# Determining the possibility of passage through narrow alleys using ultrasonic sensors

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**ABSTRACT**

The complex road topography of South Korea presents significant challenges to the timely arrival of emergency vehicles. Compounding the issue, obstacles such as legally or illicitly constructed structures, and improperly parked or stationary vehicles, frequently obstruct the path of emergency vehicles. To address these challenges, this study introduces a novel system aimed at enhancing emergency response times. The system employs ultrasonic sensors that can be integrated into personal devices to measure the width of the numerous narrow alleys prevalent in Korea's densely populated regions. Experiments demonstrate that within a 1-meter range in front of a narrow alley with widths varying between 270 cm and 450 cm where vehicle maneuvering is possible, it's possible to accurately gauge the width using two ultrasonic sensors, achieving a precision within a 5 cm margin of error. This level of accuracy enables the practical assessment of whether emergency vehicles can access the area in real-time by identifying the alley's narrowest point. The proposed system is a cost-effective method using easy-to-buy devices for augmenting emergency preparedness and enhancing emergency response times by ensuring that emergency vehicles can navigate through alleys, thereby fostering a safer living environment.



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## 1. INTRODUCTION

Data from the Korean National Fire Agency [1] indicate that, over the past five years, fire trucks have arrived within the critical “golden time” in only an average of 60% of instances. In 2018, South Korea implemented the “amendment to the framework act on firefighting and the enforcement decree,” allowing for the forcible removal of illegally parked vehicles obstructing fire trucks during a fire. However, this law does not apply to legally parked vehicles. According to data from the National Fire Agency in South Korea, 833 areas and 444 km in distance have been identified where the entry of fire trucks is difficult or impossible [2]. These challenges are caused by narrow road structures and topographical issues along with legal and illegal obstructions or parked vehicles. Such barriers can hinder the timely arrival of emergency vehicles within the golden period in case of a fire event, complicating efforts to rapidly extinguish the fire and save lives. In addition to fire trucks, emergency vehicles include ambulances, police cars, and public emergency vehicles. Table 1 details the required width for emergency vehicles’ passageways: small vehicles necessitate at least 200 cm [3]–[6], and large vehicles require at least 300 cm [6]. Consequently, in preparation for an emergency, continuous real-time monitoring of roads is imperative to ascertain whether obstacles or topographical constraints may render a road impassable for emergency vehicles.

Table 1. Width of emergency vehicles (cm)

| Emergency vehicles | Width (cm) |
|---|---|
| Fire trucks | 249, 223, and 218 |
| Ambulances | 248, 245, 241, 235, 218, 208, and 147 |
| Police cars | 186 and 183 |
| Public emergency vehicles | 192, 204, and 202 |

Currently, South Korea addresses the issue of illegal parking through parking enforcement officers, parking enforcement vehicles, and closed-circuit television (CCTV). Although existing methods can identify specific illegally parked vehicles, they are unable to determine whether an emergency vehicle can navigate a narrow alleyway at a given location. Recently, various methods of cracking down on illegal parking vehicles using CCTV have been proposed. Studies [7]–[12] have determined the illegal parking situation using image segmentation and deep learning models based on the CCTV system. However, the fixed CCTV enforcement method is only applicable to illegal parking vehicles in areas where CCTVs are installed. Meanwhile, AI-based solutions such as smart transportation systems [13] and illegal parking enforcement [14], [15] are emerging today as ways to automatically recognize illegal parking vehicles. Research by Peng *et al*. [14] provides details of illegal parking by assessing illegal parking vehicles through several types using deep learning based on vehicle black box images. This approach is greatly restricted by weather and time, and it has limitations because it can only be applied to vehicles equipped with a black box. Gao *et al*. [15] presented an algorithm to determine whether a vehicle is parked illegally by attaching a camera sensor to the vehicle while it is moving to determine the distance between the vehicle and the lane. It is an algorithm that uses lane and vehicle object recognition to judge illegal parking that cannot be judged by conventional mobile CCTV crackdowns as lane violations and has limitations that cannot be applied on laneless roads such as side roads. Peng *et al*. [14] proposed a system to distinguish between roads and vehicles from CCTV images and then check whether vehicles are parked illegally in non-parking areas on the road. Although it has cost advantages by utilizing the existing CCTV infrastructure, it is difficult to apply to narrow roads without lanes because it can be applied to places where CCTVs are installed and is an algorithm that judges based on lanes. In addition, it does not measure the width of the road that can be driven considering the location of the obstacle. Therefore, a system is required in which parking inspectors, enforcement vehicles, and citizens can assess the width of the surrounding road to ascertain whether vehicles or obstructions hinder the passage of emergency vehicles such as fire trucks. This entails identifying appropriate emergency vehicle arrangements and passage paths in advance to facilitate rapid lifesaving and early resolution of emergencies.

Consequently, this study proposes a real-time method to determine whether emergency vehicles such as fire trucks can pass through narrow alleys using ultrasonic sensors already installed in various devices, including vehicles. This method uses ultrasonic sensors [16] equipped on vehicles or an individual's mobile device and is not greatly restricted by weather, time, or material. The application of this system is not confined to identifying specific illegal parking vehicles; it can be applied to obstacles in the alley. Therefore, immediate follow-up actions such as reporting or corrective measures are possible in situations that hinder the entry of an emergency vehicle. The contributions of this study are i) Utilizing two low-cost ultrasonic sensors, the feasibility of an emergency vehicle's passage through a narrow road between buildings or a confined road due to obstacles can be determined; ii) In an actual external environment, there is minimal difference between the measurements of road width obtained through horizontal measurement of the length between two opposing walls and those obtained through oblique measurement of the walls. Therefore, measurements within angles of the two ultrasonic sensors between 130° and 180° can be utilized; and iii) By displaying measurements with an error margin of within 5 cm for roads where the width does not change significantly, and within 10 cm for sections where the width changes drastically, the possibility of an emergency vehicle's passage can be adequately ascertained.

## 2. PROPOSED METHOD

### 2.1. Characteristics of ultrasonic sensor

Ultrasonic sensors are currently employed in a diverse array of modern application technologies, including autonomous vehicles, industrial drones, and robotic equipment. The advantage of using an ultrasonic sensor is in its ability to recognize various materials and surfaces, maintain straightness, and detect objects composed of materials such as solids, liquids, and powders, irrespective of color. The surface properties of the object have minimal effect on sensing stability. However, since the speed $v$ of the ultrasonic wave is influenced by temperature, it can be corrected according to (1) considering the temperature range $t$ °C in South Korea (-10 °C ~ 40 °C). However, (1) expresses the relationship between temperature and speed when humidity is 0%, and the relationship becomes more complicated when considering both temperature and humidity [17], [18]. Herein, $v$ was calculated based on (2) where $v_h$ and $v_d$ represent the sound velocities at relative humidity h and dry air, respectively. $h_r$ denotes the relative humidity expressed as a percentage (%). $p$ equals ambient pressure, which at 1 atm air pressure is $1.013\times10^5$ Pa. Additionally, $e(t)$ denotes the vapor pressure of water at temperature $t$. Representative values of e(t) are given in 20 °C and 30 °C: $e(20)=2338$ Pa, $e(30)=4243$ Pa.

$$v(m/s) = 331.3 + 0.606 \cdot t \quad (1)$$

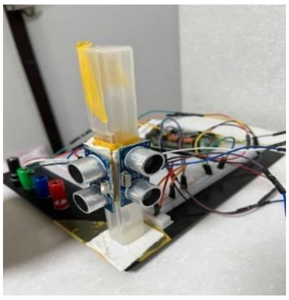
$$v(m/s) = CFh \cdot 331.45 \cdot \sqrt{1 + \frac{t}{273.15}}$$

$$CFh = \frac{vh}{vd} = 4.5513 \cdot \sqrt{\frac{7+h}{5+h} \cdot \frac{1}{29-11h}} \quad (2)$$

$$h = \frac{0.01 \cdot hr \cdot e(t)}{p}$$

Figure 1 shows devices for experiments HY-SRF05, especially in Figures 1(a) and 1(b). The HY-SRF05 depicted in Figure 1(a), used in the experiment, is a low-cost ultrasonic sensor that measures the distance between the sensor and the object by gauging the time until the ultrasonic wave sent from Trig is reflected off the object and returned to Echo, as portrayed in Figure 2 [19], [20]. Figure 1(b) shows the device prototype of Raspberry Pi connected with HY-SRF05. The operating voltage is DC 5V, the detection distance ranges from 2 to 450 cm, and the beam width is approximately 30° [21].


(a)



(b)

Figure 1. Devices for experiments (a) ultrasonic sensor (HY-SRF05) and (b) Raspberry Pi connected with HY-SRF05

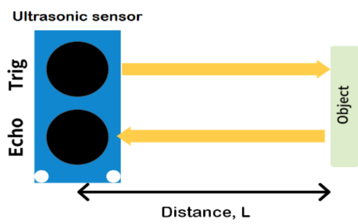



Figure 2. Distance measurement via ultrasonic sensor

Conversely, the ultrasonic sensor can experience multiple reflections as shown in Figure 3, where ultrasonic waves transmitted from Echo are reflected by various objects and returned to Trig, or the reflected ultrasonic waves may not return to Trig, as shown in Figure 3(a) [22]. Generally, multiple reflections do not occur with point-shaped objects, but for objects such as walls, the ultrasonic sensor may fail to measure the object depending on its orientation. Moreover, as depicted in Figure 3(b), the position of the target can affect the accuracy of the measurement due to the beam width. Therefore, it is initially necessary to determine the reliability of data based on the angle between the object and the sensor through experimentation.

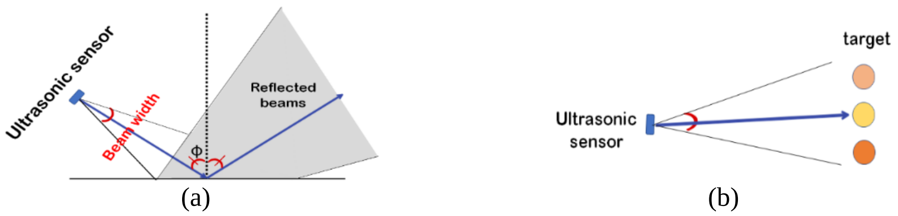



Figure 3. Characteristics of ultrasonic wave (a) beam reflection and (b) the effect of beam width

## 2.2. Experiment environment and design

Figure 4 illustrates a schematic of the proposed system in this paper. The alley-width measuring device traverses the middle of the alley, measuring distance 1 and distance 2 between the two ultrasonic sensors and each wall. By adjusting the angle formed by the two ultrasonic sensors, the width of the alley in front of the measuring instrument is obtained through distance 3. Based on this width value, it becomes feasible to determine whether an emergency vehicle can navigate the narrow alley.

As depicted in Figure 1, the hardware configuration consists of a Raspberry Pi4, two ultrasonic sensors (HY-SRF05), and an auxiliary battery to power the Raspberry Pi. This assembly represents a prototype for a personally-held, low-cost mobile device environment. The software algorithm for measuring the distance and width of alleys operates according to the flowcharts in Figures 5 and 6.

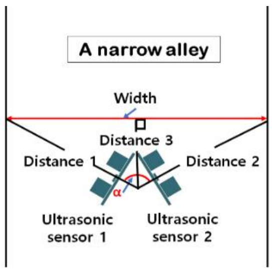



Figure 4. Alley width measurement system using ultrasonic sensor

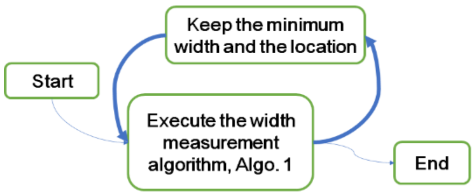



Figure 5. Schematic of a software system

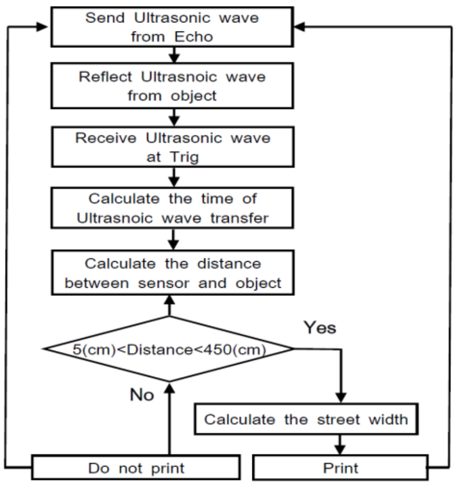



Figure 6. Emergency vehicle passability determination algorithm

### 2.3. Measurement of distance and width of alleyways using ultrasonic sensors

The distance between the two ultrasonic sensors and the object is calculated as in (3).

$$L = \frac{v \cdot t}{2} \tag{3}$$

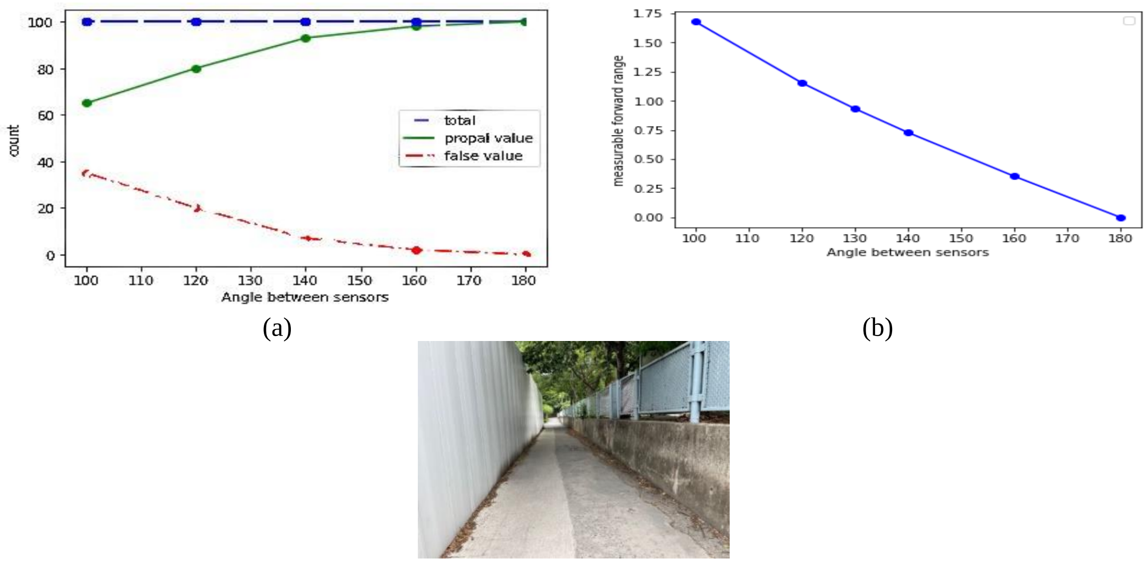
In (3), L denotes the distance between the object and sensor, and t indicates the time (second) required to emit ultrasonic waves from Echo, reflect ultrasonic waves from the object, and transmit them from Trig, as depicted in Figure 2. The speed v of ultrasonic waves in air is 34,000 cm/s at 15 °C, and for measurement in an external environment, the correction speed was calculated considering the temperature and humidity of air [17]. For each of the two ultrasonic sensors, the distance between the object and the sensor is ascertained through this calculation process [23]. The values that the ultrasonic sensor (HY-SRF05) can normally obtain range from 5 to 450 cm; any other values are erroneous and are not output. Subsequently, the angle between the two sensors is determined after the data reliability is assessed according to the angle between the two sensors. Therefore, the Width in Figure 4 can be calculated as expressed in (4).

$$Width = (Lleft + Lright) \cdot cos(\frac{\pi-\alpha}{2}) \tag{4}$$

Where $L_{left}$ and $L_{right}$ denote the distances between the ultrasonic sensor and the object obtained by each sensor through (3). The alley width at the front is calculated by multiplying the value with cos $((\pi - \alpha)/2)$.

### 2.4. Determination of data reliability according to the angle between two ultrasonic sensors

In Figure 4, the angle between the two ultrasonic sensors and the forward distance, distance 3, are inversely proportional. We set distance 3 to be approximately 1 m, a level at which the multi-interference phenomenon of the ultrasonic sensor does not interfere with the experimental purpose. The reliability metric of ultrasonic sensor measurements is shown in Figure 7. Figures 7(a) and 7(b) display the results of measurements taken over 20 seconds at a 0.2 second cycle while varying the angle between the two sensors at the location depicted in Figure 7(c). The unit of angle (X-axis) in Figures 7(a) and 7(b) is degree (°). The term "total" refers to the total number of times the sensor read the value. "propal value" denotes the instances when the difference between the sensor measured value and the actual value is 10 cm or less, and "false value" refers to the instances when the difference between the two values is 50 cm or more. As the angle between the two sensors decreases below 140°, the ratio of false values begins to increase rapidly. Based on the above results, 130° corresponding to a measurable forward distance of about 1 m, was set as the angular value between the two ultrasonic sensors, with the ratio of false value not exceeding 20%. By calculating the measurement error when the angle between the two sensors is between 130° and 180°, we examined the case where it is not a straight line at 180°, determining to what extent it is not difficult to measure the length in front with the ultrasonic sensor.




(a) (b)

(c)

Figure 7. Reliability metric of ultrasonic sensor measurements (a) error rate owing to change in angle between sensors, (b) measurable forward distance, and (c) alley1

## 3. EXPERIMENTAL RESULTS AND ANALYSIS

The experimental results were conducted in three actual alleyways, with a temperature of 30 °C and humidity of 60%. Initially, the measurer holds the hardware described in section 2.2. horizontally with the ground and moves along the center of the road at a walking speed of approximately 5-6 km/h. Additionally, the width is measured at regular intervals while walking from the start to the end of the road. When the angle between the ultrasonic sensors is 180° and 130°, the width is measured twice. The actual width is also measured with a ruler. The linear distance of the alley, in the case of the two sensor angles of 180°, and the actual width become comparison reference values when it is 130°. Initially, the system's accuracy is checked with the relatively narrow alleyways depicted in Figures 8 and 9. As indicated in Table 1, as the width of large domestic fire trucks is less than 2.5 m, experiments in alleyways, as depicted in Figure 10, are conducted to verify whether the system operates normally on a wide path that can accommodate actual fire vehicles.

### 3.1. Measurement target

Unlike straight roads with a consistent width, old alleys in South Korea are characterized by uneven width and variability due to numerous natural side roads that emerged when houses or buildings were constructed at a time when automobiles were scarce. This characteristic is not unique to South Korea; side alleys between old buildings in large cities around the world, including European old alleys, are often challenging for emergency vehicles to traverse [24]. Improving these old alleys for emergency vehicle traffic is difficult until a certain width is secured, owing to housing maintenance projects. Consequently, experimental measurements were conducted on existing narrow alleys.

### 3.2. Alley width measurement experiment #1

As depicted in Figure 8(a), the actual width of the alleyway of ~290 cm with no obstacles in the measurement section and minimal bending. Figure 8(b) exhibits the experimental result measured every 0.5 s while walking the path of Figure 8(a) one-way. Figure 8(c) displays the error between the measurement results when the angle between the sensors is 180° and 130°; as observed, an error of up to 5 cm (~1.7%) occurs. Figure 8(d) displays the error between the measurement results and the actual width of the alley when the angle between the sensors is 180° and 130°, with an error of up to 10 cm (~3.4%) occurring. These findings demonstrate that the system functions effectively, with minimal error, on roads devoid of obstacles and with little curvature.

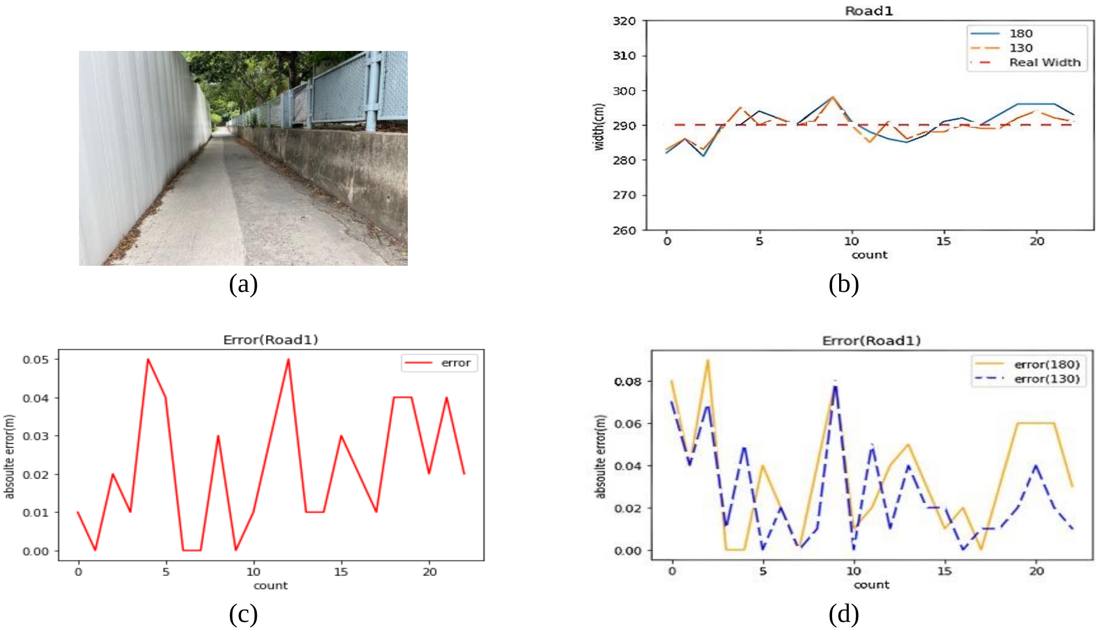



Figure 8. Measurement of alley width using ultrasonic sensor #1 (a) Alley1, (b) width measurement result, (c) width measurement error (absolute error in measured values of 180° and 130°), and (d) width measurement error (absolute error between actual width and 180°/130° measured)

### 3.3. Alley width measurement experiment #2

In Figure 9(a), the alleyway possesses one obstacle in the measurement section, and the width varies to approximately 323, 248, and 177 cm for each respective section. Figure 9(b) presents the result of measuring the width every 0.1 s while reciprocating the path tracked in Figure 9(a). Figure 9(c) illustrates the error between the measurement results when the angle between the sensors is 180° and 130°, with an error of up to 18 cm (~7.2%). Figure 9(d) displays the error between each measurement result and the actual width of the alley when the angle between the sensors is 180° and 130°, with an error of up to 18 cm (~5.5%). This particular alley had an obstacle, and a large error occurred at the point where the width of the road changed. However, in sections with a constant width, as in Figure 8(a), an error similar to the path in Figure 8 was observed.

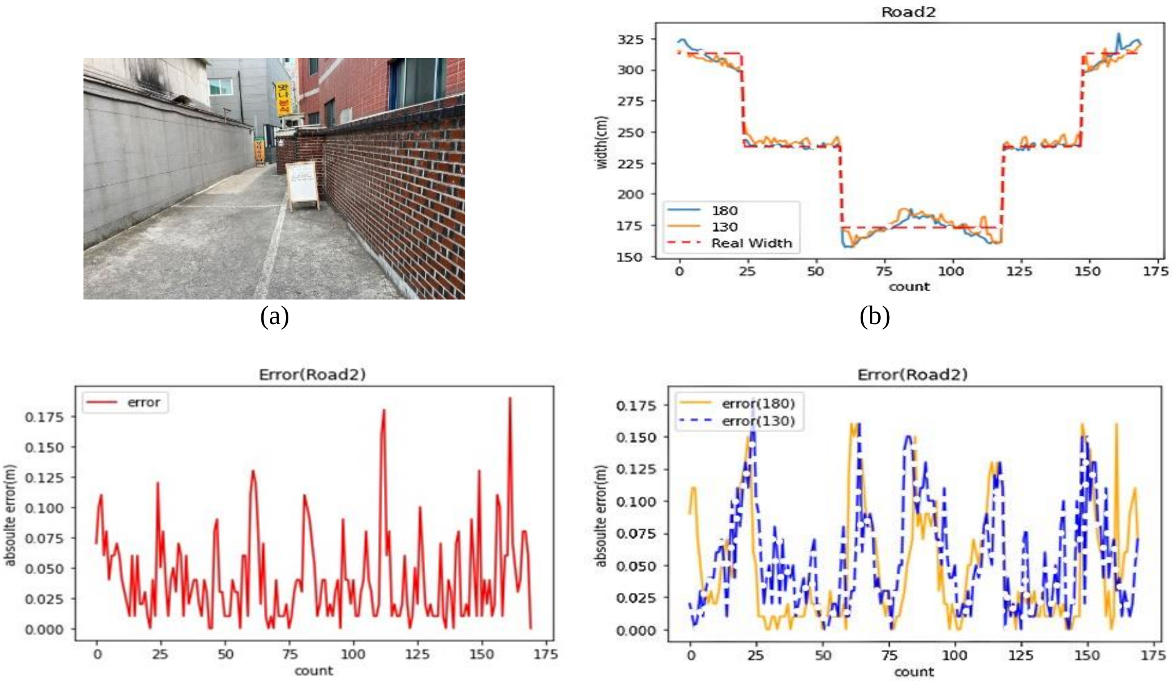
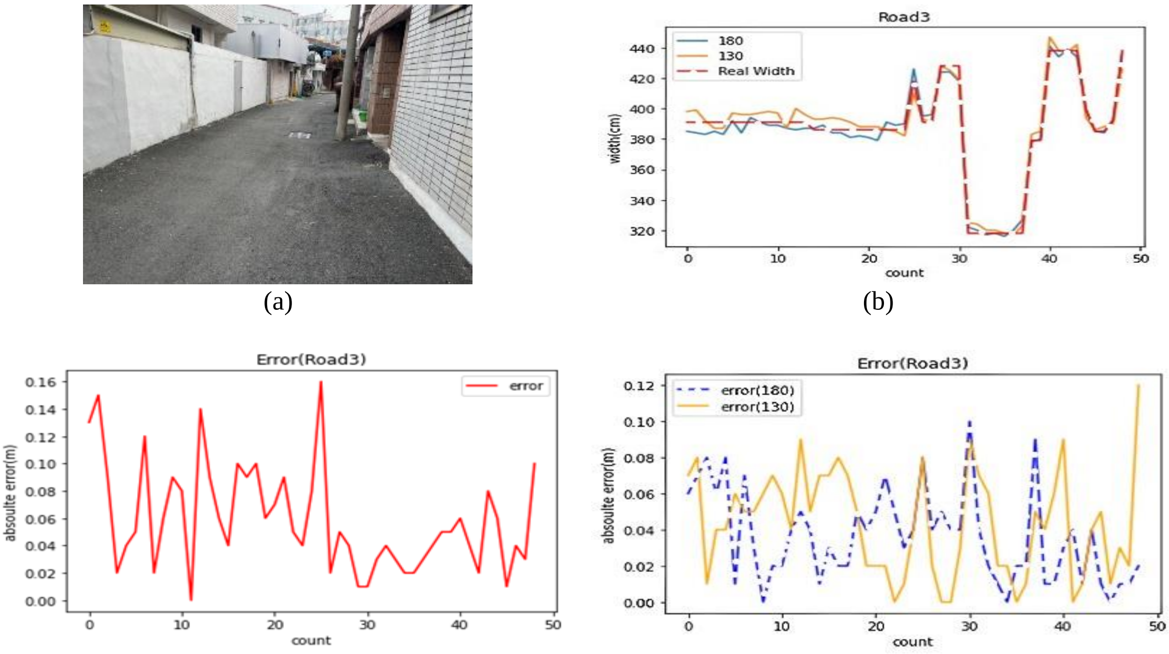



Figure 9. Measurement of alley width using ultrasonic sensor #2 (a) Alley2, (b) width measurement result, (c) width measurement error (absolute error in measured values of 180° and 130°), and (d) width measurement error (absolute error between actual width and 180°/130° measured)

### 3.4. Alley width measurement experiment #3

In Figure 10(a), the alleyway is characterized by numerous obstacles distributed throughout the measurement section, and the width varies from a minimum of 320 cm to a maximum of 450 cm. Figure 10(b) depicts the results of measuring the width every 0.1 s while walking one way along the path depicted in Figure 10(a). Figure 10(c) conveys the error between the measurement results when the angle between the sensors is 180° and 130° with an error of up to 16 cm (~3.7%). Figure 10(d) reveals the error between the measurement results and the actual width of the alley when the angle between the sensors is 180° and 130°, resulting in an error of up to 12 cm (~2.7%). Despite the presence of numerous obstacles and multiple sections with differing widths, the error did not significantly deviate from the experimental results obtained in the alleyway shown in Figure 9(a). In the section with a width of 4 m, the system was able to detect the road width approximately 90 cm ahead.




(a) (b) (c) (d)

Figure 10. Measurement of alley width using ultrasonic sensor #3 (a) Alley3, (b) width measurement result, (c) width measurement error (absolute error in measured values of 180° and 130°), and (d) width measurement error (absolute error between actual width and 180°/130° measured)

### 3.5. Analysis

The commencement and termination of all measurements should be disregarded due to subpar accuracy, and any point where the pattern of the road alters should also be excluded, as the error is prone to escalate at these locations. Furthermore, a more stable value can be procured by omitting the instances in which one or two sudden peak values appeared anomalous in comparison with surrounding values. By employing these strategies, the measurement errors relative to the actual value can be confined to less than or equal to 5 cm (~1.7%) in the measurement of alley1's width, to 10 cm (~4.0%) in the measurement of alley2's width, and to 9 cm (~2.0%) in the measurement of alley3's width at an angle of 130°.

A recent convolutional neural network (CNN) based study [25] presented a method of estimating road widths from aerial photographs. Comparing the measurement errors in this study to 8.1% on 3-5 m wide roads and 7.5% on 5-10 m wide roads, the measurement errors less than 5% in our approach are acceptable for determining emergency vehicle traffic. Since the width of the fire road through which the fire truck passes are larger than the actual width of the fire truck, it is expected that the possibility of emergency vehicle passage can be determined by considering the small error of our approach.

Figure 11 shows distance measurement via ultrasonic sensor. On roads devoid of obstacles where the width remains constant, such as the alley depicted in Figure 8(a), the width measurement results between angles of 180° and 130° between sensors exhibit negligible differences. However, in the case of alleys such as those in Figures 9(a) and 10(a), where obstacles are present and the width varies, the disparity between the two cases amplifies. If the angle between the sensors is 180°, the point exactly corresponding to the width of the road is measured perpendicularly to each wall as illustrated in Figure 11(a). Conversely, if the angle is 130°, there may be instances of measuring a part that does not correspond to the road's width, as shown in Figure 11(b).

In Figure 10(d), sections exist where the difference between the two graphs is substantial, and the obstacles corresponding to those sections correspond to Figure 12, especially in Figures 12(a) and 12(b). Conversely, in sections with minimal change in width, the measurements at 180° and 130° are nearly identical, though it is discernible that the overall error is less when measured at 130° than 180°. This demonstrates that measuring the width obliquely through an ultrasonic sensor does not significantly deviate from measuring it on a straight line.

(a) (b)

Figure 11. Distance measurement via ultrasonic sensor (a) horizontal and (b) oblique distance measurement

(a) (b)

Figure 12. Obstacles causing measurement errors (a) type 1 and (b) type 2

## 4. CONCLUSION

In this study, we introduced a system that emulates personal portable devices using merely two low-cost ultrasonic sensors and a Raspberry Pi, capable of determining the feasibility of emergency vehicles passing through narrow alleys. By conducting measurements of road widths using the device prototype in actual alleys, we demonstrated that the angle between two ultrasonic sensors of 130° or 180° does not significantly impact the measurement of an alley's width. The measured values were within an error range of less than 10 cm. Considering the characteristics of the ultrasonic sensor, the discrepancy between the real width and the measured value is attributable to the shape of obstacles, the uneven surface of the wall, and the trembling of the measuring device due to the measurer's walking movement.

Through this research, it was revealed that if there were no abrupt fluctuations in the width of the road within 1 m in front of a narrow alley with a width ranging from 270 cm to 450 cm where a vehicle could be operated, the width could be measured with an error of less than 5 cm. Considering this error, it is feasible to ascertain the possibility of real-time emergency vehicle passage by determining the minimum width of a specific section of the road. Thus, two low-cost ultrasonic sensors can be employed to verify whether emergency vehicle passageways are secured in all instances in real-time.


## ACKNOWLEDGEMENTS

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## REFERENCES


[1] "Korean National Fire Agency." Accessed: Aug. 01, 2023. [Online]. Available: https://www.nfsa.go.kr/

[2] Assemblyman Cho Eun-hee's office, "National Audit Press Release." 2022.

[3] M. Yoon, "A study on the expansion of the application of automatic fire extinguishing facilities and the improvement of entry strategies to reduce fire damage" Korean Institute of Fire Science & Engineering Research Service Report, 2010.

[4] "Emergency medical service vehicle specifications." Accessed: Aug. 01, 2023. [Online]. Available: https://www.frazerbilt.com/emergency-medical-service-vehicles/,

[5] "Ambulances specifications." Accessed: Aug. 01, 2023. [Online]. Available: https://www.demers-ambulances.com/model-comparison-chart/

[6] W. Lee and N. Kim, "Omnidirectional distance estimation using ultrasonic in wireless sensor networks," *Journal of the Institute of Internet, Broadcasting and Communication*, vol. 9, no. 5, pp. 85–91, 2009.

[7] R. Akhawaji, M. Sedky, and A.-H. Soliman, "Illegal parking detection using gaussian mixture model and kalman filter," in *2017 IEEE/ACS 14th International Conference on Computer Systems and Applications (AICCSA)*, IEEE, Oct. 2017, pp. 840–847. doi: 10.1109/AICCSA.2017.212.

[8] M. M. K. Sarker, C. Weihua, and M. K. Song, "Detection and recognition of illegally parked vehicles based on an adaptive gaussian mixture model and a seed fill algorithm," *Journal of information and communication convergence engineering*, vol. 13, no. 3, pp. 197–204, Aug. 2015, doi: 10.6109/jicce.2015.13.3.197.

[9] J. T. Lee, M. S. Ryoo, M. Riley, and J. K. Aggarwal, "Real-Time illegal parking detection in outdoor environments using 1-d transformation," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 19, no. 7, pp. 1014–1024, Jul. 2009, doi: 10.1109/TCSVT.2009.2020249.

[10] C. K. Ng, S. N. Cheong, W. W.-J. Yap, and Y. L. Foo, "Outdoor illegal parking detection system using convolutional neural network on Raspberry Pi," *International Journal of Engineering & Technology*, vol. 7, no. 3.7, p. 17, Jul. 2018, doi: 10.14419/ijet.v7i3.7.16197.

[11] X. Xie, C. Wang, S. Chen, G. Shi, and Z. Zhao, "Real-time illegal parking detection system based on deep learning," in *Proceedings of the 2017 International Conference on Deep Learning Technologies*, New York, NY, USA: ACM, Jun. 2017, pp. 23–27. doi: 10.1145/3094243.3094261.

[12] H. Tang, A. Peng, D. Zhang, T. Liu, and J. Ouyang, "SSD real-time illegal parking detection based on contextual information transmission," *Computers, Materials & Continua*, vol. 62, no. 1, pp. 293–307, 2020, doi: 10.32604/cmc.2020.06427.

[13] A. H. Sodhro, G. H. Sodhro, M. Guizani, S. Pirbhulal, and A. Boukerche, "AI-Enabled reliable channel modeling architecture for fog computing vehicular networks," *IEEE Wireless Communications*, vol. 27, no. 2, pp. 14–21, Apr. 2020, doi: 10.1109/MWC.001.1900311.

[14] X. Peng *et al.*, "Real-time illegal parking detection algorithm in urban environments," *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 11, pp. 20572–20587, Nov. 2022, doi: 10.1109/TITS.2022.3180225.

[15] J. Gao, F. Zuo, K. Ozbay, O. Hammami, and M. L. Barlas, "A new curb lane monitoring and illegal parking impact estimation approach based on queueing theory and computer vision for cameras with low resolution and low frame rate," *Transportation Research Part A: Policy and Practice*, vol. 162, pp. 137–154, Aug. 2022, doi: 10.1016/j.tra.2022.05.024.

[16] M. Kelemen *et al.*, "Distance measurement via using of ultrasonic sensor," *Journal of Automation and Control*, vol. 3, no. 3, pp. 71–74, 2015, [Online]. Available: http://pubs.sciepub.com/automation/3/3/6

[17] O. Cramer, "The variation of the specific heat ratio and the speed of sound in air with temperature, pressure, humidity, and CO2 concentration," *The Journal of the Acoustical Society of America*, vol. 93, no. 5, pp. 2510–2516, May 1993, doi: 10.1121/1.405827.

[18] Y. S. Huang, Y. P. Huang, K. N. Huang, and M. S. Young, "An accurate air temperature measurement system based on an envelope pulsed ultrasonic time-of-flight technique," *Review of Scientific Instruments*, vol. 78, no. 11, Nov. 2007, doi: 10.1063/1.2804115.

[19] L. Koval, J. Vaňuš, and P. Bilík, "Distance measuring by ultrasonic sensor," *IFAC-PapersOnLine*, vol. 49, no. 25, pp. 153–158, 2016, doi: 10.1016/j.ifacol.2016.12.026.

[20] S.-J. Shin and B.-J. Jeong, "Principle and comprehension of ultrasound imaging," *Journal of the Korean Orthopaedic Association*, vol. 48, no. 5, p. 325, 2013, doi: 10.4055/jkoa.2013.48.5.325.

[21] V. A. Zhmud, N. O. Kondratiev, K. A. Kuznetsov, V. G. Trubin, and L. V Dimitrov, "Application of ultrasonic sensor for measuring distances in robotics," *Journal of Physics: Conference Series*, vol. 1015, p. 032189, May 2018, doi: 10.1088/1742-6596/1015/3/032189.

[22] H.-M. Han, J.-T. Park, and J.-B. Song, "Grid map building based on reliability model of sonar data," *Journal of Institute of Control, Robotics and Systems*, vol. 17, no. 12, pp. 1219–1226, Dec. 2011, doi: 10.5302/J.ICROS.2011.17.12.1219.

[23] N. A. Latha, B. R. Murthy, and K. B. Kumar, "Distance sensing with ultrasonic sensor and Arduino," *International Journal of Advance Research, Ideas and Innovations in Technology*, vol. 2, 2016.

[24] "San Francisco rolls out smaller fire trucks." Accessed: Aug. 01, 2023. [Online]. Available: https://www.firerescue1.com/fire-products/fire-apparatus/articles/san-francisco-rolls-out-smaller-fire-trucks-T3k0iWDQ526wrH5F/

[25] L. Luo *et al.*, "Estimating road widths from remote sensing images," *Remote Sensing Letters*, vol. 9, no. 9, pp. 819–828, Sep. 2018, doi: 10.1080/2150704X.2018.1484957.


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