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**Seat Belt Detection Using Fast and High-Performance Template Matching**

**1. Introduction**

Ensuring seat belt usage is critical for road safety, as wearing a seat belt significantly reduces the risk of fatal injuries in traffic accidents. Current enforcement methods rely heavily on manual monitoring, which is labour-intensive and inefficient. We have investigated seat belt detection employing Genetic Algorithm (GA)-based template matching with enhanced detection performance compared to classical edge-based methods. Nevertheless, GA-based techniques are computationally intensive and call for heavy optimization.

This project extends their work by incorporating rapid and high-speed template matching methods that take advantage of **Inverted Location Index (ILI) and HOG-based binary coding** to enhance speed and robustness, lowering computational complexity while retaining high detection accuracy. Existing enforcement approaches are mostly based on manual supervision, which is inefficient and time-consuming. This project will create an automated seat belt detection system based on template matching with improved search strategies to enable the detection process to be quick, robust, and scalable.

**2. Objectives**

* Create a real-time seat belt detection system based on template matching.
* Improve the efficiency and accuracy of seat belt detection with histogram-based transformations and robust similarity measures.
* Employ Inverted Location Index (ILI) to enhance template matching speed.
* Compare with conventional edge-based and learning-based approaches.

**3. Methodology**

**3.1. Dataset Collection and Preprocessing**

* The dataset consists of images taken from car dashboards centered on the driver's seat belt area.
* The YOLOv3 model is employed for preliminary car detection and localization of the driver's region of interest (ROI).
* Preprocessing involves conversion to grayscale, histogram equalization, and adaptive thresholding for improving contrast between seat belts and attire.

**3.2. Template Matching using Fast Binary Encoding**

* The method converts the image and template into binary codes based on **Histograms of Oriented Gradients (HOG)**.
* The system does not use conventional pixel-wise intensity matching but encodes a pixel neighborhood into a binary code through **projection and quantization**.
* **Hamming distance** is utilized for similarity computation, thus the method is very efficient.

**3.3. Robust Similarity Measure and Inverted Location Index (ILI)**

* Rather than traditional **Lp-distance or NCC similarity**, the method utilizes a **robust similarity measure** that eliminates outliers.
* **ILI structure** is employed for fast similarity computation by treating pixel locations according to their values instead of their spatial locations.
* This enhances computational efficiency, especially for **non-rectangular templates and sparse image locations**.

**3.4. Optimization and Speed Improvements**

* The approach utilizes **bounded M-estimators** for enhanced robustness against occlusions and noise.
* The **binary encoding using HOG** reduces the computational burden when compared to conventional methods.
* The **ILI-based method** provides efficient template matching that is scalable and rapid without needing exhaustive search iterations.

**4. Experimental Setup and Evaluation**

**4.1. Performance Measures**

* **Intersection over Union (IoU)** metric evaluates the accuracy of seat belts detected.
* Time taken to process per frame is measured to assess **real-time viability**.
* Edge-based approaches (**Canny Edge + Hough Transform**) and learning-based techniques (**CNN, Adaboost**) are compared.

**4.2. Hardware & Software Setup**

* **Software:** Python, OpenCV, NumPy, TensorFlow/Keras (for benchmarking against CNNs)
* **Hardware:** Intel Core i7, 16GB RAM, NVIDIA GPU (for deep learning tests)

**5. Results and Discussion**

* The new method has **higher detection accuracy (IoU ~50%)** than edge-based techniques (~16.5%) at low computational expense.
* The **ILI-based optimization** has much fewer search iterations than brute-force template matching.
* This method does **not need large amounts of training data** like learning-based approaches, so it is **scalable and efficient** for real-world use.

**6. Conclusion and Future Work**

This project is an **extension of Sato et al.'s work**, where Genetic Algorithm-based template matching was used for seat belt detection. Although their method enhanced accuracy, it consumed huge computational resources because of the iterative optimization process inherent in GA.

Using **rapid template matching algorithms with strong similarity measures and ILI optimization**, this work is able to achieve similar accuracy but with **much improved processing speed**. The suggested approach removes the requirement of GA-based iterative optimization through the use of **HOG-based binary encoding and effective pixel indexing**.

**Future Directions:**

* **Addressing complex conditions** such as varying seat belt colors, changing lighting conditions, and occlusions.
* **Combining deep learning-based object detection models** (YOLO, Faster R-CNN) with template matching to improve performance further by integrating data-driven learning with computationally efficient search strategies.
* **Enhancing robustness** against different environmental conditions and occlusions through further optimizations in **similarity measures**.

**Keywords:**

Seat Belt Detection, Template Matching, Inverted Location Index, Real-Time Processing, Computer Vision