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Design and Experimental Study of an Ultrasonic Sensor System for Lateral Collision Avoidance at Low Speeds

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Abstract

In this study, we design and implement an ultrasonic sensor system for lateral collision avoidance of vehicles at low speeds. The developed sensor system is useful for detecting vehicles, motorcycles, bicycles and pedestrians that pass by the lateral side of a vehicle. The system can be adopted to enhance the rear-view mirrors of present vehicles, which have blind spots on the lateral sides. Ultrasonic sensors, which have been widely used on cars for rear object detection during parking, are developed for lateral object detection at low speeds. Detailed experimental studies are presented in this paper. Experimental results show that the proposed system can detect a vehicle at speeds up to 40km/hr with a maximum range of 6 meters. Moreover, the influence of wind on the measurement is also investigated. The developed sensor system gives satisfactory results for a wind speed up to 35km/hr.

1. Introduction

Lateral collision avoidance is important for safety driving because there are blind zones at both sides of a vehicle during driving. To improve visibility and avoid these blind zones are essential for driving in urban area at low speeds as there exist an increasing number of motorcycles, bicycles and pedestrians in city traffic. The blind zones are relatively wider for large vehicles such as buses or trucks, where lateral collision often causes severe traffic accidents. Millimetre wave radar is useful for head-on accident detection and prevention at high speeds. For low speed applications, other types of sensors are desired for object detection and collision avoidance. Ultrasonic sensors have been used for parking assistance of passenger cars. We investigate in this paper an ultrasonic sensor system that can be utilized for lateral collision avoidance, especially for large vehicles.

Several researchers have studied sensing systems for lateral collision avoidance. Existing sensor systems onboard a vehicle for lateral object detection can be categorized into three types: (i) Doppler radar system: Although radar is the most frequently used sensing device onboard a vehicle to detect other objects in traffic applications[1][2], it is not effective for low speed situations and will have error caused by cosine factor. Currently, radar systems are expensive devices and limited for luxury cars. (ii) Ultrasonic sensor system: This type of sensor has been widely used for environment detection and obstacle avoidance of autonomous mobile robots[3][4][5]. It has wide detection angle and offers a less expensive solution. However, the drawback of this type of sensor is that ultrasonic waves are transmitted through air and the reflex surface texture will affect the measurement. (iii) Vision system, Mertz *et al.* utilized cameras to detect the side space of a car. The system can be installed near the rear-view mirror [6][7]. However, vision systems cost much computation time to extract useful information. Real-time performance is a challenge issue for vision-based systems. Lighting condition will also influence the image acquisition. It would be difficult to be used during the night.

In this study, we select ultrasonic sensor system considering the following advantages:

(1) It is less expensive and will be suitable for general vehicle applications.
(2) It can easily obtain distance information from immediate objects without complex computation.
(3) It has wide surface measurement, not just single point detection.

2. Lateral Collision Avoidance System

This design of lateral collision avoidance system is especially aimed for large vehicles. Several important

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factors have been taken into consideration for the design of this system:

1) Multiple sensors need to be installed along the side of the vehicle
2) The range of the sensor should be from 0.5 m to 4m, taking into consideration of the response time and the width of a normal traffic lane.

Fig. 1 illustrates a design for sensor deployment along the vehicle. For experimental purpose, we assume the vehicle is about 4~5 meters and the interval of the ultrasonic sensor is 1 meter. Fig. 2 depicts a detection situation for an actual traffic condition.

The system transmits ultrasonic wave every 50 ms with an effective range of 0.5m~4m. The warning system consists of three functional blocks as shown in Fig 3:

1. Ultrasonic distance: The obtained distance to lateral objects.
2. Reliable distance: A filtered distance giving a more reliable measurement.
3. Dangerous warning: Use of the distance information to determine a warning alarm.

Polaroid ultrasonic ranging system[8] was adopted for the lateral collision avoidance system. An AT89C51 microcontroller is responsible for the firing sequence and functional control of the sensor system. The measured distance value is obtained and transferred to the on board unit through CANbus. The on board computer determines the waning alarm to the car driver. Fig. 4 shows the block diagram of the system hardware.

According to above-mentioned system architecture, we have developed a prototype system for lateral collision avoidance. Fig 5 shows a picture of the sensor system. As shown in Fig. 5, the system consists of two parts. The upper part of Fig. 5 shows the sensor control module, while the lower part is the transducer module. An RS232 interface is provided for initial testing of the modules when a communication to PC is required. The transducer module is composed of four Polaroid 6500 ultrasonic transducers. The transducer serves both as a transmitter and a receiver. Each of the ultrasonic sensor can detect distance range is about 0.5m to 4m. The beam angle of the ultrasonic wave is about $40°$. The CANbus interface is designed using Philips JSA1000 CANbus controller and 82C250 CANbus transceiver.

3. Experimental Results

In order to examine the performance of the developed system for lateral safety warning in the real world, we installed the sensor system on a vehicle. Fig. 6(a) shows a picture of the experimental vehicle. The deployment of the sensors on the vehicle is illustrated in Fig. 6(b). A notebook PC is put onboard for sensor control and data storage. Two experiments were conducted to investigate the performance of the sensor system.

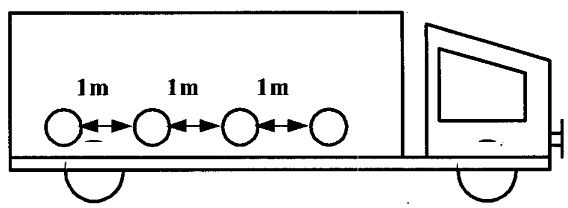


Fig. 1. Installation of ultrasonic sensors along one side of the vehicle

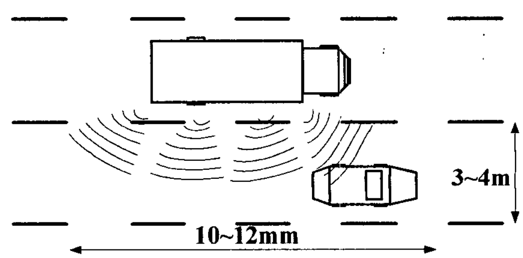


Fig. 2. Lateral detection condition

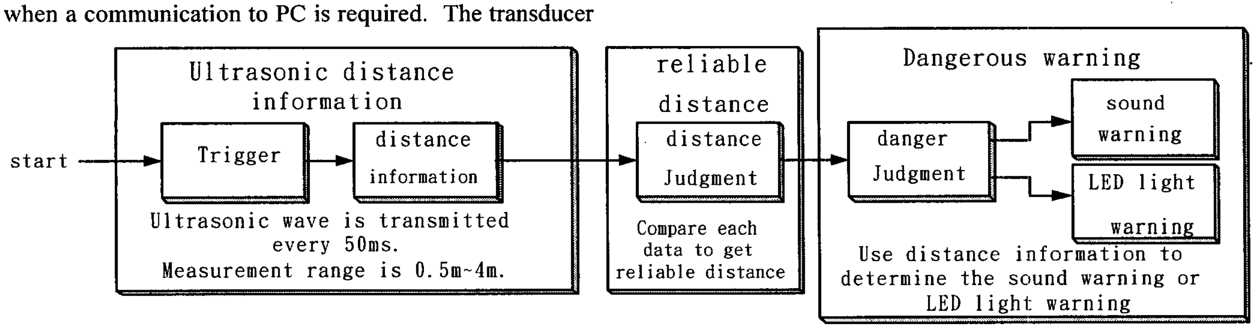


Fig. 3. System functional block

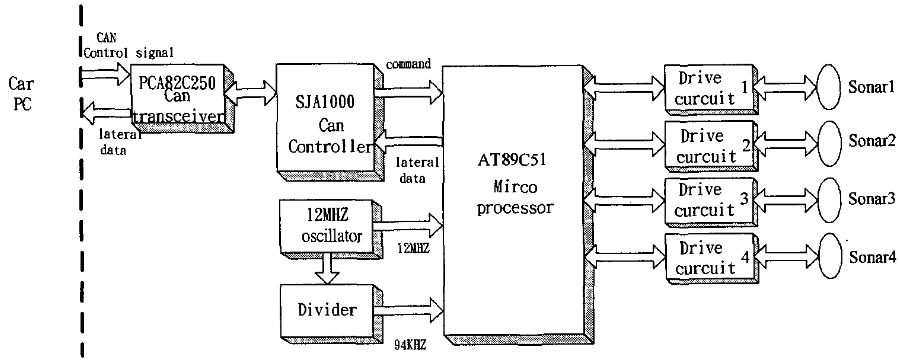


Fig. 4 Hardware block diagram

Illustration:
1. Ultrasonic contol circuit
2. Driver circuit
3. Transmitter
4. RS-232 Interface
5. CanBus Interface
6. 5V Input power
7. Sonar1 connect
8. Sonar2 connect
9. Sonar3 connect
10. Sonar4 connect

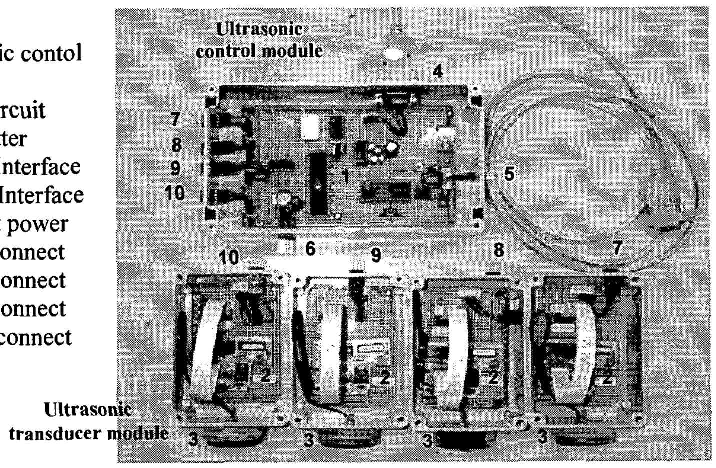
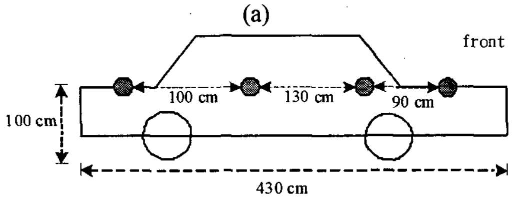


Fig. 5. Prototype of the ultrasonic ranging system

(a)



(b)

Fig. 6. (a) The vehicle in the experiment (b) sensor deployment on the vehicle

In the first experiment, the vehicle equipped with ultrasonic sensors was parked stationary with a moving motorcycle passing by at a constant speed in the lateral vicinity of the vehicle. The speed of motorcycle was set from 20km/hr to 40km/hr. The lateral distance between the motorcycle and the vehicle varied from 100cm to 300cm for various speeds of the motorcycle. The purpose of this experiment was to test the measurement result of the sensor system under different speeds. Fig. 7 shows the experimental results of four sensors with the motorcycle speed of 30km/hr. We see from Fig. 7 that in the beginning the detected distance is 5.5 meter, which is actually the open space. A result of 1 meter was measured later on as the motorcycle passed by and was detected. Four ultrasonic sensors all detected the motorcycle for the speed of 30km/hr. Figs. 8 show the measurement results of higher speeds. We see that as the motorcycle passed with a higher speed of 40km/hr, not all four sensors obtain correct results. For most cases, only two sensors detect the motorcycle and return acceptable distance data.

In the second experiment, a vehicle equipped with ultrasonic sensors drove in straight line and passed several parked vehicles. The distances to the vehicles were measured and recorded. The purpose was to investigate the capacity of ultrasonic sensors under dynamic situations. This experiment is quite practical for emulating actual traffic conditions. Fig. 9 illustrates the experimental arrangement. In the experiment, the car was driving forward with speeds from 10 km/hr to 40 km/hr for different rounds. We set two distances between the moving car and the laterally parked vehicles. Fig. 10 shows the experimental results of a 2m lateral distance and Fig. 11 is the case for 4.8m. We observe that for both distances all four lateral sensors gave acceptable distance data at 10km/hr. As the speed increased to 30km/hr, there were fewer readings recorded. This is reasonable since the

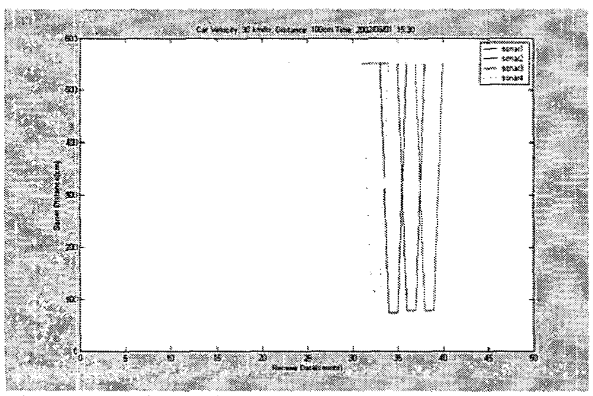


Fig. 7. Experimental results of measuring a motorcycle with speed of 30km/hr, and lateral distance 100cm

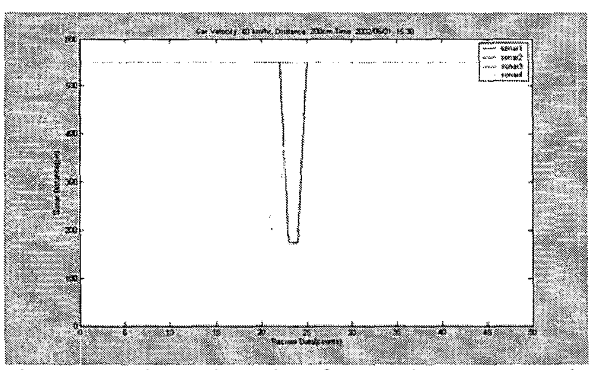


Fig. 8. Experimental results of measuring a motorcycle with speed of 40km/hr, and lateral distance 200cm

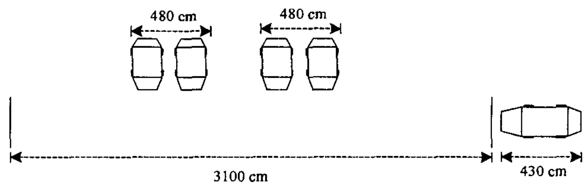


Fig. 9. Experimental environment for dynamic test

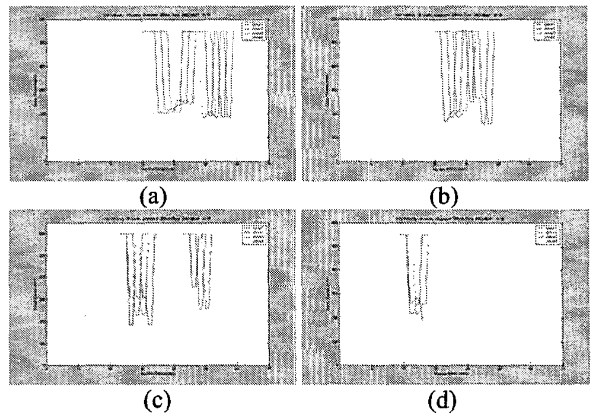


Fig. 10 Experimental results of dynamic distance measurement, with lateral distance 200cm, and speed of the vehicle (a) 10km/hr (b) 20km/hr (c) 30km/hr (d) 40km/hr

duration time becomes shorter as the speed increases. The distance measurements are still acceptable for both cases at speed of 30km/hr. However, the recorded distance is even fewer and less accurate at a speed of 40km/hr. From the above experimental observations, we see that the lateral distance measurement is valid for speed up to 40km/hr.

For practical applications, it is desired to investigate the influence of wind on the sensor system. The sensor system has been tested in an environment for both cases of with wind and without wind. Fig. 12 illustrates the test arrangement of four testing modes. A factory fan that can provide a maximum wind speed of 34.8km/hr was utilized to generate the wind in the experiment. As shown in Fig. 12, four wind modes were set up in the experiment. In mode (1), a lateral wind blew near the transducers. In mode (2), the lateral wind is generated near the detected object. In mode (3) and mode (4), the wind blew head on to the transducers or to the detected object respectively. Fig. 13 shows the experimental result of the developed ultrasonic sensor system without wind.

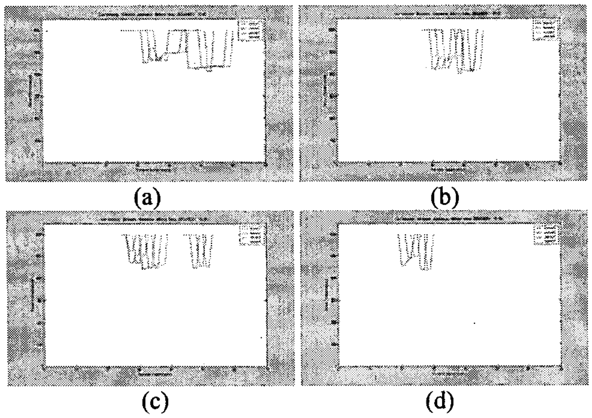


Fig. 11 Experimental results of dynamic distance measurement, with lateral distance 480cm, and speed of the vehicle (a) 10km/hr (b) 20km/hr (c) 30km/hr (d) 40km/hr

We see that the sensor is quite linear in the detection range of 0.4~4m. Here we define an error = Max (Detected distance with wind- Detected distance without wind). Figs. 14 and 15 show the experimental results of the error of mode (1) and mode (2) respectively. We see from these figures that in both modes the errors are smaller than 2cm. Moreover, the distance reading in these two modes are stable. For mode (3), each set distance has several possible readings. For example, when the actual distance is 100cm but the detected distance might vary from 99~102cm. We see in Fig. 16 that the error becomes larger as the set distance increases. The maximum error is 6cm, which is greater that that of the side wind mode. Fig. 17 shows that the error in mode (4) is similar to that of mode (3). The maximum error is about 4cm in mode (4).

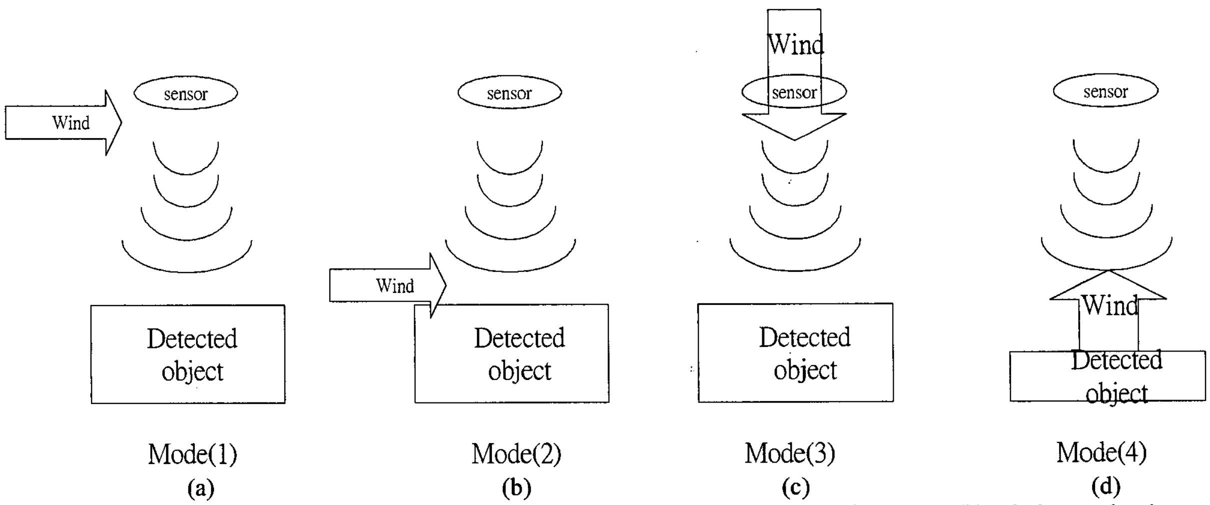


Fig. 12. Experimental arrangement for wind influence on the sensor, (a) wind near the sensor (b) wind near the detected object (c) wind head on the detected object (d) wind head on the sensor

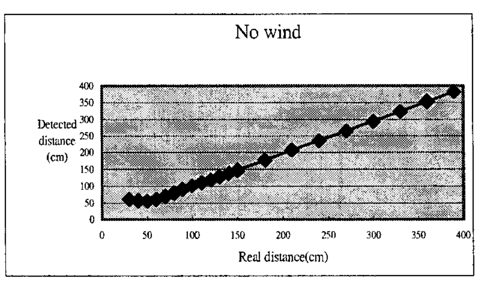


Fig13. Calibration test of the sensor without wind

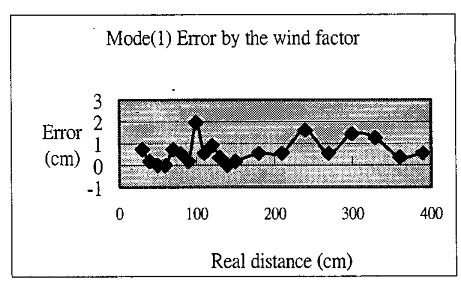


Fig.14. Error caused by wind under Mode(1)

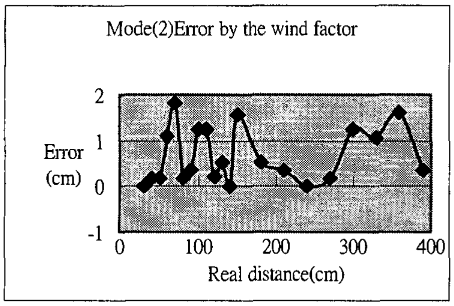


Fig. 15. Error caused by wind under Mode(2)

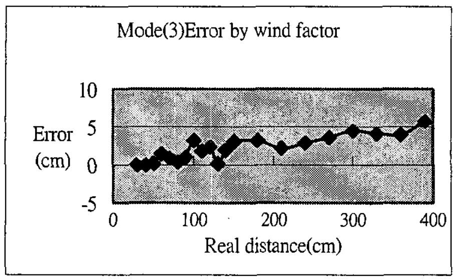


Fig. 16. Error caused by wind under Mode(3)

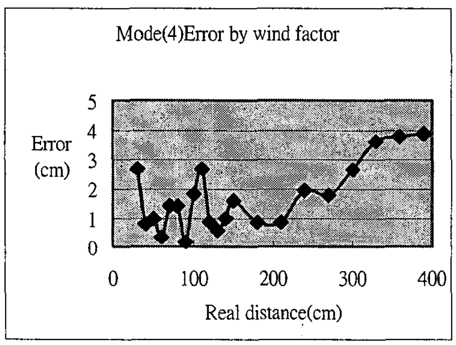


Fig. 17. Error caused by wind under Mode(4)

From the above experimental results we realize that mode(3) and mode(4) have greater errors than those in mode(1) and mode(2). This means that the head on wind will cause greater measurement error than the lateral wind. Nevertheless, under a wind speed of 35Km/hr the error is under 6cm for all modes.

4. Conclusions

A design and implementation of an ultrasonic sensor system has been developed for lateral collision avoidance at low speeds. Extensive experimental study for real world applications has been reported. Experimental results show that for both static and dynamic situations our system can detect the lateral object at low speeds. From the experimental results, we observe that the developed sensor system is useful for lateral object detection up to a speed of 40km/hr. Moreover, the wind experiments reveal that the system can detect objects with acceptable accuracy if the wind speed is under 40km/hr. In the future, a road test will be carried out to check the integrated functions of the warning system. Integration with a millimetre wave radar for higher speed applications will also be studied.

Acknowledgments

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