

The PathSync Intelligent Transparent Display Navigation System

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Abstract

The PathSync Intelligent Transparent Display Navigation System combines transparent display, AR/VR fusion, AI, and sensing technologies, surpassing traditional HUDs and early machine learning. It introduces Dynamic ROI and adaptive depth-of-field, adjusting navigation based on driver gaze, speed, and lane changes. Intelligent recognition and filtering improve lane detection accuracy and reduce distractions. Results show that PathSync reduces cognitive load, enhances navigation intuitiveness and safety, demonstrating key technological breakthroughs and application value.

Keywords

Transparent Display; AR/VR fusion; AI Navigation; Dynamic ROI; adaptive Depth of Field; PathSync.

1. Introduction

As autonomous driving technology advances, navigation systems evolve from traditional GPS-based positioning to augmented reality (AR) and advanced driver assistance systems (ADAS). However, existing technologies still face challenges in visual load, response delays, and integrating navigation information with real-world road scenes.

The PathSync Intelligent Transparent Display Navigation System (PathSync) combines transparent display technology, gaze tracking, multi-modal sensing, and artificial intelligence to address these issues (Figure 1).

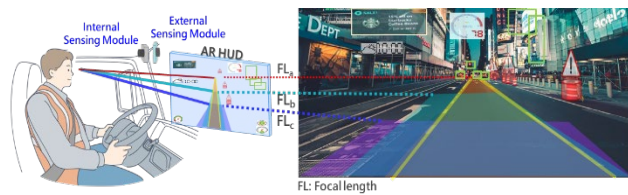


Figure 1. PathSync Intelligent Transparent Display Navigation System.

Traditional in-car navigation systems rely on GPS and pre-set maps for route guidance but cannot dynamically adjust navigation information based on the driver's gaze or driving context. This becomes particularly problematic in high-speed or complex scenarios, where frequent gaze shifts to view the screen increase cognitive load and distraction risks. Traditional HUDs and fixed AR navigation systems display information within fixed areas, requiring the driver to constantly focus on the display, thus increasing visual strain.

The PathSync overcomes these limitations by integrating transparent displays, AR virtual-real (AR/VR) fusion, AI, and multi-modal sensing technologies. It overlays navigation information directly onto real-world roads and surrounding objects. Using dynamic ROI and adaptive depth-of-field technologies, the system adjusts navigation content to the optimal field of view based on the driver's gaze, vehicle speed, and lane changes. Traditional lane recognition methods are improved through intelligent recognition and filtering strategies, reducing

the impact of distracting markings and text and enhancing lane detection accuracy. Additionally, the system dynamically adjusts display range and transparency according to driving speed and environmental conditions—extending the display range during high-speed driving and focusing on close-range turn indicators at lower speeds to reduce visual distractions and improve navigation intuitiveness.

2. Hardware and Software architecture

The PathSync system's hardware architecture includes a transparent display unit, internal and external cameras, a vehicle motion sensing module, and a high-performance AI processing unit. The transparent display panel features a projection film with $88\pm 5\%$ light transmittance, seamlessly integrating navigation arrows with real-world road scenes. It adaptively adjusts brightness based on ambient light, ensuring clear visibility under any lighting conditions. Internal sensors provide RGBD images to support FaceDetect and FacialFeature detection technologies, accurately tracking the driver's gaze direction and generating gaze-point data for dynamic navigation positioning. External sensors utilize multi-modal imaging to capture road features, including lane markings, traffic signs, pedestrians, and obstacles, maintaining stable data acquisition even in harsh weather or low-light conditions.

The software architecture (Figure 2) adopts a modular design, integrating image processing, AI inference, intelligent filtering, and dynamic ROI display control modules to enable real-time perception of the driving environment and dynamic adjustment of navigation information. The image processing module manages denoising, calibration, and enhancement to ensure high-quality input data. The AI inference module, powered by YOLOv7 (You Only Look Once Version 7), accurately detects road elements such as lane markings, traffic signs, lane boundaries, and obstacles, generating bounding box data. The intelligent filtering module refines recognition data by dynamically filtering out irrelevant objects (e.g., obstacles outside the driving lane) and optimizing navigation information based on object importance, reducing redundant data and focusing on presenting key details to the driver. The dynamic ROI module calculates the ROI range based on vehicle speed, lane changes, and driver gaze tracking, adjusting navigation display locations to ensure critical information stays within the optimal field of view. In high-speed scenarios, the system extends the navigation arrow range, while in low-speed situations, it focuses on turn indicators, providing precise navigation cues tailored to different driving contexts.

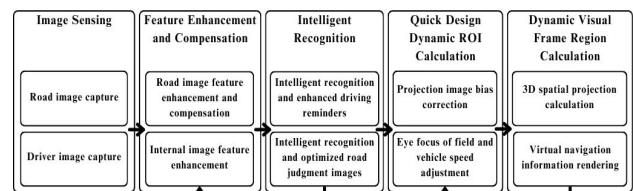


Figure 2. Software Architecture of the PathSync System.

3. Method

The overall architecture improves data processing efficiency through multi-threaded computation and intelligent filtering, ensuring the PathSync provides real-time, highly accurate, and low-interference navigation. Its core method integrates internal and external sensors with AI algorithms to enable real-time perception and processing of the driver's gaze behavior and the surrounding road environment, generating precise and dynamically adaptive navigation information.

3.1. Gaze Point Fusion and Analysis Method

The gaze tracking method integrates the driver's head posture and fixation point to accurately map the navigation data onto the transparent display device, ensuring that the information is correctly overlaid onto the road scene within the world coordinate system (Figure 3).

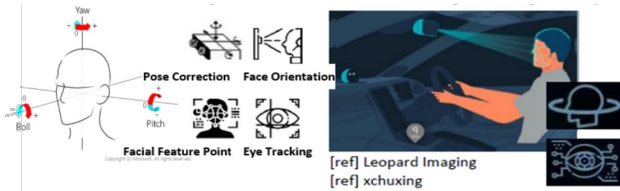


Figure 3. Active Visual Frame with Gaze Tracking.

The head rotation matrix R_h is first derived through the combination of Euler angles, as shown in Equation 1, to transform the gaze vector from the head coordinate system to the vehicle coordinate system.

$$R_h = R_x(\phi)R_y(\theta)R_z(\psi) \quad (1)$$

Where,

$$R_x(\phi) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & -\sin \phi \\ 0 & \sin \phi & \cos \phi \end{pmatrix} \quad (2)$$

$$R_y(\theta) = \begin{pmatrix} \cos \theta & 0 & \sin \theta \\ 0 & 1 & 0 \\ -\sin \theta & 0 & \cos \theta \end{pmatrix} \quad (3)$$

$$R_z(\psi) = \begin{pmatrix} \cos \psi & -\sin \psi & 0 \\ \sin \psi & \cos \psi & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (4)$$

ψ , θ , and ϕ represent head movements: ψ for yaw, θ for pitch, and ϕ for roll.

Based on the eye rotation angles (α, β), the eye's gaze direction vector G_e in the head coordinate system can be calculated as shown in Equation 5.

$$G_e = \begin{pmatrix} \cos \alpha \cos \beta \\ \sin \beta \\ \sin \alpha \cos \beta \end{pmatrix} \quad (5)$$

The gaze vector G_v in the vehicle coordinate system is obtained by combining the head rotation matrix R_h with the eye's gaze direction vector G_e , as described in Equation 6.

$$G_v = R_h \cdot G_e \quad (6)$$

Assuming the driver's gaze intersects a target plane at a fixed distance d (such as the in-vehicle display area or the road plane), the fixation point coordinates can be calculated by determining the intersection of the ray and the plane. The equation for the gaze ray is given by Equation 7, and the equation for the target plane is given by Equation 8.

$$P_g(t) = T_h + t \cdot G_v, t > 0 \quad (7)$$

$$n_x x + n_y y + n_z z + d_p = 0 \quad (8)$$

Where, $[n_x, n_y, n_z]$ represents the normal vector of the plane, and d_p is the offset of the plane from the origin. By substituting the ray equation into the plane equation, the intersection parameter t^* can be computed.

$$t^* = -\frac{n_x x_h + n_y y_h + n_z z_h + d_p}{n_x G_{vx} + n_y G_{vy} + n_z G_{vz} + d_p} \quad (9)$$

Calculate the gaze point coordinates P_G^*

$$P_G^* = T_h + t^* \cdot G_v \quad (10)$$

The gaze data is transmitted in real-time to the PathSync system's core module, using P_G^* as the reference for navigation display. This ensures that navigation arrows and information are clearly visible without obstructing the driver's view.

3.2. Object Detection and Feature Ablation Techniques

YOLOv7 is an efficient real-time object detection model based on convolutional neural networks (CNN), optimized for accuracy and speed, making it ideal for applications like autonomous driving and navigation systems requiring real-time processing. Compared to earlier versions, YOLOv7 introduces the Extended Layer Aggregation Network (ELAN) architecture, improving small object detection through multi-level feature fusion. Its dynamic label assignment technique further enhances accuracy in complex scenarios such as lane markings and traffic sign detection. YOLOv7 supports object detection, segmentation, and multi-object tracking. Its processing pipeline includes image preprocessing, feature extraction, bounding box generation, and non-maximum suppression (NMS), ensuring precise object classification and localization. Research shows YOLOv7 achieves a mean average precision (mAP) of 51.2% on the COCO dataset while maintaining speeds above 60 FPS, making it an ideal solution for efficient road object detection in the PathSync.



Figure 4. Test Batch Information of Recognition Model Training.

External cameras capture road environment images, which are processed using the YOLOv7 model for object detection and feature extraction, including lane markings, traffic signs, and potential obstacles. In this study, a dataset of 4,978 images across 7 categories is used, split into 85% for training, 10% for validation, and 5% for testing. Training parameters include 300 epochs, a batch size of 16, and 12 workers, resulting in a 20-hour training process and a best model file size of 73.1 MB. Performance indicators, such as loss function curves, precision, and recall, show stable convergence and good training results (Figure 5).

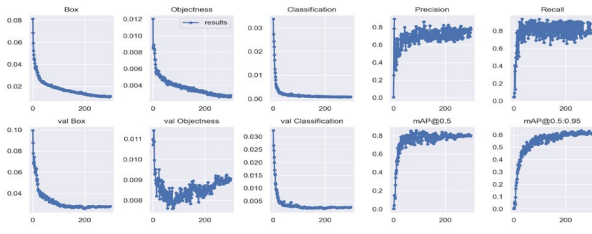


Figure 5. Feature Curves of Recognition Model Training.

Images captured by external cameras are first processed through an image processing module for geometric correction, noise filtering, and color enhancement, ensuring accuracy even in low-light conditions or when road markings are unclear. The left and right lanes are then separately enhanced to compensate for blurred or missing key data (Figure 6).

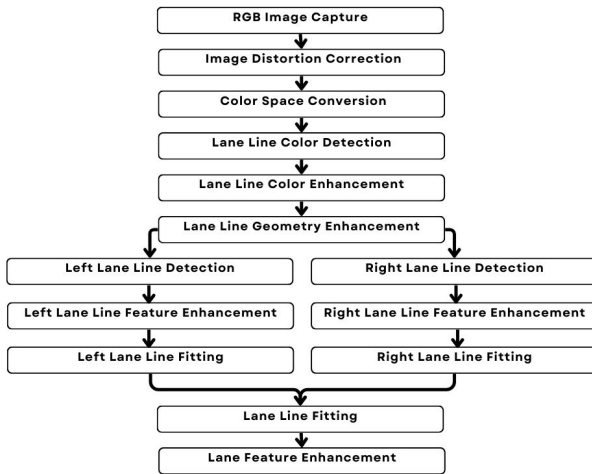


Figure 6. Framework of Lane Feature Enhancement.

After enhancing the road images, the AI inference module uses CNNs for deep analysis, identifying various road objects such as lane markings, traffic signs, and obstacles, with each object assigned bounding boxes, confidence scores, and coordinates. The intelligent filtering strategy filters out irrelevant objects that may interfere with lane detection, such as speed bump markings or unrelated road signs, significantly improving lane detection accuracy. This process dynamically adjusts recognition accuracy and range based on the evolving road scene, preventing misjudgments (Figure 7).

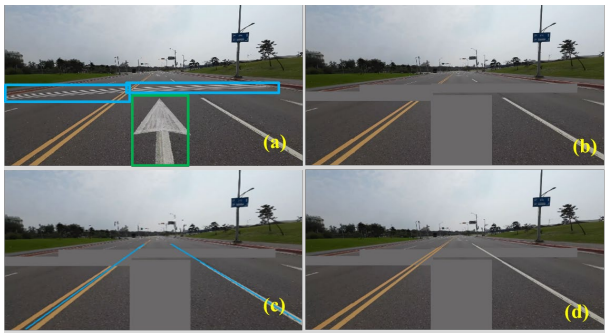


Figure 7. Intelligent Filtering Process (a) Object Detection, (b) Intelligent Filtering, (c) Feature Annotation, (d) Lane Feature Enhancement.

Additionally, the system provides virtual indicators or audio prompts to alert drivers to critical traffic information and

warnings (Figure 8).

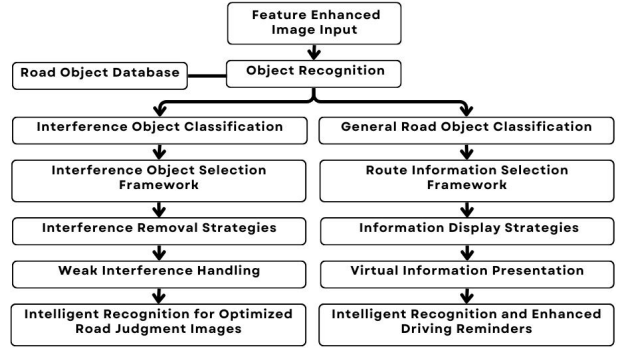


Figure 8. Lane Anti-Interference Recognition System.

The PathSync uses bidirectional imaging and sensing units for adaptive depth-of-field display, dynamically adjusting the ROI based on speed, vehicle dynamics, lane changes, and gaze direction (Figure 9). Compared to fixed ROI technologies, dynamic ROI offers greater flexibility, allowing precise adjustments of navigation information based on lane width, axial changes, and gaze direction (Figure 10). During high-speed driving, the navigation arrow range is extended, while in low-speed scenarios, it focuses on turn indicators to reduce unnecessary distractions.



Figure 9. Automatic Dynamic ROI Adjustment Based on Driving Conditions.



Figure 10. Comparison of Dynamic ROI and Fixed ROI.

Finally, the system dynamically generates navigation arrows and turn indicators, projecting them onto the transparent display using augmented reality technology. This ensures accurate spatial and depth alignment with the road scene, allowing drivers to intuitively follow navigation cues precisely aligned with actual lane markings (Figure 11).

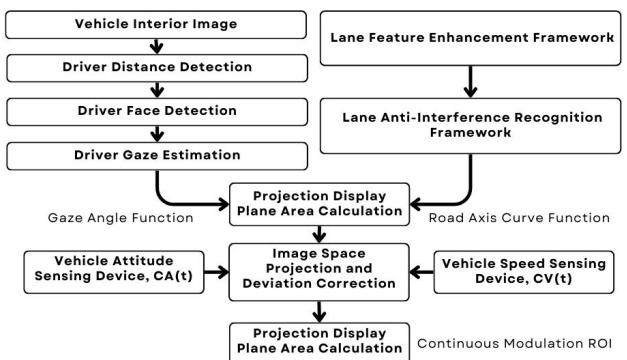


Figure 11. Framework of Active Visual Frame.

4. Result and discussion

Integrating advanced technologies, PathSync stands out in intelligent driver assistance systems. Its dynamic ROI and adaptive depth-of-field display adjust the position and transparency of navigation information based on vehicle speed, posture, lane characteristics, and driver gaze dynamics. For high-speed driving, the system extends navigation arrows for long-distance planning, while in low-speed scenarios, it focuses on nearby turn indicators, reducing distractions and improving clarity. The image processing module, combined with the YOLOv7 model, accurately detects road objects such as lane markings, traffic signs, and obstacles. Intelligent filtering excludes irrelevant objects (e.g., unrelated signs), significantly enhancing the relevance and accuracy of navigation data. Gaze fusion and depth mapping functions align navigation information with the driver's line of sight using head posture and eye vector calculations, reducing visual displacement and enhancing the driving experience. AR/VR Fusion technology seamlessly overlays navigation arrows and guidance onto a transparent display, precisely matching the real-world road scene for intuitive guidance and decision-making support (Figure 12).

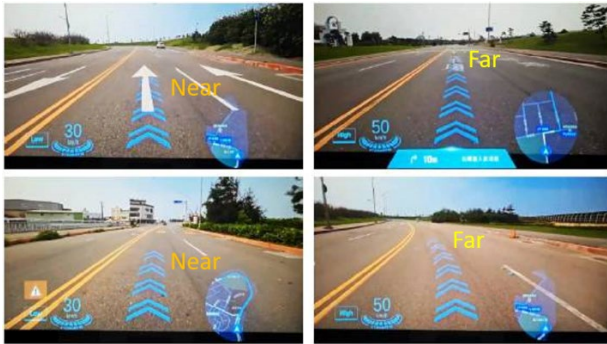


Figure 12. AR/VR Fusion Technology in PathSync Navigation System.

The PathSync technology is fully implemented and was showcased at Touch Taiwan 2024, demonstrating dynamic navigation capabilities. The system considers road curvature and driver field of view to generate virtual guiding arrows, using parallax and perspective effects to simulate spatial depth, enhancing display realism and accuracy. During simulated driving, the transparent screen displays critical real-time information, such as speed, route, and upcoming turns. Navigation arrows dynamically adjust to vehicle speed and road curvature, ensuring drivers receive accurate and timely guidance (Figure 13).



Figure 13. The PathSync at 2024 Touch Taiwan.

5. Conclusion

The PathSync overcomes the limitations of traditional systems by integrating transparent displays, AR/VR fusion, AI, and multi-modal sensing technologies. It innovatively overlays navigation information onto real-world roads and surrounding objects, creating a driver-centric assisted navigation system.

With dynamic ROI and adaptive depth-of-field technologies, the system adjusts navigation information to the optimal field of view based on the driver's gaze, vehicle speed, and lane changes. Traditional lane recognition methods are improved with intelligent recognition and filtering strategies, reducing the impact of distracting markings and enhancing lane detection accuracy and relevance, thereby optimizing navigation data. The system dynamically adjusts the display range and transparency based on driving speed and environmental conditions, expanding the display range at high speeds and focusing on close-range turn indicators at low speeds, reducing visual distractions and enhancing navigation intuitiveness.

Overall, PathSync integrates AR/VR fusion, AI, and dynamic navigation adjustment technologies, bringing significant technological breakthroughs to autonomous driving. Its vast application potential has a profound impact on the development of Intelligent Transportation Systems (ITS) and ADAS, providing strong technical support for a safer and more intuitive autonomous driving experience in the future.

6. References

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