Automated parking made possible with TI mmWave radar and ultrasonic sensors

Texas Instruments

Snehaprabha Narnakaje
Business Manager, Automotive Radar
Texas Instruments

Ram Sathappan
Marketing Manager, Sensor Signal Conditioning
Texas Instruments

A complement of new TI mmWave radar sensors and existing ultrasonic and camera systems facilitates the transition from assisted to automated vehicle parking.

Major automotive original equipment manufacturers (OEMs) are developing vehicles with ever-increasing autonomy from human operators. The transition from Society of Automotive Engineers (SAE) Level 1 driver assistance platforms to Level 2 partial automation for parking and lane assistance will start to appear this year. Hardware and software designers of advanced driver-assistance systems (ADAS) need to be ready for this transition.

The evolution of today's parking assist technology (based on ultrasonic and camera sensors) to a more effective and cost-efficient automated parking system will benefit significantly from the addition of TI millimeter-wave (mmWave) radar sensors. To appreciate what is involved with the transition from a purely ultrasonic solution to a combined mmWave radar platform, let's first review the basics of each technology.

The operational scenario modes for parking a car remain the same despite the technology; namely, search and park. In search mode, the car "looks" for and identifies a suitable parking spot. The autoparking mode then maneuvers the vehicle into the identified parking spot. In both automated parking modes, the expected measurement accuracy is up to 40 m for search mode, and near 0 to 20 m in parking mode.

Meeting this resolution accuracy is just one reason why a combination of ultrasonic, radar and camera sensors are necessary in order to determine range, speed and angle parameters for fully autonomous parking. All of these sensor types provide complementary but different views of their surroundings.

Ultrasonic fundamentals

Ultrasonic sensors have been used for object detection in the automotive space for the last 20 years. Ultrasonic refers to signals that are above the human hearing span (>20 kHz), and usually in the 40- to 70-kHz range. The frequency determines the range and resolution of the distance measurement, with the lower frequencies producing the greatest sensing range.

Ultrasonic waves radiate toward and then bounce back from objects in their path. Knowing the time of travel of the signal wave plus the speed of sound is enough to calculate the distance of a vehicle to an object (such as another car or a curb). These sensors are low cost, flexible and especially useful in shorter-range automotive applications (see **Figure 1**).

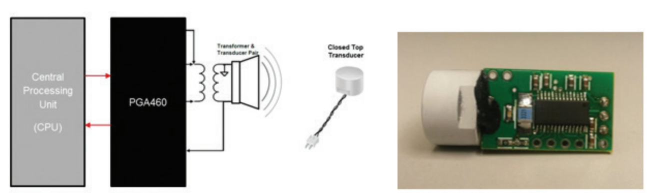

Figure 1. *An example of an ultrasonic transceiver module that combines an ultrasonic transducer sensor, signal processor and driver*

Current automotive applications of ultrasonic sensors include parking assistance, guidance and reverse warnings. These systems have evolved from simply detecting an object's presence and alerting drivers to an object's proximity with an increasing series of "beeps," to near autonomous parking of the car with little driver interaction. Typically, these ultrasonic systems require between four to 12 circular-shaped sensors placed strategically around the car to provide the desired detection coverage (see **Figure 2**).

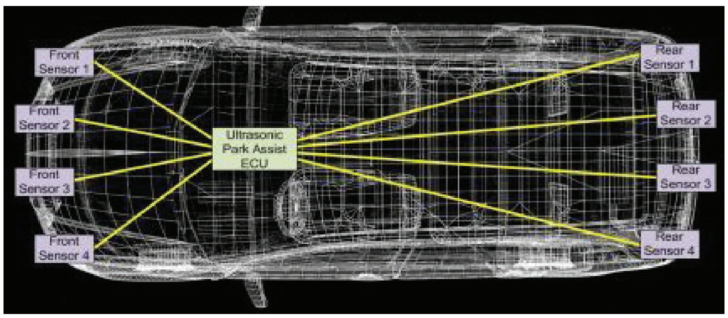

Figure 2. *Placement of ultrasonic sensors around an automobile for varying degrees of object detection coverage*

Object detection in either reverse or forward driving typically requires four sensors placed in the appropriate bumper; for example, one on each corner and two in the middle of the bumper. For detection coverage around the entire vehicle, the car may need up to two extra sensors on each side of the car (for a total of 12 sensors).

Ultrasonic challenges

While ultrasonic technology is a popular solution for reverse driving and assisted parking, there are a few challenges when using ultrasonic sensors to support automated parking functions.

The first challenge stems from the success of ultrasonic technology. As more cars use these sensors, the sensors generate more signals between them. Conflicting ultrasonic signals can pose a big problem when parking. And if two cars in proximity have active ultrasonic sensors, the signals can bounce off one another and each vehicle could read the wrong ultrasonic waves.

Fortunately, this problem has been addressed through intelligent signal coding, or the integration of a unique frequency identifier into each transmitted wave. The receiving sensor looks for the same identifier to validate the origin of the signal. By encoding a known frequency, ultrasonic technology can help with automated parking. But there is still one other challenge.

The major drawback with ultrasonic systems – especially when compared to TI mmWave radar – is that the former works best in short-range applications of 30 cm to 7 m. Beyond that distance, the ultrasonic signal decays and falls off beyond the detection capability of the receiving sensor. The challenge when parking is that a vehicle might hit a pole or wall or another car beyond – or below – the ultrasonic detection threshold.

Even with this range drawback, mature and proven ultrasonic sensor systems have become a mandated technology. By 2019, many parts of the world will require the installation of systems in new cars for object detection and avoidance.

TI mmWave radar basics

By 2020, frequency-modulated continuous wave mmWave data sensor technology will start to appear in automobiles. Millimeter-wave refers the spectrum band between 30 GHz and 300 GHz. These sensors provide range, velocity and angle measurements for object detection.

The spectrum for automotive applications is the 24-GHz band (expected to be phased out by 2022) and 77-GHz band, which covers 76 GHz to 81 GHz. The 77-GHz band is typically divided into two banks: 76 GHz to 77 GHz and 77 GHz to 81 GHz. Note that the higher the channel bandwidth (4 GHz between 77 GHz to 81 GHz), the better the range resolution. Also, higher gigahertz frequencies are better for accurate velocity measurements.

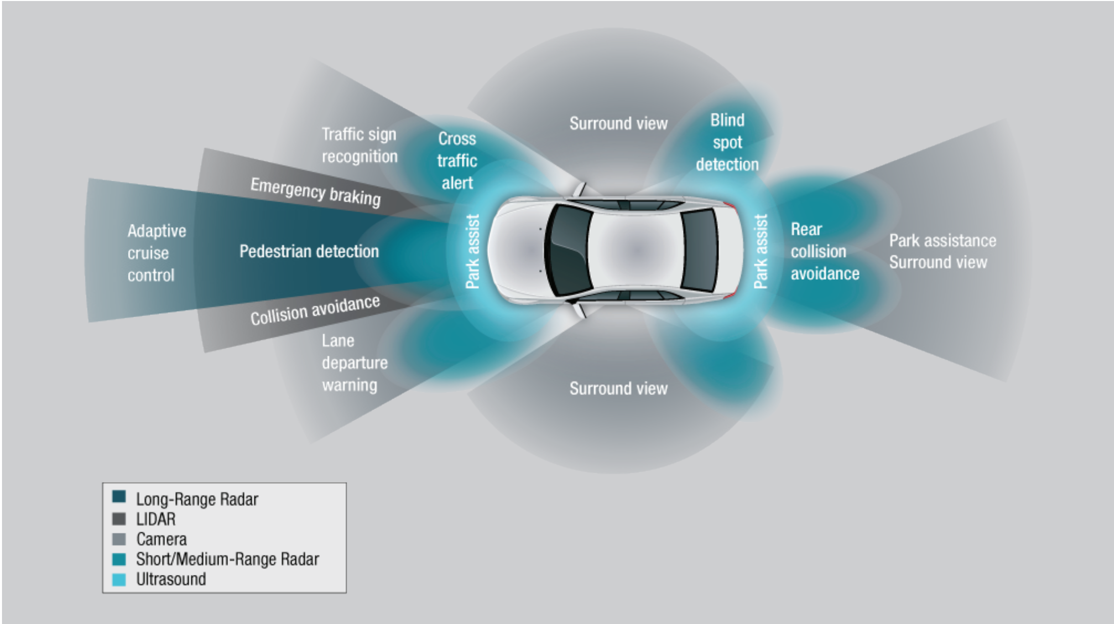

Figure 3. *Current uses for ultrasound and TI mmWave sensors in ADAS applications*

The 77-GHz band radar is expected to provide both short- (below 30 m) and long-range detection for all future automotive radars (see **Figure 3**).

As mentioned, TI mmWave radar-based systems are used to measure the range, velocity and angle of arrival of objects in front of the sensors. This technology can easily provide a surround view of a vehicle with 360-degree sensing capabilities. Let's consider how the radar makes measurements for each of these three key parameters.

Range, velocity and angle

The range from the radar sensor to an object is determined with a transmitted signal called a chirp. The chirp is typically a sine wave that gradually increases in frequency. It is a continuous wave whose frequency is linearly modulated. This type of radar system is known as a frequency modulated continuous wave, or FMCW for short.

A local oscillator or synthesizer generates a linear frequency ramp (the chirp) that is sent to a transmitting (TX) antenna. Once the chirp wave encounters an object, it is reflected back to a receiving (RX) antenna. The RX signal and the original TX signal are mixed, resulting in an intermediate frequency signal that is digitized via an analog-to-digital converter. The digitized data undergoes Fast Fourier transform (FFT) processing via a digital signal processor (DSP) that changes peak frequencies into specific object ranges (see **Figure 4**).

FFT processing resolves an object's peak frequencies into actual range measurements for the object. The phase of these peak frequencies is very sensitive to small changes in the range of the object. For example, a change in the object's position by a quarter of a wavelength (≈1 mm at 77 GHz) translates to a complete phase reversal of 180 degrees. Phase information forms the basis for velocity estimation between the car and the object (see **Figure 5**). This type of radar is called mmWave radar because of these mmWave measurements.

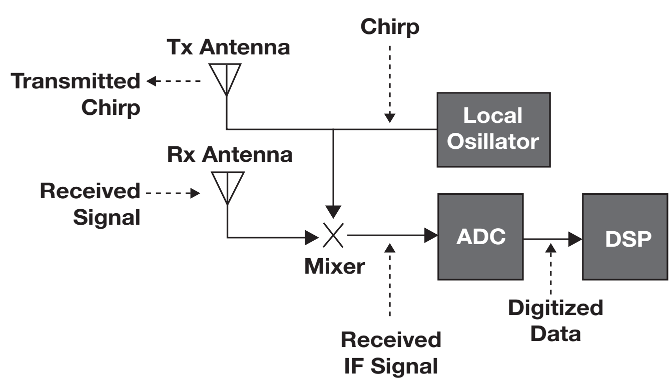

Figure 4. *A simplified block diagram of an FMCW radar with a single TX and single RX antenna*

FFT processing yields both range and velocity data of objects in front of the radar. But what about information concerning the object's angle of arrival?

Resolving objects in the angular dimension requires multiple receiving antennas. Processing FFT calculations across these multiple antennas provides the necessary angle information.

Range, velocity and angle measurements are critical parameters needed in the detection of a curb and estimation of the curb's height for automated parking. But curb elevation information can be difficult to obtain from ultrasonic sensors alone. Radar is a cost-efficient way to address these requirements.

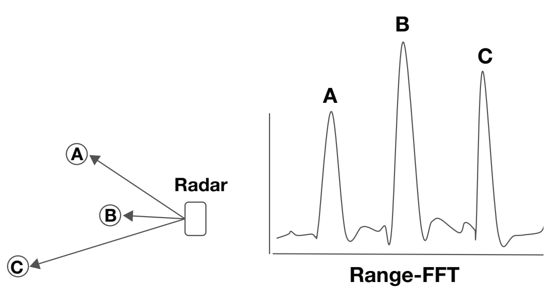

Figure 5. *FFT processing translates peak frequencies from signals bounced back from an object into range measurements*

Also, mmWave radar can provide a wide field of view over ultrasonic sensors – depending on the antenna. For example, mmWave can see at 40 m in search mode. The field-of-view parameter provides both horizontal and vertical measurements, which are necessary in order to estimate the height of the curb. This is a new requirement for autonomous parking.

TI mmWave at the curb and beyond

Radar sensors are very useful for determining the minimum distance from a car to a curb or another object. It's even possible to repurpose the existing corner radars used for blind-spot detection to serve parking radar functions, thus reducing the number of sensors at the system level. Finally, mmWave signals are less affected by bad weather conditions.

Judging a vehicle's closeness to the curb is particularly crucial when maneuvering into tight, compact parking spots. Unfortunately, a single ultrasonic sensing unit has a physical detection limit of about 10 cm. This "minimum measurable distance" between an ultrasonic sensor and an object results from the time that the receiver must wait before it can accurately monitor the reflected signal. In the typical ultrasonic sensor, both the transmitter and receiver are the same unit. That is why the receiver must wait for the transmitter vibrations to decay below its threshold.

Using a separate ultrasonic transmitter and receiver eliminates this decay time problem – assuming that both are far enough apart not to cause crosstalk. But two devices mean double the cost, so most vehicles use a combined transmitting/receiving sensor.

Instead of adding more ultrasonic sensors, automotive designers are considering a TI mmWave radar sensor. In addition to detecting curbs as close as 3 cm away, these radar systems provide better performance and additional measurement capabilities, such as an object's velocity and angle from the sensor.

Granted, the performance and cost trade-offs between ultrasonic and TI mmWave radar systems are not a balanced comparison. While TI mmWave radar sensors provide better resolution, additional parameter measurements and require fewer sensors, they are currently more expensive than ultrasonic sensors.

An additional consideration for TI mmWave radar sensors is the cost of the antenna. On the plus side, new packaging designs are integrating the antenna on-chip, which results in a much smaller sensor size and form factor.

Environmental considerations also favor TI mmWave over ultrasonic sensors. Dirt and debris – common on automotive bumpers – can hamper ultrasonic but not radar measurements. Plus, radar does not need the nonmetallic bumper cutouts that ultrasonic sensors require.

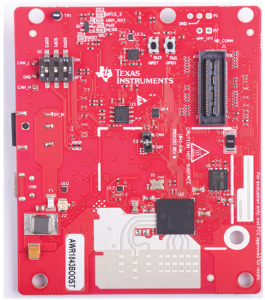

Figure 6. *TI's AWR1843BOOST 77-GHz automotive mmWave evaluation module*

Alleviating these cutouts further protects the radar sensors from the environment while maintaining the aesthetic look of the car.

Finally, there may be advantages from the additional processing power of mmWave technology. For example, TI's AWR family of radar-on-chip devices provide all of the necessary sensor processing on-chip. **Figure 6** shows an evaluation module for the AWR1843 parking sensor. The output from these automated parking chips can go right to the systems controlling the vehicle's parking or steering systems – no additional computations are needed.

Summary

The benefits of mmWave radar sensors include complete 360-degree coverage around the vehicle, as well as accurate measurements of an object's range, velocity and angle. These features enable mmWave radar sensors to complement today's ultrasonic and camera systems for assisted and automated parking.

Starting as early as 2020, automotive OEMs will repurpose existing ultrasonic sensors with additional mmWave radar functionality to perform all of the measurements and processing necessary for automated parking, blind-spot detection, collision avoidance and much more.

Additional resources

- Read the white paper, "TI's smart sensors ideal for automated driving applications."
- Read the blog post, "Where are ultrasonic sensors used? – Part 1."
- Check out the reference designs, Automated parking system reference design using 77-GHz mm Wave sensor and Automotive Ultrasonic Sensing Module Reference Design for Park Assist
- Watch the TI Training video, "Introduction to mmWave Sensing: FMCW Radars, Module 1: Range Estimation."

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