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# Triangulation in automotive ultrasonic park-assist systems

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5/21/2013 02:39 PM EDT

2 comments

## Abstract

Automotive advanced driver assistance systems (ADAS) help a person drive her/his vehicle and thereby enhance driver and road safety. A commonly used ADAS is ultrasonic park assist. When installed in a vehicle, ultrasonic park assist systems use ultrasonic distance-ranging methodologies to assist the vehicle driver with back-up parking, parking spot identification, automatic parking and detection of objects in the driver's blind spots. A key figure of merit of distance-ranging systems is the accuracy of distance measured by such systems. Many factors including object, ultrasonic transducer, electronics, and signal processing algorithms influence the accuracy of the measured distance. In this article, we focus on signal processing. Specifically, we investigate the method of triangulation as a way to improve distance measurement accuracy.

## Introduction

In automotive ultrasonic distance-ranging applications, ultrasonic sound wave time-of-flight (TOF) is used to calculate the distance to objects from the passenger vehicle. This distance is used to assist the driver in parking the vehicle, identifying parking spots, or detecting objects in the driver’s blind spots.

A key metric used to characterize the performance of automotive distance-measuring systems is accuracy of the measured distance.

A number of factors influence the accuracy of the distance measured. These factors include the object itself, the distance between the vehicle and the object, the transducer characteristics and the electronics used to drive the transducer and signal chain used to process the echo signals.

In this article, we investigate the use of triangulation. Specifically, we look at whether triangulation is effective in improving the accuracy of the distance measured.

## Ultrasonic park assist systems

An ultrasonic park assist (UPA) system consists of an UPA ECU (electronic control unit), and multiple smart ultrasonic transducers. Ultrasonic transducers typically are installed in front and rear bumpers, and wing mirrors of an automobile. Up to four transducers can be installed in each bumper.

## Measuring the distance

***Figure 1*** shows a passenger car with two ultrasonic transducers in the car's rear bumper. Further, this picture also shows an object (such as a parking pole) behind the car.

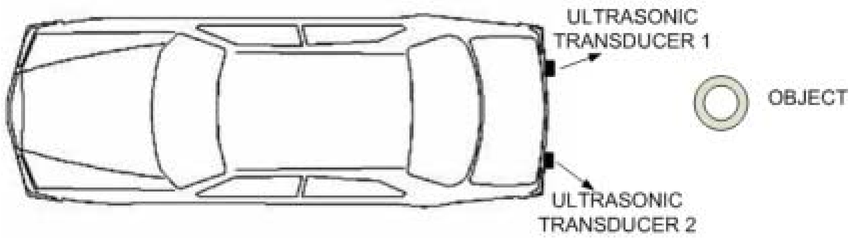

***Figure 1: Ultrasonic park assist system***

In an ultrasonic park assist system with multiple smart ultrasonic transducers, the UPA ECU coordinates the measurement of distance. In a typical scenario, the UPA ECU first commands "ultrasonic transducer 1" to measure the distance. It then commands "ultrasonic transducer 2" to measure the distance. This sequence is cycled through as long as the park assist system is activated. An example scenario in which the transducers in the rear bumper are activated is when the driver selects reverse gear to back the vehicle into a parking spot.

## Inherently inaccurate

The time-cycled distance algorithm described in the previous section is inherently inaccurate. This is because the correct distance between the vehicle and the object is not the distance measured by the transducers from themselves to the object. Rather, the correct distance between the vehicle and the object is the closest distance from the bumper to the object, which is along the perpendicular line from the bumper to the object.

***Figure 2*** geometrically illustrates this inherent inaccuracy. In this figure, *T1* and *T2* at a distance *x* from each other, are the two ultrasonic transducers in the car's rear bumper.

The ultrasonic transducer *T1* measures distance *l1* while the transducer *T2* measures distance *l2*, while the correct distance between the vehicle and object is *d*.

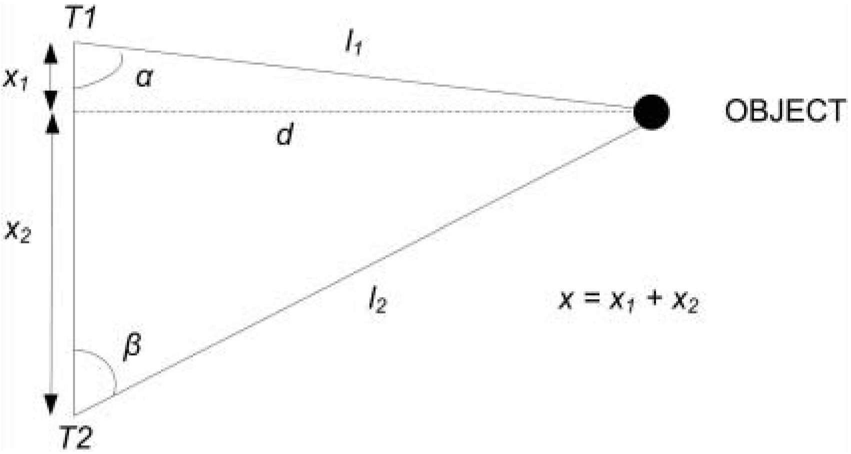

***Figure 2: Geometry of the ultrasonic transducers and the object***

A simple example is used to illustrate this error. Consider an example in which two ultrasonic transducers are installed in the car's rear bumper. Assume that the distance between the transducers is two feet, and the object is one-and-a-half feet away from the vehicle, rather the perpendicular distance between the rear bumper and the object is one-and-a-half feet.

In this example, if the object is located exactly perpendicular to *T1*, or *x1* in ***Figure 2*** is zero, then transducer *T1* measures the correct distance. However, if the object is located exactly perpendicular to *T2*, or *x1* in

***Figure 2*** is two feet away, then the relative error of the distance measured by *T1* is large. ***Figure 3*** shows this relative error of the distance measured by transducer *T1* as a function of the object's position as indicated by *x1*. This figure shows that the relative error can be as large as 67 percent!

Note that the relative error in the distance measured by *T2* has a similar profile. However, this profile is a mirror image of the curve in ***Figure 3***. That is, the relative error of the distance measured by *T2* is large when the object is located exactly perpendicular to *T1*, while the distance measured by *T2* is correct – if the object is located exactly perpendicular to *T2*.

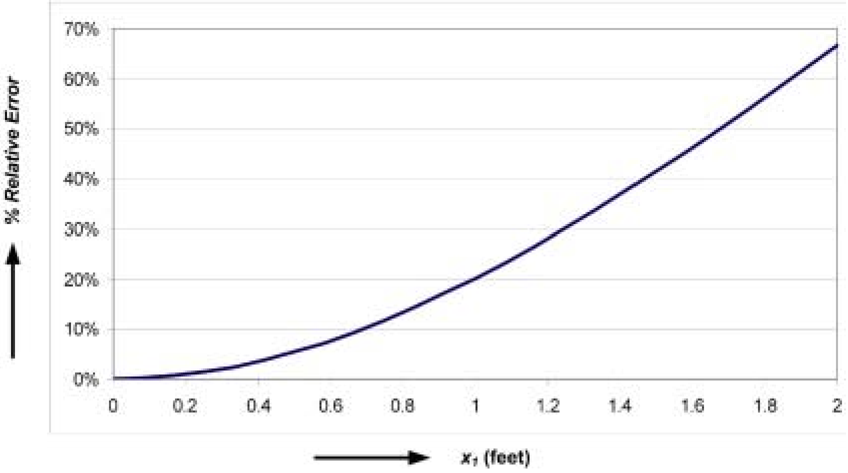

***Figure 3: Relative error in the measurement of distance***

If the object is located exactly perpendicular to one of the transducers, then the system is able to inform the driver (or the parking control system) the exact distance. However, if the object is located such that the perpendicular line from the vehicle to the object is between the two transducers, errors in the measured distances by both transducers are large.

### Triangulation improves accuracy

Instead of reporting the distance measured by the two transducers independently, the two distances can be combined to improve the accuracy of the measured distance. One approach to combining the distances is the triangulation algorithm.

The triangulation algorithm can be used to infer the correct distance *d*.

Consider the geometrical representation of the transducers and object as illustrated in ***Figure 2***. Using the Pythagorean theorem, the relationships between *l1, l2, d, x1, x2*,, and *d* are given by (***Equation 1***):

$$l_1^2 = x_1^2 + d^2$$
$$l_2^2 = x_2^2 + d^2$$

Using ***Equation 1***, we obtain (***Equation 2***):

$$l_2^2 - l_1^2 = x_2^2 - x_1^2 = (x_2 - x_1)(x_2 + x_1) = (x_2 - x_1)(x)$$
$$\Rightarrow x_2 - x_1 = \frac{l_2^2 - l_1^2}{x}$$

***Equation 2***

By simple algebraic manipulation of ***Equation 2***, the expression for *x2* can be obtained as shown in (***Equation 3***):

$$x_2 = \frac{x_1(x_1 + x_2)}{x} + \frac{l_2^2 - l_1^2}{x}$$

$$\Rightarrow x_2 = \frac{x_1(x_1 + x_2)}{x} + \frac{l_2^2 - l_1^2}{x} + \frac{x_2(x_2 + x_1)}{x} - \frac{x_2(x_2 + x_1)}{x}$$

$$\Rightarrow x_2 = \frac{x^2}{x} + \frac{l_2^2 - l_1^2}{x} - x_2$$

$$x_2 = \frac{1}{2}\left(\frac{x^2 + l_2^2 - l_1^2}{x}\right)$$

***Equation 3***

Using ***Equation 3***, *d* can be calculated using (***Equation 4***):

$$d = \sqrt{l_2^2 - x_2^2}$$

***Equation 4***

Thus, the transducers measurements *l1* and *l2* along with the knowledge of *x* (the distance between the two transducers), can be used to calculate the correct (perpendicular) distance of the object from the vehicle.

### Impact of time-cycled measurement of l1 and l2

As described earlier, the UPA ECU time-cycles the two transducers to measure the distance to the objects. In other words, *l1* and *l2* are measured at different times. To understand the impact of measurement at different times, let's assume that the vehicle is backing up at a speed of approximately 5 mph into an object that is 1.5 feet behind it when the vehicle starts backing. Furthermore, the transducers are assumed to be two feet apart and the object is assumed to be perpendicular from the point on the bumper that is exactly midway between the two transducers.

Assume that the transducers are time-cycled every 25 ms. The first measurement by *T1* occurs at time zero. At this time, *l1* is measured as 1.80 ft. The measurement by *T2* occurs 25 ms later. In this duration, the vehicle would have inched closer to the object by 0.18 ft. Thus, the distance measured by *T2* is 1.65 ft.

Using the triangulation algorithm described by ***Equations 3*** and ***4***, distance *d* is calculated when l2 becomes available and is calculated to be 1.40 ft, while the actual distance is 1.32 ft. That is triangulation algorithm introduces a relative error of approximately seven percent.

Measuring *l1* and *l2* simultaneously to further improve accuracy

The time-cycled measurement of *l1* and *l2* shows the impact of time-cycled measurement algorithm. In order to eliminate the inaccuracy caused by measuring the distances at different times, it is necessary for these distances to be measured simultaneously. This is because when a vehicle is in a parking application, the vehicle is in motion. For example, the vehicle is constantly getting closer to the object that it is trying to avoid bumping into.

To measure *l1* and *l2* simultaneously, the approach of one transmit while all listen can be used. In this approach, transducer *T1* emits ultrasonic waves and both the transducers receive the echo from the object. Knowing when the ultrasonic signal was transmitted by *T1* and the times at which the echoes were received by *T1* and *T2*, *l1* and *l2* can be calculated simultaneously. This eliminates the error introduced by measuring *l1* and *l2* at different instances in time.

The above algorithms can implemented with smart ultrasonic transducers that have flexible electronics based on devices such as TI's PGA450-Q1 [**1**].

## References

1. Download a datasheet for the PGA450-Q1.
2. Learn more about this and other automotive solutions from TI: www.ti.com/auto-ca.

## About the author

Arun Tej Vemuri is a Systems Architect with TI where he is responsible for product definition of automotive and industrial sensor signal conditioners. Arun received his Ph.D. in Electrical Engineering from the University of Cincinnati, Ohio, his MS in Systems Science from IISc Bangalore, India, and BSEE in Electrical Engineering from IIT Roorkee, India. Arun can be reached at ti_arunvemuri@list.ti.com.

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