Combined Physics and Event Camera Simulator for Slip Detection

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Introduction

Objective:
Develop an event camera simulator for detecting slip in pick-and-place tasks, focusing on relative motion detection.

Motivation:
Reduce data collection time, enable flexible set changes, and generate large synthetic datasets efficiently.

Approach:
Create synthetic event data using photorealistic images from physics-based pick-and-place simulations, suitable for AI training.

Verification:
Train ANNs with simulated data and analyze performance on simulation and real-world data.

Pipeline
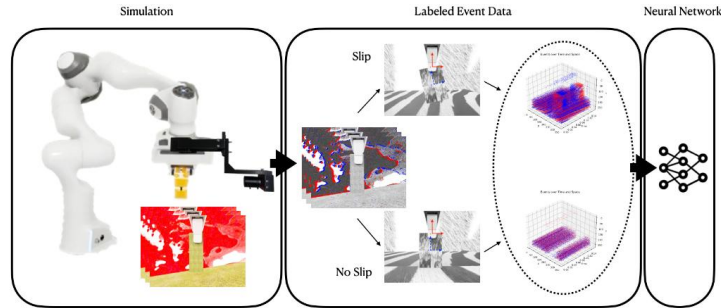
Physics Simulation: Rendered frames from NVIDIA Isaac Sim.
Ground Truth: Thresholding angular difference between object & gripper.
Synthetic Events Generation: Events from v2e.
Artificial Neural Networks: slip detection using MLP, SNN and 3D-CNN.

Real-World Setup

- **Manipulator**: Franka Emika Panda
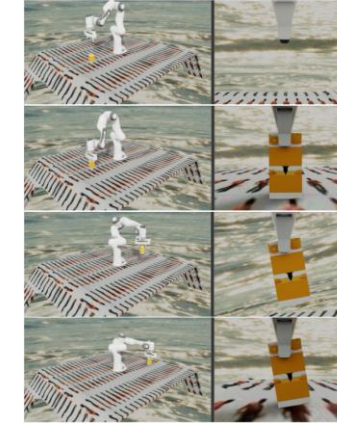- **Object**: Cuboid, Book
- **Surface**: Flat, White

Custom Camera Mount

Sample event-camera data

Simulation Setup

- **Manipulator**: Franka Emika Panda.
- **Object**: Cuboid with several textures.
- **Surface**: Flat with different textures.
- **Background**: different textures.
- **Scene Brightness**: controllable by ambient light intensity.
- **Shadows**: controllable by intensity and position of a light sphere.
- **Movement**: controllable by pick-and-place positions.
- **Slip/Non Slip**: defined by gripping position and object mass.
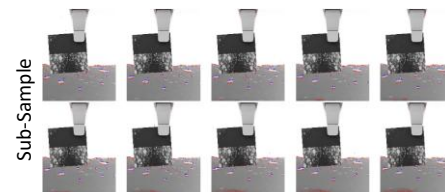
Simulation Parameters
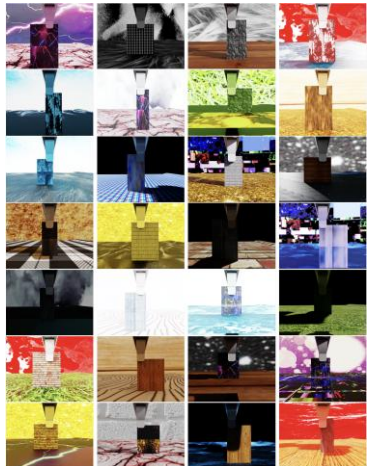
- Size of cuboid.
- Mass of cuboid.
- Texture sets.
- Light sphere position and brightness.
- Background sphere brightness.
- Gripping position horizontally & vertically.

Pre-processing for Neural Network Training and Labelling

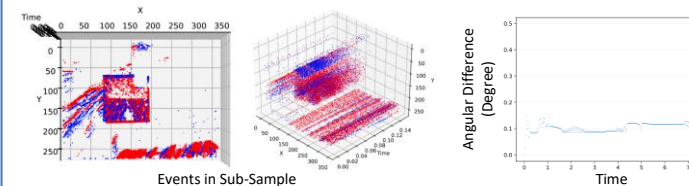Every simulated sample is split into 16ms sub-samples for slip/non-slip classification

Subsamples are labelled into slip or non-slip by a threshold on the angular difference of gripper and cuboid

Slip Detection Results

Two simulated and a real-world datasets for pipeline validation and artificial neural network (ANN) training:

- *Simple Set*: Small, simulated set with 192 samples and 1-3 different values per parameter.
- *Complex Set*: Bigger, simulated set with 1000 samples and a 200 samples test set. Both separated and with a maximum complexity by choosing random values for every sample.
- Additional real-world dataset for sim-to-real gap inspection.

Architecture	Trained on	Validation Accuracy	Test Accuracy	Real Data Accuracy
MLP	Simple Set	98%	N/A	N/A
SNN	Simple Set	96%	N/A	N/A
3D-CNN	Simple Set	99%	N/A	N/A
MLP	Complex Set	72%	69%	63%
SNN	Complex Set	70%	69%	59%
3D-CNN	Complex Set	80%	78%	63%