Ultrasonic Floor-Type and Cliff Detection on Automated Vacuum Robots

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Introduction

Autonomous vacuum robots today use sensors for obstacle detection, and there is a drive to integrate other additional sensing technologies for floor-type and cliff detection. Ultrasonic sensing can be used in these applications due to its ability to distinguish between different material types and its immunity to smoke and dust while providing a reliable response.

Currently, separate cleaning robots are required to vacuum and mop, which doubles the cost of the solution. To integrate these functions into one system, it is important for the cleaning robot to know what type of floor it is on. Ultrasonic technology is able to determine the hardness of a target, based on the strength of the received echo amplitude observed by the sensor. Harder surfaces like tile reflect a stronger echo than softer surfaces like carpet.

Physical barriers are needed to prevent service robots from falling down a flight of stairs as these drops can lead to costly malfunctions. One solution is to implement cliff detection sensors to avoid these dangers. The immunity of ultrasonic sensors against dust makes it a reliable solution for cliff detection applications, considering that the sensor will be mounted underneath the robot.

Ultrasonic Theory of Operation

Ultrasonic sensors emit high-frequency sound waves above the upper limit of human hearing. The time it takes for the emitted sound wave to bounce back to the transducer determines the distance between the object and the sensor as shown in Figure 1. The distance is calculated by multiplying the time of flight by the speed of sound and dividing that by two.

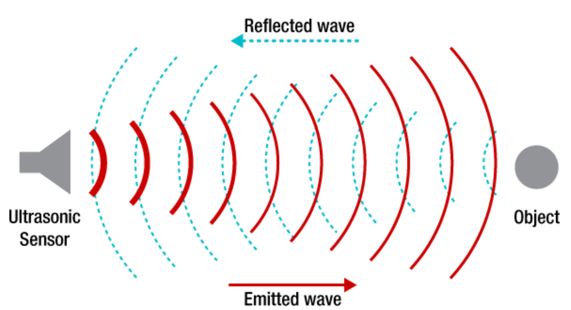

Figure 1. Ultrasonic Sensor Theory of Operation

Hardware Configuration

The BOOSTXL-PGA460 was used in all the experiments listed in this document. The PGA460 is an ultrasonic transducer driver and signal conditioner.

To optimize the performance of the system, it is important to consider the frequency and topology of the transducer. As the frequency increases, the resolution, directivity, and attenuation increase while the measurable distance decreases. Topology is whether the transducer has the emitter and receiver combined (monostatic) or are independent as a dedicated pair (bistatic).

Table 1 shows the advantages and disadvantages of each transducer type. Table 2 shows how topology affects the effectiveness of your transducer selection.

Table 1. Transducer Type

TRANSDUCER TYPE	PREFERRED DRIVE MODE	ENVIRONMENTAL CONDITIONS	COST
Closed-Top	Transformer Drive	Applicable in harsh environments	$$
Open-Top	Direct Drive	Limited to protected environments	$

Table 2. Transducer Topology

TOPOLOGY	RANGE	COST
Monostatic	Mid to Long Range	$
Bistatic	No blind-zone allows for near 0cm detection	$$

Figure 2 shows how the BOOSTXL-PGA460 was set up to simulate these applications.

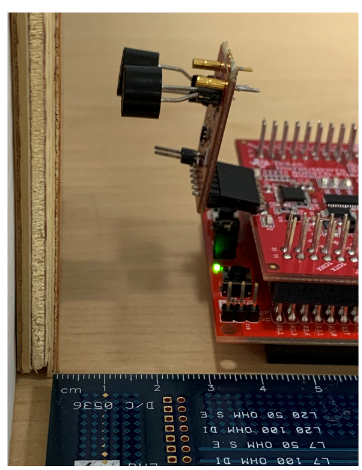

Figure 2. BOOSTXL-PGA460 Test Setup

Floor-Type Detection

Figure 3 shows a high level representation of floor-type detection by using ultrasonic sensing. For hard surfaces, the echo response saturates whereas soft surfaces have a weak echo response. The 40 kHz bi-static PUI Audio UTR-1440K-TT-R transducer pair was used for this experiment.

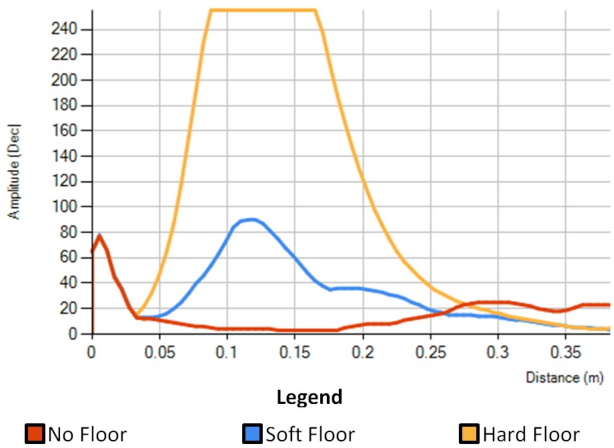

Figure 3. Floor-Type Detection

Figure 4 shows the echo responses across hardwood, tile and, carpet types that are 1 cm away from the surface (due to the limited spacing between where the sensor is mounted and the floor). The graph depicts how the echo response across each surface varies slightly. For example, carpet is an extremely porous surface, therefore more sound is absorbed and not reflected back. Tile is a hard material that allows sound waves to reflect off more effectively, producing a higher amplitude response. With this information, the vacuum robot is able to determine the floor type it is on. For this experiment, the MuRata MA40S4S transmitter and MuRata MA40S4R receiver were used in a bi-static configuration to allow a detection range less than 5 cm because there is no blind-zone.

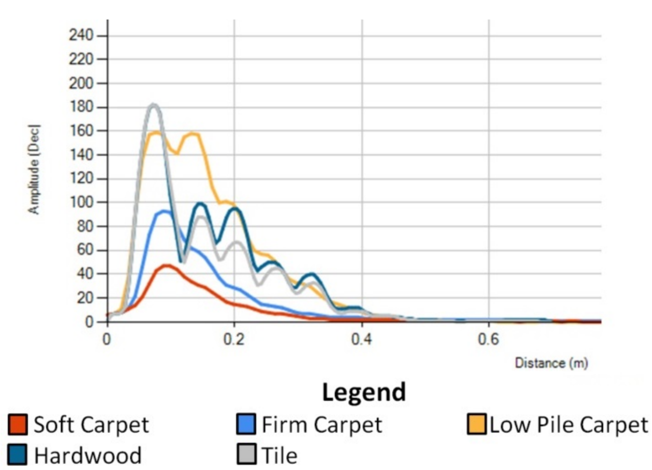

Figure 4. Echo Response Across Different Surfaces

Cliff Detection

It is imperative for the vacuum robot to detect when it is approaching a cliff so that the system can change directions and prevent a sudden fall.

The transducer is mounted 1 cm above the floor, therefore the robot will halt and change directions if a distance of more than 1 cm is detected. Figure 5 shows the echo response of hardwood at a distance of 1 cm from the transducer pair, along with different floor samples that are each 20 cm away from the transducer pair, which is the standard stair height in an American household. Under a bistatic configuration with a dedicated transmitter and receiver, there is no observable transducer ring time.

Because of the transducer's wide field of view, it was unable to detect a cliff until the sensor passed over the hardwood edge by 2 cm, therefore a transducer with a narrower field of view is recommended for faster cliff detection.

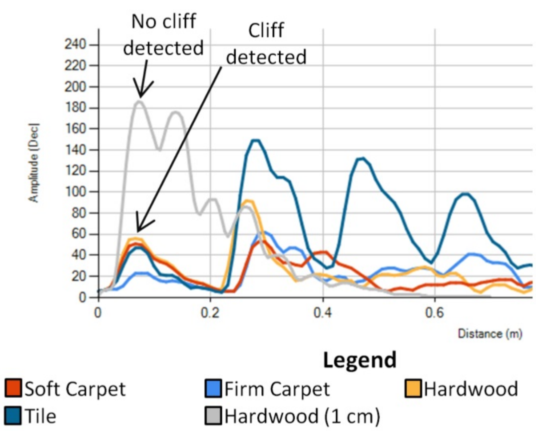

Figure 5. Cliff Detection at 20 cm

Device Recommendations

Ultrasonic sensing benefits vacuum robot applications because it enables both cliff and floor-type detection. TI recommends that the designer use a closed-top transducer in a bistatic configuration in these applications, because the transducer will be exposed to dust and dirt and will require short range detection.

Table 3 has a list of collateral resources to help ensure proper usage of the BOOSTXL-PGA460, along with different transducers that are available. For more information, visit ti.com/ultrasonic.

Table 3. Recommended Collateral

COLLATERAL	DESCRIPTION
Application Note	*PGA460 Ultrasonic Module Hardware and Software Optimization*
Quick Start Guide	*PGA460-Q1 EVM Quick Start Guide*
Excel Spreadsheet	PGA460: Air-Coupled Ultrasonic Transducers & Transformers Listing