Estimating physical properties of an object through interaction

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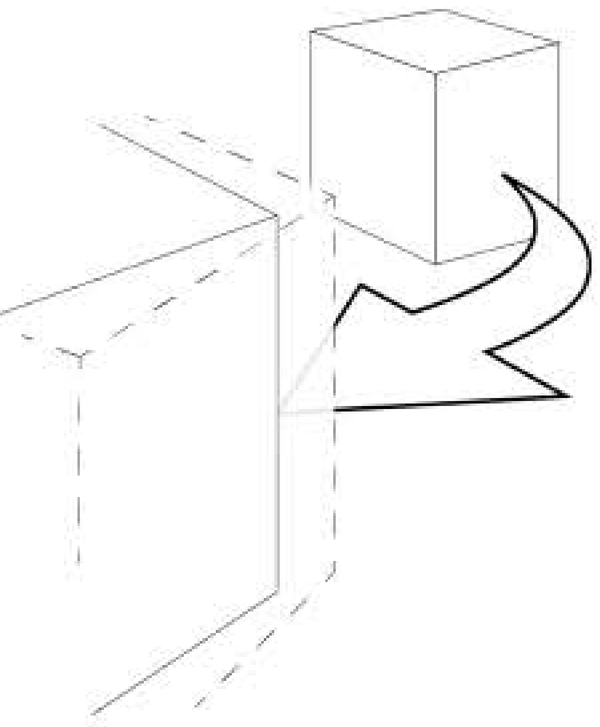


1. Background

Tactile Internet
The perception of the force being exerted
Little to no delay

Solution: use of a local model
Physics simulation
Initial values

differences can result in instability

Mass
Center of Mass (CoM)

Research Question

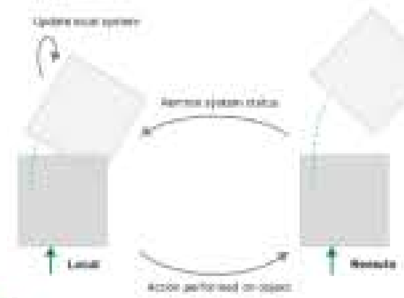
How can the physical properties of an object be estimated through interaction?

2. Methodology

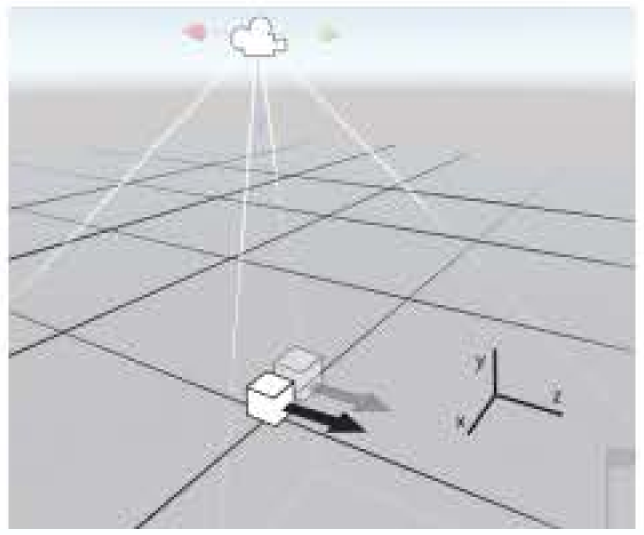
2.1 The setup

Although the estimation will be done in 2D, A scene is created in Unit3D for realistic friction. The linear movements only in the xz plane. Rotation is only around the y axis.

At a specified rate, information is received from the remote object. These values are chosen because it is realistic that they could be measured in a physical setup



- ❑ Position
- ❑ Rotation
- ❑ Linear velocity (v)
- ❑ Angular velocity (ω)



System assumptions

- The local and remote cube have equal meshes
- Movements only in 2D
- No compound objects are used
- The forces are point pressures

2.2 Mass

Linear movement

$p = mv$

Friction is tuned for performance and stability. Although the remote linear momentum can not exactly be known, it can be estimated

$$m_{\text{new local}} = \frac{m_{\text{local}} v_{\text{local}}}{v_{\text{remote}}}$$

"The friction model used by the Nvidia PhysX engine is tuned for performance and stability of simulation, and does not necessarily present a close approximation of real-world physics." [10]

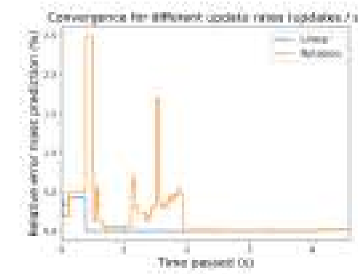
Step	Formula	Explanation
1	$p_{\text{local}} = m_{\text{local}} v_{\text{local}}$	Calculate local linear momentum
2	$m_{\text{remote}} = \frac{p_{\text{local}}}{v_{\text{remote}}}$	Calculate remote mass with local p and remote v
3	$m_{\text{local}} \leftarrow m_{\text{remote}}$	Update local mass

Angular movement

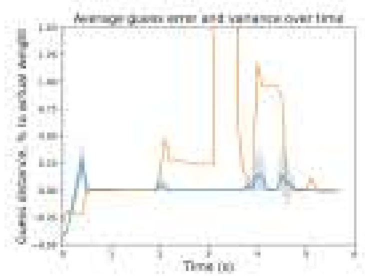
$L = I\omega$

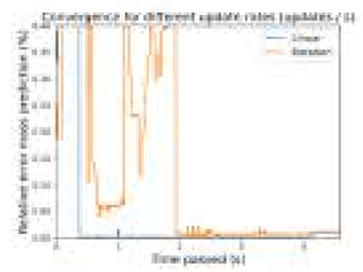
$I = mr^2$

$$m_{\text{new}} = \frac{m_{\text{local}} \omega_{\text{local}}}{\omega_{\text{remote}}}$$



Comparison linear and angular





2.3 Center of mass

To initially simplify: only differences in CoM location on the plane perpendicular to the force.

- the **difference in rotation** tells how far away the COM point in the plane is orthogonal to the force.
- The **direction** tells which way to move the COM towards

$$\text{CoM}_{\text{new}} = \text{CoM}_{\text{previous}} + \frac{f_{\text{dir}} f_{\text{difference}}}{r_{\text{cube}}}$$

Various factors were analyzed, including rotational velocity, rotation, torque, acceleration, and inertia tensor. Yet no discernible coherence was found.

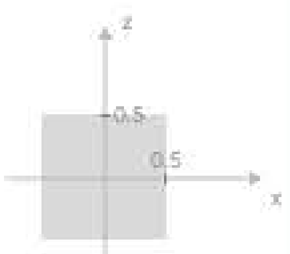
3. Results

3.1 The experimental setup

It is important that all test runs, where factors are compared, are based on the same forces and movements. Therefore an order of forces has been defined on which all tests are based. The sequence contains different forces that result in linear and rotational movements over time.

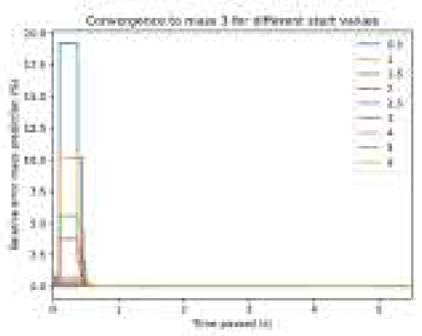
Direction	Position	Duration (sec)
←	z = 0.3 x = 0.5	1
↑	z = -0.5 x = 0.0	1
→	z = 0.4 x = -0.5	1
↓	z = 0.5 x = -0.1	1
•	z = 0.0 x = 0.0	0.5
↖	z = 0.0 x = 0.0	0.5
↘	z = 0.0 x = 0.0	0.5

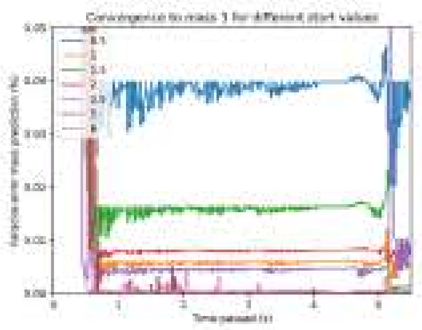
Cube and axes for reference



3.2 Performance with different initial estimate error

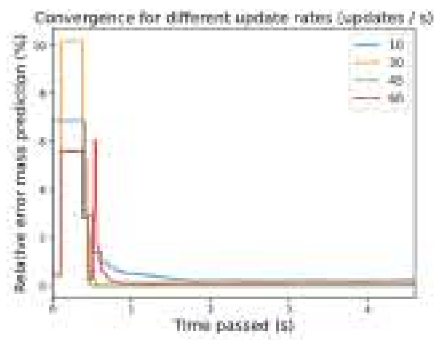
The accuracy of the initial guess has minimal impact on the convergence time and eventual accuracy of the estimation. Lower estimates may result in early peaks during the estimation process

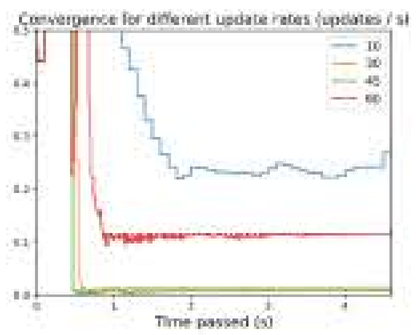




3.3 Performance sensitivity to update frequency

The accuracy of the initial guess has minimal impact on the convergence time and eventual accuracy of the estimation. Lower estimates may result in early peaks during the estimation process





5 Conclusions

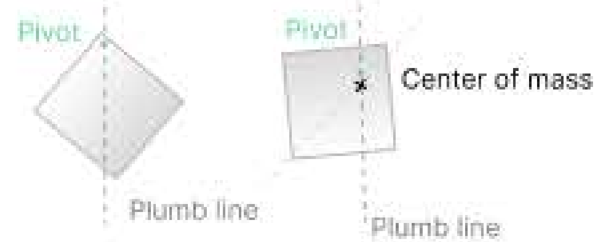
The established mass estimation technique achieves stable mass estimation with an error rate of less than 0.01%, if the initial value is above 66% of the actual mass.

The mass estimation system also shows solid performance at lower update frequencies.

The Center of Mass prediction method has proven to be more complex than anticipated. While a descent method can theoretically be developed, Unity is optimized for performance and not necessarily for realism in physics aspects, thus relying solely on differences in rotational velocity values and physics-based calculations is challenging

6. Future work

- Add certainty factor to diminish noise
- Calibration (for efficiency perspective)
- Compound and more complex objects
- 3 dimensions



References

[10] Unity Technologies. Physic material. https://docs.unity3d.com/520/Documentation/Manual/class-PhysicMaterial.html. Accessed Jun. 14, 2023.