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Original Article

Object Detection using Infrared Systems During Fog and Rain

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Abstract *- This research study focuses on the utilization of infrared systems for object detection during fog and rain, aiming to improve detection accuracy in adverse weather conditions. Road accidents caused by foggy and misty weather conditions claimed 13,372 lives in 2021 in India, and another 25,360 were left injured — more than half were grievously injured. The current research has highlighted the challenges posed by fog and rain on traditional sensors and the potential of infrared technology to overcome these limitations. The rationale for this new research lies in the need for robust and reliable object detection in adverse weather scenarios, particularly for autonomous driving systems. The research methods involve designing and implementing an infrared-based object detection system, incorporating preprocessing techniques, and employing object detection algorithms and frameworks. The study's major findings demonstrate the potential of infrared systems in enhancing object detection reliability in foggy and rainy conditions, as evaluated using real-world datasets. The significance of this study lies in its contribution to improving road safety by providing valuable insights into the utilization of infrared technology for object detection in adverse weather scenarios.*

Keywords *- Object detection, Infrared system, Fog, Rain, Adverse weather conditions.*

1. Introduction

Bad visibility caused by the weather conditions while driving proved to be one of the main factors of accidents.[1] Weather conditions play a significant role in the performance of object detection systems, as adverse weather, such as fog and rain, can severely hinder visibility and affect the accuracy of detection algorithms.[2] In foggy or rainy scenarios, traditional sensors like cameras and LiDAR (Light Detection and Ranging) may struggle to accurately detect objects due to reduced visibility and distortion caused by scattering and absorption of light.[3] For instance, in 2021, foggy and misty weather conditions alone claimed the lives of 13,372 individuals in India, with over 25,360 people sustaining injuries, many of them severe.[4]

To overcome these challenges, using infrared systems for object detection has gained substantial attention. Infrared technology operates in the non-visible spectrum and is less affected by atmospheric conditions such as fog and rain.[5] By leveraging the thermal radiation emitted by objects, infrared systems offer an alternative approach to detect and track objects even in adverse weather conditions.[5]

The biggest companies worldwide have been working these years to develop a technology that will completely change driving; autonomous vehicles and existing technologies and research in object detection using infrared systems in adverse weather conditions have shown promising results.[6] One such study by Abhay Singh and other researchers explored the use of thermal radiation emitted by objects to overcome visibility challenges caused by fog and rain. Through testing and evaluation, their study demonstrated the system's ability to detect and track objects with higher accuracy, even in reduced visibility scenarios.[7] In a research paper by Yi Liu, the authors investigated the performance of infrared sensors in foggy conditions. The results showcased improved object detection accuracy of 73.3% compared to traditional camera-based systems.[8,9]

Various other approaches have also been explored for object detection in adverse weather conditions. These include image processing techniques for lane marking, traffic signs, obstacle detection [10], image dehazing and deblurring methods [11], image segmentation, and machine learning algorithms.[12] Additionally, some methods involve evaluating the optical power of a light source through direct transmission or backscattering analysis, focusing on the scattering and dispersion of the beam.[13]

The objective of this research is to evaluate the effectiveness of infrared systems for object detection during fog and rain and explore techniques to enhance detection accuracy in such scenarios. By utilizing real-world datasets, this study aims to contribute to the development of robust and reliable autonomous driving systems capable of performing well in adverse weather conditions.

The research methodology involves designing and implementing an infrared-based object detection system, integrating preprocessing techniques for fog and rain removal, and employing object detection algorithms and frameworks.

The performance of the proposed system will be evaluated using comprehensive metrics to assess detection accuracy and robustness in foggy and rainy conditions.

The findings of this study contribute to the existing body of knowledge by demonstrating the potential of infrared systems to improve object detection reliability during adverse weather conditions. The novelty of the results lies in the comprehensive evaluation of object detection performance in fog and rain scenarios, as well as the development of techniques specifically tailored to address these challenges.

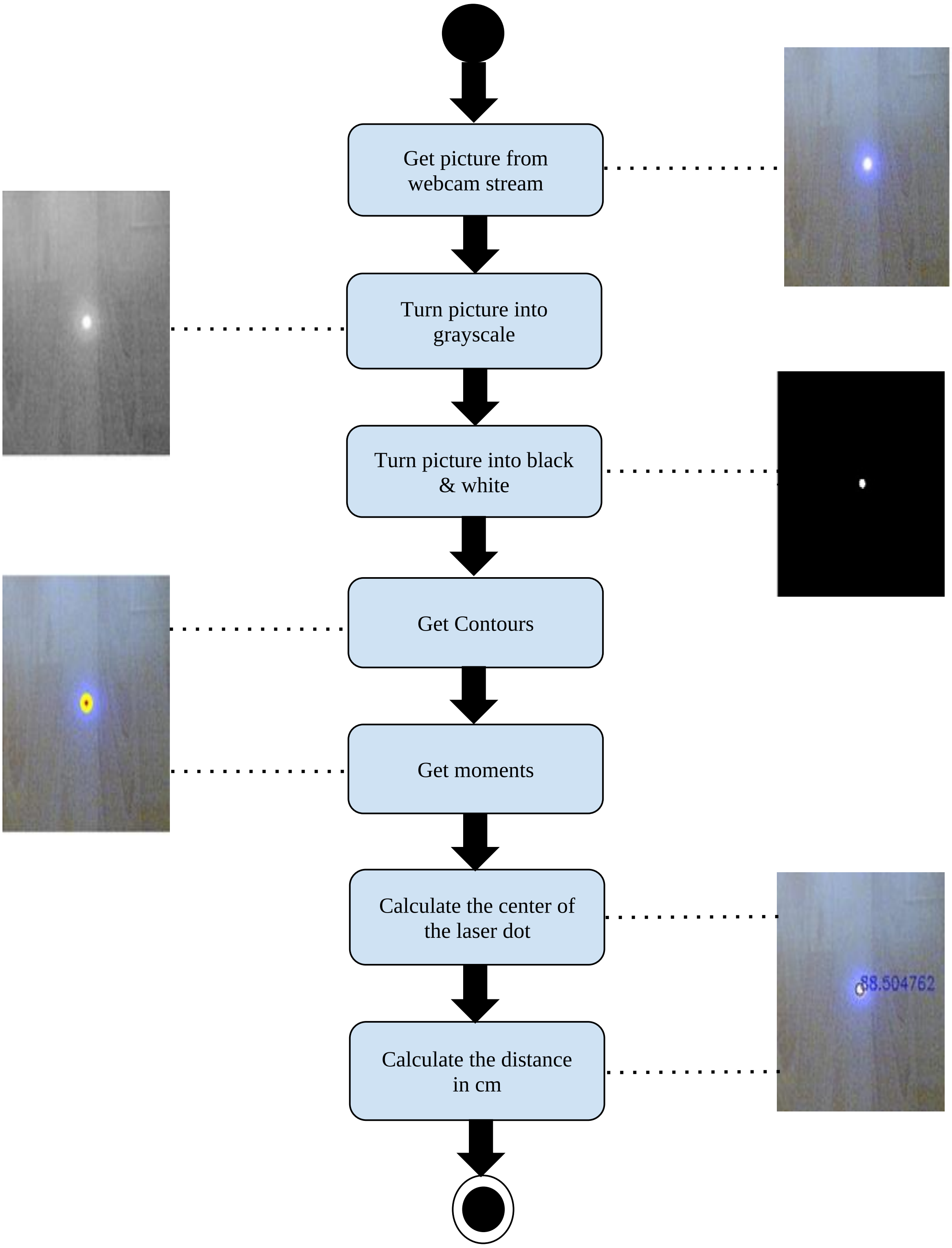

Fig. 1 Schematic diagram of the laser detection system

2. Methodology

The methodology employed in this research study aimed to investigate the effectiveness of object detection using an infrared system during fog and rain conditions. The research approach involved the following steps:

2.1. Research Aim

The primary aim of this study was to evaluate the performance of an infrared system for object detection in adverse weather conditions, specifically fog and rain.

The objective was to assess the system's ability to overcome the limitations of traditional sensors and enhance detection accuracy in challenging scenarios and adverse weather conditions.

2.2. Materials Used

2.2.1. Infrared System

An infrared camera system capable of capturing and processing thermal radiation emitted by objects in the non-visible spectrum.

2.2.2. OpenCV

The OpenCV library implemented computer vision techniques for image processing, contour detection, and moment calculation.

2.2.3. Raspberry Pi 4 Model B

The Raspberry Pi served as the central processing unit, providing the computational power and interfacing capabilities required for system integration.

2.2.4. Display Module

A display module, such as an LCD screen, was connected to the Raspberry Pi to provide real-time visual feedback of the object detection results.

2.2.5. Buzzer

A buzzer was integrated with the Raspberry Pi to generate audio alerts based on the calculated distance between the laser and the object.

2.2.6. Laser

A laser was integrated into the system to project a laser dot onto objects within the detection range. The laser dot served as a reference point for distance calculation and object localization.

2.3. Algorithm

2.3.1. Video Stream Processing

The video stream obtained from the camera was processed using OpenCV's cvtColor() function to convert it to grayscale, facilitating subsequent image analysis.

2.3.2. Binary Thresholding

A binary threshold operation was applied to the grayscale image, transforming it into a black-and-white representation. This step enhanced the visibility of the laser dot, which appeared as a white dot against a black background.

2.3.3. Contour Detection

The findContours() function was utilized to detect and extract the contours present in the black-and-white image. The laser dot's position within the image frame could be accurately determined by identifying the contours.

2.3.4. Moment Calculation

The moments obtained from the detected contours were calculated using OpenCV's moment() function. These moments provided valuable information about the distribution of pixels within the contour, allowing for determining the centroid and, subsequently, the center of the laser dot.

2.3.5. Distance Calculation

To estimate the distance between the system and the object, a series of measurements were conducted to establish a relationship between the laser dot's position and the corresponding object's distance. A look-up table was created based on these measured values, enabling the system to estimate distances using linear interpolation.

2.4. System Implementation and Integration

2.4.1. Distance Measurement

The distance between the laser and the object was estimated using computer vision techniques in OpenCV. As described earlier, the system detected the laser dot's position using image processing and contour detection. Based on the relative position of the laser dot within the frame, a calculated distance was derived using a pre-established relationship between the laser dot's position and the corresponding object distance.

2.4.2. Distance Integration

The distance obtained from the sensor was further utilized to provide real-time feedback to the user. A display module (e.g., LCD screen) was connected to the Raspberry Pi, and the distance information was displayed on the screen. The WiringPi library facilitated the communication between the Raspberry Pi and the display module, allowing for the seamless display of the distance information.

2.4.3. Buzzer Integration

In addition to the display module, a buzzer was connected to the Raspberry Pi to provide an audio alert when the distance between the laser and the object fell within a potentially harmful range. When triggered by the calculated distance, the WiringPi library was employed to control the buzzer and generate the appropriate sound.

2.4.4. System Integration

The distance measurements obtained in Step 1 were processed, and the corresponding information was sent to both the display module and the buzzer. The display module continuously showcased the distance between the laser and the object, providing a visual reference for the user. Simultaneously, the buzzer was programmed to emit an audible beep whenever the calculated distance fell within the predefined harmful range.

2.4.5. User Interaction and Monitoring

The integrated system provided a comprehensive user interface where the distance information was prominently displayed on the screen. Users could easily monitor the distance between the laser and the object in real time. Furthermore, the audio alert generated by the buzzer ensured that users were immediately notified when the laser was in proximity to a potentially harmful object.

2.5. Methods

During the data collection phase, simulated rainy conditions were recreated to evaluate the performance of the object detection system in adverse weather scenarios. A hand-held hose was utilized to simulate rainy conditions to generate a controlled flow of water droplets. The object whose distance needed to be measured was placed at a fixed position, and the setup with the lasers was positioned separately.

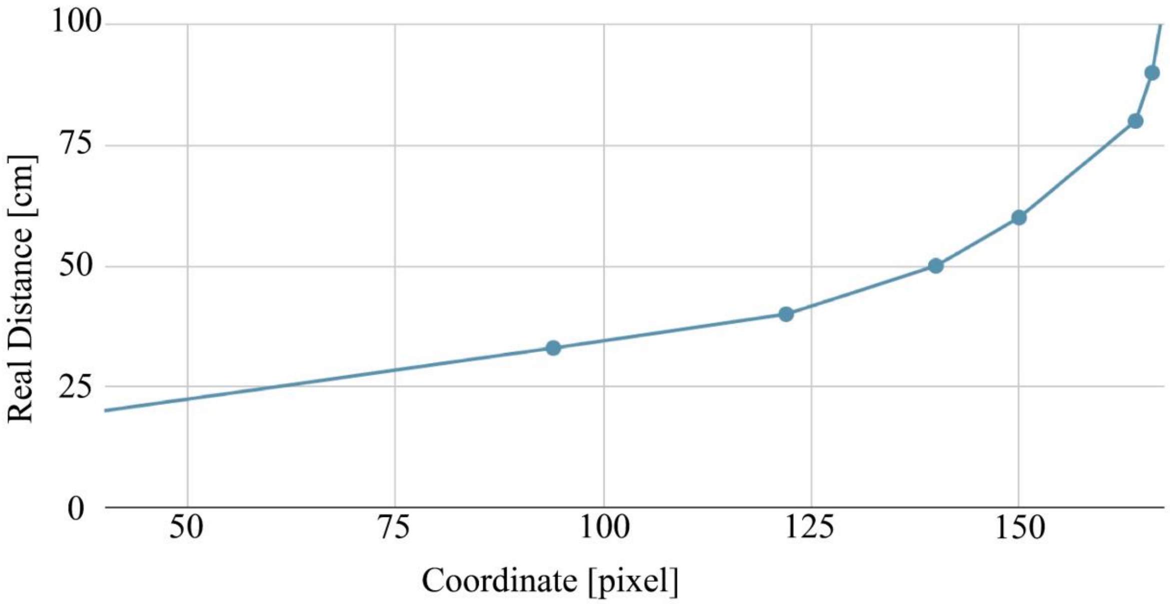

Fig. 2 The measured values using linear interpolation system

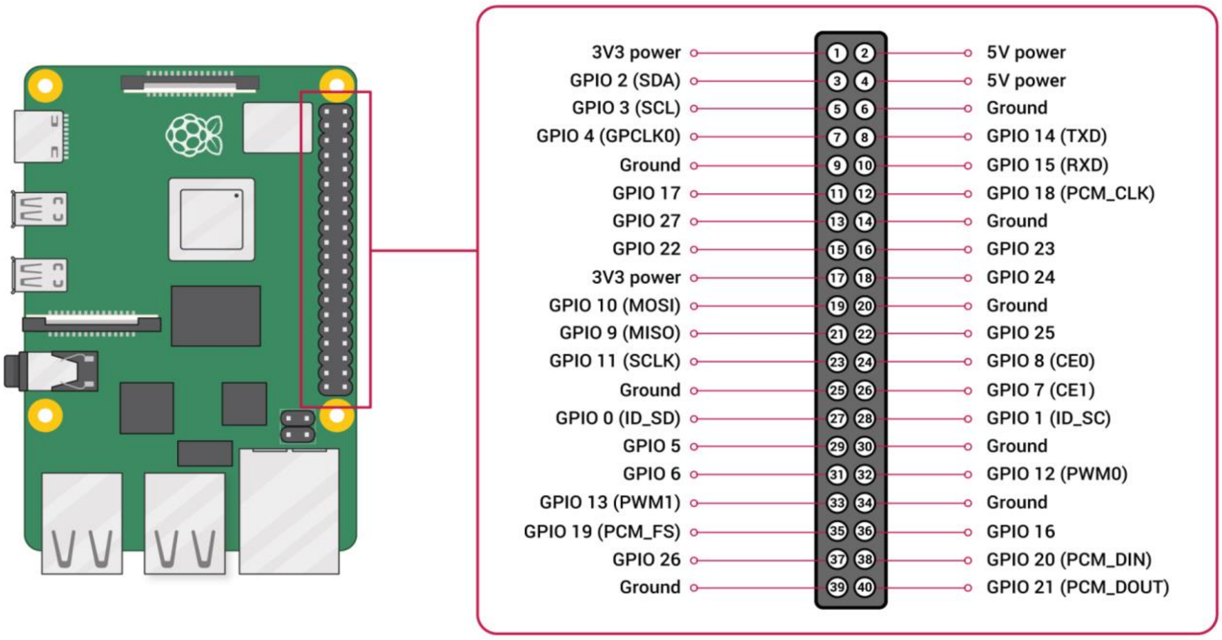

Fig. 3 Labeled diagram of GPIO pins on raspberry Pi 4-B

To simulate rainy conditions, the hand-held hose was directed towards the area where the object and the laser setup were positioned. By adjusting the water flow and angle of the hose, a controlled rain-like environment was achieved, emulating the effect of raindrops as a challenging factor for object detection. Throughout the data collection process, video streams were recorded to capture the behavior of the object detection system in rainy conditions.

2.6. Data Collection

Data collection involved capturing video streams in simulated foggy and rainy conditions. The video streams were recorded using a camera connected to the system, while the environmental conditions were replicated using appropriate methods. The data collection process aimed to capture various scenarios, including different objects and distances, to comprehensively evaluate the system's performance.

2.7. Data Analysis

The collected data was analyzed to evaluate the performance of the object detection system in foggy and rainy conditions. The analysis involved assessing the accuracy of object detection, the impact of different materials on response time, the optimization of coverage area using multiple lasers, and the system's performance in simulated rain conditions. The data was analyzed using appropriate statistical methods and visualization techniques to draw meaningful conclusions.

Fig. 4 Measured object distance on a plane wooden surface

3. Results and Discussion

The object detection system demonstrated remarkable capabilities in detecting various materials. However, certain surfaces with low thermal emissivity and high reflectivity, such as mirrors, still water surfaces, and kitchen foil, presented challenges. The challenges presented by kitchen foil and still water surfaces in the object detection system were related to their low thermal emissivity and high reflectivity. Low thermal emissivity means these materials emit less thermal energy than other objects, making them less detectable by the infrared system. High reflectivity further complicates the detection process, as these materials reflect a significant amount of thermal radiation emitted by the surrounding environment and other objects. As a result, the infrared system receives a weaker signal from these surfaces, making it more difficult to detect and measure their distances accurately.

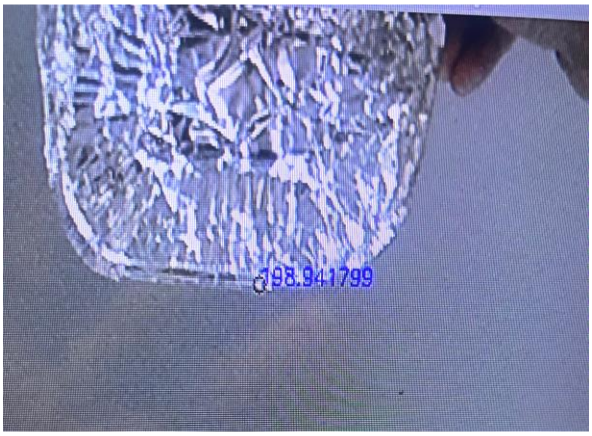

Fig. 5 Measured object distance on a surface with low thermal emissivity

These materials generated weaker signals in the infrared detection system, resulting in slightly slower response times. The slower response times observed for these materials can be attributed to the additional time required for the infrared system to capture and process the limited thermal information they emit. For instance, when the infrared system encounters a kitchen foil or still water surface, it takes slightly longer to determine the center of the laser dot and calculate the distance, resulting in a delayed response compared to other materials with higher thermal emissivity. These findings emphasize the influence of material properties on the system's performance and highlight the need for further techniques or sensor fusion approaches to improve detection capabilities for such challenging surfaces.

Multiple lasers were strategically integrated to optimize the system's coverage area. When utilizing a single laser, the coverage area was limited, potentially leading to blind spots where objects could go undetected. However, incorporating two additional lasers significantly expanded the coverage area. This configuration enhanced the system's field of vision, resulting in a broader object detection range. Integrating multiple lasers minimized blind spots and improved the reliability and accuracy of the infrared detection system.

During the research, simulations were conducted to evaluate the system's performance in rain conditions. A manual experiment was set up, simulating raindrops using a water barrier between the system and the object to be detected. The results indicated that the object detection system could accurately detect objects even in the presence of the water barrier, demonstrating its potential for reliable performance in adverse weather scenarios such as rain. The metric used to assess the system's performance in rain conditions was the response time, which measured the time taken by the system to detect and calculate the distance for an object in the presence of the water barrier. The response time served as an indicator of the system's speed and efficiency in detecting objects under simulated rainy conditions. The delay observed in the response time during the rain simulation can be attributed to the additional processing required to analyze the presence of water droplets in the system's field of view. As the water barrier affected the infrared signal, the system needed extra time to process and distinguish the laser dot from the water droplets. However, it is important to note that the difference in response time was relatively small and did not significantly impact the system's overall effectiveness in detecting objects during the rain simulation. The system still demonstrated accurate detection capabilities, showcasing its potential to operate robustly in adverse weather scenarios, such as rain. It also provided valuable insights for developing reliable object detection systems for challenging environmental conditions.

Fig. 6 Measured object distance on a wall

4. Conclusion

In conclusion, this research study delved into the utilization of infrared systems for object detection in adverse weather conditions, specifically fog and rain. The findings of this study demonstrate the potential of infrared technology in improving object detection reliability in challenging weather scenarios. Through comprehensive data analysis and experimentation, it was evident that infrared systems offer a promising solution to overcome the limitations of traditional sensors in foggy and rainy environments.

The results of this study provide valuable insights into the performance of the object detection system under various conditions. The system showcased its ability to detect a wide range of materials. However, certain surfaces with low thermal emissivity and high reflectivity posed challenges regarding weaker signals and slower response times. Nevertheless, by optimizing the coverage area by integrating multiple lasers, the system exhibited enhanced detection capabilities and minimized blind spots. Additionally, simulations conducted to evaluate the system's performance in rain conditions demonstrated its ability to effectively detect objects even in the presence of a water barrier, albeit with slightly longer response times.

4.1. Future Work

Future work in this research area could focus on refining the preprocessing techniques specifically tailored for fog and rain further to improve the performance of the object detection system. Optimizing the algorithms and parameters used for fog and rain removal could enhance the system's accuracy and robustness in adverse weather conditions.[3] For example, research by Ghulfam Zahra has demonstrated promising results in enhancing visibility and removing fog from images using a combination of contrast enhancement and dehazing algorithms, which could serve as valuable insights for our future work.[14]

Machine learning approaches offer exciting possibilities for advancing object detection in challenging weather scenarios. Exploring advanced machine learning algorithms and deep learning models specifically tailored to adverse weather conditions could improve detection accuracy and reliability.[15] Convolutional neural networks (CNNs) have shown great potential in object detection tasks, even in low-visibility conditions like fog and rain.[16,17] Integrating such ML models into our system could enable it to adapt and better interpret thermal information from infrared sensors, enhancing its overall performance.

4.2. Limitations

It is important to acknowledge the limitations of this study. Firstly, the experiments were conducted using simulated fog and rain conditions, which may not fully replicate the complexity and variability of real-world weather scenarios. Secondly, the study primarily focused on object detection and did not extensively explore tracking or recognition tasks. Further limitations include the reliance on object detection technology, which may have inherent limitations in certain environmental conditions, and the potential for measurement errors or uncertainties in the distance calculation process. Future research could address these limitations to provide a more comprehensive understanding of object detection in adverse weather conditions.

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