a 10mm diameter, 20 MHz focused probe (Panametrics V312-N-SU) and transverse wave velocity was measured by a 10 mm diameter, 5 MHz contact probe (Panametrics V155) are mounted in the robot grasp including transverse and longitudinal which in turn send ultrasonic wave to samples as shown in the figure 3. And as coupling material, SAE 15W41 lube oil was used for the longitudinal wave measurements while honey was used for the transverse wave measurements. The time of flight of the longitudinal and transverse waves in each specimen was measured between the second and third back wall echoes.

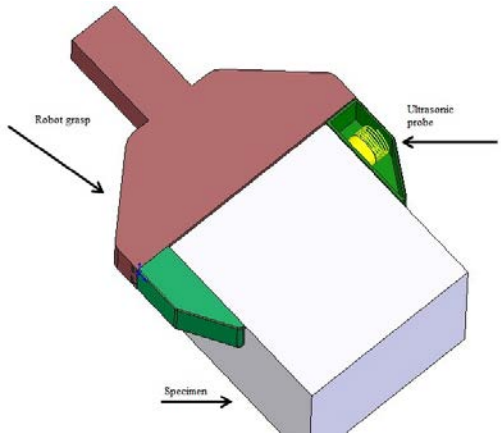

Fig.3. Robot grasp including ultrasonic transducers

2.3 Ultrasonic Velocity Test System

An ultrasonic commercial instrument, GCTS Ultrasonic Velocity Test System, has been used. The System can be programmed to obtain an instantaneous measurement. The GCTS Ultrasonic Velocity Software can determine transverse and longitudinal wave velocities and stores the waveforms digitally (Figure 4). The stored data import to the written software in MATLAB which is a simple written program that analyze data and compare them.

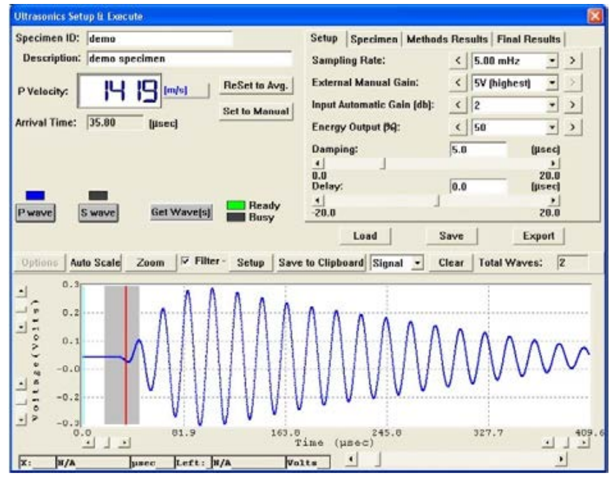

Fig.4. Ultrasonic velocity software which is used for measuring velocities

As mention before, for omitting the effect of near field, a delay line which is including a captive water column in a small plastic waveguide is used to couple sound energy from the transducer element to the test piece in figure 5.

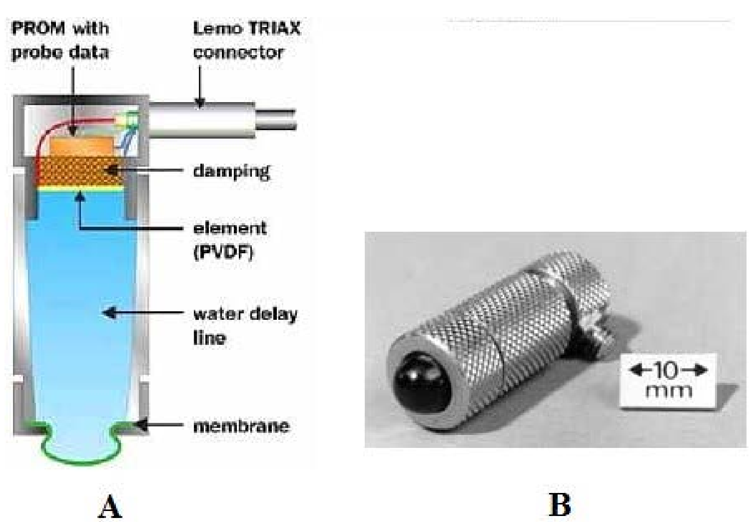

Fig.5.A: delay line (column of water in plastic membrane) B: ultrasonic probe with 12 MHz and 12 mm in diameter

3. Results and Discusses

commercial robot is used and the ultrasonic probes are mounted on the grasp of the robot. Robot grasps touch the surface of samples which are identical in dimensions and appearances. Ultrasonic probes mounted in the grasp of the robot, send ultrasonic wave to the samples. The GCTS Ultrasonic Velocity Software collects data, the transverse and longitudinal velocities are compared with the table 1.

The algorithm is shown in the figure 6.

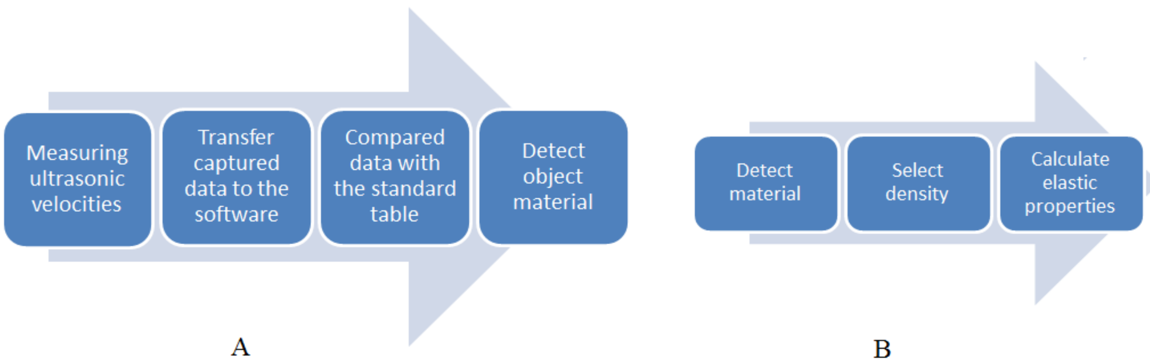

Fig.6.The algorithm that is used for calculate elastic modules

Table.1 Acoustic Velocity in Engineering Material

Sample number	Material	Longitudinal Velocity Transverse Velocity (m/s)	Transverse Velocity (m/s)
1	Aluminum	61511	3111
1	Bronze	3511	1141
3	Copper	4711	1171
4	Lead	1151	711
5	Tin	3311	1661
6	Zinc	4131	1411
7	Titanium	6111	3115
9	Stainless steel (314)	5741	3111

The result of this comparison is shown in Table 1.

Table.2 Measured Acoustic Velocity in sample

Material	Longitudinal Velocity Transverse Velocity (m/s)	Transverse Velocity (m/s)	Material Density kg/m
Aluminum	6311	3131	1711
Bronze	3531	1131	9961
Copper	4711	1161	9811
Lead	1161	711	11411
Tin	3311	1671	7311

It is obvious from the data that the robot is able to identify the 6 samples from each other. The robot could easily identify object materials due to the fact that the difference between the ultrasonic velocities in the material is remarkably great. After detecting the materials, with using the density of materials presented in equations, robot can calculate the elastic properties of each material which would be useful data for prediction of materials behavior for different tasks. So as expected, test results have acceptable accuracy. However, the measured velocities have slight differences with the presented velocity in the standard. This difference is due to the fact that the slightest changes in the microstructure of the material lead to change in ultrasonic velocities. The changes in the material microstructure can be created by heat treatment and production methods. For example, several ultrasonic velocities have been reported for steel, AISI 1145, after heat treatment. Ultrasonic velocities related to transverse waves were measured with 5 MHz frequencies. The ultrasonic velocities for specimen is 3195 (m/s) when quenched in water, 3115 (m/s) in oil and 3135 (m/s) in the open air [11]. Similar results have also been reported by other investigators [19]. Obviously these changes are insignificant; so the robot has been able to detect objects.

4. Conclusion

In this research ultrasonic sensors are applied for detecting thin wall objects can significantly enhance the process quality and thereby product properties. The study shows that detecting thin wall objects made of different materials by using ultrasonic velocities is acceptable with high accuracy and convenient, meanwhile several studies have confirmed that even a minor difference between two types of a metal, such as changes in the microstructure of a metal due to heat treatment, can be detected by this method. However, One of the disadvantages of this method is that robot grasp should measure the distance of two surfaces between which ultrasonic waves transmit. And also, in the presented technique the ultrasonic sensors should touch the object walls that set some limitations so in the future studies developing non-touching ultrasonic sensors would be beneficial in robot industries.

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