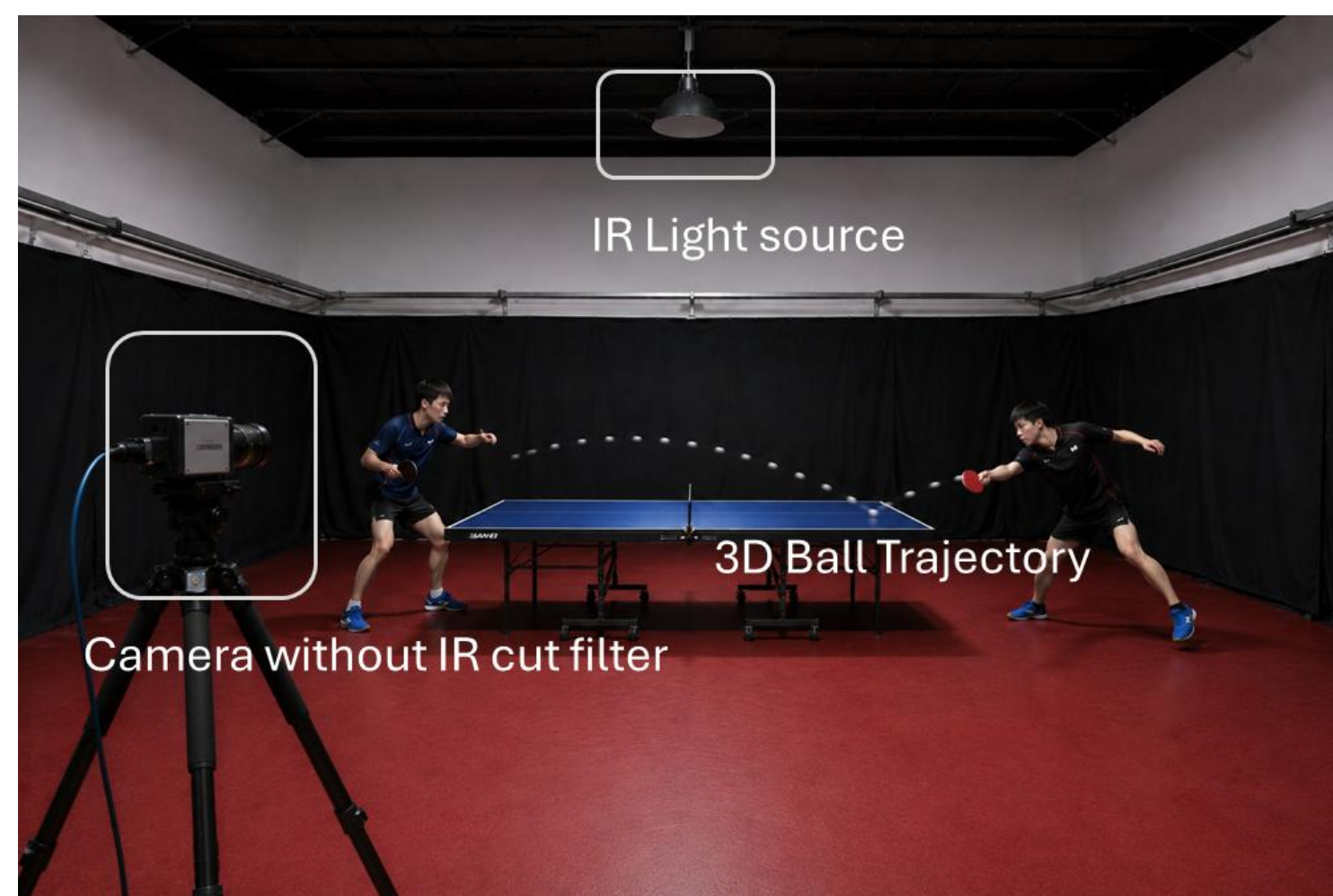


Objective: 3D Ball Position Estimation Using a Monocular Camera

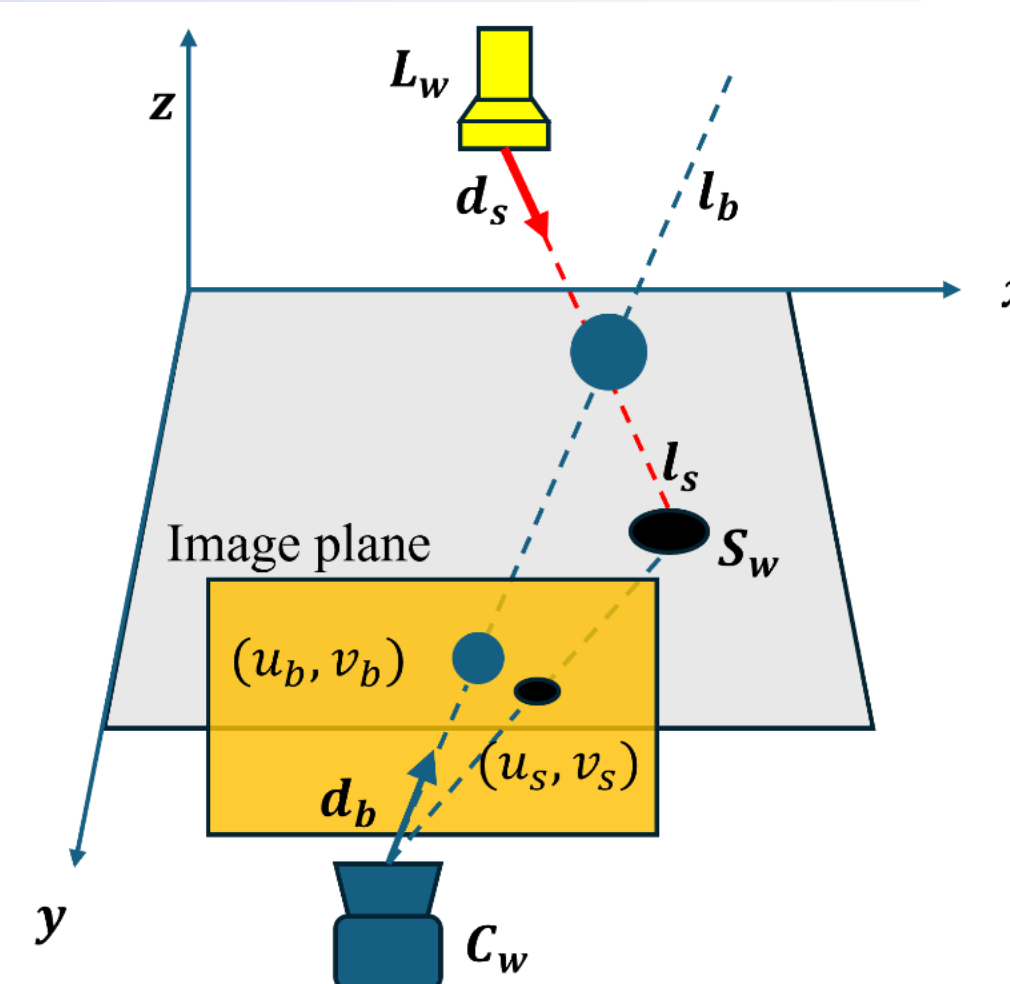


Technical Core

Shadow creates a virtual viewpoint
The light source, ball, and shadow are collinear.
3D ball position is estimated via triangulation
Using the camera and shadow rays.

Features

- Single-camera setup
- Perfect synchronization (single-frame observation)
- Non-intrusive to players and spectators

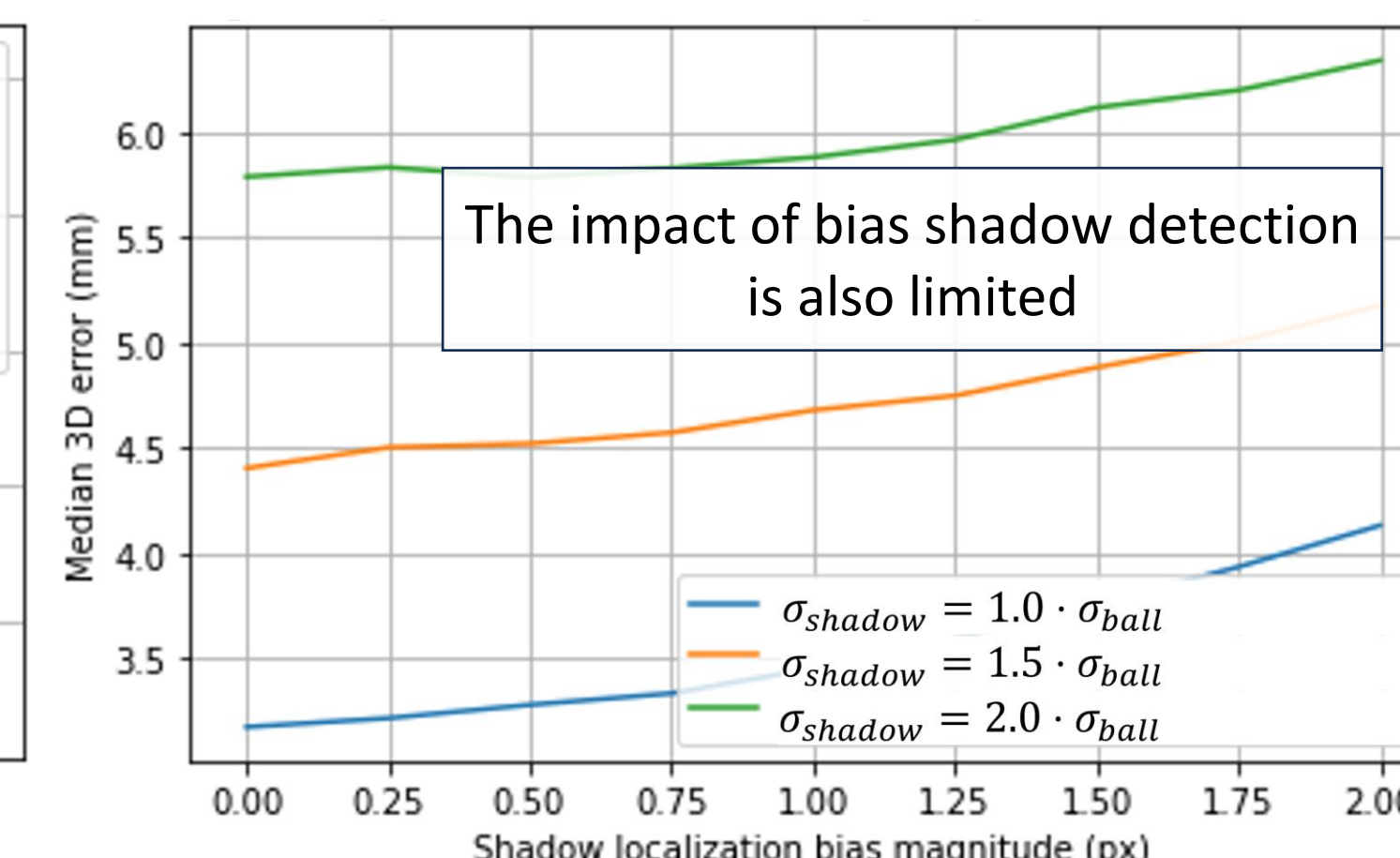
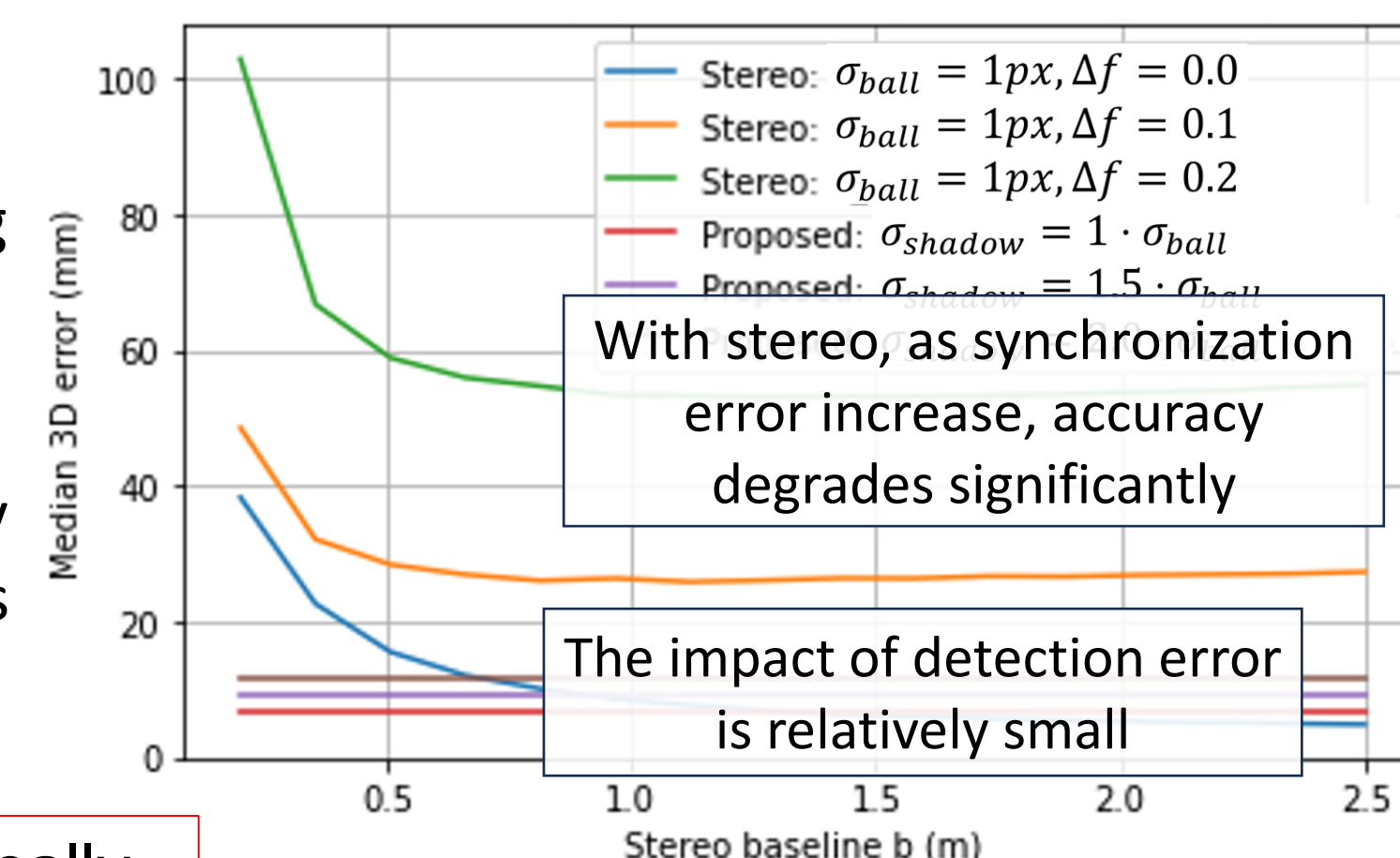


Comparison with Stereo Camera 3D Measurement

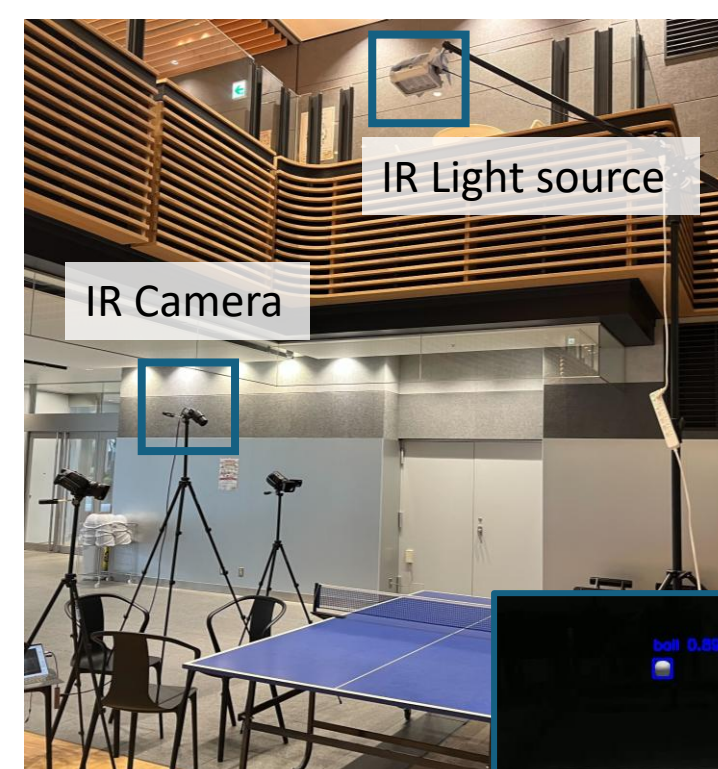
Comparison based on the following modeled parameters:

- Baseline distance
- camera synchronization accuracy
- Ball and shadow detection errors (ball velocity: 100km/h)

The proposed method is intrinsically synchronized. Thus, it is robust under high-speed motion.



Implementation



Hardware Specifications

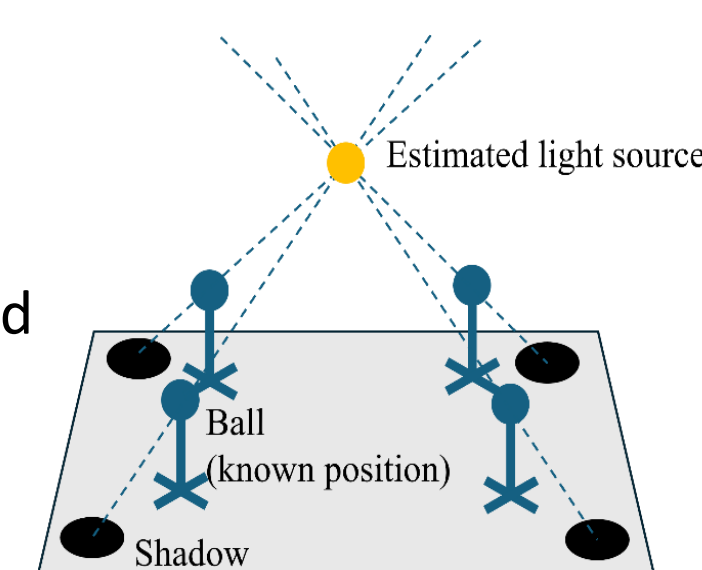
IR Light source : S20D-TR (wavelength: 940nm, power: 40W)

IR Camera : STC-MBE132U3V (1280x1024, max60fps)



2. Light Source position Estimation:

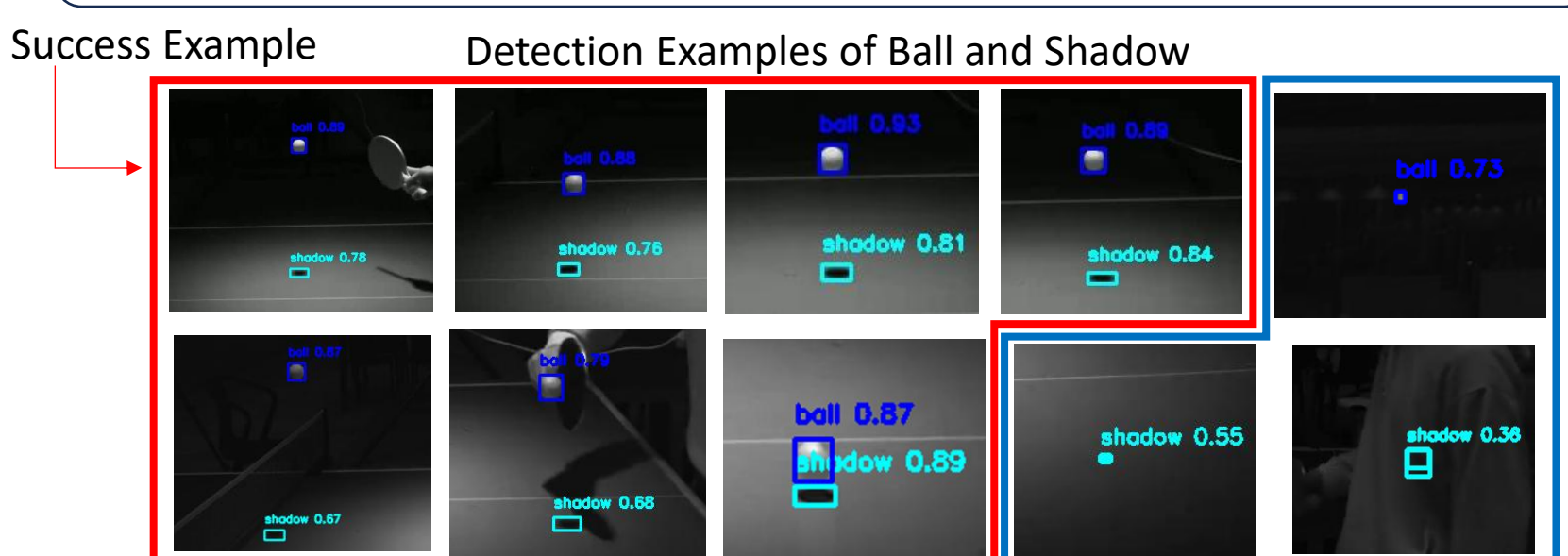
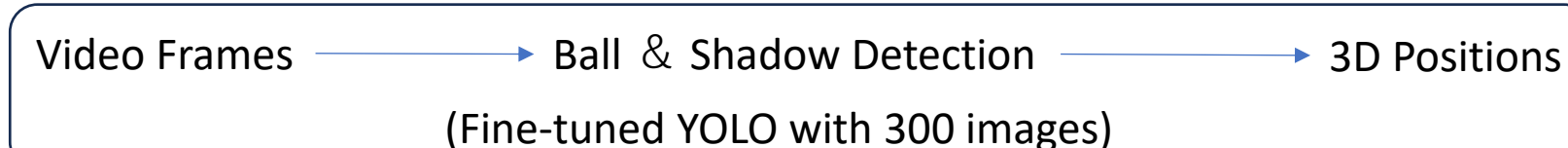
Known 3D ball positions and their shadows define multiple collinear constraints. The light source position is estimated from the intersections of these lines.



Preparation

1. Camera Position Estimation: Determined via geometric camera calibration

Measurement Pipeline



Failure Examples

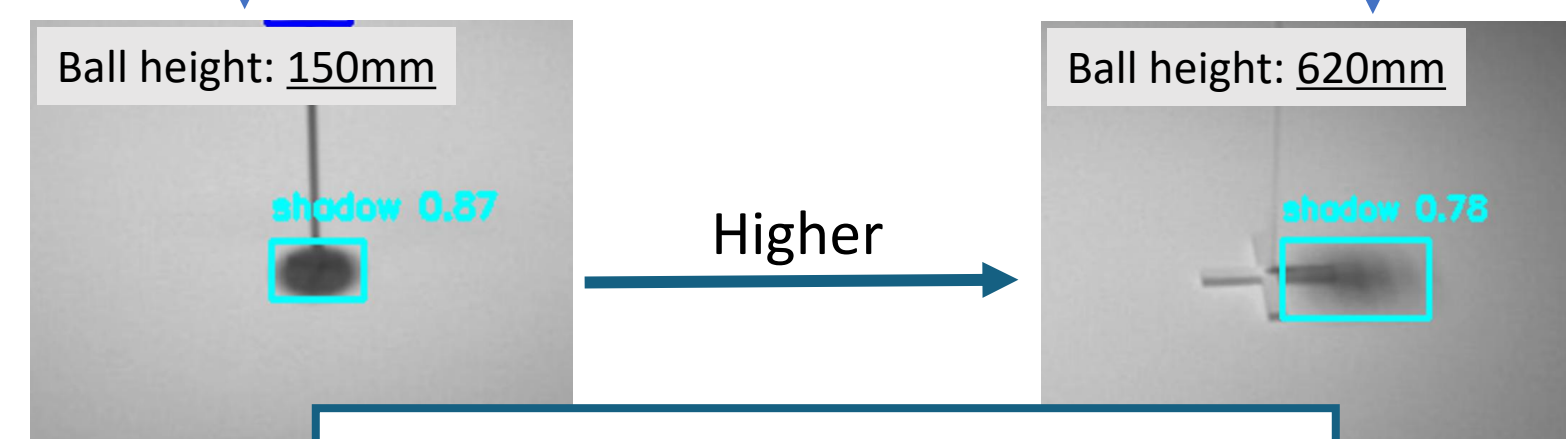
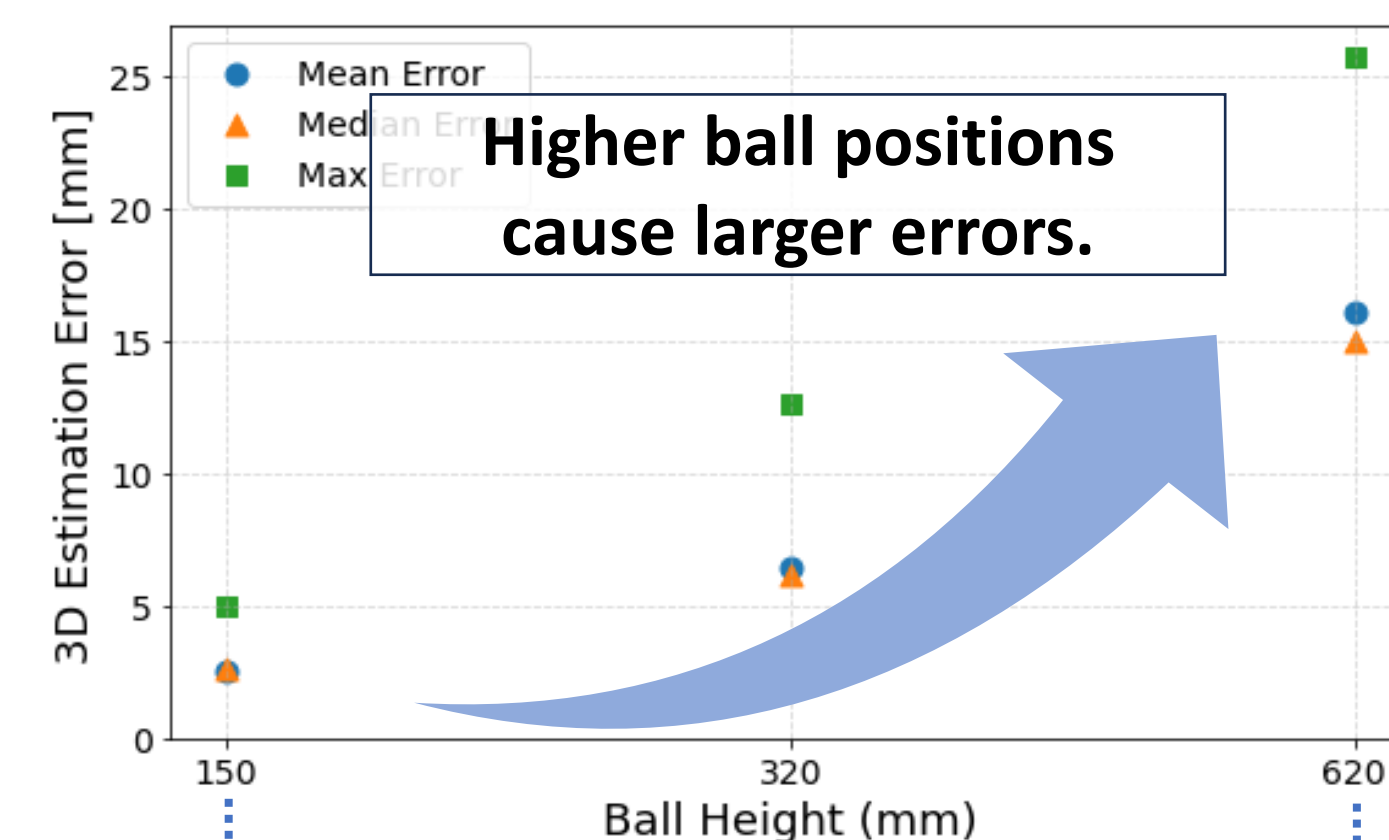
False positives were filtered out using a detection threshold and manual data cleaning

Results

Experiment 1: Static Accuracy Evaluation

Evaluated measurement error at fixed heights using a rigid grid

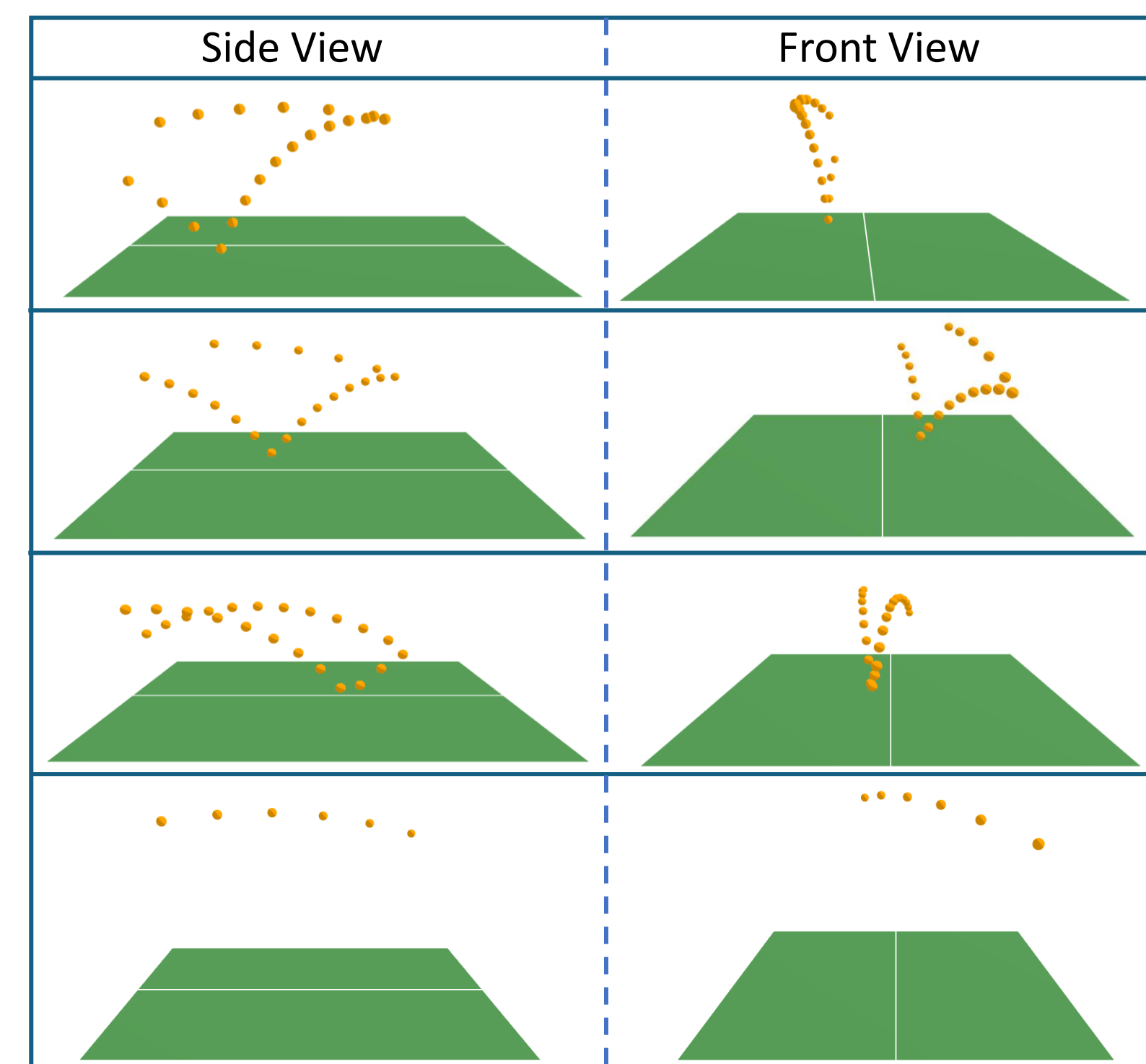
	Geometric reference			Stereo reference		
	Mean	Median	Max	Mean	Median	Max
150 mm	2.52mm	2.61mm	5.02mm	0.94mm	0.93mm	1.17mm
320 mm	6.41mm	6.19mm	12.6mm	0.93mm	0.89mm	1.32mm
620 mm	16.1mm	15.0mm	25.7mm	1.59mm	1.54mm	2.50mm



As height increases, penumbra grows

Experiment 2: Dynamic Trajectory Reconstruction

Examples of measured sequences from serve to return (Trajectories with no bounce do not include a return)



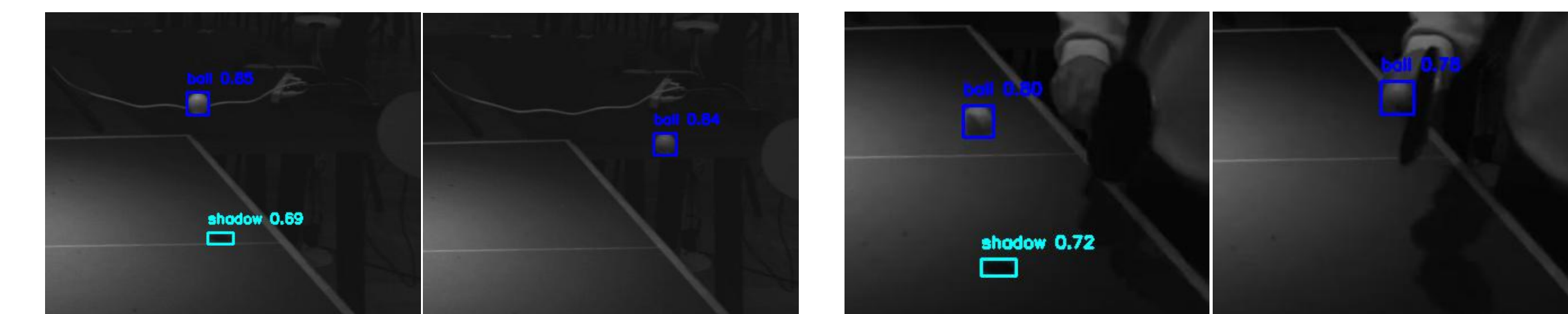
Although some monocular methods use 3D constraints at the bounce point, the proposed method can reconstruct 3D trajectories even for motions that do not include a bounce.

Limitation & Future work

Limitation

3D ball tracking is impossible when the shadow cannot be observed on the table

- Case 1: Shadow falls outside the table surface
- Case 2: An obstacle blocks the light-to-shadow line



Future Work

- Utilize time-series data to achieve even cleaner and more precise trajectory reconstruction
- Expand the measurement range by incorporating multiple IR light sources

Formulation

