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Parking Space Detection Using Ultrasonic Sensor in Parking Assistance System

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Abstract— **This paper deals with parking space detection by using ultrasonic sensor. Using the multiple echo function, the accuracy of edge detection was increased. After inspecting effect on the multiple echo function in indoor experiment, we applied to 11 types of vehicles in real parking environment and made experiments on edge detection with various values of resolution. We can scan parking space more accurately in real parking environment. We propose the diagonal sensor to get information about the side of parking space. Our proposed method has benefit calculation and implementation is very simple.**

I. INTRODUCTION

Parking is considered for a driver to be the hardest when driving a car because parking is a high-stress maneuver. This paper deals with parking space detection by using ultrasonic sensor. As safety and convenience for driving are paid attention, many researches are progressing vigorously for parking assistance system. Research of making Parking Environmental Map using ultrasonic is developed with various methods.

The most fundamental method is to determine the direction of measurement distance with right angle under the assumption that the surface is rough [1], [2]. But this method has the error increment in proportion to the distance because of uncertain direction within beam width range. To identify corner, plane and edge of the surface of an object, Bozman modeled in ultrasonic and reflection surface [3]. Additionally, another method is detecting edge using ultrasonic sensors that have a wide beam width [6]. Moreover Satonaka got the parking space with modeling in the rounded edge side of vehicles [7]. It needs to make lots of calculations. For example, if there is right angle structure in an underground parking lot, Satonaka's method can not be applied.

The ultrasonic sensor measures the distance by TOF (Time of Flight), which is travel time from a sensor to an object with acoustic wave. A sensor circuit makes amends the amplitude of the detected echo that has spreading loss and air loss occurred in proportion to TOF, t_o during travelling [4]. Equation (1) shows, for compensated echo signal, the distance, R is obtained by TOF measurement.

$$R = \frac{ct_o}{2} \tag{1}$$

where c = 340 m/s at 20 °C

When making an environment map by ultrasonic sensor, the most critical problem is angle information as uncertain as beam width ($\pm\theta_0$). In Fig. 4, to illustrate, the error of the single echo function shows that error of edge detection, which estimates larger than an original object's width. The beam width is determined by the center frequency (f_R) and diameter of the transmitter (a) in equation (2) [5].

$$\theta_0 = \sin^{-1}\left(\frac{0.61\lambda}{a}\right) \tag{2}$$

where $\lambda = c / f_R$

Consequently parking space is measured more narrowly than real parking space because of uncertain angle information of ultrasonic sensor. To solve edge detection error, we can reduce the beam width by increasing the center frequency, f_R or increasing the diameter of the transmitter, a. However, this method has a serious problem that multi path occurs because of reduced incidence angle when ultrasonic beam width is decreased [5].

There are various sensors for parking assistance system including LRF (Laser Range Finder), Vision sensor and SRR (Short Range Radar). LRF is able to get accurate information of angular distance within 180°. However it can not detect a projected structure except scanning surface because LRF detect not the volume but the point. To make up for this problem, LRF is installed with tilt toward bottom, which brings more accurate 3D information [8]. Despite such advantages, Laser can not detect black color surface of vehicles for natural property of light. It is really founded in experiment status. Therefore LRF can not be applied to parking assistance system because of such a fatal problem. In case using vision sensor, lane detection at parking lot is being developed actively. Vision sensor has good points that it has

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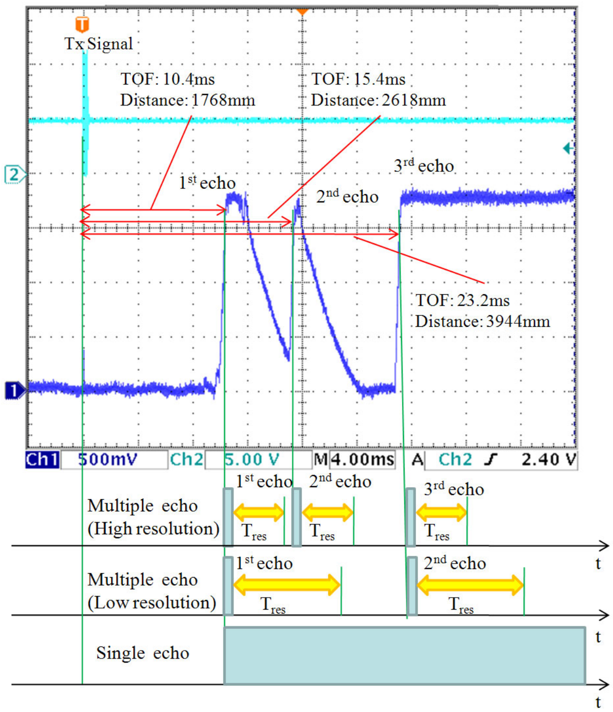

Fig. 1. The single echo function and the multiple echo function

much information more than range sensor has. Thus, it can decide various situations and cope with status. However, if a lane is damaged or is hid by another vehicle then vision sensor can not detect the parking lot in spite of enough parking space. In case using SRR (Short Range Radar), SRR is able to get information about angles, distances and relative velocity and etc [9]. However, SRR has some problems that have to solve the scattering phenomenon on edge and its price is far higher than other sensors.

The conventional research is building an environment map by transmitting ultrasound and receiving just one echo. We propose, however, once transmitting ultrasound and receiving multi-echoes more than 2 times. In accordance with this method, we can build more accurate environment map. Besides we propose the diagonal sensor. It offers information about the side of parking space.

II. Multiple Echo

As you can see in Fig. 1, the single echo function is that once transmitting ultrasound pulse set is sent and just one echo s received. Then the distance is calculated by TOF. The ultrasonic sensor detects the nearest object placed in effective beam width by the single echo function. And it estimates the direction of the object or assumes the direction is orthogonal angle. Contrarily, the multiple echo function is after transmitting ultrasound pulse set once and the first echo is gotten. Also it has to check the more multiple echo signal at

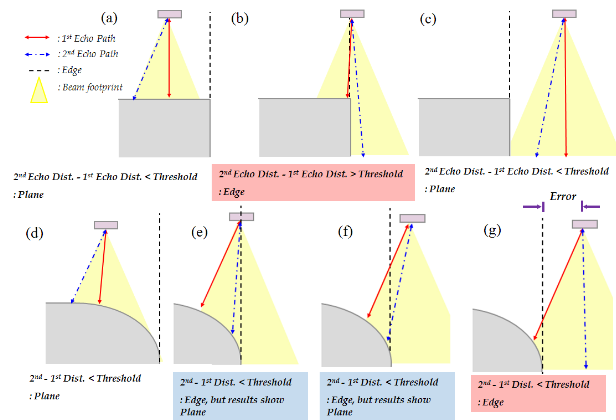

Fig. 2. Classification of surface shape for right angle edge side and rounded edge sides.

each T_{res} (Multiple echo Resolution Time). Then the distance is calculated by TOF of the first echo. The object is identified by the multiple echo function.

$$R_{res} = \frac{cT_{res}}{2} \tag{3}$$

As an equation (3), we can calculate the radial resolution, R_{res} of multiple echoes, the minimum distant difference among objects or the surface of an object, by checking interval time of multiple echo, T_{res} .

III. Classification of Surface Shape and Error Increment at Rounded Shape

Fig. 2 shows that classification of surface shape by the multiple echo function using equation (4).

$$\begin{aligned} R_{2nd} - R_{1st} &> Threshold : \quad Edge \\ R_{2nd} - R_{1st} &\le Threshold : \quad Plane \end{aligned} \tag{4}$$

where : R_{1st} is the calculated distance by TOF of 1st echo

R_{2nd} is the calculated distance by TOF of 2nd echo

In Fig. 2 (a), since R_{2nd} -R_{1st} is about R_{res} and smaller than threshold, the surface shape is estimated to plane. In Fig. 2 (b), on the other hand, R_{2nd} -R_{1st} is about the depth of object and larger than threshold. Therefore the surface shape is estimate to edge when we assume the depth of the object is even deeper than threshold. In other words, the 1st echo is reflected from the forward part of an object and the 2nd echo is reflected from the back side. When ultrasonic sensor passes by the object, the back side is detected as you can see in Fig. 2 (c). In this case, R_{2nd} -R_{1st} is about R_{res} and smaller than threshold. Then the surface appearance is estimated to plane. In reality parking status, however, the edge of vehicles is too

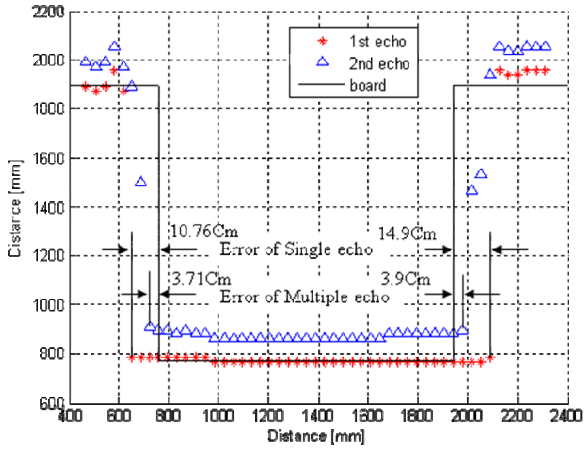

Fig. 3. In indoor experiment, comparison with the single echo function and the multiple echo function.

rounded-shaped to get accurate information. Fig. 2 (d)-(g) shows errors of the edge detection. Whereas in right angle edge (fig. 2(b)) R_{2nd} -R_{1st} is larger than threshold, Fig. 2 (e) shows that R_{2nd} -R_{1st} is smaller than threshold. Hence despite edge point, the surface shape is estimated to plane. Also, in Fig. 2 (f), the surface shape is miscalculated because R_{2nd} -R_{1st} is smaller than threshold. In status Fig 2 (g), since R_{2nd} -R_{1st} is larger than threshold, the surface shape is estimated to edge. Therefore Fig 2 (g) shows enormous error.

Consequently to reduce such above shown errors, we need to adjust the radial resolution of the multiple echo function, the amplitude gain of receiving part and rotation of ultrasonic sensor appropriately.

IV. Adjust of Resolution, Gain and Angle

The radial resolution of multiple echoes (R_{res}) means the resolution of detection distance by calculating minimum interval time of between the 1st echo and the 2nd echo (T_{res}). For instance, when R_{res} is 30cm, ultrasonic sensor can detect the object or the surface shape of the object placed in more than 30cm after receiving the 1st echo. In conformity with adjusting R_{res} , accuracy of edge detection is variable.

Our goal is to detect the parking space of vehicles. When we assume the vehicle is 150cm wide, we want to get value of R_{2nd} -R_{1st} with near 150cm. Because vehicles are designed variously and have many concave and bulge areas (especially wheel parts), the surface of vehicle generates irregularly diffused reflection wave. Too small R_{res} brings bad effect since sensor receives the continuous echoes. On the other hand, sensor can not receive the echo within T_{res} after receiving the 1st echo. It is say that we can not get the information. Too large R_{res} makes errors of edge detection.

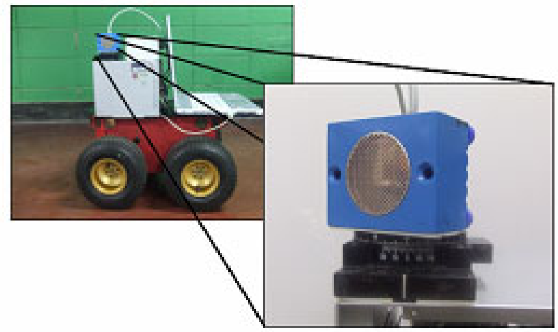

Fig. 4. Mobile robot, PIONNER 2-AT2 and it is possible to rotate sensor.

In flat board case, when R_{res} is 10cm, the smallest value, has the best performance because flat board (an ideal case) has not concave and bulge areas. Ultrasonic sensor can receive regular reflection wave.

As another method to reduce the error of edge detection, we need to adjust the amplitude gain of receiving part. The reflection power of round-shaped surface is smaller than that of the plane-shaped surface. Reducing the amplitude gain of receiving part has an effect on making effective beam width narrow. As the result of adjusting the amplitude gain of receiving part, we can reduce the error in edge detection.

The sensor in the orthogonal direction of moving direction gets information related to only parallel side. As we can see in Fig. 3, by above referred method, we couldn't get information related to the side of parking space. However we experimented to get the data of the side by rotating diagonal sensor with various angles. By data fusion both from orthogonal and from diagonal sensors, we can get more accurate parking environment map. Fig. 4 shows it is possible to rotate the sensor on auto-mobile robot.

V. Experimental Results

A. *Experimental environments*

In this experiment, we used the mobile robot, PIONEER 2-AT2 (P2-AT2) of Active Robot Company. P2-AT2 is driven by the selection of direction, speed and distance in VC++ software created by our team. The AVR processer measures the movement distance of the robot and receives the TOF of ultrasound wave with real time processing. The AVR processer sends ultrasonic data including robot's location to VC++ software of notebook via UART port. This system can conveniently scan parking space in any parking environment. The speed of the mobile robot is fixed on 5km/h and the distance from the mobile robot to vehicles is fixed on 1m.

The Ultrasonic sensor is Polaroid 600 series smart sensor of SensComp company. It's f_R is 50 kHz and a is 3.87cm, therefore, beam width, θ_0 is 12.4779°. As the result of

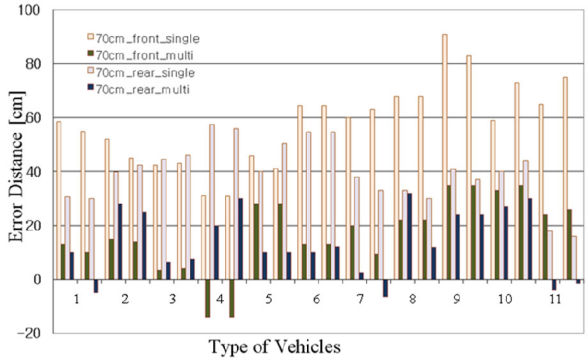

Fig. 5. In real parking environment, comparison with the single echo function and the multiple echo function for various vehicle types. 70cm_front_single means that error of edge detection of front side at 70cm resolution using the single echo function. (1 : AVANTE XD, 2 : BMW330i, 3 : CARSTAR, 4 : SANTAFE, 5 : SEPHIA, 6 : SPOTAGE, 7 : OPIRUS, 8 : KORANDO, 9 : SM3, 10 : GRANSER XG, 11 : EF SONATA)

experiment, θ_0 is measured to 11.8 ~ 12.4°. The detective range of sensor is 0.25 ~ 8m and installment height of one is the bumper height of vehicles. The sampling period is 69ms (14.5Hz) and R_{res} is 10cm in indoor experiment.

The reference map is created by Laser Range Finder (LRF) of SICK to get the accurate parking environment map. LRF can get distance data within 0 ~ 180° direction with 1° interval, and the reference map is created.

B. *Experimental results*

Fig. 3 shows the difference of error in between the single echo function and the multiple one when using ideal flat board in indoor experiment. The reason of the existence of such errors is uncertainty direction angle of ultrasonic.

At the 1st edge, whereas the error of the single echo function was 10.76cm, the error of the multiple one was 3.71cm. Hence the multiple echo function had an effect to reduce the error of 7.05cm. At the 2nd edge, 14.9cm, the error of the single echo function, was reduced to 3.9cm by the multiple echo function. The gap was 11cm and it was immense gains. In indoor experiment, the error of the single echo function was less than 15cm but that of multiple one was less than 5cm.

Fig. 5 and Table 1 are the experimental results for other 11 type's vehicles in real parking environment. We made experiments on edge detection with various value of R_{res} from 10cm to 100cm. Table 1 shows the error of edge detection with the single echo function and the multiple echo function for R_{res} of 10, 50 and 70cm. According to the result, when R_{res} was 70cm, the best performance was at the mean value with 15.42cm and the maximum value with 32cm. The multiple echo function performed better than the single echo function. And the maximum error of the multiple echo function was less than half of the error of the single echo function for each resolution. Especially at 70cm resolution,

TABLE 1
ERROR OF THE EDGE DETECTION ABOUT THE SINGLE ECHO FUNCTION AND THE MULTIPLE ECHO FUNCTION AT 10, 50, 70CM RESOLUTION.

Resolution		Single echo	Multiple echo	Unit
10cm	Mean	49.82	26.05	Cm
	Variance	254.88	168.82	Cm
	RMS	52.26	29.05	Cm
	MAX	83	42	Cm
50cm	Mean	45.58	18.80	Cm
	Variance	243.10	155.21	Cm
	RMS	50.97	22.48	Cm
	MAX	83	40	Cm
70cm	Mean	49.01	15.42	Cm
	Variance	266.98	172.52	Cm
	RMS	51.6	20.16	Cm
	MAX	91	32	Cm

TABLE 2
ERROR OF THE EDGE DETECTION TO ADJUST THE AMPLITUDE GAIN OF RECEIVING PART.

Types of Vehicle	Front		Rear		Unit
	Full Gain	Low Gain	Full Gain	Low Gain	
GRANDEUR XG	+25.7	+19.9	+35.7	+16.6	Cm
AVANTE	+21.0	+20.3	-13.0	0.5	Cm
	+16.4	+16.9	-8.0	-10.0	Cm
	+21.3	-10.0	0.3	0.2	Cm
CARENS	+26.8	+23.5	+16.3	0.3	Cm
	+24.7	+23.5	+18.1	+11.6	Cm
	+30.9	+23.5	+13.7	+11.6	Cm
LAVITA	+24.3	-6.8	-3.9	-2.7	Cm
	-6.3	-8.5	+3.4	0.3	Cm
	+22.8	-5.0	0.4	0.5	Cm

91cm, the maximum error of the single echo function, became 32cm with the multiple echo function. Its value was about one third times. Also variance 266.98 of the single echo function became 172.52 with the multiple echo function. It means the more stable edge detection. Fig 5 shows the error of 70cm resolution for the front edge and the rear edge of vehicles. 11 types of vehicles include sedan and SUV of various companies (HUNDAI, KIA, SSANG YOUNG, RENAULT SAMSUNG, and BMW) We can see the reduction of edge detection error in proportion to larger R_{res}. If we assume a vehicle is 150cm wide, when R_{res} is 70cm, about half of vehicle width, we would get good results from experiments.

As another method to reduce the error of edge detection, we need to adjust the amplitude gain of receiving part.

Table 2 shows the reduction of edge detection error in proportion to less amplitude gain. If the edge is right angle shaped, we would achieve the desired result. In case of GRANDEUR XG, the rear edge side has larger curvature than the front edge side. At full gain, 35.7cm error became 16.6cm error by adjusting amplitude gain of receiving part. In

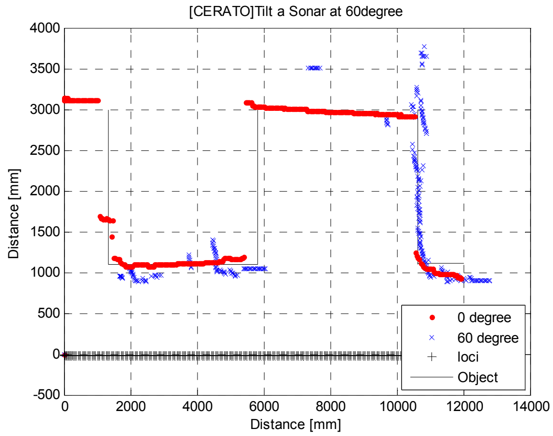

Fig. 6. The parking environment map using the orthogonal sensor and the diagonal sensor in real parking status.

case AVANTE, CARENS and LAVITA, the front edge side has more large curvature than the rear edge side. By adjusting the amplitude gain of receiving part, we obtained good results. The reason is that the effective beam width of ultrasonic sensor reduces proportionately to the amplitude gain of receiving part. However we should be cautious that too low amplitude gain makes the sensitivity of ultrasonic debased.

Fig. 6 shows the result from the sensor in orthogonal direction of the robot's moving direction and 60° diagonal sensor. Using the sensor in orthogonal direction, we got information related to just parallel side of the robot's moving direction. To get data of the side of parking space, we need diagonal sensor. 60° data in Fig. 6 shows the right side of parking space. The data of left side of parking space could be obtained by -60° diagonal sensor. In Fig. 6, there is not left side because of absence of -60° diagonal sensor. This result shows the accurate information about parking space. The wrong data from the distance over about 3m are able to be removed by orthogonal direction data.

VI. Conclusion

Using the multiple echo function, we could detect parking space more accurately in real parking environment. First we inspected effect on the profit of the multiple echo function in indoor experiment. 10 ~ 15cm, error of the edge detection with the single echo function becomes less than 5cm with the multiple echo function in indoor experiment. Therefore we confirmed utility of the multiple echo function.

Next step, we applied to 11 types of vehicles in real parking environment. Using the multiple echo function we got more accurate edge detection than the single echo function. We made experiments on edge detection with various value of R_{res} from 10cm to 100cm. We could get good performance at 70cm R_{res}. The maximum error 91cm of the single echo function became 32cm with the multiple echo function. Its value is about one third times. Also variance 266.98 of the single echo function becomes 172.52 with the multiple echo function. It means the more stable edge detection.

To reduce the error in edge detection, we inspected closely edge which had errors more than 20cm. These edges have large curvature. Therefore we reduced the amplitude gain of receiving part because the effective beam width of ultrasonic sensor reduces proportionately to the amplitude gain of receiving part. In case of GRANDEUR XG, 35.7cm error of the rear side edge became 16.6cm error.

We propose the diagonal sensor to get information about the side of parking space. We experimented to get the data of the side by rotating diagonal sensor with various angles within 0 ~ 90°. As above shown result, it is appropriate to use 60° diagonal sensor for recognition of the side of parking space.

We compared with the performance by other methods. Satonaka's method using modeling of rounded shape of vehicle edge side had edge detection error less ±30cm for 5 types of vehicles [7]. Our proposed method is verified by 11types of vehicles such as sedan and SUV of various companies. We obtained the final result of this work that edge detection error was from -10cm to 30cm. Furthermore, proposed method has benefit calculation and implementation is very simple. Whereas Satonaka's method has enormous error for right-angled post at parking lot or right-angled edge such as rear side of a truck, our proposed method can detect more accurate edge detection in this case.

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