Poster: Power spectrum analysis of reflected waves with ultrasonic sensors indicates "what the target is"

Poster: Power Spectrum Analysis of Reflected Waves with Ultrasonic Sensors Indicates "What the Target is"

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ABSTRACT
We consider that ultrasonic waves can be used not only for measuring the distance to a target but also for comprehending what the target is simultaneously. We assumed that the physical characteristics of a target object (especially, surface information) are embedded in the power spectrum structure of the ultrasonic waves reflected from the target. The results of our investigation to analyze the characteristics of the power spectrum structure of waves reflected from various kinds of target materials showed whether target objects are soft and deformable or hard and undeformable.

Categories and Subject Descriptors
H.5.m. [**Information interfaces and presentation**] (e.g., HCI): Miscellaneous; H.5.2 [**User Interfaces**] (D.2.2, H.1.2, I.3.6) Input devices and strategies (e.g., mouse, touchscreen)

General Terms
Measurement.

Keywords
Ultrasonic; reflected waves; power spectrum; total harmonic distortion.

1. INTRODUCTION
Distance-sensing methodologies that work in a non-contact manner have been proposed in various studies, and ultrasonic waves are commonly used for various kinds of applications, such as range finders for robots [1,2], medical inspection [3,4], fish detection [5,6], and non-destructive inspection [7,8,9]. These methodologies are used to determine the distance to a target object by measuring the arrival time of the reflected ultrasonic waves.

We then assumed that certain information especially surface information of the target is embedded in the reflected ultrasonic waves that are utilized for distance-sensing. To confirm this assumption, we transmitted ultrasonic waves to various kinds of objects and measured the reflected ultrasonic waves. We then investigated whether certain attributes of reflected waves can represent physical characteristics (surface information) of an object or not.

We assumed that the power spectrum structure of the reflected waves contains the physical characteristics of a target object. We then focused on two characteristics, differential total harmonic distortion (THD_N) and primary signal to noise ratio (S_1NR). We then define THD_N as the differences of THD and THD+N in [dB] to eliminate the factors of harmonics as follows.

$$\mathrm{THD}_N = THD - (THD + N) = \frac{\sqrt{V_2^2 + V_3^2 + \cdots V_n^2}}{V_1} - \frac{\sqrt{V_2^2 + V_3^2 + \cdots V_n^2 + N^2}}{V_1}$$

Here, V_1 is the voltage swing of the primary factor, and V_i is the voltage swing of the factor whose frequency is a multiple of the ith by the primary factor. THD represents the distortion of a wave, while THD+N does the distortion of the wave with factors other than the harmonics taken into account. So THD_N is a measurement that represents the ratio of the primary factor to other factors except for the harmonics. In addition, we define a novel measurement for comprehending the power spectrum characteristics of a reflected ultrasonic wave, the primary signal to noise ratio (S_1NR), as defined below.

$$S_1NR = \frac{V_1^2}{P_{total}}$$

Here, P_{total} is the power of the whole received wave, defined as the sum of the square of all the factors' voltage swings. Note that S_1NR is defined as the square of V_1 divided by the power to adjust the unit dimension.

These measures represent the relationship of the primary factor to other factors that are expected to contain information on the physical characteristics of a target object, such as whether it is hard or soft.

2. EXPERIMENT
We measured the THD_N and S_1NR of reflected ultrasonic waves from various kinds of objects. We prepared 13 different materials as target objects, shown in Table 1. These objects were selected because they are typical daily items. The shape of these objects was almost a square, with roughly 300 [mm] on each side.

The transmitting ultrasonic signal of a 40 [kHz] sinusoidal wave is generated by a micro controller (Cypress, CY8C24123) and drives the ultrasonic transducer (SPL, UL1612MPR) by using an amplifier (Liner Technology, LT1632) with a high-current drive capability at a voltage swing of 20 [Vp-p]. Note that the half-power angular of the transducer is 50 [deg]. An ultrasonic wave reflected from a target object is received by an ultrasonic microphone (Knowles Electronics, SPM0404UD5), which is sensitive up to 65 [kHz], and amplified by ×1,000 by an operational amplifier (National Semiconductor, LM358) to

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capture the PC-controlled digital oscilloscope (Pico Technology, Picoscope2205A) for calculating its power spectrum. The gap between the transmitting transducer and the receiver was set at 100 [mm]. Figure 1 shows the set-up of equipment and object (left) and actual experimental scene (right).

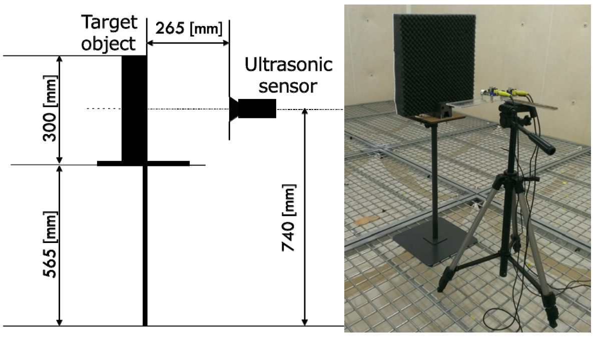

Figure 1. (left) Set-up of equipment and object, (right) In action (object: acoustic absorption material).

3. RESULTS

We measured the THD_N and S_1NR twice for each object. The average measured values of THD_N and S_1NR are listed in Tables 1. The order of measuring the object was the same as the numbering shown in the left column of this table. Tables 1 shows that the objects that showed smaller values of THD_N and S_1NR were the (2) bath mat, (5) sponge, (1) acoustic absorption material, and (6) handy mop, which are soft and deformable materials, while the objects with larger values were the (4) Styrofoam, (3) steel sheet, (12) cork board, and (10) plywood, which are hard and undeformable materials. As the result of our investigation, we found that the measured values of THD_N and S_1NR clearly represented one of the physical characteristics of the objects; that is, whether a target was soft and deformable or hard and undeformable.

Table 1. Measured Average THD_N [dBc] and S_1NR [V^2/M]

No.	Object	**THD_N**	**S_1NR**
1	Acoustic absorption	-9.56	2.43
2	Bath mat	-10.47	2.29
3	Steel sheet	-2.79	5.11
4	Styrofoam	-2.34	5.61
5	Sponge	-10.08	2.34
6	Handy mop	-8.13	2.54
7	Plastic mat	-4.98	3.68
8	Artificial grass	-5.59	3.66
9	Vibration absorber	-4.29	2.98
10	Plywood	-3.63	4.63
11	Acrylic board	-4.03	3.64
12	Cork board	-2.91	4.98
13	Polypropylene film	-2.71	4.91

4. DISCUSSIONS AND CONCLUSION

The results of our investigation clearly showed that objects that are soft and deformable showed lower THD_N and S_1NR values, while those that are hard and undeformable had higher values. Eventually, this investigation revealed that our assumption was confirmed. Future investigation is indispensably required to comprehend in detail the meanings of the THD_N and S_1NR values, respectively.

In our investigation, in parallel with measuring the power spectrum structure of the reflected waves, we measured the arrival time of these waves in order to measure the distance to the target object, and we could confirm that this measurement had the same quality as traditional ultrasonic distance sensors, e.g., about 265 mm, as shown on the left of Figure 1. Among these two measurements (one for power spectrum and the other for arrival time), one measurement does not interfere with the other measurement, and vice versa, so our proposed measurement simply augmented the function of traditional ultrasonic sensors. We believe that our framework could have an impact on current user interface technologies.

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