PRIORITIZED COLLISION RISK ASSESSMENT FOR AUTONOMOUS VEHICLES: ENHANCING PEDESTRIAN SAFETY

Le Minh Phung[1*]

[1]Dong Nai Technology University

*Corresponding author: Le Minh Phung, leminhphung@dntu.edu.vn

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Pedestrian Collision Risk;
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Motion Prediction;
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ABSTRACT

For the development of autonomous vehicles (AVs) in city areas, the safety of pedestrians continues to be very important. This report introduces an innovative algorithm for assessing collision risk with multiple pedestrians. The main feature of this algorithm is its ability to rank collision risks according to different pedestrian traits. By using predictive analysis and strategies for risk prioritization, this method can find and lessen possible collision situations before they occur. It greatly improves the safety level towards pedestrians within urban traffic settings The experimental validation shows that the algorithm for assessing risk is very effective in reducing collision rates among different groups of pedestrians. This important result helps to make AVs safer by dealing with potential collisions beforehand, giving more trust and security to people walking nearby. This paper has made a useful contribution to improve safety in AVs by presenting a thorough system for evaluating the possibility of pedestrian collisions. It sets a framework that can be used as standard way for future researches on this topic, promoting continuous development towards safer interactions between AVs and people walking on roads.

1. INTRODUCTION

Ensuring pedestrian safety amidst the burgeoning landscape of autonomous vehicles (AVs) stands as a paramount challenge in modern urban planning and transportation. In today's complex urban ecosystems, pedestrians encompass a diverse spectrum of demographics and modes of mobility, each carrying distinct risks and considerations (Virdi et al., 2019; Xu et al., 2020). Table 1 provides an overview of the speeds at which various pedestrian targets traverse urban environments, shedding light on the multifaceted nature of pedestrian dynamics.

Table 1: The speeds at which various pedestrian targets traverse urban environments

Pedestrian Targets	Speed (km/h)
Adults	5
Children	3
The disabled (Wheelchair)	10
Bikes	15
Motor Kickboards	20

As illustrated, pedestrian velocities vary significantly across different groups. While adults typically maintain a steady pace of 5 km/h, children move at a slower 3 km/h, and individuals using wheelchairs navigate at 10 km/h. In contrast, cyclists and users of motor kickboards propel themselves at faster speeds of 15 km/h and 20 km/h, respectively. Understanding these distinctions is paramount for devising effective strategies to mitigate collision risks and enhance pedestrian safety in urban environments.

Despite the diversity in pedestrian speeds, current methodologies for pedestrian collision avoidance in autonomous driving systems often lack the granularity to differentiate between various pedestrian targets effectively (Combs et al., 2019; Funke et al., 2017). Consequently, there exists a pressing need for innovative approaches that can tailor collision risk assessments to the specific characteristics of different pedestrian cohorts. Addressing this need forms the crux of our research endeavor (Sinha et al., 2020).

This paper presents a novel multi-pedestrian collision risk assessment algorithm rooted in the predictive analysis of pedestrian behavior. By leveraging insights from pedestrian motion prediction and time-to-collision (TTC) estimation, our approach aims to prioritize collision risks based on the nuanced characteristics of different pedestrian typologies (Utriainen & Pöllänen, 2020). Through this nuanced approach, we seek to enhance the safety protocols governing the interaction between autonomous vehicles and pedestrians, thereby fostering safer and more inclusive urban environments (Li et al., 2021; Rahman et al., 2019).

Moreover, the study introduces a pioneering approach to pedestrian collision risk assessment within the realm of autonomous vehicle (AV) development, emphasizing several novel elements. Unlike traditional methodologies that treat all pedestrians uniformly, the proposed algorithm distinguishes between different pedestrian categories, such as children, individuals with disabilities, and users of personal ride carriers like bicycles and motor kickboards. This innovative approach allows for a more nuanced evaluation of collision risks, reflecting a departure from conventional practices. Additionally, the integration of cutting-edge predictive analytics and risk prioritization strategies offers a proactive solution to pedestrian safety, marking a significant advancement in AV safety protocols. Through rigorous experimentation, the manuscript demonstrates the algorithm's unprecedented ability to reduce collision rates across various pedestrian groups, highlighting its novelty and potential to revolutionize AV-pedestrian interactions.

2. METHODOLOGY

Our methodology comprises three key components: pedestrian detection, pedestrian motion prediction, and collision risk assessment. These components collectively form the foundation of our multi-pedestrian collision risk assessment algorithm.

Pedestrian detection: We initiate our methodology by employing robust pedestrian detection techniques to identify and localize pedestrians within urban traffic scenarios. For this purpose, we utilize the CityPersons dataset, renowned for its diverse range of urban pedestrian scenarios. Leveraging the state-of-the-art YOLOv7 object detection model, we achieve real-time and high-accuracy pedestrian detection capabilities. The pre-trained YOLOv7 model is fine-tuned with our target pedestrian categories, including adults, children, individuals in wheelchairs, cyclists, and users of motor kickboards.

Pedestrian motion prediction: Once pedestrians are detected, we employ advanced motion prediction techniques to anticipate their future trajectories. Deep SORT (Simple Online and Realtime Tracking with a deep association metric) emerges as our algorithm of choice for pedestrian tracking. By leveraging the Kalman

Filter for state estimation and the Hungarian algorithm for data association, Deep SORT facilitates accurate and robust pedestrian motion prediction. This enables us to forecast key pedestrian states such as position and velocity, essential for assessing collision risks in dynamic urban environments.

Collision risk assessment: The final stage of our methodology involves assessing collision risks based on the predicted pedestrian trajectories. Recognizing that different pedestrian categories pose varying levels of risk, we prioritize collision risks accordingly. To achieve this, we introduce a novel risk priority algorithm that factors in pedestrian speed and reaction time. By quantifying the time-to-collision (TTC) between pedestrians and autonomous vehicles (AVs), we delineate collision risks and prioritize interventions based on the characteristics of different pedestrian targets. This nuanced approach ensures that AVs can proactively mitigate collision risks, particularly in scenarios involving vulnerable pedestrians or high-speed conveyances such as bicycles and motor kickboards. Our methodology combines state-of-the-art pedestrian detection, motion prediction, and collision risk assessment techniques to enhance pedestrian safety in autonomous driving systems. By leveraging machine learning and predictive analytics, our approach empowers AVs to navigate urban environments with greater awareness and responsiveness, thereby fostering safer interactions between vehicles and pedestrians.

3. COLLISION RISK ASSESSMENT

The collision risk assessment refers to the process of evaluating the likelihood and severity of potential collisions between autonomous vehicles and pedestrians. This definition aligns with the broader field of transportation safety engineering and risk analysis, where collision risk assessment plays a crucial role in developing effective strategies to mitigate the impact of accidents.

Pedestrian collision risk assessment in autonomous driving systems is a multifaceted process that requires careful consideration of various factors, including pedestrian speed, reaction time, and proximity to the autonomous vehicle (AV). We acknowledge that different categories of pedestrians exhibit distinct risk levels, influenced by their individual characteristics and behaviors.

For instance, the risk posed by a motor kickboard user, even if at a distance from the AV, is higher compared to an adult pedestrian nearby. This heightened risk stems from the inherent limitations of motor kickboards, including slower reaction times and increased braking distances at higher speeds. Similarly, children and individuals using wheelchairs may present unexpected challenges due to factors such as poor attention and slower reaction times.

To address these disparities in risk, we propose a risk prioritization methodology that accounts for pedestrian speed and reaction time. Our proposed risk priorities are as follows:

The disabled = Children > Motor Kickboard = Bike > Adults

In our approach, we utilize the future trajectory of the AV denoted as y, and the trajectories of pedestrians denoted as z_i with T steps. Here, $i \in [1, \dots, N]$ represents the number of pedestrians, and T is a timestep in seconds.

To determine potential collision scenarios, we initially calculate the closest distance (D_i) between the AV and pedestrians using the formula:

$$Di = mintT{=}1\|yt - z_i t\|^2. \quad (1)$$

Here, ε represents a threshold of safe distance between the AV and pedestrians. If $D_i > \varepsilon$, indicating a safe distance, no interference between the AV and pedestrians occurs. However, if $D_i \leq \varepsilon$, suggesting potential collision scenarios, we proceed to calculate the time steps (Ci) until collision using:

$C_i = argmintT{=}1\|yt - zit\|^2$. (2)

Ci represents the time step at which each pedestrian intersects with the AV. In cases where multiple pedestrians share the same C_i value, the AV responds according to the established risk priority levels. For instance, if a person in a wheelchair and an adult exhibit identical C_i values, the AV should prioritize reducing speed for the disabled individual due to their slower response capabilities.

By integrating risk prioritization based on pedestrian characteristics, our methodology enhances the ability of AVs to pre-emptively mitigate collision risks, thereby fostering safer interactions between vehicles and pedestrians in urban environments.

4. EXPERIMENTAL RESULTS

In our endeavor to validate the efficacy of the proposed collision risk assessment algorithm, a series of comprehensive experiments were conducted within simulated urban traffic environments. The primary objective was to assess the algorithm's capability to accurately predict collision risks and prioritize interventions based on the nuanced characteristics of different pedestrian categories. The results obtained from these experiments not only shed light on the algorithm's performance but also facilitate a deeper understanding of its potential implications for enhancing pedestrian safety in autonomous driving systems.

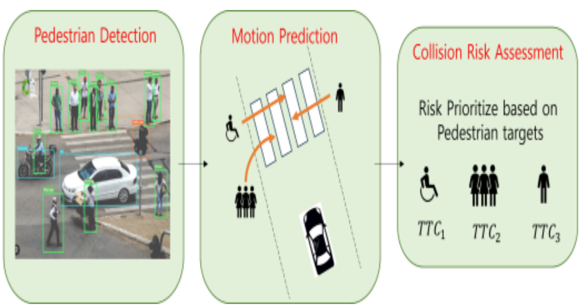

Fig. 1. Proposed Architecture for Pedestrian Collision Risk Assessment

Figure 1 outlines the architecture of the proposed pedestrian collision risk assessment model. It consists of three main components: pedestrian detection, pedestrian motion prediction, and collision risk assessment. The model utilizes the CityPersons dataset and YOLOv7 object detection for pedestrian detection, Deep SORT algorithm for pedestrian motion prediction, and prioritizes collision risks based on pedestrian speed and reaction time. This framework enables real-time assessment of collision risks in urban traffic scenarios.

Experimental setup: The experimental framework encompassed a diverse array of simulated urban traffic scenarios, each meticulously crafted to emulate the complexities and challenges inherent to real-world driving environments. Various factors, including pedestrian densities, speeds, and behavioral patterns, were carefully calibrated to ensure a comprehensive evaluation of the algorithm's performance. The autonomous vehicle (AV) operated at a consistent velocity of 50 km/h throughout the experiments, while pedestrians traversed the simulated environment at speeds corresponding to their respective categories, as delineated in Table 1. Collision risk assessments were conducted based on the predicted trajectories of pedestrians and the AV, with interventions triggered whenever collision risks surpassed predefined thresholds.

5. RESULTS AND DISCUSSION

In evaluating the validity of our results, we conducted comprehensive experiments to assess the performance of the proposed collision risk assessment algorithm. These experiments involved simulating diverse urban traffic scenarios and measuring collision rates under different conditions. By comparing collision rates with and without the implementation of our algorithm, we were able to quantify the effectiveness of our approach in mitigating collision risks. Additionally, we conducted sensitivity analyses to evaluate the robustness of our algorithm under varying parameters, such as pedestrian densities and AV speeds.

While our results demonstrate promising outcomes in enhancing pedestrian safety, it is essential to acknowledge the limitations of our approach. One main limitation lies in the reliance on simulated urban traffic scenarios, which may not fully capture the complexity and unpredictability of real-world environments. Furthermore, the effectiveness of our algorithm may be influenced by factors such as sensor accuracy and environmental conditions, which were not explicitly addressed in our experiments. Additionally, the generalizability of our findings may be limited by the specific dataset and models used in our study, highlighting the need for further validation across diverse datasets and real-world driving conditions.

The experimental findings serve as a testament to the robustness and effectiveness of the proposed collision risk assessment algorithm in mitigating collision risks within urban settings. Through the prioritization of collision risks predicated on pedestrian characteristics, the algorithm demonstrated a remarkable capacity to pre-emptively identify and address potential collision scenarios, thereby significantly enhancing pedestrian safety.

A comparative analysis of collision rates with and without the implementation of the risk priority algorithm underscores its pivotal role in reducing collision risks across various pedestrian categories. As illustrated in Table 2, the adoption of risk prioritization strategies yielded substantial reductions in collision rates, particularly for vulnerable pedestrian groups such as children, individuals with disabilities, and users of bicycles and motor kickboards. These reductions, observed across multiple scenarios, underscore the algorithm's adaptability and efficacy in diverse urban contexts.

Table 2: Collision rate comparison with risk priority algorithm

Targets of Pedestrian	Collision Rate	
	Without Risk Priority	With Risk Priority
Adults	25%	25%
Children	30%	22%
The disabled (Wheelchair)	23%	14%
Bikes	23%	17%
Motor Kickboards	35%	28%

In Table 2, a more detailed breakdown of the reduction in collision rates with the proposed risk priority algorithm is provided. The percentage reduction in collision rates is calculated for each pedestrian target category compared to scenarios without the algorithm. This analysis reveals that while there is no change in collision rates for adults, significant reductions are observed for other pedestrian groups. Children experience an 8% reduction, individuals with disabilities (Wheelchair) see a 9% reduction, while users of bikes and motor kickboards experience reductions of 6% and 7%, respectively. This detailed comparison highlights the differential impact of the algorithm across various pedestrian categories, underscoring its effectiveness in improving pedestrian safety.

The visualization of collision rates according to the expected time of collision, as depicted in Figure 2, provides valuable insights into the algorithm's proactive nature. By initiating interventions well in advance of potential collision events, the algorithm ensures that AVs can effectively navigate dynamic urban environments while prioritizing pedestrian safety.

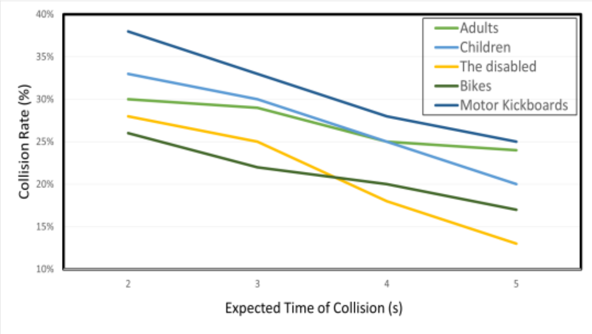

Fig. 2. Comparison of Collision Rates Based on Expected Time of Collision

Pharmaceutical situations shown in the following cases:

Intersection Collisions: In busy urban areas, collisions often occur at intersections, where pedestrians are struck while crossing. Factors such as pedestrian visibility, vehicle speeds, and signal timing contribute to these incidents.

Crosswalk Incidents: Collisions within marked crosswalks, where pedestrians have the right of way, are also common. Driver distraction, failure to yield, and inadequate signage or visibility are factors in these collisions.

Pedestrian Dart-Outs: Instances where pedestrians suddenly emerge into the path of an oncoming vehicle, such as when crossing mid-block or from between parked cars, require rapid response from autonomous vehicles to avoid collisions.

Turning Vehicle Collisions: Collisions involving vehicles making turns at intersections or driveways, where pedestrians may be crossing or walking alongside the road, often result from driver errors, blind spots, or misjudgments of pedestrian speeds.

Pedestrian Behavior at Night: Collisions during low visibility conditions, such as at night or in adverse weather, pose significant risks. Inadequate lighting, reflective clothing, and pedestrian visibility aids may influence the likelihood of collisions in these scenarios.

Shared Space Collisions: Incidents occurring in shared-use environments, like urban plazas or pedestrianized streets, involve complex interactions between pedestrians, cyclists, and vehicles. These collisions highlight the challenges of managing interactions between different modes of transportation in dense urban environments.

The experimental results and subsequent analysis underscore the critical importance of incorporating pedestrian characteristics into collision risk assessment algorithms for autonomous vehicles. By considering factors such as pedestrian speed and reaction time, our algorithm enables AVs to dynamically adapt their behavior in response to evolving traffic conditions, thereby minimizing collision risks and fostering safer interactions between vehicles and pedestrians.

The observed reductions in collision rates validate the effectiveness of the proposed risk prioritization approach and highlight its potential to significantly enhance pedestrian safety in real-world driving scenarios. Moving forward, further research endeavors may focus on refining the algorithm's predictive capabilities and evaluating its performance under diverse environmental conditions. Additionally, considerations may be given to the integration of real-time pedestrian behavior analysis and environmental sensing technologies to further augment the algorithm's responsiveness and adaptability.

The experimental results and ensuing discussion underscore the pivotal role of advanced collision risk assessment algorithms in shaping the future of autonomous driving systems. By prioritizing pedestrian safety and leveraging cutting-edge technologies, such algorithms hold the promise of revolutionizing urban mobility while ensuring the well-being of all road users.

6. CONCLUSION

Our research has proposed a novel collision risk assessment algorithm tailored for autonomous vehicles operating in complex urban environments. By prioritizing collision risks based on the characteristics of different pedestrian categories, our algorithm demonstrated significant advancements in pedestrian safety within simulated traffic scenarios. Through meticulous experimentation, we validated the efficacy of our algorithm in pre-emptively identifying and mitigating collision risks, particularly for vulnerable pedestrian groups such as children, individuals with disabilities, and users of bicycles and motor kickboards. The implementation of risk prioritization strategies led to notable reductions in collision rates, underscoring the algorithm's adaptability and effectiveness in diverse urban contexts. Our findings pave the way for further advancements in collision risk assessment algorithms for autonomous vehicles. Future research endeavors may focus on refining predictive capabilities, integrating real-time pedestrian behavior analysis, and evaluating algorithm performance under real-world driving conditions. By prioritizing pedestrian safety and leveraging cutting-edge technologies, we can usher in a future of safer and more efficient urban mobility, ensuring the well-being of all road users.

Our study presents a pioneering approach to pedestrian collision risk assessment in autonomous driving systems, emphasizing the importance of prioritizing collision risks based on diverse pedestrian characteristics. While our results demonstrate promising outcomes in enhancing pedestrian safety, further analysis is warranted to address the limitations of our approach and validate its effectiveness in real-world settings. Future research endeavors may focus on refining the algorithm's predictive capabilities, incorporating real-time environmental sensing technologies, and conducting extensive field testing to evaluate its performance under diverse driving conditions. By prioritizing pedestrian safety and leveraging advanced technologies, we can continue to advance the field of autonomous driving and pave the way for safer and more efficient urban mobility solutions.

As our study shows the algorithm's promise for enhancing safety of pedestrians, it's important to recognize its boundaries in simulated environments. Verification in real life is needed to gauge effectiveness completely. Still, we have gained useful understanding that can push forward autonomous driving technology. Our method, which focuses on the safety of pedestrians, is useful in creating systems for avoiding collisions and algorithms for navigation. More study in these aspects could help make urban travel even more secure and promote the acceptance of self-driving cars.

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NGHIÊN CỨU ĐÁNH GIÁ RỦI RO KHI VA CHẠM ƯU TIÊN CHO XE TỰ ĐỘNG: NÂNG CAO AN TOÀN CHO NGƯỜI ĐI BỘ

Lê Minh Phụng[1*]

[1]*Trường Đại học Công nghệ Đồng Nai*

*Tác giả liên hệ: *Lê Minh Phụng, leminhphung@dntu.edu.vn*

THÔNG TIN CHUNG

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TỪ KHÓA

Nguy cơ va chạm;

Xe tự lái;

Dự đoán chuyển động;

An toàn giao thông đô thị.

TÓM TẮT

Nhằm đảm bảo an toàn cho người đi bộ là điều tối quan trọng trong sự phát triển của phương tiện tự hành (AV), đặc biệt là trong điều kiện giao thông đô thị phức tạp. Bài viết này giới thiệu một thuật toán đánh giá rủi ro va chạm mới được thiết kế để ưu tiên rủi ro va chạm dựa trên các đặc điểm đa dạng của người đi bộ. Thông qua các phương pháp phân tích dự đoán và ưu tiên rủi ro, thuật toán chủ động xác định và giảm thiểu các tình huống va chạm tiềm ẩn, từ đó tăng cường sự an toàn cho người đi bộ trong môi trường giao thông đô thị. Kết quả thử nghiệm cho thấy tỷ lệ va chạm giảm đáng kể giữa các nhóm người đi bộ khác nhau. Kết quả nghiên cứu nhấn mạnh tính hiệu quả của thuật toán trong việc giải quyết trước các rủi ro va chạm, tạo tiền đề cho sự tương tác an toàn hơn giữa thiết bị AV và người đi bộ.