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AI-Powered Smart Bike Light: Enhancing Cyclist Safety Through Real-Time Hazard Detection and Alerts

Arnav Purbiya[1], Tony Smoragiewicz[#] and Ted Shinta[#]

[1]Monta Vista High School, USA
[#]Advisor

ABSTRACT

Cyclist safety is a growing concern as accidents due to limited visibility and inadequate real-time hazard detection persist. This study introduces an AI-powered smart bike light that enhances hazard detection and improves road safety for cyclists with the help of increased visibility to drivers. Built using a Raspberry Pi, TensorFlow for machine learning, and a Pi Camera, the system detects hazards—such as vehicles and pedestrians—up to 220 feet away. Alerts are provided to the cyclist with the help of a RGB strip and buzzer on the handlebar and surrounding drivers via a multicolor RGB matrix and audible buzzers. Field tests were conducted with 3 different devices: using the smart bike light, a regular bike light, and no light. When comparing the distance at which a car stopped behind the bicyclist the smart light increased vehicle stopping distances from 4.3 to 7.5 feet ($p < 0.001$) and reduced passing speeds from 37 mph to 28 mph. These results demonstrate the system's potential to significantly enhance cyclist awareness and safety, reducing accidents. Future improvements should include performance testing in adverse weather conditions and low lighting to assess the robustness and reliability of the system.

Methods

The smart bike light system was designed with several key hardware and software components to achieve effective real-time hazard detection and alerting. The system used a Raspberry Pi 3 Model B as the primary computing unit, paired with a Pi Camera Module V2 (2). The camera was calibrated for a backward-facing view to monitor the rear blind spot of the cyclist. Additionally, an RGB LED matrix and a piezo buzzer were integrated to deliver visual and auditory alerts as seen in Figure 1, 2. The case was resin printed on the Formlabs Form 3 in clear resin; the two parts of the case are joined with screws, and an O-ring along with a tongue-and-groove style connector ensures waterproofing. Powering the unit is a lithium-ion battery, similar to those in phones, which can power the light for up to seven hours continuously.

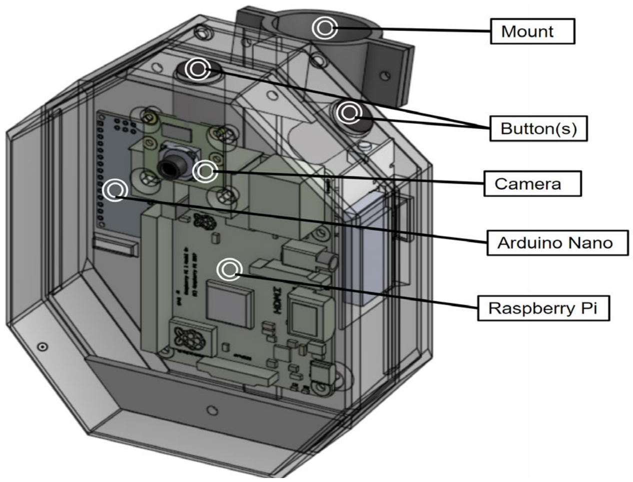

Figure 1. CAD (Computer Aided Design) preview of the Smart Bike Light

Field testing was conducted on various urban roads with a speed limit of 35 mph, which reflects typical cycling conditions in cities. The regular bike light used in all of the tests was a simple flashing LED based light purchased from Amazon (3). Tests showcased in Figure 3, 4 were done under the same weather condition at the same time of day with the cyclist wearing the same outfit for each test. Whereas the passing speed test 2 showcased in Figure 5 was done during the dusk time 5:45 - 6:30. Each of the three test conditions (smart bike light, regular bike light, and no light) was tested over five tests. Each of the 5 tests consisted of data points from 30 vehicles. The system's camera recorded video data at a resolution of 640x480 pixels, processed in real-time at 10 frames per second (FPS).

Figure 2. Smart Bike Light with red lights mounted to the bike.

Statistical analysis was critical to ensure the validity of the results. The data for stopping distances and passing speeds were recorded using a laser rangefinder mounted beneath the bike light system. ANOVA (Analysis of Variance) was employed to compare the different conditions. A p-value threshold of 0.05 was used to determine statistical significance, indicating that differences observed in the data were highly unlikely to occur by random chance. Post-hoc analyses were conducted to compare the individual performance of the smart light against both the normal light and no light conditions.

The object detection model was trained using TensorFlow’s Object Detection library with a custom dataset with most of the photos collected while biking (4). The dataset consisted of road images labeled to identify vehicles, pedestrians, and other potential hazards, collected over various times of day to improve accuracy in different lighting conditions. The training was carried out with 1,500 images, and the model reached an accuracy rate of 92% in hazard detection during live testing.

Results

To evaluate the effectiveness of the smart bike light alerting system, two types of tests were conducted: 1) stopping distance tests and 2) passing speed tests. Each test was performed under three conditions: using the smart bike light, using a normal bike light, and using no bike light, resulting in a total of six permutations. Each permutation was tested five times, yielding a total of 30 data points. Each of the five tests consists of data collected from 30 cars. The primary objective was to compare vehicle stopping distances and passing speeds across these different conditions to assess the impact of the smart bike light on vehicle interactions with cyclists.

Vehicles stopped at significantly greater distances when the smart bike light was used compared to the normal bike light and no light in Figure 3. For example, in Test 3, vehicles had an average stopping distance of 7.5 feet with the smart bike light, whereas the average stopping distances were 6.2 feet with the normal bike light and 4.3 feet with no light. The smart bike light's flashing frequency of 1.42 - 1.62 hertz likely contributed to this increased stopping distance by enhancing driver awareness and reaction time (5).

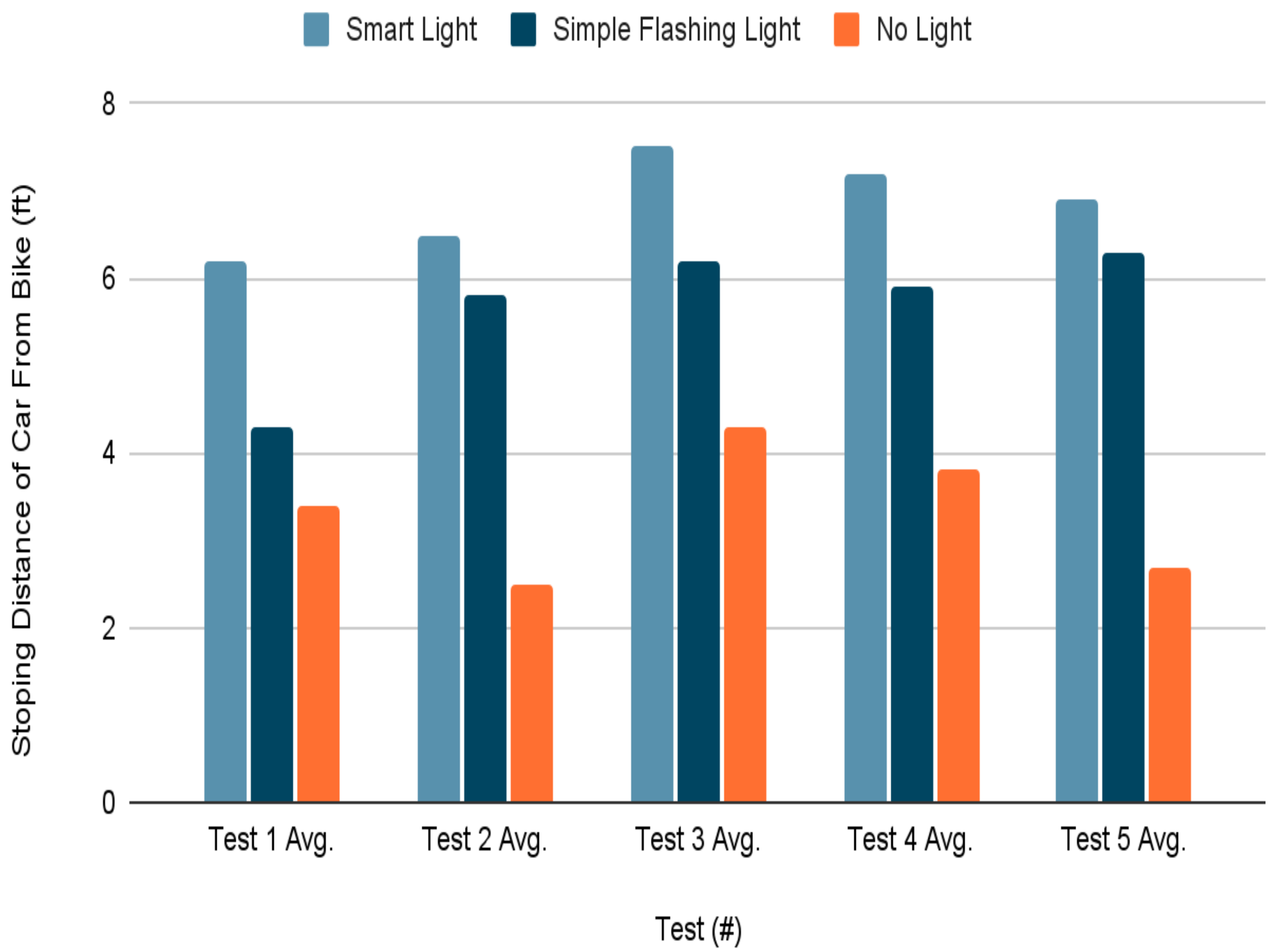

Figure 3. Comparison of Car's Stopping Distances with Different Bicycle Lights

The impact of the bike light on vehicle passing speeds was also assessed and charted in Figure 4. On a road with a 35 mph speed limit, vehicles passed at or above the speed limit when no bike light was used, with an average speed of 37 mph. However, when the smart bike light was used, the average passing speed of vehicles decreased to approximately 28 mph. The differences in passing speeds across the three conditions were statistically significant. This reduction demonstrates the smart bike light's effectiveness in encouraging drivers to slow down, thereby improving safety for cyclists.

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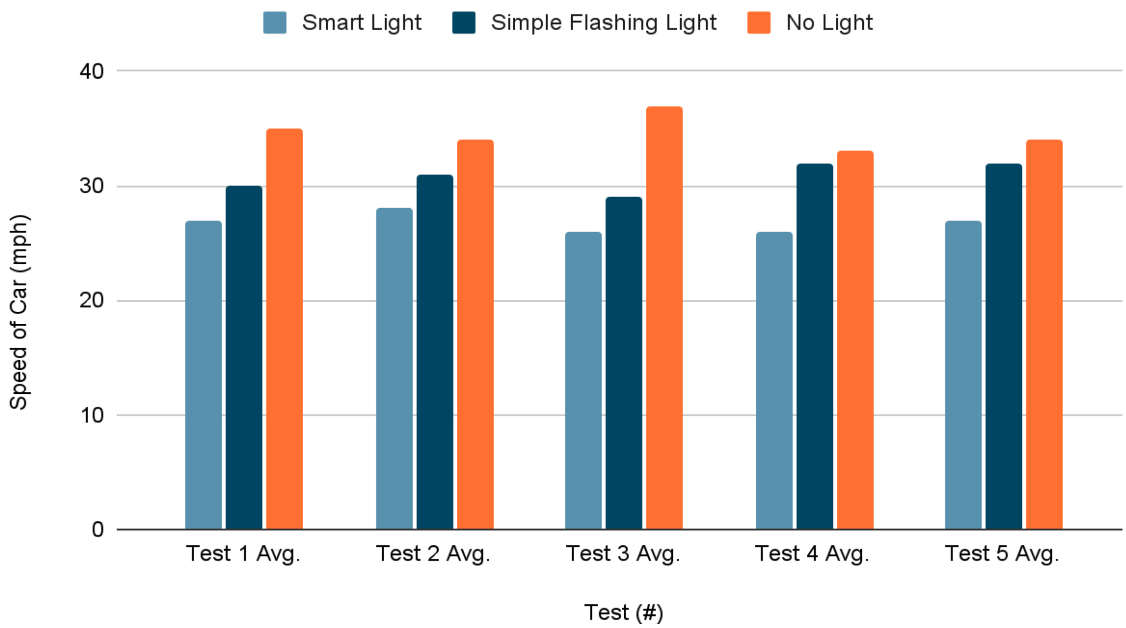

Figure 4. Comparison of Car's Passing Speed with Different Bicycle Lights during the day

When passing speed was tested during dusk from 5:45 pm to 6:30 pm, results showed that the AI-powered smart bike light significantly influenced driver behavior compared to a regular bike light or no light in Figure 5. Vehicles passing cyclists equipped with the smart light reduced their average speed to 28 mph, a marked improvement over speeds observed with traditional lighting. Unlike passive safety gear, such as mirrors, which only caution the cyclist if they notice approaching vehicles in time, the smart bike light proactively alerts both the cyclist and the driver to each other's presence. This dual alert system enhances safety by increasing visibility and awareness in real-time, particularly in low-visibility conditions, fulfilling the study's objective of leveraging AI-driven alerts to improve cyclist safety.

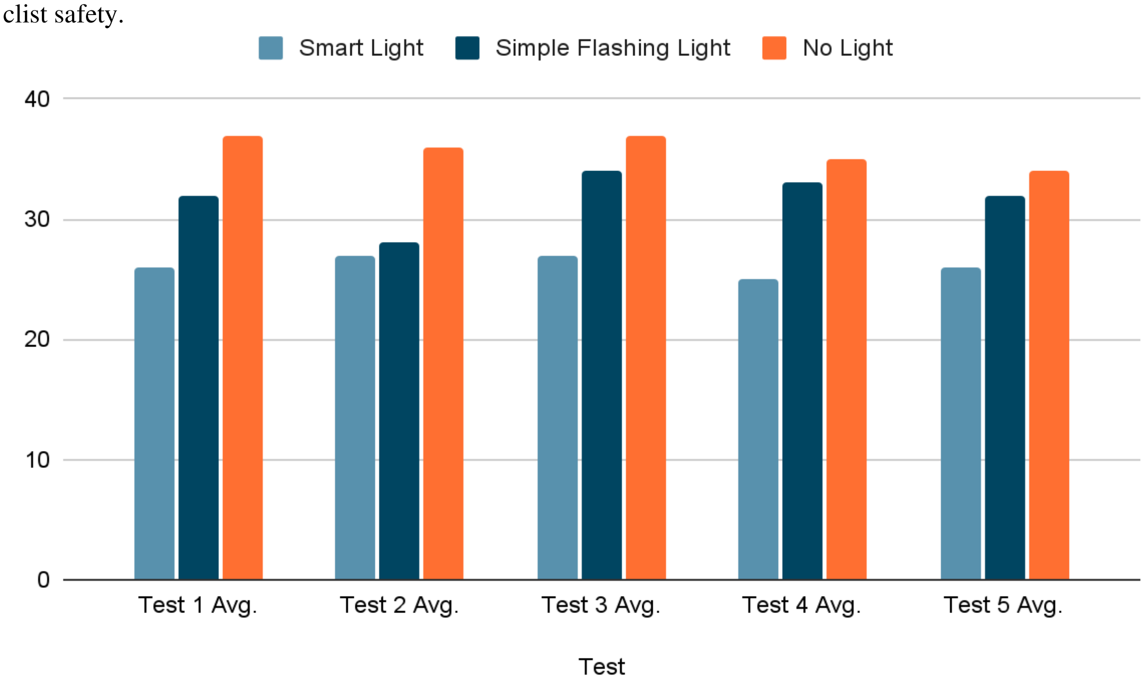

Figure 5. Comparison of Car's Passing Speed with Different Bicycle Lights during dusk

In summary, the smart bike light system significantly improved both vehicle stopping distances and passing speeds, thereby enhancing cyclist safety beyond what traditional passive safety gear can achieve. Unlike mirrors or other passive measures that rely on the cyclist's timely awareness of approaching vehicles, the smart bike light actively engages both cyclist and driver, alerting them to each other's presence. This dual-layered approach demonstrates the system's effectiveness in encouraging safer interactions between cyclists and drivers, even in challenging low-light conditions. These results underscore the smart bike light's potential as an advanced solution to reduce accident risk and improve road safety for urban cyclists.

Discussion

The results of this study support the hypothesis that an AI-powered smart bike light can significantly enhance cyclist safety by increasing bikers' visibility to drivers and providing warnings to cyclists when a car is driving behind them. The observed increase in vehicle stopping distances and the reduction in passing speeds suggest that the system's alerts were successful in prompting drivers to react earlier, thereby reducing the risk of collisions. Unlike radar-based systems like the Garmin Varia, the AI-powered system offers a more comprehensive solution. However, there are limitations to the study, including its reliance on specific environmental conditions. Testing was conducted in fair weather, and it remains unclear how the system would perform in adverse conditions such as rain, fog, or extreme heat. Additionally, further testing is needed to assess long-term durability and battery life under real-world conditions. Future studies should also focus on user feedback to improve ease of installation and overall usability. The rise of electric bikes presents a unique opportunity for integrating this system, as e-bikes often travel at speeds of around 25 mph, providing cyclists with approximately 15 seconds of reaction time to avoid hazards.

According to the Cleveland Clinic's safety tips on cycling at night, technology that provides real-time alerts to both cyclists and surrounding drivers is key to enhancing road safety, whether during day or night rides (6). Currently, radar-based systems provide up to 200 meters of rear view detection, attempting to fulfill this role. However, these devices are costly and, despite their reach, have limitations in effectively alerting drivers to the presence of cyclists in all conditions.

Unlike traditional directional indicators or brake-activated rear lights, which operate passively and do not detect whether a vehicle is approaching from behind, the smart bike light actively alerts both the cyclist and the driver, enhancing safety through mutual awareness. Because the camera system is rear-facing, it primarily detects vehicles approaching from behind; however, adjustments to the image library and code could enable the system to identify other types of hazards as well. This reliance on the smart light system should not reduce cyclist vigilance, as cyclists remain responsible for making safe riding decisions.

This study demonstrates that an AI-powered smart bike light can significantly enhance cyclist safety by improving hazard detection and reducing the risk of possible accidents as seen from tests conducted on passing speeds. The system's ability to increase vehicle stopping distances and reduce passing speeds provides compelling evidence of its effectiveness. By offering real-time alerts to both cyclists and drivers, the smart bike light presents a dual-layered approach to road safety. Although further testing is required to optimize the system for diverse weather conditions and longer-term use, the current results offer a promising foundation for the development of affordable, advanced safety solutions for urban cyclists.

Conclusion

The AI-powered smart bike light has demonstrated significant improvements in cyclist safety by effectively increasing vehicle stopping distances and reducing passing speeds. Unlike passive safety measures, this system proactively alerts both cyclists and drivers, enhancing mutual awareness and response times. While the study confirms the system's reliability under controlled conditions, future research must address performance in diverse weather conditions and refine long-term durability. With continued development, this smart bike light holds promising potential to become a standard safety feature for urban cyclists, offering an innovative and accessible solution to reduce road accidents.

Limitations

Despite its promising results, the study has certain limitations. Testing was conducted exclusively under fair weather conditions, leaving its performance in adverse environments, such as rain, fog, or extreme temperatures, unverified. Additionally, long-term durability and battery life were not extensively evaluated, which are crucial factors for practical deployment. These constraints highlight the need for extended field testing across diverse weather scenarios and longer durations to ensure consistent performance.

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