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Collision prevention systems due to the radius difference between inner vehicle wheels

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Abstract *- When a vehicle turns, the front and rear wheels do not have the same forward or backward trajectory. This situation is called the radius difference between inner wheels. The front wheels with the "wheelbase" length and "angle" are different from those of the rear wheels. Road tragedies have occurred due to motorcycle drivers and pedestrians getting caught in a turning truck's swept path width. A novel collision prevention system is presented to prevent the motorcycle drivers or pedestrians from the range of the radius difference between inner vehicle wheels. A steering angle sensor is used to calculate the turning angle of the wheels. According to the different steering angles, when the vehicle is turned, different voltage is output to an Arduino board. The ultrasonic transducers have been used to detect the motorcycle or pedestrians. The results show that a warning system could effectively remind the vehicle driver when the motorcycle or pedestrians are in danger.*

Keywords — *radius difference, inner wheels, wheelbase, road tragedies, swept path width*.

I. INTRODUCTION

According to the basic vehicle structure and the principle's role, when a vehicle turns, the front and rear wheels will not move along the same track. The front and rear wheels will travel along two different offset radii [1]. This situation is called the swept-path offset, as shown in Fig. 1. The difference between the wheelbase length and steering angle will vary [1]. The longer the vehicle wheelbase is, the greater the difference is. A large truck will produce a big difference between inner wheels than a small truck. The front wheels will make the turn at a greater radius than the rear wheels during a relative turn, creating a narrower swept-path by the rear wheels. A danger zone will be created in the right side swept-path [1]. This study designed a collision prevention system due to the radius difference between inner vehicle wheels. Ultrasonic transducers are installed on a bus or truck's side to detect if an object has entered the inner rear wheel swept path while the bus or truck is turning. An audible buzzer will warn the driver of the potential danger. According to the Bureau of Highway Statistics, there are more than 34,000 buses and 165,000 large trucks in Taiwan [2]. In 2015 there were 24 bus accident cases that 25 people were killed and 29 people were injured. Large trucks killed 153 people and injured 45 people in 140 accident cases [2]. Most of the long-wheelbase vehicle accidents occurred during turns where the driver's eye view is lost in the rear wheel swept path. In recent years, ultrasound has been widely used in different fields, such as distance measurement, fish detection, and ultrasonic flaw detection machines. Distance measurement is also used in reverse driving warning devices and self-propelled robots. The frequency of ultrasonic transducers varies with the measurement distances and ranges. Ultrasonic transducers are very common components in many applications [3, 4, 5].

II. THEORY OF RADIUS DIFFERENCE BETWEEN INNER WHEELS

The difference in turn radius between the front and rear wheels is the difference between the vehicle's front end's turning radius and the vehicle's rear end's turning radius when the vehicle turns[1, 2]. For a semi-trailer, this is the difference between the turning radius of the inner rear wheel of the tractor and the trailer's inner rear wheel. Due to the inner wheel differential, the turning path of the front and rear wheels does not coincide when the vehicle turns [1]. Fig. 2 is a schematic diagram of the inner wheel differential generated when a semi-trailer makes a 90˚ turn to the right. The fan-shaped area 1 in the figure shows that when the vehicle enters the intersection, the wheel differential quickly increases to a maximum value, which creates a huge safety hazard. As can be seen from the fan-shaped area 2, the wheel difference still exists after a long turning of the large truck body is completed. This can be seen from the semi-trailer turning the wheel with a large distance, producing fast, disappearing, and slowing. The large truck wheel slip becomes the main cause of road traffic safety problems. When the vehicle runs at a certain turning radius, the front wheel angles are generated at different driving speeds. Therefore, when the front wheel angle is constant, the vehicle's speed will affect the size of the inner wheel circle. The following calculation is for a vehicle traveling along a specific turning radius and is not aimed at a specific front wheel angle. Therefore, the calculated inner wheel differential is independent of the vehicle speed. We derive the difference between the inner and outer wheels generated by the vehicle turning 180° and 360° at a certain radius along a certain path. As shown in Fig. 3, the result can be regarded as the theoretical maximum inner wheel differential that the big truck can produce when turning at the intersection. For three-axle or four-axle heavy-duty non-trailer trucks with wheelbase L, the internal wheel slip principle and the definition of the parameters are shown in Fig. 4. The parameters in the figure can be expressed as follows [1]:

$$a_1 = \sqrt{R_1^2 - L^2} - \frac{d_2}{2} \quad (1)$$

$$\cos\alpha = \frac{a_1 + \frac{d_2}{2}}{R_1} \quad (2)$$

$$b = \sqrt{R_1^2 - \left(\frac{d_1}{2}\right)^2 - d_1 R_1 \cos\alpha} \quad (3)$$

$$m_1 = b - a_1 \quad (4)$$

Where a_1 is medial rear wheel centerline of the radius of motion, R_1 is vehicle lane where the turning radius, L is the wheelbase, d_1 is the front track, d_2 is the rear track, α is tractor front axle and rear axle center point, b is the radius of the medial front wheel center of the radius of motion, m_1 is a non-trailer vehicle within the wheel (in units of m).

In this study, ultrasonic transducers have been used to detect the other vehicle. The normalized data can be easily observed. The ultrasonic transducer beam concept is shown in Fig. 5 [6, 7], and the parameters can be expressed as follows.

$$\lambda = \frac{c}{f} \quad (5)$$

$$\bar{\lambda} = \frac{\lambda}{a} \quad (6)$$

$$\bar{z} = \frac{z}{a} \quad (7)$$

$$\bar{r} = \frac{r}{a} \quad (8)$$

Where
λ is the wavelength of ultrasound.
c is the speed of sound.
f is the frequency of the ultrasonic transducer.
A is the radius of the transducer.
r is the radius of the ultrasonic beam.
z is the distance to the object.
The operation frequency of the ultrasonic transducer is very important to the distance measurement. The ultrasonic transducers have the best distance measurement result when the frequency response is at 40 kHz. The frequency is inversely proportional to the measured distance and the beam radius. The relationship is shown in Fig. 6 [3, 4]. The presence of sound depends on the sound frequency. The frequency and measurement range of the ultrasonic transducers used in this work is calculated from the following formula [3, 4]. The extinction equation can be expressed as:

$$\mathrm{E} = 5 \times 10^{13}/\mathrm{f}^2 \quad (9)$$

Where
E is the ultrasound extinction distance.
f is the sound frequency.

The relationship between radius and distance can be shown in Fig. 7. When the ultrasonic range is measured, the radius of curvature affects the measurement accuracy. The radius equation of curvature range can be shown as follows.

$$\mathrm{R} \geq \frac{r^2 + 0.01}{0.2} \quad (10)$$

R is the curvature radius, r is the ultrasonic beam radius at the reflecting surface.

If the radius of curvature exceeds this range, the error will be more than 0.1mm. Controlling the error within 0.1mm will get the correct measurement. The curvature radius effect is shown in Fig. 8 [1]. There are many kinds of ultrasonic transducers, so they have different functions at different frequencies. The most basic range of 30 kHz ~ 500 kHz for long-distance; they can be used as life-detection equipment, car peripheral warning device, and submarine fish sonar detectors. The 500 kHz ~ 25 MHz range is used for non-destructive testing and fetal inspection. The range of 1 MHz ~ 5 MHz is the most commonly used range. High - frequency detection is used to determine the density of objects or to know whether the object is damaged. Different frequencies for different applications are shown in Fig. 9. In this study, the ultrasonic transducers are operated at 40 kHz [6, 7]. When physical pressure is applied to the piezoelectric crystal, the material body's electric dipole moment will be shortened due to compression. At this time, the piezoelectric crystal will resist the change and generate an equal amount of positive and negative charges on the material's opposite surface to maintain the original shape. This electrical polarization phenomenon due to deformation is called the positive piezoelectric effect. The positive piezoelectric effect is essentially the process of converting mechanical energy into electricity. Due to the different types of materials used, the transducer will have different pressure frequencies and produce different response frequencies.

When the voltage is applied to the surface of a piezoelectric material, the electric dipole moment will be elongated due to the electric field. The piezoelectric material will stretch in the electric field's direction to resist the change. This process of generating mechanical deformation by the electric field is called the inverse piezoelectric effect. The inverse piezoelectric effect is essentially the process of converting electrical energy into mechanical energy. Applying a high-frequency square wave with a maximum peak voltage of 30V to the ultrasonic transducer, the transducer converts the electric energy into mechanical energy called an ultrasonic wave. The ultrasonic wave propagates along the transducer's axis at the speed of sound to the other end. Obstacles in front of the sound wave will rebound that wave. If no obstruction is present, sound waves will be passed until the energy is completely decayed.

III. RESULTS

Fig. 11 shows the measurement process of the warning system. Two sets of HC-SR04 ultrasonic transducers are used to measure the distance between the motorcycle and vehicle to calculate the safety area. If there is an obstacle within the safety distance, a warning lamp will light up in the dashboard and achieve the warning effect. According to different steering angles, a voltage signal of 0-5V measured from a steering angle sensor is sent to the Arduino board to calculate the safety area. The ultrasonic detectors were installed on the side of the vehicle. Different steering angles will produce different safety area.

The hall effect sensor was used in the steering wheel angle measurement. The measured voltage range of the Hall effect sensor is 0V - 5V. If the detection voltage is 0V-2.5V, then it can represent that the vehicle turns to the left. If the detection voltage is 2.5V-5V, then it can represent that the vehicle turns to the right. The voltage change can also identify the steering angle. An experiment was performed at an interval of 6 degrees turning angle. In addition to using the program to calculate the safety distance, the program also triggers the warning system. We found that the ultrasonic transducer sometimes produced a smaller value than the safety distance when measuring. Therefore, we increased the safety distance by 2-3cm to ensure that the warning system would be triggered to achieve the warning effect.

After the experimental measurement, the safety distance error fell within 2cm. The error is not large. A vehicle with a 2700mm wheelbase was used in the experiment. The measured data are shown in Table 1. The table shows that the measured error was small, and the warning system can effectively perform for different steering angles. In this study, the effect of wind and rain on the measured data has also been investigated. Table 2 shows the results for the effect of wind and rain on the measured data for different obstacles. From the table, we can see that the wind and rain could affect the measured data. However, the effect is not very significant.

IV. CONCLUSIONS

In this study, a collision prevention system of radius difference due to inner vehicle wheels has been designed. The theory of radius difference due to the vehicle's inner wheels has also been presented. Some experiments have also been conducted to evaluate the performance of the warning system. The results showed that the measured error was small, and the warning system can effectively perform for different steering angles. Also, the effect of wind and rain on the measured data has been investigated. The results showed that the wind and rain could affect the measured data. However, the effect is not very significant. Therefore the warning system for collision prevention could perform well.

REFERENCES

[1] R. Wang, H. Qian, X. Tan and X. Tan, Difference of Radius between Inner Wheels for Vehicles on Urban Road and Safety Countermeasures, Open Journal of Transportation Technologies. 3 (2014) 72-79.

[2] Cheng et al., Prevention of radius difference between inner wheels for trucks, Digital technology, and innovation conference. (2011).

[3] Sangeethu Sharma and Santini, "Accident Avoidance and Safety System for Vehicular Communication" SSRG International Journal of Industrial Engineering 4(2) (2017) 1-4.

[4] G.S.K. Wong and S. Zhu, Speed of sound in seawater as a function of salinity, temperature and pressure, J. Acoust. Soc. Am., 97(3) (1995) 1732-1736.

[5] L. E. Kinsler et al., Fundamentals of acoustics, 4th Ed., John Wiley and Sons Inc., New York, U.S.A. (2000).

[6] A. J. Zuckerwar, Handbook of the Speed of Sound in Real Gases, Academic Press, (2002).

[7] L. Zhengdong, H. Shuai, L. Zhaoyang, L. Wolfing, H. Daxi, -The Ultrasonic Distance Alarm System Based on MSP430F449, ICMTMA IEEE. (2013) 1249-1251.

[8] D. A. Bohn, -Environmental Effects on the Speed of Sound, J. Audio Eng. Soc. 36(4) (1988).

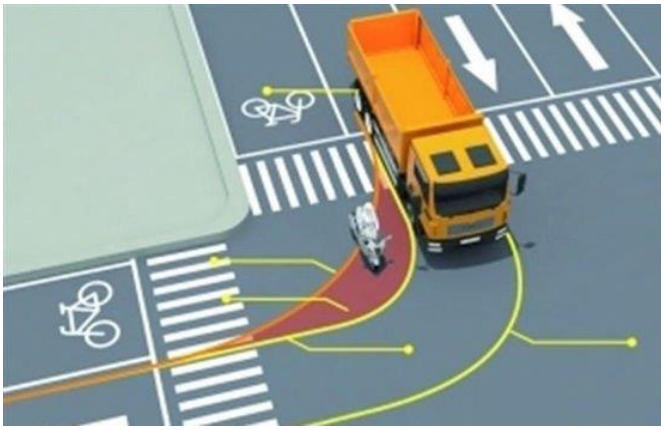

Fig. 1 The radius difference between the inner front and rear wheels

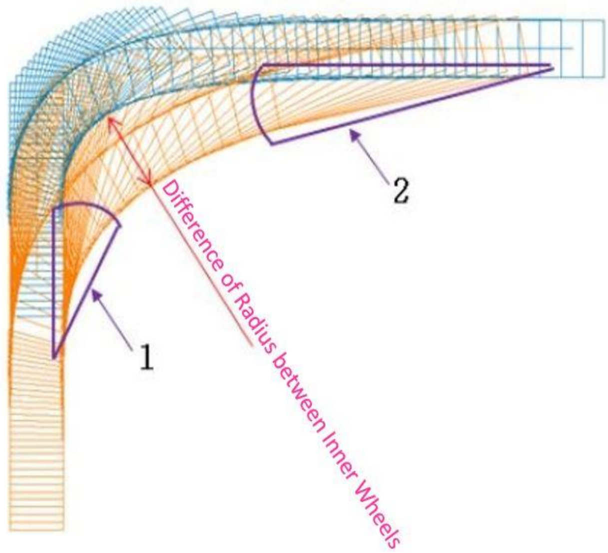

Fig. 2 Difference of radius between semi-trailer inner wheels

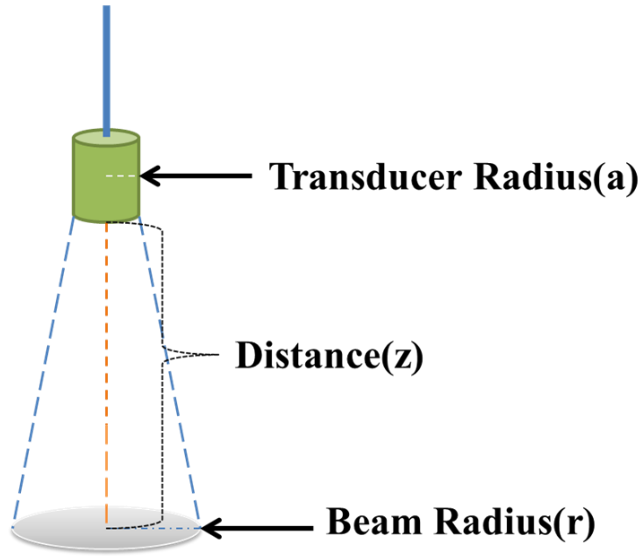

Fig. 5 The parameters of the ultrasonic transducer beam

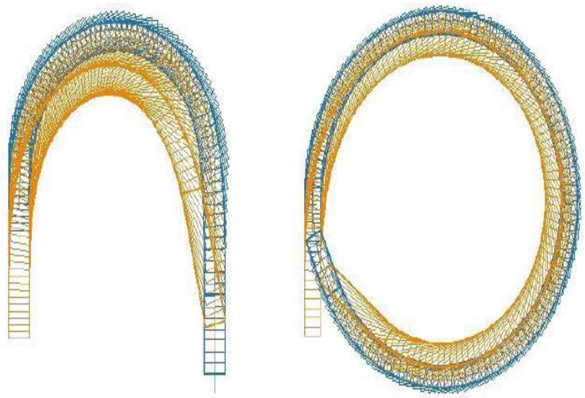

Fig. 3 Difference of radius between inner semi-trailer wheels turning 180° and 360°

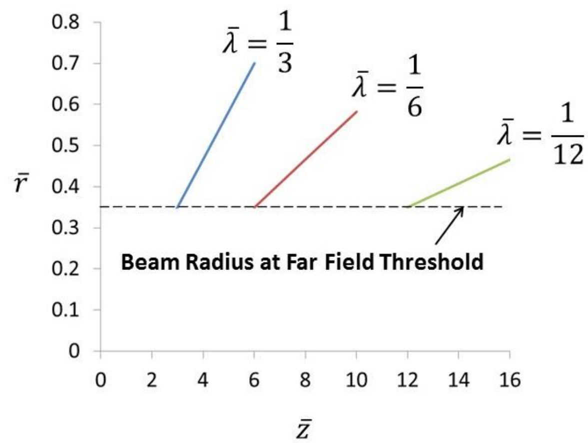

Fig. 6 The relationship between radius and distance

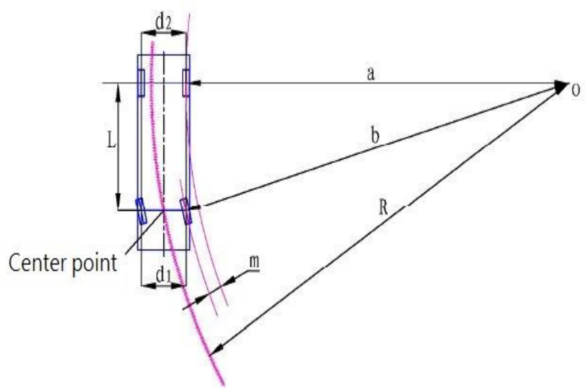

Fig. 4 Calculation of difference of radius between inner wheels for non-trailer

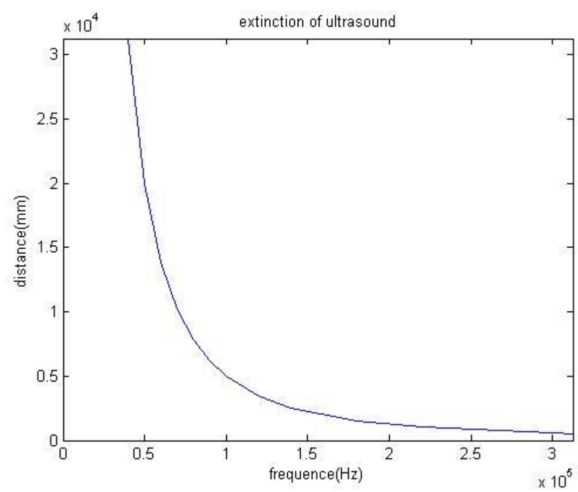

Fig. 7 The relationship between radius and distance

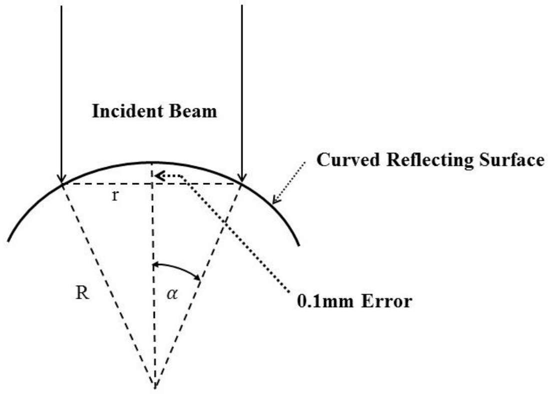

Fig. 8 The Curvature Radius Effect

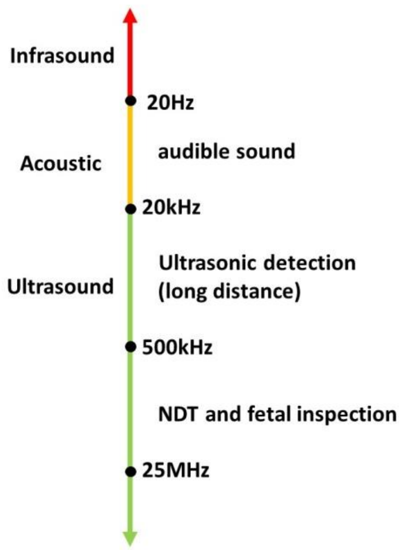

Fig. 9 Ultrasonic transducer frequency

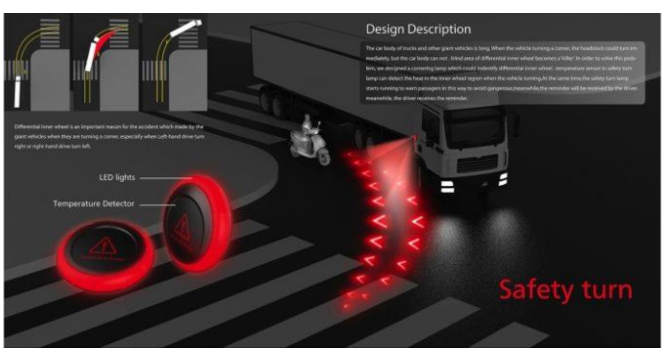

Fig. 10 The concept of safety distance in measurement

Fig. 11 The measurement processes of the warning system

TABLE 1 The measured data for 2700mm wheelbase vehicle

Steering angle	**Safe distance**	**Actual distance**	**Average measurement distance**	**Error distance**	**Warning notice**
2°	3.3cm	3.5cm	3.43cm	0.07cm	Y
6°	9.7cm	10cm	9.64cm	0.36cm	Y
12°	20.2cm	21cm	20.57cm	0.43cm	Y
18°	44.7cm	45cm	43.73cm	1.27cm	Y
24°	51.3cm	52cm	52.44cm	-0.44cm	Y
30°	62.6cm	63cm	63.1cm	-0.1cm	Y
36°	80.9cm	81cm	82.7cm	-1.7cm	Y

TABLE 2 The effect of wind and rain on the measured data for 2700mm wheelbase vehicle

Steering angle	Safe distance	Wind	Wind and Rain	15∘	20∘
2∘	3.3cm	3.9cm	4.6cm	93.2%	60.2%
6∘	9.7cm	10.1cm	11.3cm	93.4%	61.3%
12∘	20.2cm	21.3cm	19.3cm	92.5%	58.5%
18∘	44.7cm	44.7cm	45.8cm	91.9%	54.1%
24∘	51.3cm	54.0cm	54.2cm	90.2%	54.0%
30∘	62.6cm	62.7cm	60.9cm	90.6%	53.8%
36∘	80.9cm	81.9cm	83.8cm	89.9%	51.2%