Motion Capture Analysis of Diabolo Juggling

Jeb Cui (Computer Systems Lab ’22)

01

BACKGROUND

CS world of diabolos

02

METHODS

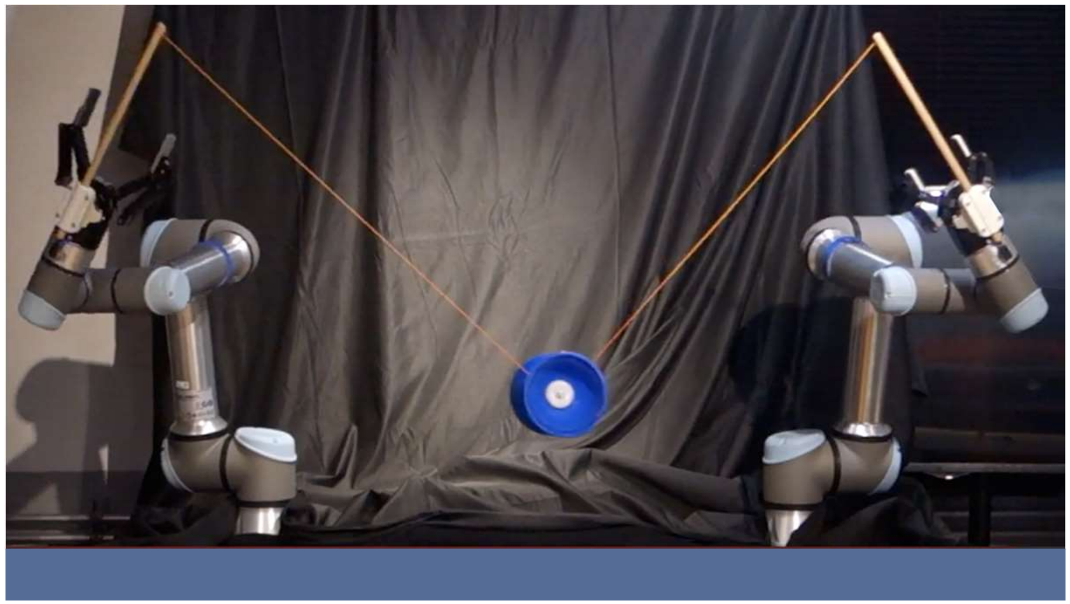
Vicon, Models, and Flask

03

RESULTS

Comparing the models

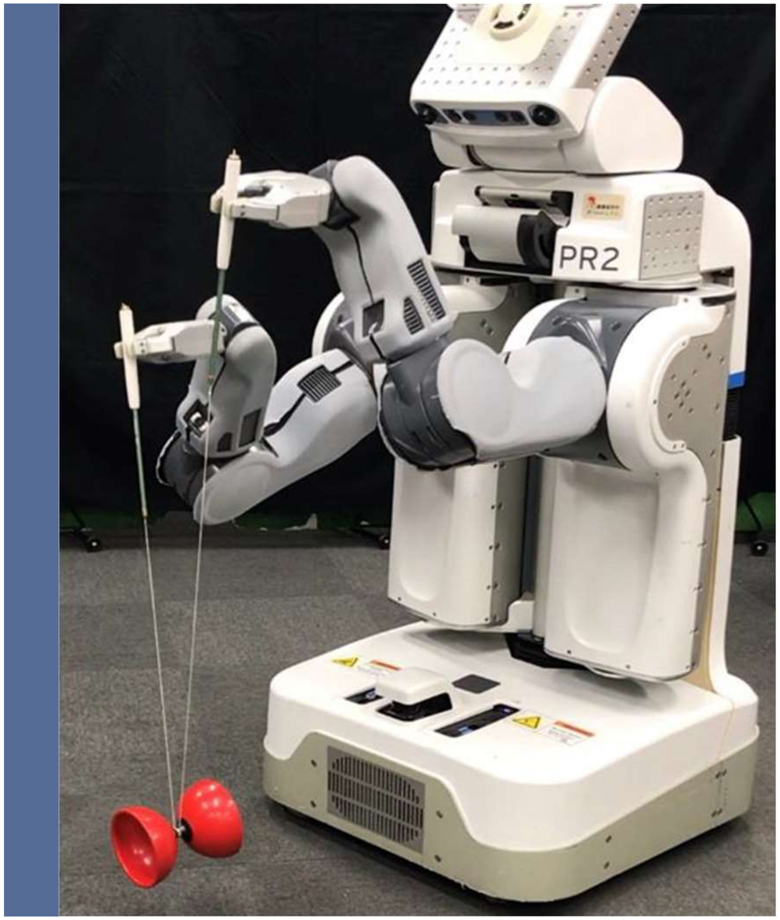
Background: CS world of Diabolos



von Drigalski et al.

A diabolo predictor that estimates the next state based on the current state and the stick positions. Using the forward Euler method with constraints.

Background: CS world of Diabolos



Murooka et al.

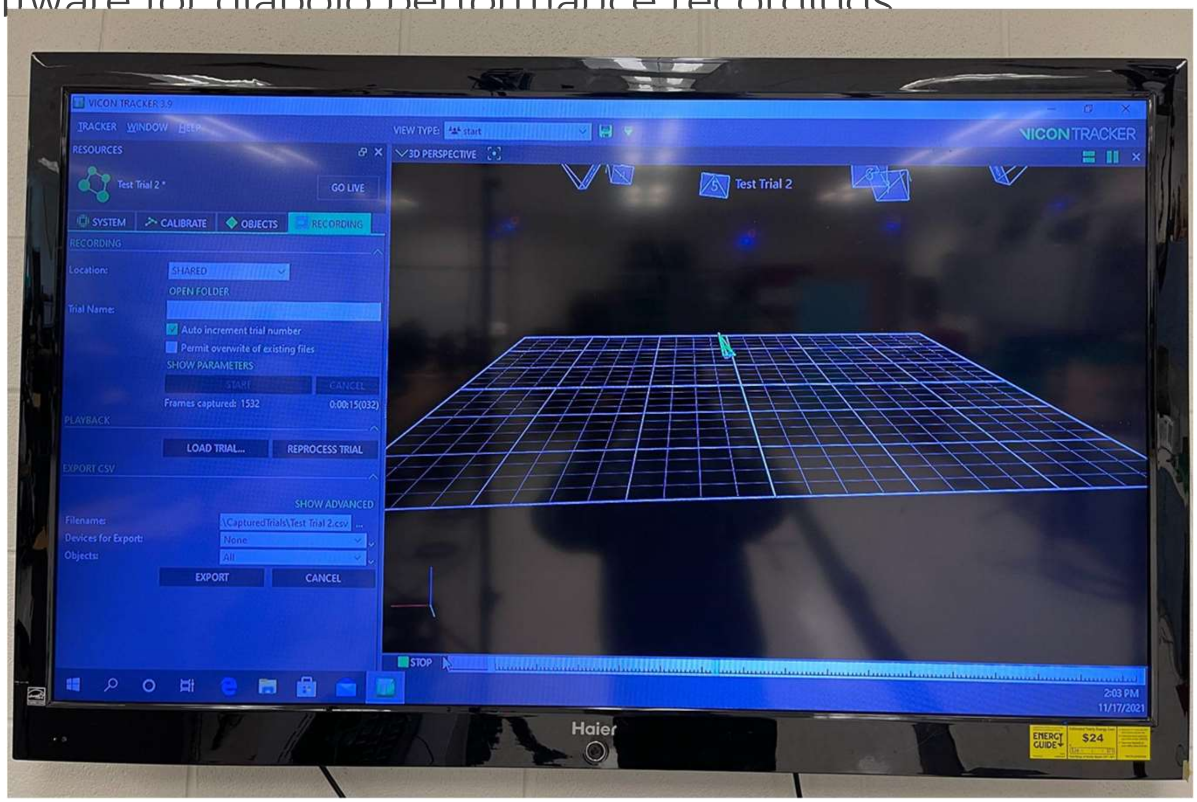
Diabolo-Manipulation-Net trained using the diabolo's pitch and yaw, and the robot's arm height difference and robot's spin speed.

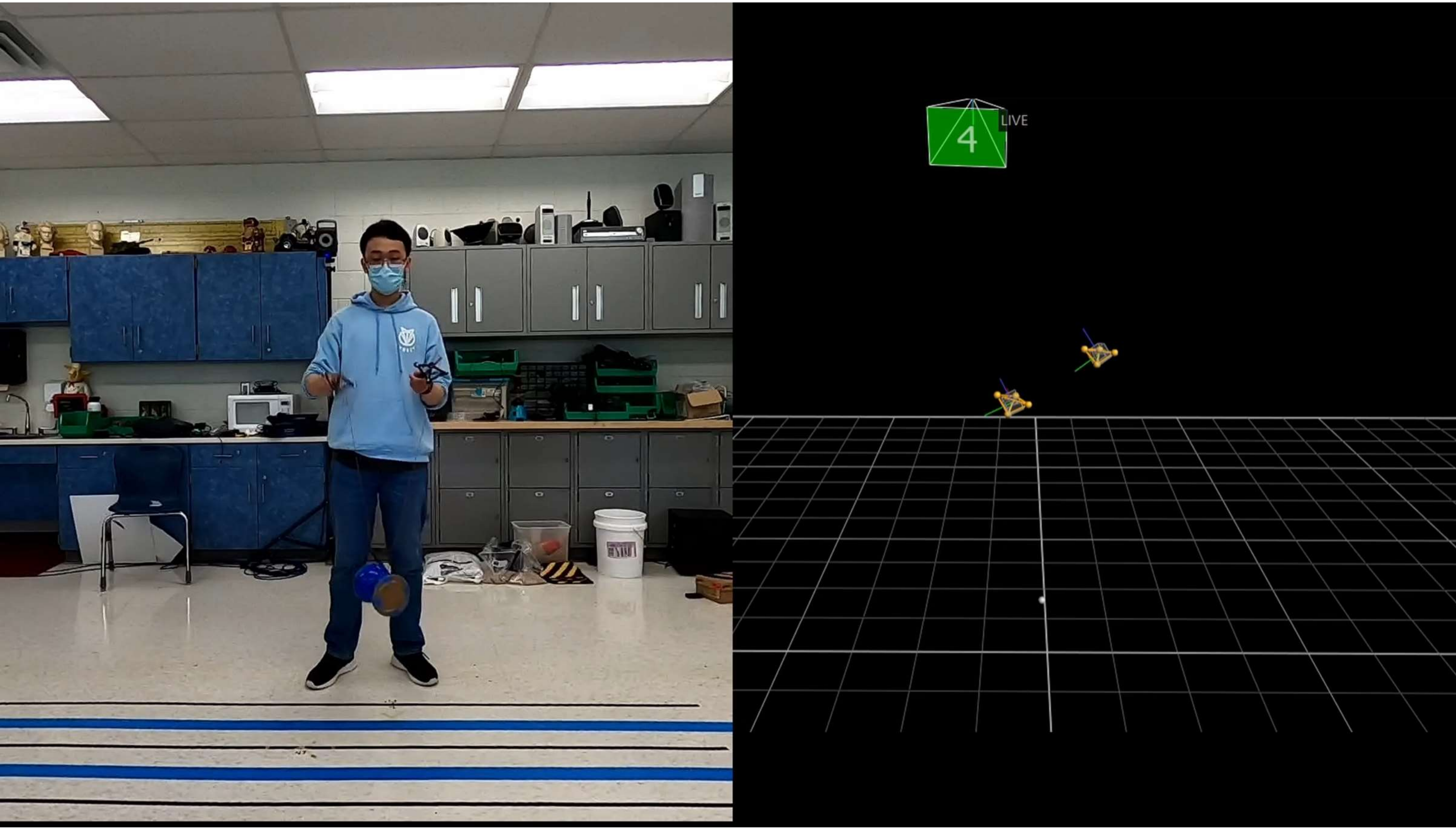
Vicon Motion Capture System

9 Cameras (MX T20's and MX T40's) and retroreflective marker

Vicon Motion Capture System

Vicon Tracker Software for diabolo performance recordings

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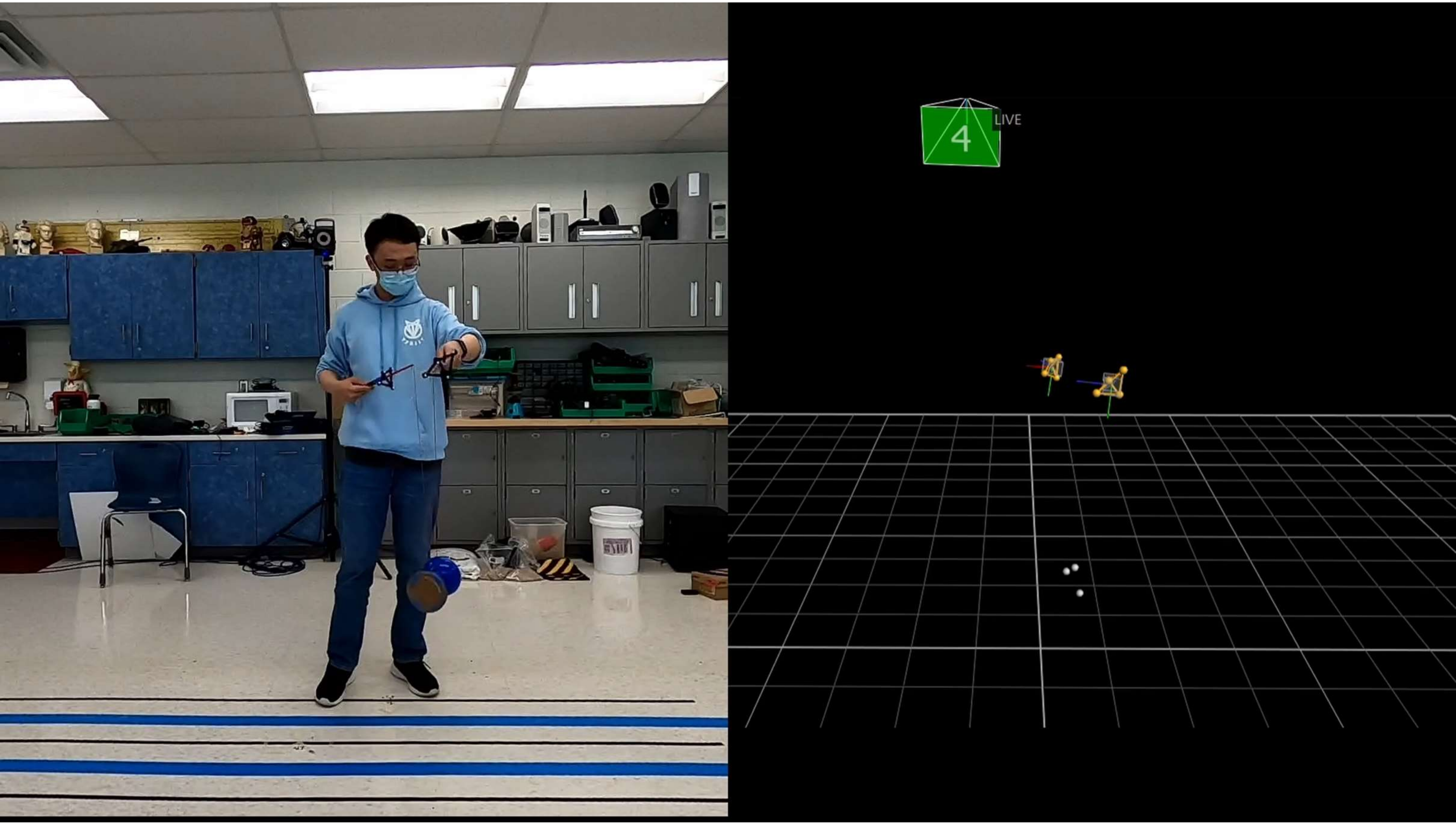
LIVE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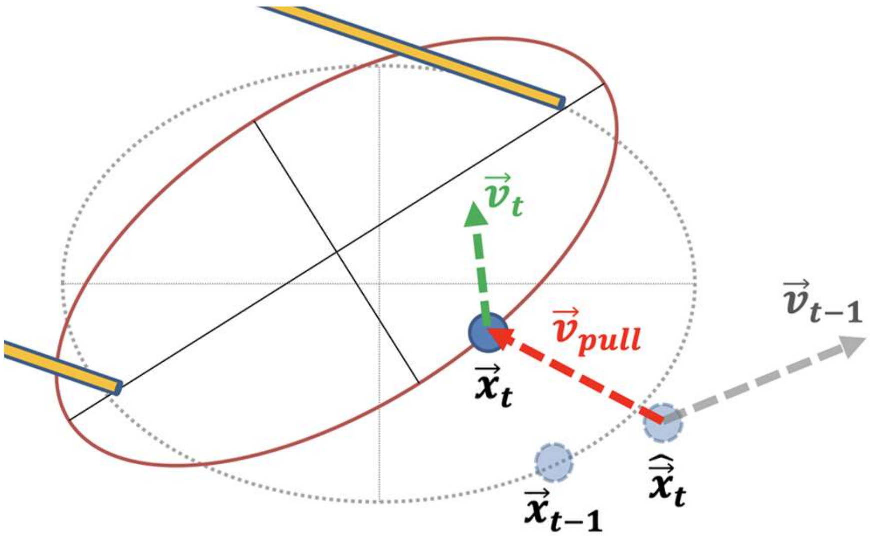
LIVE

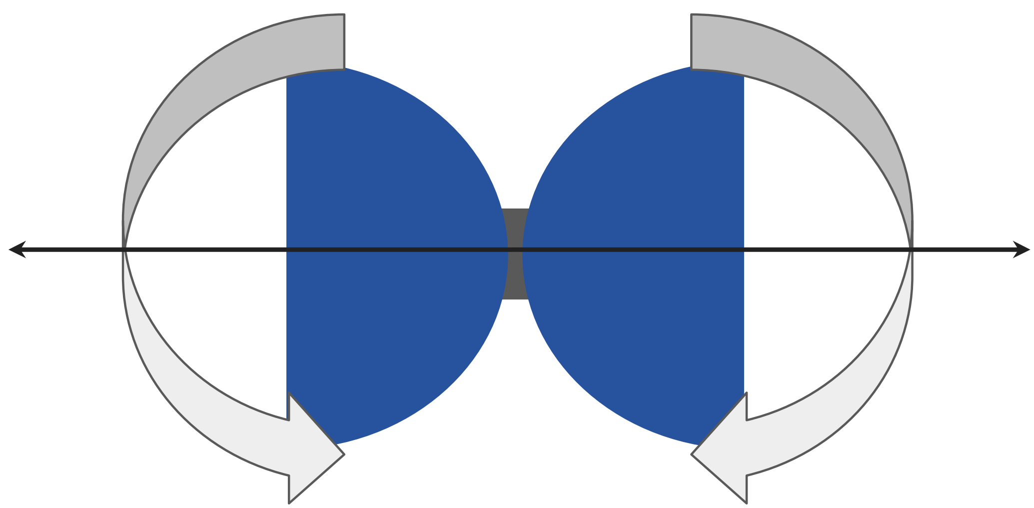
Analytical Model

- Built on von Drigalski et al.'s model by incorporating pitch prediction
- Transpiled researcher's algorithm into Python
  - Removed C++ specific library dependencies



Pitch Prediction Algorithm

- Diabolo Skill Analysis by Rodriguez Ladron de Guevara et al.
- Pitch is calculated based on stick’s offset angle and angular velocity



Pitch Prediction Algorithm

Algorithm 1 Pitch predicting algorithm

Require: Q = Quaternion angles, ω = rotational speeds, R, L = right and left stick positions

function PITCH-PREDICTION(Q, ω, R, L)

  $|\text{Pitches}| \leftarrow n$ ▷ n is total number of time steps

  $|\text{Offsets}| \leftarrow n$

  for $t \leftarrow 1 \ldots t_n$ **do**

    $d \leftarrow Q_t\langle 0, 0, 1\rangle Q'_t$ ▷ Quaternion rotation

    $h \leftarrow \frac{\langle d_1, d_2, 0\rangle}{\|\langle d_1, d_2, 0\rangle\|}$

    $\Delta s \leftarrow R_t - L_t$

    $\Delta s \leftarrow \frac{\langle \Delta s_1, \Delta s_2, 0\rangle}{\|\langle \Delta s_1, \Delta s_2, 0\rangle\|}$

    $\text{Offsets}_t \leftarrow cos^{-1}(\Delta s \cdot h) - \pi/2$

    if $t = 1$ **then**

      $\text{Pitches}_1 \leftarrow cos^{-1}(d \cdot h)$

      if $d_3 \leq 0$ **then**

        $\text{Pitches}_1 \leftarrow -\text{Pitches}_1$

      end if

    end if

  end for

  SAVITZKY-GOLAY FILTER(Offsets, 101, 5)

  for $t \leftarrow 1 \ldots t_{n-1}$ **do**

    $\frac{dP}{dt} \leftarrow k \cdot \frac{\text{Offsets}_t}{\omega_t}$ ▷ k is the empirical constant of proportionality

    $\text{Pitches}_{t+1} \leftarrow \text{Pitches}_t + \frac{dP}{dt}\Delta t$

  end for

  return Pitches

end function

Pitch Prediction Algorithm

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        $\text{Offsets}_t \leftarrow cos^{-1}(\Delta s \cdot h) - \pi/2$

        if $t = 1$ **then**

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            if $d_3 \leq 0$ **then**

                $\text{Pitches}_1 \leftarrow -\text{Pitches}_1$

            end if

        end if

    end for

Pitch Prediction Algorithm

$$\textsc{Savitzky-Golay Filter}(\text{Offsets}, 101, 5)$$

Pitch Prediction Algorithm

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$\text{Pitches}_{t+1} \leftarrow \text{Pitches}_t + \frac{dP}{dt}\Delta t$

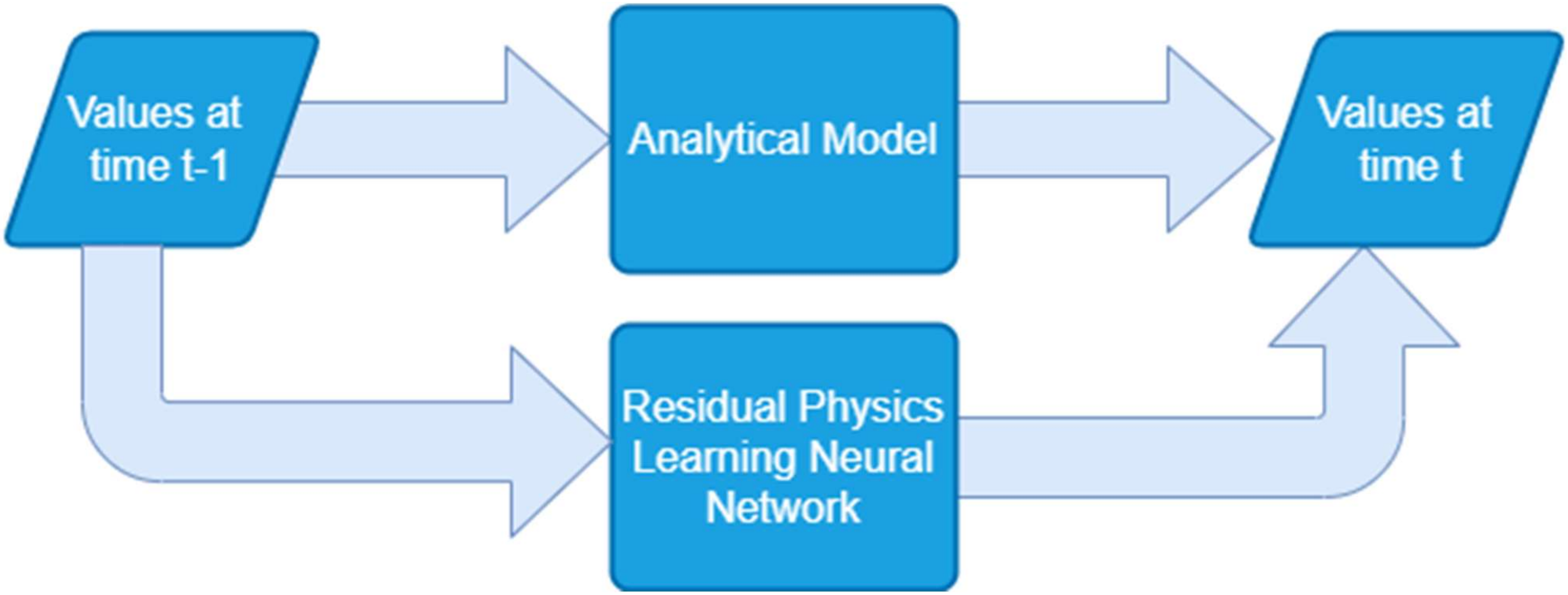
end for

return Pitches

end function

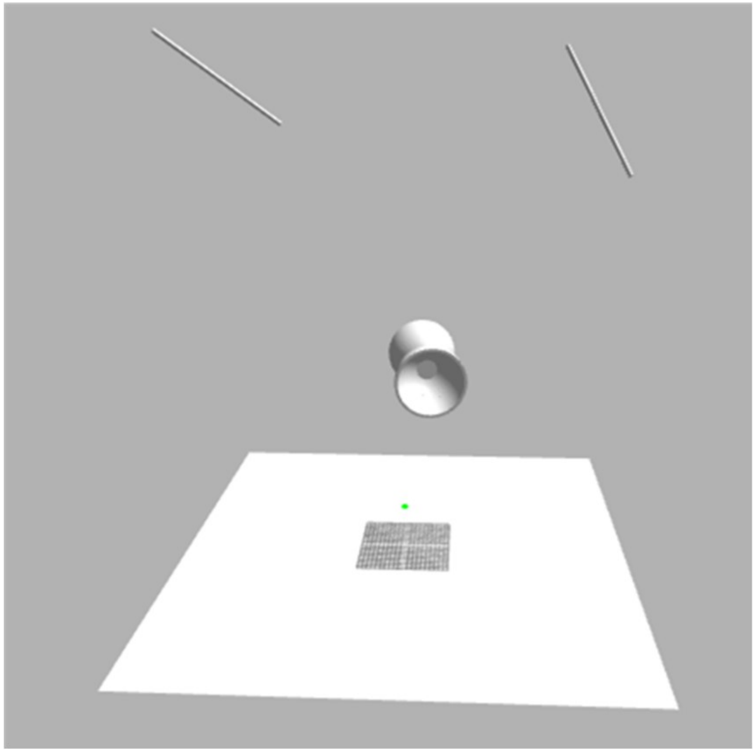
Residual-Physics Learning Neural Network

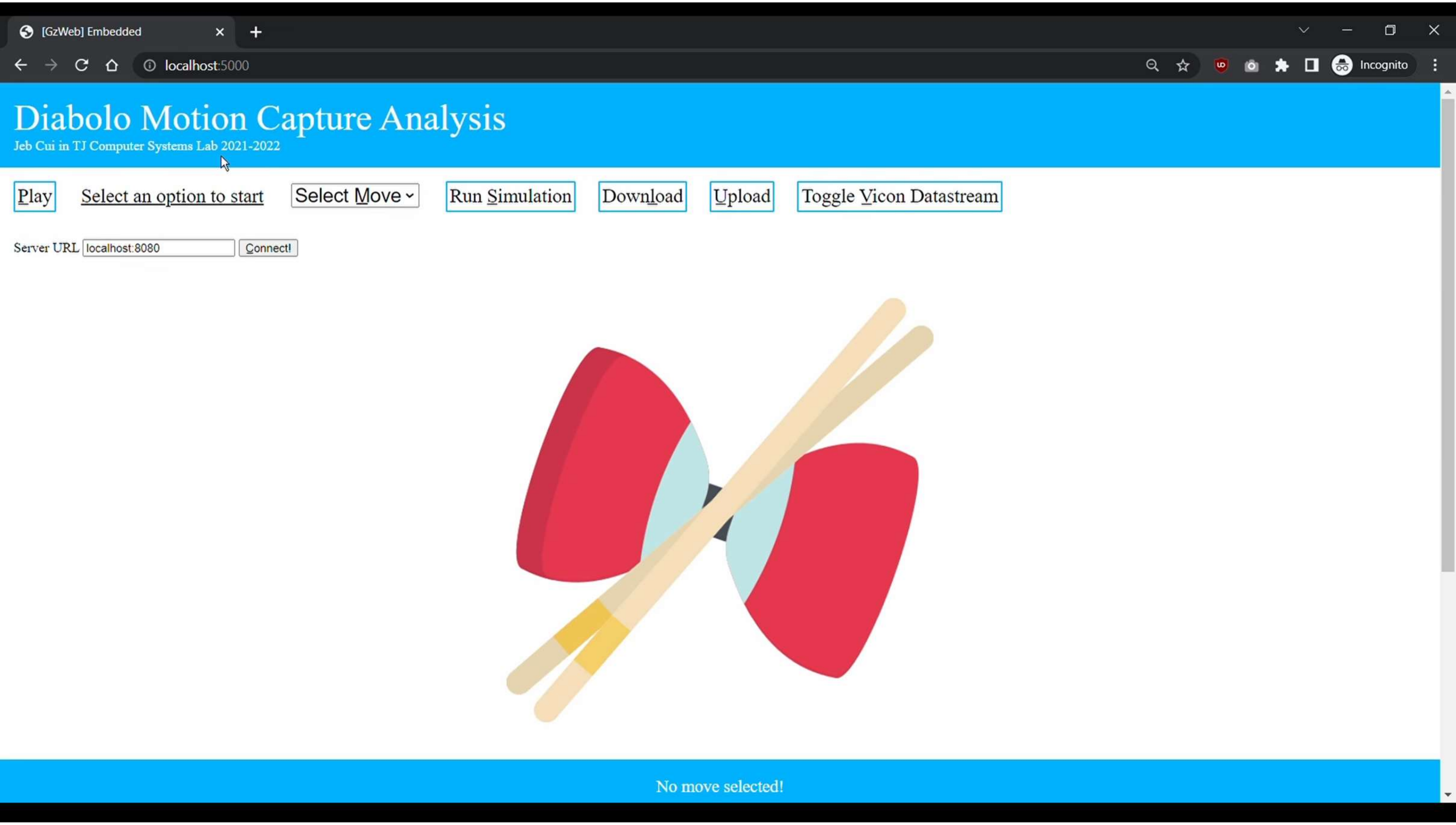
- The analytical model deviates from real life
- A Residual-Physics Learning Neural Network (R-PLNN) predicts the differences
- von Drigalski et al. vs Zeng et al.
- R-PLNN: Keras/Tensorflow and Sequential Model

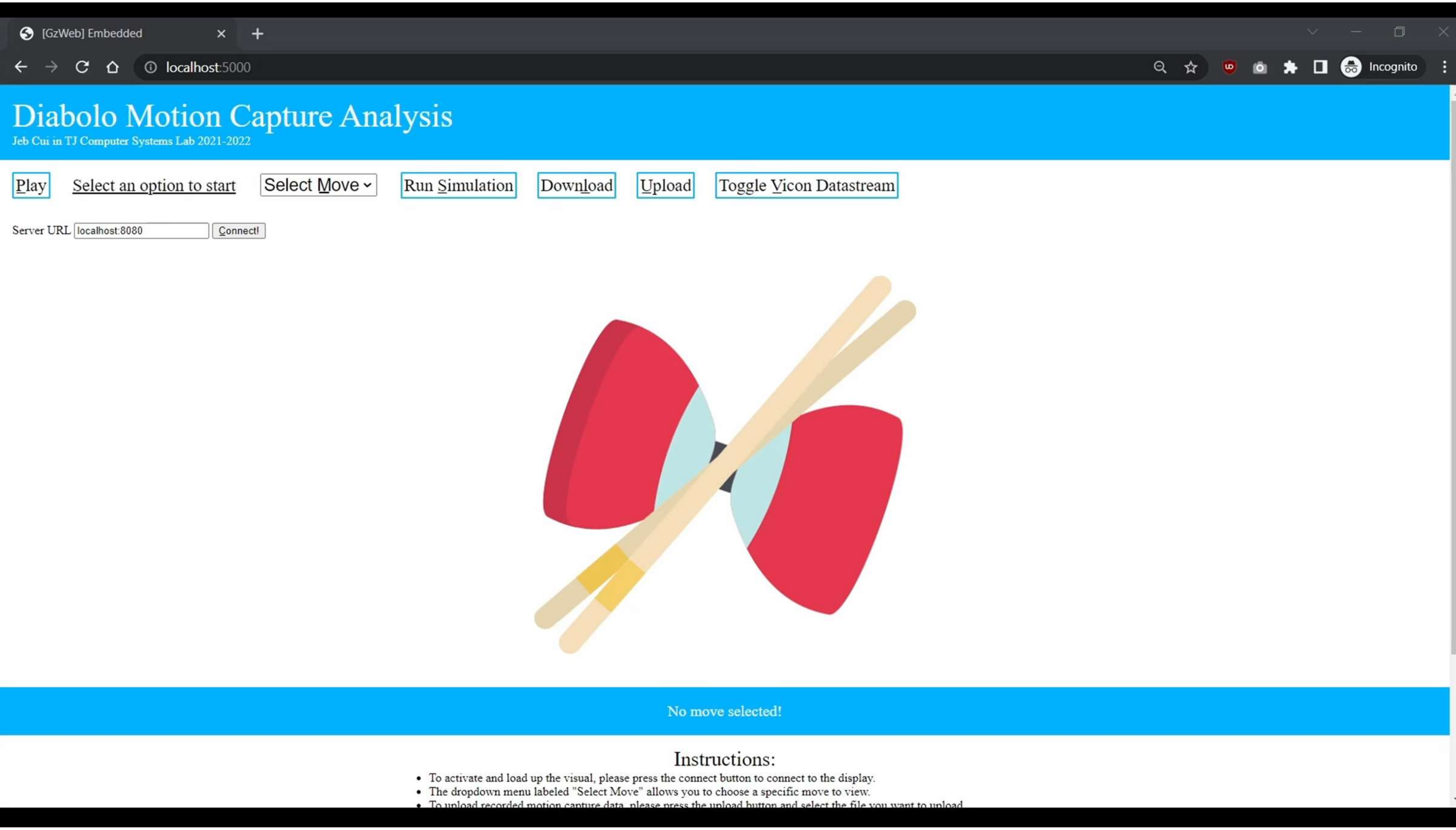

Values at time t-1
Analytical Model
Values at time t
Residual Physics Learning Neural Network

Flask - My Site

- Flask (Python) backend
- JavaScript heavy frontend
- The model and Vicon Data streaming
- Connecting to Gazebo and displaying data




[GzWeb] Embedded
localhost:5000
Incognito
Diabolo Motion Capture Analysis
Jeb Cui in TJ Computer Systems Lab 2021-2022
Play
Select an option to start
Select Move
Run Simulation
Download
Upload
Toggle Vicon Datastream
Server URL
localhost:8080
Connect!
No move selected!


[GzWeb] Embedded
localhost:5000
Incognito
Diabolo Motion Capture Analysis
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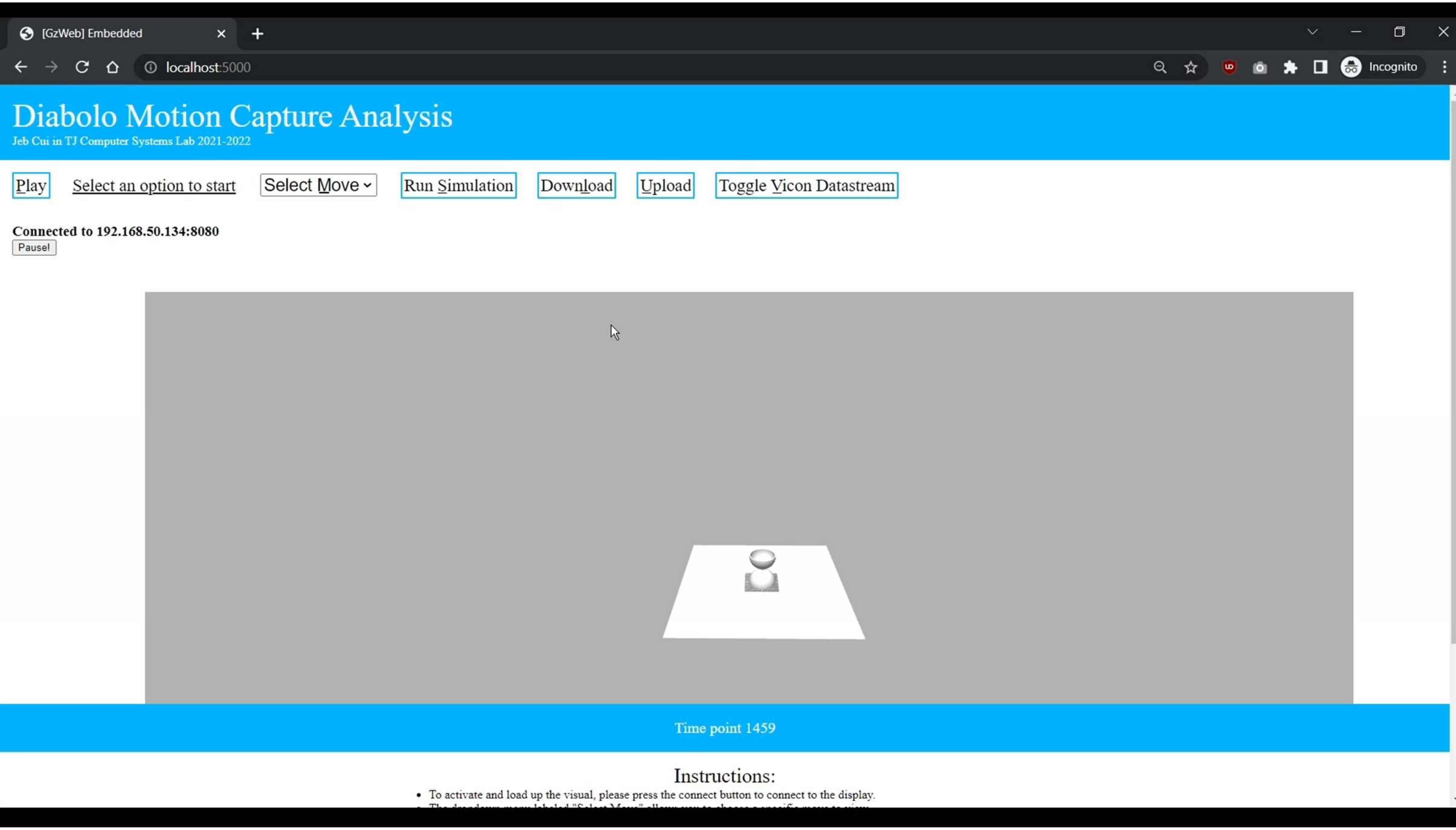
Play
Select an option to start
Select Move
Run Simulation
Download
Upload
Toggle Vicon Datastream
Server URL
localhost:8080
Connect!
No move selected!
Instructions:
To activate and load up the visual, please press the connect button to connect to the display.
The dropdown menu labeled "Select Move" allows you to choose a specific move to view.


[GzWeb] Embedded
localhost:5000
Incognito
Diabolo Motion Capture Analysis
Jeb Cui in TJ Computer Systems Lab 2021-2022
Play
Select an option to start
Select Move
Run Simulation
Download
Upload
Toggle Vicon Datastream
Connected to 192.168.50.134:8080
Pause!
Time point 1459
Instructions:
To activate and load up the visual, please press the connect button to connect to the display.

Results

- Various site functionalities

- Improved predictor ability
  - R-PLNN: MSE of **$0.132m^2$** when predicting the differences
  - Analytical + R-PLNN: MSE of **$0.188m^2$** VS Analytical: MSE of **$0.771m^2$**

Visit my site at

bit.ly/jebcui-syslab

Questions?

References

Murooka, T., Okada, K., & Inaba, M. (2020, October 25). Diabolo Orientation Stabilization by Learning Predictive Model for Unstable Unknown-Dynamics Juggling Manipulation. *IEEE/RSJ*. International Conference on Intelligent Robots and Systems, Las Vegas, NV, USA (Virtual). http://ras.papercept.net/images/temp/IROS/files/3245.pdf

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