3D Bowling Ball Trajectory And Spin Analysis

The problem

Objectives

- Detect and track bowling ball trajectory and estimate spin rate and rotation axis orientation

Challenges

- High ball speed, lighting and reflections of bowling alleys

Usage

- Bowling performance analysis.

The proposed solution

Detection

- YOLO Neural Network for real-time ball detection

Three-dimensional reconstruction

- Camera calibration and geometric calculations

Motion analysis

- Optical flow with corner detection

State of the art

Bowling ball detection

- From background subtraction with Hough circles to Deep Learning
- YOLO for high speed and accuracy

Motion estimation

- Optical flow with corner detection
- Fast Flow Transformer (not used)

The processing pipeline

Calibration

Intrinsic calibration

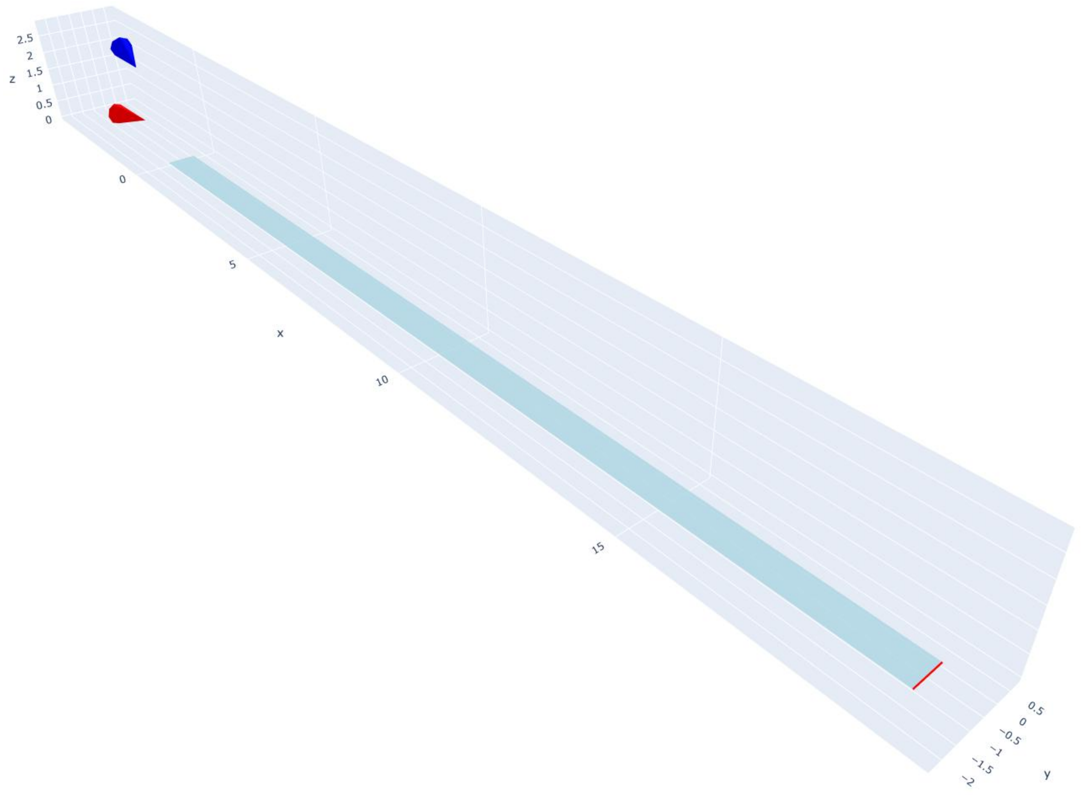
- Goal: Correct lens distortion and find camera calibration
- Method: Corner detection on a 9×6 checkerboard and subsequent reprojection error minimization

Output: Calibration matrix **K** and distortion vector **D**

Extrinsic calibration

- Goal: Estimate camera position and orientation
- Method: Manual lane corners detection and Perspective-n-Points algorithm with IPPE solver to project these points in world coordinates

Output: Rotation matrix **R**, translation vector **t**, and projection matrix **P = K [R|t]**



Video preprocessing

Synchronization

- Goal: Align two independent video streams for stereo analysis
- Method: Cross-correlation of audio tracks to compute time offset and resampling

Outputs: Two frame-aligned videos with same sample rate

Undistorsion

- Goal: Correct lens distortions for geometric accuracy
- Method: Apply intrinsic calibration with pixel-wise correction and re-computation of K

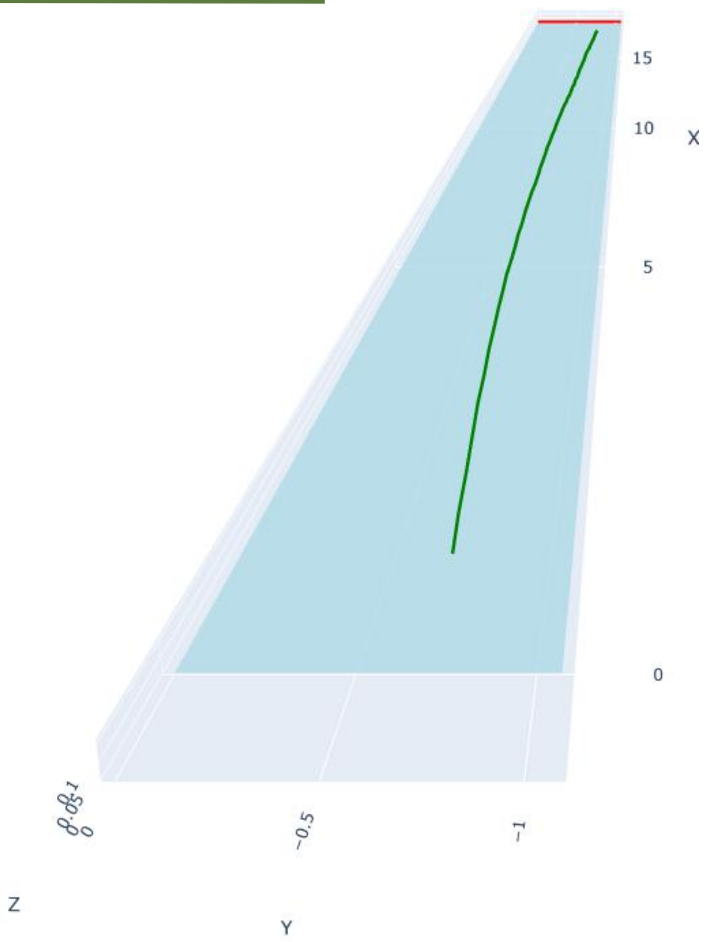
Output: Geometrically correct video frames

Tracking

- Pretrained YOLO (sports ball class) which returns bounding box per frame with ball center and radius
- Dynamic ROI cropping for faster and more accurate detection
- Interpolation for missing radii or centers to have a smooth and complete trajectory

Output: Continuous 2D ball path with radius estimates per frame

Localization



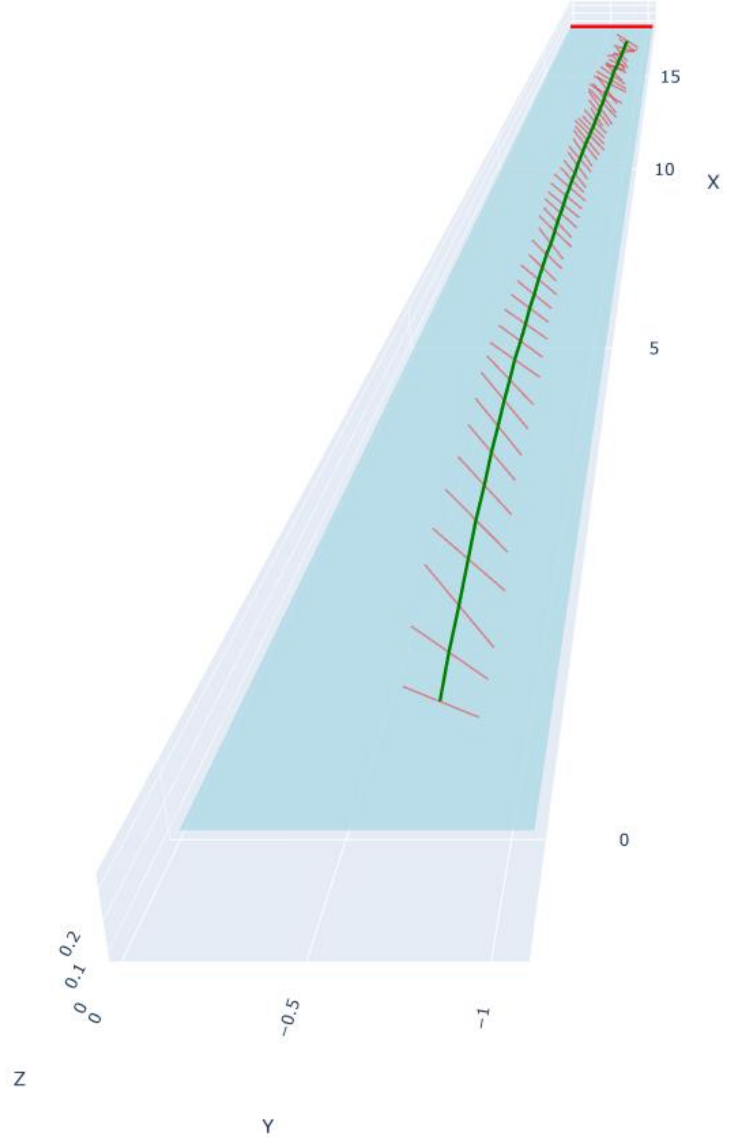
- Triangulation of corresponding points from synchronized videos using the projection matrices **P** using Direct Linear Transform to find the 3D point

Output: Coherent 3D ball trajectory in world coordinates

Rotation axis and speed

- Feature detection using Shi-Tomasi corners inside ball ROI ad tracking with Lucas-Kanade optical flow
- Project tracked points onto ball surface using predicted radius and compute the 3D displacement vectors
- Compute the rotation axis with the cross product of 3D vectors (and average them)
- Compute the angular displacement with the dot product between consecutive positions vectors and weight features by radial distance from center and compute the spin rate.

Output: Smoothed, per-frame spin rate and 3D rotation axis



Conclusions

Ball detection

- Classical methods are limited by reflections and distance
- YOLO object detection is more accurate, reliable frame-by-frame tracking

Motion estimation

- Spin rate consistent across trajectory with a slight discrepancies between camera views due to perspective and lighting
- 3D rotation axis robust and physically accurate

Limitations and improvements

- Tracking challenges as ball moves away from start of lane and goes in darker zones
- Higher-resolution cameras, additional camera placements along the lane, Multi-view tracking for improved spin and trajectory accuracy