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Multi-Object Tracking Project

1. Introduction

This report outlines my experience with the development and enhancement of a **Multi-Object Tracking (MOT)** system. The project was implemented in three phases, progressively improving tracking performance and robustness:

- **TP2**: Developed a basic IoU-based object tracker with the Hungarian algorithm for association.
- **TP3**: Enhanced the system with Kalman filter integration for motion prediction and smoother tracking.
- **TP4**: Incorporated a Re-Identification (ReID) model alongside Kalman filter and IoU-based matching for identity retention across frames.

The results are visualized in the output videos **`tracking_result_TP2.mp4`**, **`tracking_result_TP3.mp4`**, and **`tracking_result_TP4.mp4`**, each demonstrating the evolution in tracking capabilities.

2. Tasks Undertaken

2.1 TP2: IoU-Based Tracking System

Tasks completed:

- Implemented an **IoU-based association algorithm** to match detected objects across consecutive frames.
- Used the **Hungarian algorithm** for efficient assignment of detections to tracks.
- Managed lost tracks with a `max_lost` threshold (30 frames) to retain tracks temporarily.
- Visualized results by rendering bounding boxes with unique IDs over each frame.
- Output tracking results to a CSV file for evaluation.

2.2 TP3: Kalman Filter Integration

Tasks completed:

- Integrated a **Kalman filter** for motion prediction, improving the system's ability to handle occlusions and fast-moving objects.
- Predicted object motion between detections, reducing reliance solely on IoU matching.
- Implemented state updates to refine Kalman predictions with new detections when available.
- Adjusted bounding box updates to incorporate motion predictions, improving tracking stability.

2.3 TP4: ReID-Based Tracking Enhancement

Tasks completed:

- Integrated a **Re-Identification (ReID) model** for appearance-based matching of objects, ensuring identity consistency across occlusions or re-entry into the frame.
- Combined IoU matching, Kalman filter prediction, and ReID features into a hybrid association strategy.
- Enhanced multi-object tracking performance in crowded scenarios by leveraging appearance similarity.
- Visualized results with bounding boxes and track IDs in **`tracking_result_TP4.mp4`** and exported tracking outputs to CSV.

3. Challenges and Solutions

3.1 TP2 Challenges (IoU-Based Tracking)

Issue	Solution
Objects disappeared when occluded for a few frames.	Introduced a `max_lost` threshold to retain tracks for 30 frames after detection loss.
ID switching occurred when objects overlapped.	Tuned the IoU threshold to improve association accuracy, although overlaps still posed challenges.
Fluctuations in object detections caused inconsistency.	Smoothed bounding boxes by averaging positions over past frames.

3.2 TP3 Challenges (Kalman Filter Integration)

Issue	Solution
IoU-based matching struggled with fast-moving objects.	Integrated a Kalman filter to predict positions between detections.
Kalman filter initialization needed fine-tuning.	Adjusted noise parameters to balance responsiveness and stability for varied object speeds.
Track loss during long occlusions.	Added single-step predictions, but long-term occlusions remained unresolved.

3.3 TP4 Challenges (ReID-Based Tracking)

Issue	Solution
ReID model performance depended on lighting and object appearance.	Preprocessed image patches to normalize features before feeding into the ReID model.
Increased computational cost with ReID features.	Optimized the tracker pipeline to balance accuracy and processing speed.

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4. Results and Analysis

4.1 TP2 Performance

- **Strengths**:
  - Successfully tracked objects across frames in simple scenarios with minimal overlap.
  - Efficient association of detections using the Hungarian algorithm.
- **Limitations**:
  - **Frequent ID Switching**: Objects close to each other often switched IDs.
  - **Track Loss**: Occlusions caused tracks to reset or disappear entirely.
- **Observation**:
  - Output tracking results were inconsistent, with fluctuating object counts across frames.

4.2 TP3 Performance

- **Strengths**:
  - Kalman filter improved bounding box stability by predicting positions between detections.
  - Reduced ID switches during partial occlusions or fast motion.
- **Limitations**:
  - **Single-Step Prediction**: Failed to handle extended occlusions, leading to track loss for objects obstructed for multiple frames.
- **Observation**:
  - Improved stability and reduced ID switches compared to TP2.
  - Failed to retrieve tracks for objects obstructed for multiple frames due to single-step Kalman predictions.

4.3 TP4 Performance

- **Strengths**:
  - ReID-based matching enabled identity retention across occlusions and re-entry into the frame.
  - Combined IoU, Kalman filter, and ReID features delivered robust tracking in crowded scenes.
  - Bounding boxes were stable and IDs consistent, even in challenging conditions.
- **Limitations**:
  - Computational overhead due to ReID feature extraction.
- **Observation**:
  - Best performance among all versions, with minimal ID switches and robust handling of occlusions.
  - Objects retained their IDs even after temporary loss or re-entry.