



Image Detection and Distance Estimation for Rear Collision Avoidance using YOLOv4 on Jetson Nano

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ABSTRACT

Traffic accidents pose a significant global challenge, resulting in millions of non-fatal injuries annually. Addressing road safety issues and implementing comprehensive measures are crucial. This study evaluates a rear-end pre-collision avoidance system (CAS) utilizing the YOLOv4 algorithm on a small, powerful embedded computer, NVIDIA® Jetson Nano™. The system integrates image detection and distance estimation techniques within a monocular vision framework. Experimental results demonstrate the system's remarkable accuracy in distance estimation. Under normal lighting conditions, it achieved an accuracy rate of 94.60% with a confidence level of 0.778. Even in altered lighting conditions, it maintained a commendable accuracy of 94% with an increased confidence level of 0.8376. Additionally, the system effectively generated warning messages and responded when predefined distance thresholds were reached. These findings highlight the system's practical applicability, particularly in rear collision avoidance scenarios. In a broader context, this research contributes to advancing collision avoidance systems by addressing the critical need for precise distance estimation in rear-end collision scenarios. By enhancing safety and reliability, these systems have the potential to reduce accident risks and elevate road safety significantly. Future research should focus on refining the algorithm, integrating advanced technologies, and conducting extensive tests in diverse environments to optimize further and validate the system's capabilities. These efforts promise to improve road safety and extend the system's applicability in various domains.

1. Introduction

Every year, millions of non-fatal injuries result from traffic accidents worldwide, with road traffic injuries becoming the leading cause of death among individuals aged 5 to 29 [1]. This statistic highlights the urgent need for comprehensive road safety measures, especially in addressing automobile-to-automobile collisions, the most prevalent type of road traffic accident. Advanced driving systems incorporating intelligent features like vehicle detection and collision warning can significantly enhance traffic safety. These systems rely on object detection techniques, using computer vision, machine learning, and advanced algorithms to identify and localize objects like cars, buses, motorcycles, and bicycles [2]. Additionally, distance estimation plays a crucial role in collision

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avoidance systems, providing information about the proximity of detected objects to the host automobile. Integrating object detection and distance estimation using deep learning algorithms and optical sensors can provide substantial benefits across various applications [3].

Recent advances in deep learning, particularly integrating object detection and distance estimation using artificial neural networks (ANN), have shown great potential in enhancing real-time collision avoidance [4,5]. ANN, notably the YOLOv4 algorithm, offers superior accuracy in image classification and object recognition tasks while being versatile and easy to retrain. By implementing YOLOv4 on NVIDIA's Jetson Nano development board with a monocular camera, real-time collision avoidance can be achieved, improving road traffic safety.

The rise in road accident fatalities due to negligent driving behaviors has raised concerns, necessitating the development of collision avoidance systems (CAS) [6]. However, there is a lack of comprehensive research evaluating the effectiveness of these technologies in reducing accidents and improving road user safety [7]. This study aims to assess the effectiveness of CAS in reducing collisions and enhancing road safety using the Jetson Nano and YOLOv4 algorithms to detect and track vehicles and obstacles, providing timely warnings and assistive functions.

The proposed collision avoidance system, utilizing the capabilities of the Jetson Nano and YOLOv4 algorithm, is a cost-effective and energy-efficient approach to addressing road safety concerns. This system can detect and monitor environmental vehicles and obstacles by utilizing the Jetson Nano's real-time video analysis capabilities via an embedded camera. The cutting-edge YOLOv4 algorithm assures precise and rapid identification, allowing the system to issue timely collision prevention alerts. This integration has the potential to significantly reduce incidents caused by human error and distraction by enhancing real-time obstacle detection in a variety of conditions. However, it is essential to recognize the project's limitations and scope.

While the system excels at recognizing objects within a 120-degree angle on the driver's front side, its reliance on monocular vision imposes limitations, especially regarding depth perception. When evaluating its efficacy in real-world scenarios, these limitations must be considered.

The Jetson Nano and YOLOv4-based collision avoidance system has far-reaching implications. It can increase the security and effectiveness of automation applications in agriculture, mining, and logistics [8]. In transportation, it can improve the safety of autonomous vehicles, unmanned aerial vehicles (UAVs), and cargo transport. In addition, the system's real-time object detection and tracking capabilities can be valuable for security and monitoring when applied to surveillance. In essence, this system offers a cost-effective and adaptable solution that has the potential to increase safety and efficacy across multiple industries.

2. Methodology

The collision avoidance system was developed by integrating the YOLOv4 algorithm with custom Python code tailored for object detection and avoidance, employing a single camera setup. The system's workflow is illustrated in Fig. 1, depicting the step-by-step progression of its operation. In this process, the algorithm first analyzes incoming images, pinpointing the coordinates of bounding boxes around detected objects and estimating the distances to these objects.

Subsequently, it evaluates whether these estimated distances surpass a predefined safety threshold. It is worth noting that the primary emphasis of this study centered on creating an object detection system and incorporating a distance-based alarm system. This system represents a significant advancement in road safety by utilizing state-of-the-art object detection techniques and intelligent algorithms to assess and respond to potential collision risks in real time.

The combination of YOLOv4 and custom Python code underscores the system's potential to enhance driver safety and mitigate accidents caused by human error and distraction.

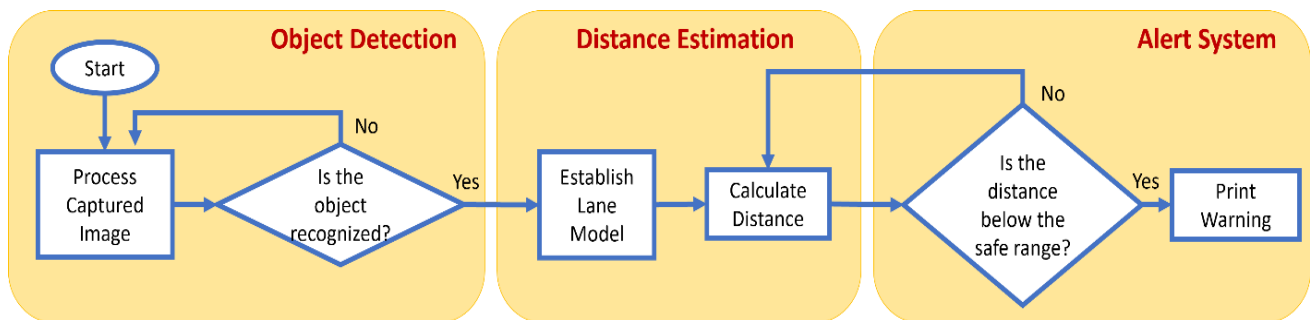


Fig. 1. Object detection and estimation algorithms development

The YOLOv4 algorithm, a critical component of the collision avoidance system, underwent training using GOOGLE Colab's cloud computing resources. The training dataset was sourced from the KITTI dataset, comprising 7,481 images related to vehicles. During training, the neural network's weights were saved in a file hosted on Google Drive, with periodic updates occurring every 100 iterations, ensuring the algorithm's continuous improvement.

A two-stage experiment was conducted under different lighting conditions to evaluate the algorithm's effectiveness. The experimental setup occurred within an automotive workshop, specifically in a garage environment. The first stage replicated low-light conditions, while the second recreated regular lighting conditions. The computer vision system, equipped with the Logitech C270 web camera, was strategically positioned at various distances to simulate real-world scenarios, as depicted in Fig. 2. This comprehensive experiment and analysis serve to validate the algorithm's effectiveness in real-time object detection and distance estimation, which are pivotal for collision avoidance systems.

All lights were turned off initially to create a controlled low-light environment. The subsequent stage aimed to simulate typical lighting conditions by turning on the lights. Data capture was facilitated through a securely mounted Logitech C270 web camera placed at 4m, 5m, 6m, 7m, and 7.5m, with 4m as the measurement reference point. The experiment assessed the algorithm's distance estimation accuracy in three distinct cases: distances exceeding 5.5m, distances between 4m and 5m, and distances less than 4m. Each case triggered a different system reaction, with results communicated through printed messages for experimental purposes. Subsequently, data transcription and analysis were conducted using SPSS version 26, and mean error calculations in Excel were employed to evaluate the algorithm's performance, accuracy, and reliability.



Fig. 2. Experimental setup and measurement

3. Results and Discussion

The system efficiently processed the captured images, successfully detecting the car's rear and providing real-time distance measurements from the camera. Fig. 3 visually represents the processed image, using yellow and green colors to convey the level of confidence in object detection and the estimated distance, respectively. This visual representation enhances the system's usability and offers a clear and intuitive way for users to interpret the results, facilitating quick and informed decision-making in potential collision scenarios.

The implemented algorithm demonstrated accurate detection of the trained item and consistent estimation of its distance from the camera. However, some minor variations in distance measurements were observed, even though the system performed well. For instance, at a reference distance of 4m, the camera's distance output ranged from 3.81m to 3.93 m. To comprehensively assess the system's performance, a rigorous evaluation was conducted, consisting of 10 iterations. These iterations involved incrementing the distance by 1m, starting from 4m and extending up to 7m, with an additional evaluation conducted at 7.5m. This systematic approach allowed for a thorough examination of the algorithm's behavior across various distance conditions, providing valuable insights into its reliability and accuracy.

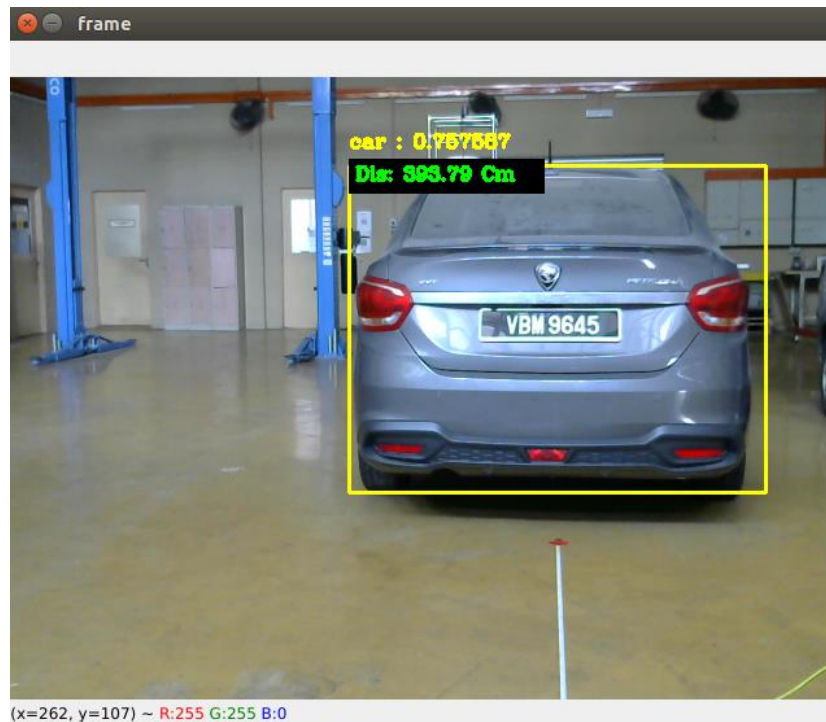


Fig. 3. Example result of the proposed method

Furthermore, the experiment considered the impact of lighting conditions by repeating the evaluation with the workshop lights turned off and doors closed to minimize interference from sunlight. It is important to note that the observed variations in distance estimation can be attributed to using a monocular vision system, which relies on a single camera for depth perception. Considering the inherent limitations of such a system, these variations were anticipated and served as valuable data for further refining the collision avoidance system.

Table 1 provides a comprehensive summary of the system's distance readings, including the calculated error percentages determined by comparing the estimated values to the actual values. These error percentages offer valuable insights into the accuracy of the system's distance measurements across various distances. The system's confidence level plays a crucial role in understanding its performance. With each distance estimation, the system provides a confidence indication, reflecting its level of certainty in recognizing and estimating distances to detected objects. This confidence level is essential for assessing the reliability of the system's readings.

Table 1
 The result of the proposed method

Lighting	Actual Distance (m)	Distance Estimation (m)	Error (%)	Confidence in Object Detection
On	4	3.9379	-1.552	0.741
	5	4.8922	-2.156	0.971
	6	5.7790	-3.683	0.907
	7	6.3466	-9.335	0.7
	7.5	6.7304	-10.261	0.572
	Total			-5.3976
Off	4	3.8840	-2.901	0.766
	5	4.8978	-2.044	0.973
	6	5.8094	-3.176	0.889
	7	6.2318	-10.975	0.899
	7.5	6.6774	-10.968	0.651
	Total			-6.0128

Interestingly, when the lights were turned off, the system exhibited more significant errors in distance readings, as expected due to the challenges posed by low-light conditions. However, a surprising observation was made when the lights were turned on: the system's confidence in recognizing objects slightly decreased compared to the off-lighting condition. Further investigation is necessary to uncover the factors contributing to this unexpected phenomenon, including changes in illumination or the presence of shadows. Notably, a significant increase in error was observed beyond 6m, suggesting a possible exponential relationship between measured distance and actual range. This range-dependent performance underscores the system's reliability within specific distance ranges and provides valuable insights into its operational characteristics.

The results of this comprehensive evaluation hold significant implications for the design and implementation of safety systems, particularly in collision avoidance. The demonstrated accuracy of the collision avoidance system in estimating distances represents a noteworthy achievement, showcasing its ability to provide precise and trustworthy information about the proximity of detected objects.

Regarding the system's confidence levels, the highest confidence was observed at 5m, corresponding to the typical range when the reference point was set at 4m. Confidence decreased linearly as the distance increased, with the lowest confidence readings observed at 7.5m. This confidence trend was consistent for both lighting conditions. However, it is worth noting that the confidence at 4m was not as high as at 5m, possibly due to the expected measuring distance. This observation highlights the system's efficiency and reliability, which decreases linearly as the distance extends beyond the lowest possible reference point.

The experimental outcomes emphasize the system's remarkable accuracy in distance estimation. Under normal lighting conditions, the system achieved an impressive accuracy rate of 94.60%, with a confidence level of 0.778. Even when subjected to altered lighting conditions, the system maintained a commendable % accuracy rate of 94%, coupled with an increased confidence level of 0.8376. These findings underscore the system's practical utility, especially in rear collision avoidance scenarios, where accurate distance estimation is paramount.

Fig. 4 displays the effective implementation of a warning system based on the calculated distances, which demonstrates the system's potential for seamless integration with an automated warning system. This integration is of the utmost importance for enhancing road safety because it enables the system to provide timely alerts and preventive measures to drivers, potentially preventing accidents and minimizing the effects of human error and distraction.

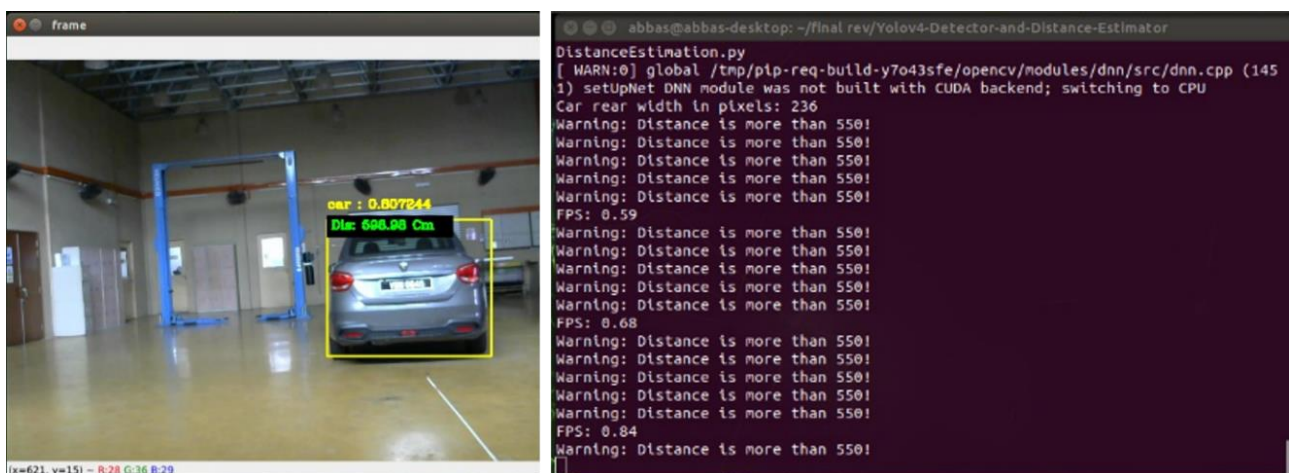


Fig. 4. Example of the warning system and alert

Comparing these results to previous research on monocular vision systems, some similarities and differences are observed. Both studies achieve high levels of accuracy in distance estimation, but our system consistently underestimates distances, while Chen's system tends to overestimate them. These variations can be attributed to differences in experimental setups, distance ranges, camera specifications, and calibration methods.

The study also highlights the impact of lighting conditions on system confidence. Surprisingly, the system exhibits higher confidence readings when lighting is off compared to well-lit conditions. This unexpected behavior suggests that factors beyond lighting, such as object reflectivity and algorithmic complexities, might influence confidence levels. Future research should investigate these factors and explore techniques to improve system reliability under varying lighting conditions.

A significant contribution to collision avoidance systems by highlighting the potential of monocular vision systems in achieving accurate distance estimation has been achieved. While particular challenges persist in different lighting conditions, and there are variations compared to previous research findings, the study firmly emphasizes the need for continued exploration of factors influencing system performance.

This study advances the collision avoidance systems field and enhances road safety. The demonstrated accuracy and reliability of the system's distance estimation capabilities have the potential to reduce the risk of accidents significantly, particularly in scenarios involving rear-end collisions. These findings underscore the system's real-world applicability and its potential to make our roadways safer for all.

4. Conclusions

In conclusion, the study's findings validate the collision avoidance system's accuracy in distance estimation and its potential for real-world applications, especially in automated warning systems. These findings contribute to advancing road safety technology and promise to reduce accidents and enhance traffic safety.

The insights gained from this research provide a solid foundation for future endeavors in collision avoidance systems and road safety technology. These findings open various avenues for further research and development, enabling us to improve these systems effectively and address their limitations. Future efforts can focus on optimizing the system's performance within specific distance ranges, capitalizing on the observed accuracy within certain proximity limits. This optimization could involve fine-tuning the algorithm or employing specialized techniques to enhance distance estimation in critical situations.

Additionally, investigating the underlying causes of unexpected behavior, such as decreased confidence levels when lights are turned on, is crucial for system refinement. Understanding these factors can lead to adjustments or enhancements that ensure consistent and reliable system performance under various lighting conditions. Exploring potential enhancements to mitigate the inherent limitations of monocular vision systems is another avenue for improvement. This could involve incorporating additional sensors or developing algorithms that compensate for depth perception challenges associated with single-camera setups.

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References

- [1] World Health Organization. World Health Organization. *Global status report on road safety 2018*. World Health Organization, 2018.
- [2] Phillips, Derek J., Juan Carlos Aragon, Anjali Roychowdhury, Regina Madigan, Sunil Chintakindi, and Mykel J. Kochenderfer. "Real-time prediction of automotive collision risk from monocular video." *arXiv preprint arXiv:1902.01293* (2019).
- [3] Saleh, Shadi, Sinan A. Khwandah, A. Heller, A. Mumtaz, and Wolfram Hardt. "Traffic signs recognition and distance estimation using a monocular camera." In *6th International Conference Actual Problems of System and Software Engineering.[online] Moscow: IEEE*, pp. 407-418. 2019.
- [4] Saleh, Hadi, Shadi Saleh, Nathan Teyou Toure, and Wolfram Hardt. "Robust Collision Warning System based on Multi Objects Distance Estimation." In *2021 IEEE Concurrent Processes Architectures and Embedded Systems Virtual Conference (COPA)*, pp. 1-6. IEEE, 2021. <https://doi.org/10.1109/COPA51043.2021.9541452>
- [5] Halimi, Siti Nur Atiqah, Mohd Azizi Abdul Rahman, Mohd Hatta Mohammed Ariff, Nurulakmar Abu Husain, Wira Jazair Yahya, Khairil Anwar Abu Kassim, Mohd Azman Abas, and Syed Zaini Putra Syed Yusoff. "Monocular Distance Estimation-based Approach using Deep Artificial Neural Network." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 32, no. 1 (2023): 107-119. <https://doi.org/10.37934/araset.32.1.107119>
- [6] Lin, Huei-Yung, Jyun-Min Dai, Lu-Ting Wu, and Li-Qi Chen. "A vision-based driver assistance system with forward collision and overtaking detection." *Sensors* 20, no. 18 (2020): 5139. <https://doi.org/10.3390/s20185139>
- [7] Halimi, Siti Nur Atiqah, Susijanto Tri Rasmana, Dimas Adiputra, Wira Jazair Yahya, Mohd Azizi Abdul Rahman, Mohd Hatta Mohammed Ariff, Nurulakmar Abu Husain, and Khairil Anwar Abu Kassim. "A review of safety test methods for new car assessment program in Southeast Asian countries." *Open Engineering* 13, no. 1 (2023): 20220501. <https://doi.org/10.1515/eng-2022-0501>
- [8] Moe, Signe, Kristin Y. Pettersen, and Jan Tommy Gravdahl. "Set-based collision avoidance applications to robotic systems." *Mechatronics* 69 (2020): 102399. <https://doi.org/10.1016/j.mechatronics.2020.102399>