Initial Mass and Center of Mass Estimation of Objects from Their Point Clouds

Sven Pegels (s.x.l.pegels@student.tudelft.nl)
Supervisor: Kees Kroep
Responsible professor: Dr. Ranga Rao Venkatesha Prasad

1. Background

- **Tactile Internet** aims to allow for the perception of physical touch over the internet.
- A **round-trip-latency requirement** of 1 ms limits the operating distance to 150km [1].
- A possible alternative is to **simulate the remote environment** on a local computer to provide near-instant feedback.
- The simulation requires several **properties** like **mass** and **Center of Mass** of the objects in the environment.
- An **initial estimation** of these properties is required before any physical interaction takes place.
- The remote environment can be observed using **depth cameras**, providing **3D point clouds**.

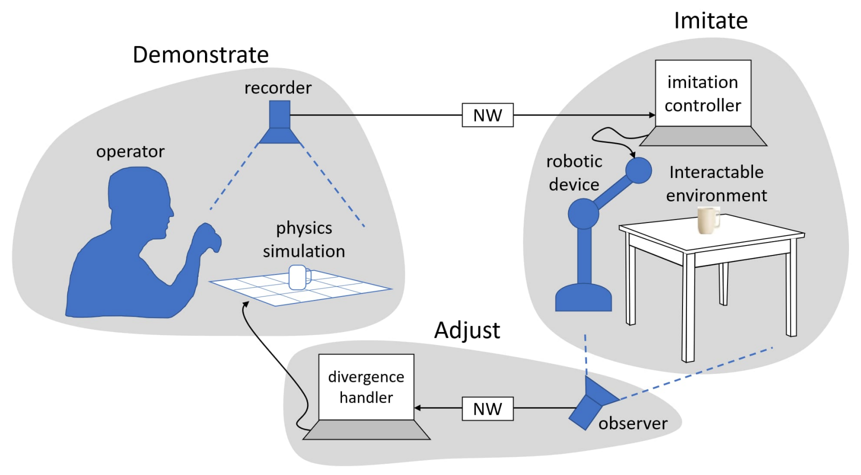

Figure 1. Teleoperation setup using a local simulation [2].

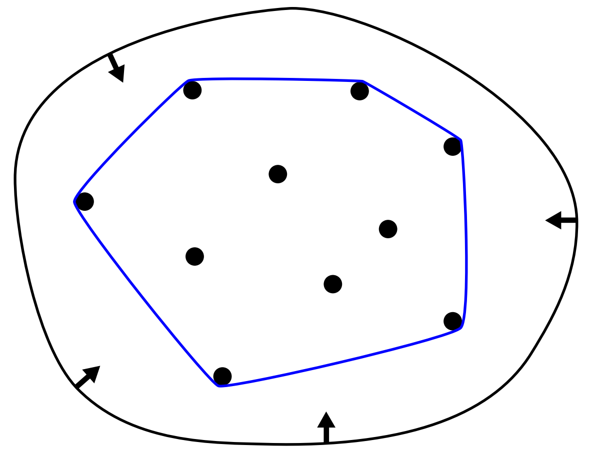

Figure 2. 2D Convex Hull [3].

2. Research Question

We want to make an initial estimation of the mass and Center of Mass of an object, thus we ask **"What techniques can be used to make an initial estimation of the mass and Center of Mass of objects?"**

- How **accurately** can the mass and Center of Mass of an object be estimated?
- Are these estimates still accurate when part of the **object is occluded**?
- How does the **resolution of sensors** impact the accuracy of the estimations?

Object	AABB error	OBB error	Convex Hull error
Sphere	2.08	2.07	1.00
Cube	1.00	1.00	1.00
Cylinder	1.28	1.28	1.00
Cone	3.84	3.84	1.00
Torus	2.66	2.66	1.89
Mug	9.68	10.35	6.51

Table 1. Volume estimation results from full data.

Object	AABB error	OBB error	Convex Hull error
Sphere	0.00	0.00	0.00
Cube	0.00	0.00	0.00
Cylinder	0.00	0.00	0.00
Cone	5.00	5.00	4.39
Torus	0.00	0.00	0.00
Mug	2.73	2.47	2.27

Table 2. CoM estimation results from full data.

3. Methodology

- Assume noiseless data [4], ability to separate objects [5], and known density [6].

Mass

- Known density leaves only **volume** to be estimated.
- 3 volume estimation approaches:
  a. Volumes of an Axis-Aligned Bounding Box (**AABB**) and Oriented Bounding Box (**OBB**) of an object.
  b. Volume of a **convex hull** around an object (Figure 2).

Center of Mass (CoM)

- 3 similar CoM estimation approaches:
  a. Centers of the **AABB** and **OBB**.
  b. Vertex average of a **convex hull**.

Occlusion

- Assuming a **single viewpoint**, about **50%** of the object is **visible**.
- **Volume**
  a. **AABB** and **OBB** volume, as extra space in the boxes compensates missing part.
  b. **Convex hull** volume **multiplied by 2**, as it fits more tightly around the points.
- **Center of Mass (CoM)**
  a. Centers of the **AABB** and **OBB**.
  b. Vertex average of the **convex hull, projected onto a plane** perpendicular to camera direction, positioned at the back of the hull.

4. Results

Experiments

- On complete point clouds of 6 virtual objects.
- On partial views generated from **multiple angles** and at a **range of resolutions**, using a virtual depth camera [#].

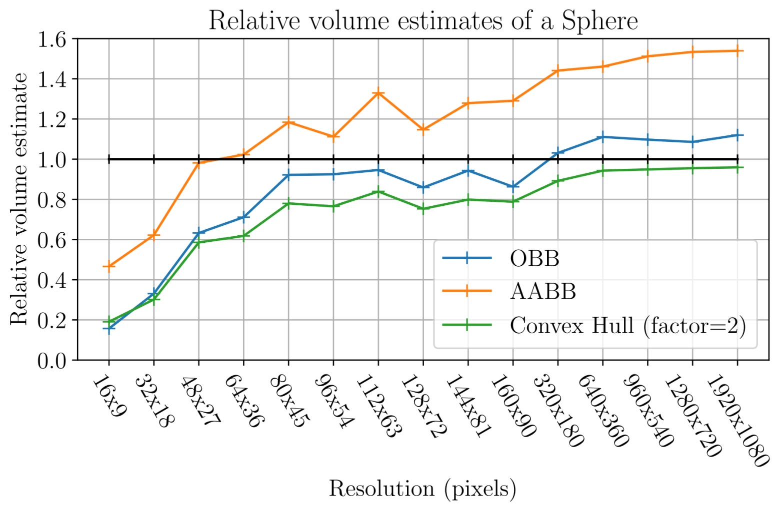

Figure 3. Volume estimation results from the partial view of a Sphere over a range of resolutions.

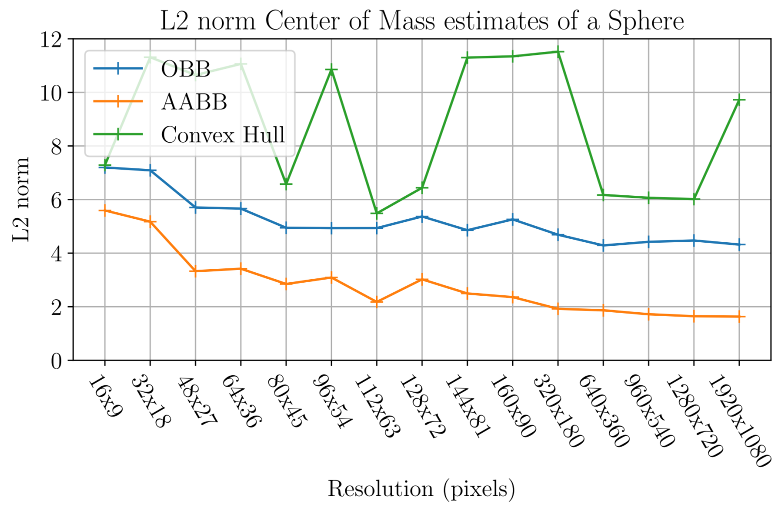

Figure 4. CoM estimation results from the partial view of a Sphere over a range of resolutions.

5. Conclusion

Volume (Table 1)
- For **simple** objects, the **convex hull** approach provides **accurate** volume estimates, as well as an **improvement** over previous results [7].
- For objects with holes and other **concave features**, **none** of the approaches are sufficiently accurate. A **concave hull** might provide better estimates.

Center of Mass (CoM) (Table 2)
- For relatively **symmetrical objects**, all three approaches provide a highly **accurate** CoM estimate.
- For **less symmetrical** objects, the estimates have a **greater error**, but still provide a **usable** CoM.

Occlusion
- For **volume**, the **convex hull** approach is generally the **most accurate**. The error is greater for objects with **hard edges**, as well as with **concave features**.
- For **CoM**, the **error significantly increases** for all objects.
- Thus **gathering multiple viewpoints** of the object will likely **increase accuracy** of both properties.

Resolution (Fig. 3 & 4)
- For **volume**, the errors of all approaches stabilise at a resolution of '640×360'.
- For **CoM**, convex hull is **highly inconsistent**. AABB and OBB error **stabilise** at a much **lower resolution**.
- These results are **highly dependent** on **distance** from the object, **size** of the object and **Field of View** (FoV)

6. Future Work

- Explore the **convex hull** approach **using the CoM** instead of vertex average.
- Look into using a **concave hull** to allow for better estimates on object with concave features

[1] Gerhard P. Fettweis. The tactile internet: Applications and challenges. IEEE Vehicular Technology Magazine, 9(1):64–70, 2014.
[2] Figure by Kees Kroep.
[3] User:Prboks3, https://en.wikipedia.org/wiki/Convex_hull, 2008.
[4] Radu Bogdan Rusu and Steve Cousins. 3d is here: Point cloud library (pcl). In 2011 IEEE international conference on robotics and automation, pages 1–4. IEEE, 2011.
[5] Eleonora Grilli, Fabio Menna, and Fabio Remondino. A review of point clouds segmentation and classification algorithms. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 42:339, 2017.
[6] Tamas Aujeszky, Georgios Korres, Mohamad Eid, and Farshad Khorrami. Estimating weight of unknown objects using active thermography. Robotics, 8(4):92, 2019.
[7] Thomas Baars, "Estimating the mass of an object from its point cloud for Tactile Internet", 2022.