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Comparison of Measurement Accuracy between Infrared and Ultrasonic Sensors for Collaborative Robot

Rudianto[1], Kevin Ilham Apriandy[2], Choirun Nisa[3]

Politeknik NSC Surabaya[1], Politeknik Internasional Taman Siswa Mojokerto[2], Politeknik NSC Surabaya[3]

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E-MAIL

rudianto2025a@gmail.com
berkas.p3m1@gmail.com
berkas.p3m1@gmail.com

*Corresponding author:
Rudianto
rudianto2025a@gmail.com

PUBLISHER

LPPM- Institut Teknologi Adhi Tama Surabaya
Address:
Jl. Arief Rachman Hakim No. 100, Surabaya 60117, Tel/Fax: 031-5997244

ABSTRACT

Penelitian ini bertujuan untuk membandingkan akurasi dua jenis sensor jarak yang umum digunakan pada sistem robotika, yaitu sensor ultrasonik HC-SR04 dan sensor infrared Sharp GP2Y0A21YK0F, untuk mendukung pengembangan collaborative robot (cobot) yang membutuhkan navigasi dan deteksi objek yang andal. Pengujian dilakukan dalam empat tahap, yaitu pengujian akurasi dasar pada rentang jarak 5–50 cm dengan interval 2,5 cm, pengujian pengaruh suhu dan pencahayaan, pengujian akurasi terhadap lima jenis bahan pantul (logam, kaca, kayu, plastik, dan kain), serta pengujian variasi sudut kemiringan objek pada sudut 0°, 15°, 30°, dan 45°. Hasil penelitian menunjukkan bahwa sensor ultrasonik memiliki performa yang lebih stabil dan toleran terhadap variasi kondisi lingkungan dan sudut kemiringan, dengan error maksimum sekitar 2,5 cm pada sudut 45°. Sebaliknya, sensor infrared menunjukkan akurasi tinggi pada jarak dekat, tetapi sensitif terhadap pencahayaan dan bahan pantul tertentu, dengan error mencapai 8–10 cm pada bahan transparan atau penyerap cahaya. Temuan ini mengindikasikan bahwa sensor ultrasonik lebih cocok untuk penggunaan umum pada cobot yang bekerja di lingkungan dinamis, sementara sensor infrared dapat digunakan untuk skenario terkontrol atau sebagai pelengkap. Penelitian ini memberikan dasar untuk pemilihan atau kombinasi sensor jarak dalam pengembangan sistem navigasi dan keselamatan robot kolaboratif yang lebih akurat dan efisien.

Keywords: *Sensor Ultrasonik; Sensor Inframerah; Akurasi Pengukuran; Robot Kolaboratif.*

ABSTRACT

This study aims to compare the accuracy of two commonly used distance sensors in robotics systems, namely the ultrasonic sensor HC-SR04 and the infrared sensor Sharp GP2Y0A21YK0F, to support the development of collaborative robots (cobots) that require reliable navigation and object detection. The experiments were conducted in four stages: basic accuracy testing over a distance range of 5–50 cm with 2.5 cm intervals, testing under varying temperature and lighting conditions, accuracy testing on five types of reflective materials (metal, glass, wood, plastic, and fabric), and testing with varying object inclination angles of 0°, 15°, 30°, and 45°. The results indicate that the ultrasonic sensor demonstrates more stable performance and greater tolerance to environmental variations and inclination angles, with a maximum error of approximately 2.5 cm at a 45° angle. In contrast, the infrared sensor provides high accuracy at close ranges but is highly sensitive to lighting conditions and certain reflective materials, with errors reaching 8–10 cm for transparent or light-absorbing surfaces. These findings suggest that the ultrasonic sensor is more suitable for general use in cobots operating in dynamic environments, while the infrared sensor is best applied in controlled scenarios or as a complementary sensor. This research provides a foundation for selecting or combining distance sensors in the development of more accurate and efficient navigation and safety systems for collaborative robots.

Keywords: *Ultrasonic Sensor; Infrared Sensor; Measurement Accuracy; Collaborative Robot.*

INTRODUCTION

The rapid development of robotics technology, particularly collaborative robots (cobots), has created significant opportunities to enhance productivity across various sectors, including manufacturing, logistics, and healthcare services [1], [2]. Unlike conventional robots, cobots are designed to operate alongside humans without physical barriers, making safety and sensor system reliability critical priorities [3]. One of the key components in ensuring the safety and effectiveness of cobots is the distance sensor used to detect surrounding objects and human presence [4]. Infrared (IR) and ultrasonic (US) sensors are two widely adopted technologies due to their relatively low cost, compact size, and ease of integration with robotic control systems [5], [6]. However, despite their widespread use, the accuracy of distance measurements from both sensors is influenced by various complex environmental factors, necessitating in-depth investigation to understand their respective advantages and limitations [7], [8].

One of the main challenges in implementing IR and US distance sensors is the instability of measurements under diverse real-world conditions [9]. IR sensors, although offering good resolution at short distances, are highly sensitive to surface color, reflectivity, and ambient light intensity, which can significantly degrade their performance in environments with extreme lighting conditions [10]. Meanwhile, US sensors, which operate based on ultrasonic wave propagation, are affected by temperature, humidity, and the reflection angle of object surfaces, leading to measurement variations under certain conditions. These challenges become more pronounced when cobots are deployed in real-world scenarios, such as detecting objects on inclined surfaces, interacting with different reflective materials, or operating in environments with extreme temperature and lighting variations [11]. Without a thorough understanding of the optimal operating conditions and limitations of each sensor, the risk of detection errors and potential workplace accidents may increase.

This study aims to comprehensively compare the accuracy of IR and US-based distance sensors by considering various environmental variables commonly encountered in cobot applications [12]. The research focuses on evaluating the performance of both sensors under conditions involving flat and inclined reflective surfaces, variations in reflective material types (color and texture), extreme temperatures (high and low), and extreme lighting conditions (bright and dim). Through a systematic and controlled experimental approach, this study is expected to provide empirical results that can be used to determine which sensor performs better under specific testing conditions, as well as to offer an overall assessment of the performance consistency of each sensor technology [13].

The results of this study are expected to contribute not only to the development of sensor systems for cobots but also to serve as an important reference for further research in robotics and industrial automation. Empirical findings regarding the strengths and limitations of IR and US sensors under various conditions may serve as a foundation for the development of sensor fusion techniques, enabling more accurate and reliable technology integration [14]. Consequently, this research is anticipated to enrich the literature on cobot safety and effectiveness while supporting the development of operational standards that enhance efficiency and workplace safety in the future.

LITERATURE REVIEW

Several previous studies have explored the performance of IR and US sensors in different applications, such as research by Sasidharan et al. [15] evaluating ultrasonic sensor performance in robotic navigation, and studies by Anghel and Dumitescu comparing the reliability of IR and US sensors in distance detection based on material color and texture [16]. Zieliński [17] focused on comparing ultrasonic, IR, and laser sensors in autonomous vehicle applications, while Aliew [18] proposed calibration approaches to improve ultrasonic sensor accuracy. However, these studies generally emphasize only one or two environmental variables, and comprehensive evaluations that simultaneously assess sensor performance under extreme conditions such as high and low temperatures, extreme lighting, and variations in reflection angles remain limited.

The primary distinction of this study lies in its more integrated and realistic testing approach for collaborative robot (cobot) applications. This research not only compares the performance of IR and US sensors individually but also considers complex combinations of environmental variables and real-world characteristics of collaborative robot operations. Through this approach, the study is expected to provide practical recommendations for cobot developers and users in selecting and configuring appropriate distance sensors.

Previous studies have compared the performance of ultrasonic and infrared distance sensors in various applications. Santoso and Irawan [2] analyzed the performance of HC-SR04 and Sharp GP2Y0A21YK sensors using ThingSpeak and Wireshark platforms, with a primary focus on data transmission performance and network-level analysis in Internet of Things (IoT)-based monitoring systems. Their study emphasized communication reliability and data visualization rather than a comprehensive evaluation of sensor accuracy under diverse environmental and physical conditions.

Similarly, Afudin [13] conducted a comparative analysis of infrared and ultrasonic distance sensors for an automatic hand washing machine application. The study focused on short-range distance measurement performance in a controlled indoor environment, with limited variations in object properties and sensor orientation. The evaluation was primarily application-specific and did not extensively examine the influence of environmental factors such as temperature, lighting conditions, surface inclination angles, or reflective material characteristics.

In contrast, the present study extends beyond application-oriented performance evaluation by systematically investigating the measurement accuracy of both ultrasonic and infrared sensors under multiple real-world conditions relevant to collaborative robot applications. This study explicitly considers the effects of temperature and lighting variations, different reflective surface materials, and object surface inclination angles. Furthermore, unlike previous studies [2][13], this research employs a multi-stage experimental framework to assess sensor robustness and consistency across diverse operating scenarios, thereby providing a more comprehensive basis for sensor selection and integration in dynamic and safety-critical cobot environments.

METHOD

This study employs a laboratory-based experimental approach to compare the accuracy of ultrasonic- and infrared (IR)-based distance sensors under various testing conditions that represent real-world scenarios in collaborative robot working environments. The ultrasonic sensor used in this study is the HC-SR04, which operates based on the reflection of ultrasonic waves and has a measurement range of 2–400 cm with an accuracy of ±3 mm. The infrared sensor used is the Sharp GP2Y0A21YK0F, which operates using an optical triangulation principle with a measurement range of 10–80 cm and an accuracy of ±5 mm. Both sensors were connected to an Arduino Uno R3 microcontroller programmed to automatically acquire measurement data and store them in digital format for further analysis. The overall configuration and data acquisition architecture of both sensor systems are illustrated in Figure 1. The experiments were conducted in a controlled laboratory environment, including regulated room temperature and lighting conditions, to ensure reproducibility of the results.

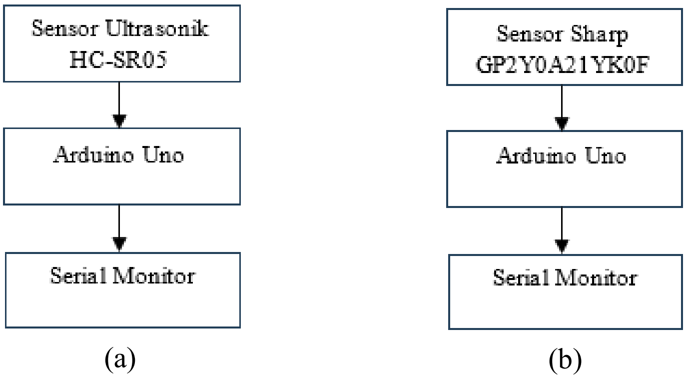

Figure 1. a) Block diagram of the ultrasonic sensor testing system,
b) the infrared sensor testing system

To ensure precise positioning of the reflective object, a custom measurement setup equipped with a calibrated ruler was used, allowing the object to be placed at predetermined distances according to the testing model. In addition, a sensor mounting bracket was employed to maintain a stable sensor position and angle during data acquisition. An initial calibration procedure was applied to ensure that both sensors operated under optimal conditions before the experiments began. This calibration was performed by comparing sensor readings with a standard distance measurement tool, such as a ruler, to minimize initial offset errors that could affect the results. Furthermore, a Kalman filter was implemented during data acquisition to reduce measurement noise in the sensor readings [19].

The first testing stage aimed to obtain the basic accuracy profile of both sensors under ideal conditions without environmental disturbances. A reflective object made of matte-painted plywood was placed at distances ranging from 0 cm to 50 cm with increments of 2 cm. At each distance point, 25 measurement readings were collected for each sensor, after which the mean value and measurement error were calculated. This stage served as a baseline for evaluating the nominal accuracy of both sensors and as a reference prior to more complex testing conditions.

The second stage focused on evaluating the influence of environmental factors on sensor accuracy, particularly temperature and light intensity. In this scenario, the reflective object was positioned at a fixed distance of 50 cm from the sensor, while environmental conditions were varied across five different scenarios. This testing stage was designed to provide insight into how variations in temperature and lighting conditions affect the measurement accuracy and stability of each sensor. The overall experimental workflow and sequential testing stages adopted in this study are illustrated in Figure 2.

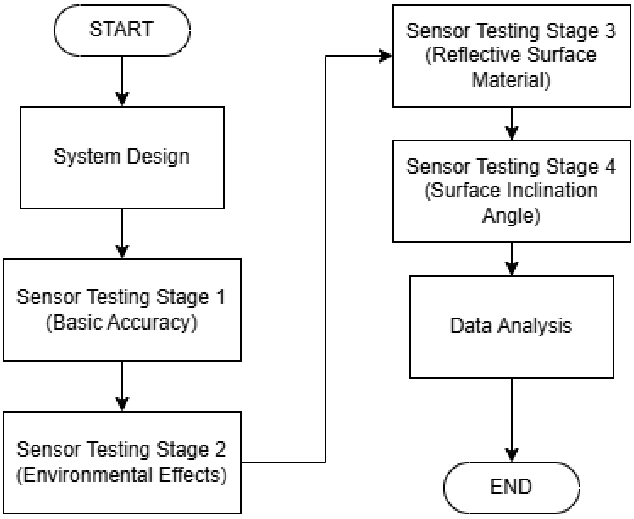

Figure 2. Research stages

sensor responds to extreme environmental variations, which are relevant to robot applications in industrial and warehouse environments where temperature and lighting conditions are not always constant.

The third experimental stage examined the effect of reflective surface properties on sensor measurement results. Test materials were selected based on variations in optical and acoustic reflectivity, including polished aluminium metal, wood, glass, plastic, fabric, and styrofoam. The analysis of this stage is expected to explain the sensitivity of each sensor to the physical characteristics of the reflective objects.

The fourth testing stage was designed to evaluate sensor accuracy when the reflective object was not perpendicular to the sensor. The object was positioned at inclination angles of 0°, 15°, 30°, and 45° relative to the sensor measurement axis to represent realistic operating conditions. The results of this stage illustrate the extent to which measurement accuracy degrades as the surface inclination angle increases.

To ensure result reliability, each experiment was repeated using identical procedures and conducted at different time intervals to evaluate the consistency of sensor readings over time. The experimental data were also visualized in tabular form to clearly compare measurement errors between the two sensors. Through this detailed and systematic experimental design, a comprehensive understanding of the strengths, limitations, and optimal operational scenarios for each sensor is expected to be obtained.

RESULTS AND DISCUSSION

This study aims to compare the measurement accuracy of the HC-SR04 ultrasonic sensor and the Sharp GP2Y0A21YK0F infrared sensor through four types of testing, as follows:

1. Basic Accuracy Testing
2. Environmental Effect Testing
3. Reflective Surface Material Testing
4. Surface Inclination Angle Testing

The results of these four tests are presented and discussed in the following sections.

Results of Test 1 – Basic Accuracy Measurement

In the first test, distance measurements were conducted from 5 cm to 50 cm with an interval of 2.5 cm. At each distance point, 19 measurement readings were recorded from both sensors. The average values and absolute measurement errors were then calculated and compared. The comparison of distance measurement results obtained from both sensors during the basic accuracy test is summarized in Table 1.

Table 1. Comparison of Sensor Readings in Basic Accuracy Measurement

Measurement No	Actual Value	Ultrasonic Sensor Measurement		Infrared Sensor Measurement	
		Value	Error	Value	Error
1	5.0	5.2	0.2	5.6	0.6
2	7.5	7.6	0.1	7.8	0.3
3	10.0	10.0	0.0	10.2	0.2
4	12.5	12.6	0.1	12.7	0.2
5	15.0	15.0	0.0	15.1	0.1
6	17.5	17.5	0.0	17.7	0.2
7	20.0	20.0	0.0	20.1	0.1
8	22.5	22.6	0.1	22.7	0.2
9	25.0	25.0	0.0	25.1	0.1
10	27.5	27.6	0.1	27.7	0.2
11	30.0	30.0	0.0	30.3	0.3
12	32.5	32.6	0.1	32.8	0.3

Measurement No	Actual Value	Ultrasonic Sensor Measurement		Infrared Sensor Measurement	
		Value	Error	Value	Error
13	35.0	35.1	0.1	35.4	0.4
14	37.5	37.6	0.1	38.0	0.5
15	40.0	40.1	0.1	40.6	0.6
16	42.5	42.6	0.1	43.2	0.7
17	45.0	45.1	0.1	45.8	0.8
18	47.5	47.6	0.1	48.6	1.1
19	50.0	50.2	0.2	51.2	1.2
Average			0.09		0.46

The basic accuracy test was conducted to evaluate the initial performance of both sensors under ideal conditions without environmental disturbances. Based on Table 1, the HC-SR04 ultrasonic sensor demonstrated highly stable readings with an average error of approximately 0.09 cm over a distance range of 5–50 cm. This indicates that the ultrasonic sensor is capable of providing consistent distance estimation in medium- to long-range measurements.

In contrast, the Sharp GP2Y0A21YK0F infrared sensor exhibited accurate performance at short to medium distances, with errors ranging from 0.1 to 0.3 cm at distances below 30 cm. However, its accuracy began to degrade at distances above 40 cm, reaching an error of up to 1.2 cm at 50 cm. This trend is consistent with the technical specifications of the infrared sensor, which indicate an optimal operating range of up to 80 cm, beyond which measurement accuracy decreases as the maximum range is approached.

These results confirm that the ultrasonic sensor is more suitable for medium- to long-range distance measurements, whereas the infrared sensor is more appropriate for short-range applications that require compact size and high sensitivity.

Results of Test 2 – Effects of Temperature and Lighting

In this test, the sensors were evaluated under three environmental conditions: room temperature without additional lighting, high temperature without lighting, and high temperature with strong illumination. The reflective object was positioned at a fixed distance of 50 cm, and measurements were conducted for each condition. The effects of temperature and lighting variations on the distance measurement accuracy of both sensors are summarized in Table 2.

Table 2. Effects of Environmental Conditions on Sensor Readings

Environment Condition	Actual Value	Ultrasonic Sensor Measurement		Infrared Sensor Measurement	
		Value	Error	Value	Error
Normal Room (20–25°C), normal light	50	50.3	0.3	49.5	0.5
High Temperature (~40°C), normal light	50	50.7	0.7	48.8	1.2
High Temperature with strong illumination	50	51.0	1.0	48.0	2.0
Low Temperature (~5–10°C), normal light	50	50.5	0.5	49.0	1.0
Low Lighting (min lighting)	50	50.2	0.2	50.8	0.8

Based on Table 2, changes in environmental temperature have a more pronounced impact on the ultrasonic sensor compared to the infrared sensor. Under both high and low temperature conditions, the ultrasonic sensor exhibits measurement errors of approximately ±1 cm due to variations in the speed of sound propagation in air, whereas the infrared sensor experiences smaller fluctuations of approximately ±0.4–0.6 cm because its performance is primarily influenced by optical factors.

In contrast, extreme lighting conditions significantly affect the infrared sensor. Strong illumination results in measurement errors of up to 2 cm due to interference from external light sources on the optical receiver. The ultrasonic sensor remains relatively stable under all lighting conditions, with errors below 0.3 cm. These findings indicate that ultrasonic sensors are more susceptible to temperature variations, while infrared sensors are more sensitive to ambient lighting. This consideration is particularly important for applications in industrial or warehouse environments, where temperature and lighting conditions can vary significantly.

Results of Test 3 – Effect of Reflective Surface Materials

This test evaluated sensor distance readings for six commonly used reflective materials: metal, wood, glass, plastic, fabric, and styrofoam. Each material was tested at a fixed distance of 50 cm, with measurements recorded for each data acquisition. The comparison of distance measurement results obtained from both sensors for different reflective surface materials is presented in Table 3.

Table 3. Comparison of Distance Estimation Based on Reflective Surface Materials

Material	Actual Value	Ultrasonic Sensor Measurement		Infrared Sensor Measurement	
		Value	Error	Value	Error
Metal	50.0	50.1	0.1	50.2	0.2
Glass	50.0	51.5	1.5	58.0	8.0
Wood	50.0	50.3	0.3	50.8	0.8
Plastic	50.0	50.4	0.4	51.0	1.0
Fabric	50.0	52.0	2.0	60.0	10.0
Styrofoam	50.0	51.0	1.0	55.0	5.0

Based on Table 3, variations in reflective surface materials have a significant impact on the accuracy of both sensors. The ultrasonic sensor remains relatively stable on hard and flat surfaces such as metal, wood, and plastic, with errors below 0.5 cm. However, its accuracy decreases when measuring porous or sound-absorbing materials such as fabric and styrofoam, where errors increase to up to 2 cm due to attenuation of ultrasonic wave reflections.

The infrared sensor exhibits higher sensitivity to surface characteristics. For transparent objects such as glass, the measurement error increases sharply to up to 8 cm because most infrared light either passes through the surface or is reflected at different angles, preventing it from returning to the receiver. Light-absorbing materials such as fabric also produce large errors of up to 10 cm, indicating the limitations of infrared sensors when measuring objects with low reflectivity.

Overall, the ultrasonic sensor is more reliable across a wider range of reflective materials, although its performance degrades on sound-absorbing surfaces. In contrast, the infrared sensor performs well on opaque and reflective objects but is less accurate when measuring transparent or light-absorbing materials. These findings are particularly relevant for cobot applications that interact with objects of varying material properties in real-world working environments.

Results of Test 4 – Effect of Surface Inclination Angle on Sensor Readings

The fourth test was conducted by varying the inclination angle of the reflective object relative to the sensor axis at 0°, 15°, 30°, and 45°. These angles simulate real-world conditions in which objects are not perfectly aligned with the sensor. The comparison of distance measurement results obtained from both sensors under different surface inclination angles is presented in Table 4.

Table 4. Comparison of Sensor Readings Based on Surface Inclination Angle

Angle	Actual Value	Ultrasonic Sensor Measurement		Infrared Sensor Measurement	
		Value	Error	Value	Error
0°	50.0	50.1	0.1	50.2	0.2
15°	50.0	50.3	0.3	50.8	0.8
30°	50.0	51.0	1.0	53.0	3.0
45°	50.0	52.5	2.5	57.0	7.0

The results in Table 4 indicate that surface inclination significantly affects the measurement accuracy of both sensors. At an angle of 0°, both ultrasonic and infrared sensors produce readings very close to the actual value, with errors below 0.2 cm. However, as the inclination angle increases, measurement errors increase progressively.

The ultrasonic sensor begins to show noticeable deviation at an angle of 30°, with an error of approximately 1 cm, and reaches an error of 2.5 cm at 45°. Meanwhile, the infrared sensor is more sensitive to surface inclination, with errors increasing to 3 cm at 30° and reaching 7 cm at 45°. This behavior is attributed to the reflection characteristics of infrared light, which are highly dependent on the angle of incidence, causing reflected signals to fail to return directly to the receiver when the surface is inclined.

Overall, the ultrasonic sensor demonstrates better tolerance to variations in surface inclination compared to the infrared sensor. These findings suggest that ultrasonic sensors are more suitable for cobot applications involving objects with non-uniform alignment, whereas infrared sensors are more effective in scenarios where object positioning relative to the sensor is consistent.

CONCLUSION

This study compared the accuracy of the HC-SR04 ultrasonic distance sensor and the Sharp GP2Y0A21YK0F infrared sensor through four main tests: basic accuracy, effects of temperature and lighting, variations in reflective surface materials, and object inclination angle. The results indicate that the ultrasonic sensor exhibits more stable performance, with an average error of approximately 0.09 cm across the 5–50 cm measurement range, while the infrared sensor shows high accuracy at short to medium distances but experiences increased error of up to 1.2 cm at a distance of 50 cm. Temperature variations affect ultrasonic sensor accuracy, resulting in errors of approximately ±1 cm, whereas the infrared sensor is more sensitive to strong lighting conditions, with errors reaching up to 2 cm. In tests involving reflective materials, the ultrasonic sensor is more tolerant of material variations, although its accuracy decreases on sound-absorbing surfaces such as fabric, while the infrared sensor exhibits significant errors on transparent and light-absorbing materials such as glass and fabric, reaching 8–10 cm. Furthermore, inclination angle testing shows that the ultrasonic sensor is more tolerant of object tilt, with an error of 2.5 cm at a 45° angle, whereas the infrared sensor experiences a substantial decrease in accuracy, with an error of 7 cm at the same angle. Based on these findings, the ultrasonic sensor is more versatile and reliable for collaborative robot applications in environments with varying object positions and conditions, while the infrared sensor is better suited for short-range distance measurements under controlled conditions. These results provide a foundation for developing more accurate cobot navigation and safety systems through appropriate sensor selection or sensor fusion strategies.

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