Comparative Study of Optical Speed Estimation Methods for Vehicles Using Video-Based Motion Analysis

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April 2025

Abstract

As a working student at Trenpex, I've been actively involved in various projects in the field of computer vision. Drawing from this practical experience, I propose a Master's thesis topic that addresses a real-world challenge we are currently facing—one that also offers strong scientific research potential. The idea originates directly from my work at Trenpex and is closely related to concepts covered in C1 and C6 of the Master's program. My company advisor is Dr. Christian Schüller, who has extensive experience supervising Bachelor's and Master's theses at TU Munich. His guidance will streamline the process and potentially reduce the workload on the academic side.

At Trenpex, we specialize in dynamically weighing trains and identifying visual features such as wagon numbers through optical detection and recognition. The collected data is made available through a proprietary web portal. Our measurement sites are placed orthogonally to the railway tracks, approximately 1–2 meters away, and use line-scan cameras to capture high-resolution images of passing trains. Speed measurement is currently based on two track-mounted sensors that detect axle positions. Accurate speed estimation is essential, as line-scan cameras require precise horizontal pixel scaling to adjust images dynamically to the train's velocity. More information about the company is available at: https://trenpex.com/.

A major issue arises in shunting operations where trains stop and restart near the measurement site, disrupting data consistency. When a train halts before entering the measurement area, our current system lacks a robust method for distinguishing valid motion frames from stationary ones using only track-mounted sensors. This affects pixel selection, as we need a precise way to discard invalid frames and resume correct processing upon motion. Current heuristics based on axle position and time lack the precision required for reliable operation.

To address this, we propose adding an optical motion detection system: a secondary camera aligned along the track to detect vehicle movement states directly via video analysis. The goal is not to replace, but to en-

hance current sensor-based methods, ultimately allowing for more robust and flexible speed estimation.

This Master's thesis will explore multiple approaches to estimating vehicle speed from video streams. These include:

- **Structural Similarity Index (SSIM)**: Shift consecutive frames until the maximum SSIM score is reached, as an indirect measure of motion.
- **Optical Flow Estimation**: Use flow fields to compute motion vectors and estimate velocity.
- **Object Detection & Tracking**: Track train wheels frame by frame using camera calibration and known physical dimensions.
- **Custom AI Model**: Train a deep learning model to predict speed directly from two consecutive frames and scene parameters.

This research aims to improve speed estimation accuracy, particularly in challenging stop-and-go scenarios, and contribute to more resilient optical measurement systems.