

Development of a Long-Range Ultrasonic Sensor for Automotive Application

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ABSTRACT

In recent years, short-range sensors like stereo cameras, radar and infrared cameras have become essential components of safety systems and user-friendly convenience systems, such as pre-crash safety or parking assist systems. However, they are generally too expensive to implement on lower-end vehicles. On the other hand, a conventional backup-assistance sonar has a very small coverage area, but it is more cost effective than the above-mentioned sensors.

This paper proposes an effective method to increase the range of detection of conventional sensor with the help of a pseudo-Wigner distribution-based likelihood function. The reflected wave detected by maximizing the p-WD-based likelihood function with respect to the parameter related to the time delay. This method is verified in actual experiment and the maximum detection range was found to be extended by about 2.5 times beyond that of the conventional approach.

INTRODUCTION

Ultrasonic sensors typically measure distance or velocity based on the time-of-flight method by transmitting high-frequency sound pulses and receiving the reflected wave. Automotive applications of ultrasonic sensors include their use in user-friendly parking assist systems and very short range crash-avoidance safety systems, in which they are used to measure the distance to a stationary vehicle or a relatively close approaching object or its velocity. Based on the measured distance or velocity, the system then controls the steering or brakes of the host vehicle or informs the driver of the distance or the risk of a collision by issuing an audible indication or flashing a lamp^[1]. At present, ultrasonic sensors are a popular sensing technology used to navigate mobile robots automatically by sensing and mapping their surrounding environment^[2]. The maximum detection range in automotive applications is around 2-3 m in most cases, but distances of up to around 10 m are obtained

for applications in other fields. As the detection range is directly proportional to the power of the sensor, compact but relatively long-range ultrasonic sensors suitable for real world crash mitigation applications are still not available.

This study examined a method of improving the maximum detection range of ultrasonic sensors, the performance of which tends to be inferior to that of other types of sensors used to measure distance. The purpose of this work was to extend the use of ultrasonic sensors to other automotive applications beyond their traditional use only in backup-assistance sonar systems.

There are two main approaches that can be considered for increasing the maximum detection range of ultrasonic sensors:

1. Improvement of hardware: This approach involves increasing the sound pressure level of the ultrasonic waves emitted from the transmitter.
2. Signal processing: This approach involves the use of signal processing to separate the reflected wave from noise so as to make the wave detectable. Previously, the reflected wave has been undetectable because it was masked by noise.

There are different ways of raising the sound pressure such as by increasing the size of the transmitter or by attaching a cone. For example, ultrasonic sensors for non-automotive applications are often open-type devices that are large in size as well. However, sensors mounted on vehicles must be waterproof, which requires a hermetically sealed structure. Increasing the sensor size or attaching a cone is not desirable from standpoint of the vehicle design. For these reasons, the latter method of using signal processing was selected in this research as the approach for improving the maximum detection range.

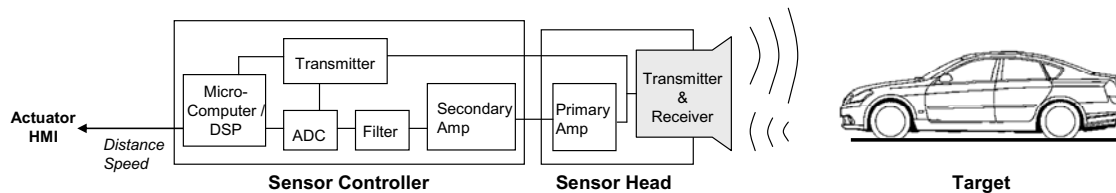


Figure 1 Block diagram of ultrasonic sensor for automotive application

ULTRASONIC SENSORS

The time-of-flight method is one of the typical techniques used for measuring distance with ultrasonic sensors. With this technique, an ultrasonic pulse is emitted from the transmitter and is reflected back from a target. The time until the reflected wave is detected by the receiver is measured, and the distance to the target is calculated from the result. In this case, the relative velocity is obtained by calculating the Doppler shift from the frequency of the received pulse. An example of an ultrasonic sensor configuration for vehicle application is shown in Fig. 1.

Although separate devices can be used to transmit and receive ultrasonic pulses, the transmitter usually doubles as the receiver. Because the received pulse is extremely weak, it is amplified using several stages of amplifiers. Typical waveforms of the transmitted and received pulses with the time-of-flight method are shown schematically in Fig. 2. From the time difference between the transmitted pulse and the received pulse, the distance R to the target can be found by

$$R = \frac{T_{Rx} V_s}{2}, \quad (1)$$

where T_{Rx} is the round-trip travel time and V_s is the speed of sound.

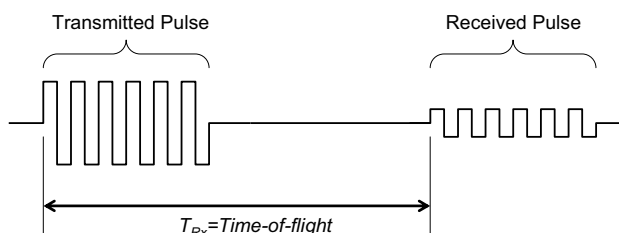


Figure 2 Time-of-flight method

ENHANCEMENT OF DETECTION RANGE

A wave reflected from a far distance is attenuated at a rate inversely proportional to the square of the distance, which means the amplitude of the reflected wave becomes smaller rapidly with increasing distance from the target. Since the signal to noise(S/N) ratio also deteriorates, a wave reflected from a far distance is quite difficult to detect because it is corrupted by surrounding random disturbance noise.

Figure 3 shows a typical waveform of the actual observation data of a reflected pulse that was received by an ultrasonic sensor. Usually, an automatic gain control (AGC) circuit is employed to amplify the received signal from a long distance. Because random disturbances are also amplified by the AGC circuit, so that the resultant observation data consist of the received signal to be detected and the additive random noise whose amplitude is almost the same level as that of the relevant signal. Consequently, some effective signal processing procedure is needed to accomplish detection of the reflected signal masked by the random noise.

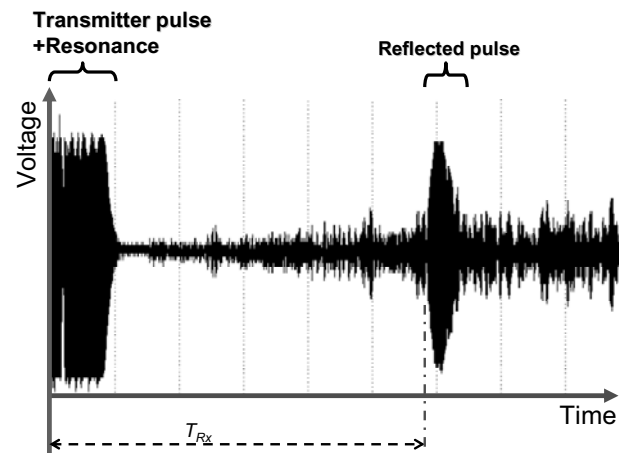


Figure 3 Waveform of received signal

WIGNER DISTRIBUTION FOR NOISY OBSERVATION DATA

In this work, a Wigner distribution (WD) based likelihood function was developed to estimate the time delay of the transmitted signal.

The WD is employed widely in signal processing operations^[3] and some researchers have used the WD for automotive applications^{[4][5]}. While the wavelet transformation is linear in the signal, the WD is quadratic and provides a powerful theoretical basis for time-frequency analysis. It is well known, however, that the WD has some shortcomings in terms of irregular behavior referred to as interference or the appearance of cross-terms between signal components. Furthermore, it is not so robust for noisy signals as pointed out by Cohen^[6].

To cope with noisy observation data, one of the authors and his colleagues^{[7]-[9]} have proposed an effective