Estimating the mass of an object from its point cloud for Tactile Internet

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1. Background

- Tactile Internet (TI) aims to allow real-time interaction between remote systems.
- However, ultra-low latency (ULL) networks have a distance limitation, as the speed of information is limited to the speed of light.
- A possible solution is to use a local physics simulation that matches the remote environment.
- But how can we simulate any remote environment locally? By using visual information to estimate the properties of objects.
- An RGB-D camera, such as the Microsoft Kinect, can be used to obtain both color and depth information of the objects in its field of view.
- This information can be represented in a point cloud - an array of points with XYZ-coordinates (and RGB-values).

Figure 1. Microsoft Kinect v1 [1].

Figure 2. A point cloud of objects on a table [2].

2. Research Question

- We want to be able to estimate the physical properties of objects in scenes similar to Figure 2.
- This is a complex problem, so perhaps a good starting question is: how to estimate the mass of an object from its point cloud?
- Assuming the density of the object can be obtained based on the material properties estimated from its point cloud.
- Then all we need is the volume of the object.

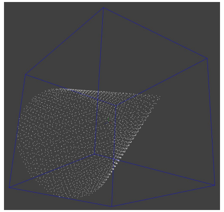

Figure 3. The computed oriented bounding box (OBB), shown in blue, for the downsampled point cloud of a cone.

3. Methodology

- A test set of synthetic point clouds was generated using artificial objects with varying rotations.
- Using this test set, we evaluated two volume estimation approaches:
  1. Based on the volume of the oriented bounding box (OBB).
  2. Based on the volume of the mesh.
- The mesh was created using a greedy triangulation surfacing algorithm implemented by the Point Cloud Library (PCL).
- The volume of the resulting mesh was estimated by subdividing it using tetrahedrons.

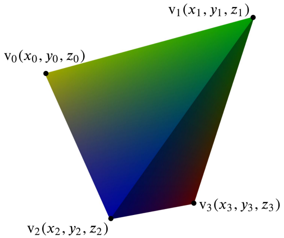

Figure 4. A tetrahedron - created from the vertices of a triangular face in the mesh, v_1, v_2, and v_3, and the approximate center of the mesh, v_0.

- The volume of the tetrahedron can be calculated as follows:

$$\frac{1}{6}|-(x_2-x_0)(y_3-y_0)(z_1-z_0)+(x_3-x_0)(y_2-y_0)(z_1-z_0) +(x_2-x_0)(y_1-y_0)(z_3-z_0)-(x_1-x_0)(y_2-y_0)(z_3-z_0) -(x_3-x_0)(y_1-y_0)(z_2-z_0)+(x_1-x_0)(y_3-y_0)(z_2-z_0)|$$

- The sign of the volume is determined by the inner product of the vector from the center, v_0, to the vertex v_1, and the normal of the triangular face.

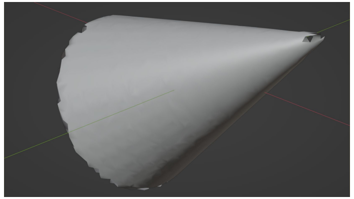

Figure 5. The resulting mesh of the pont cloud for a cone (rotated 45°).

4. Results

Object	Rotation (degrees)	Expected Value (cm³)	Mean OBB Estimate (cm³)	Mean Mesh Estimate (cm³)	Mean OBB Error (%)	Mean Mesh Error (%)
Box	0.00	20,250.00	20,253.93	18,629.75	0.02%	8.00%
	7.00	20,250.00	20,857.21	18,689.14	3.00%	7.71%
	45.00	20,250.00	20,506.21	19,161.78	1.27%	5.37%
Cone	0.00	4,581.66	17,931.24	4,655.32	291.37%	1.61%
	7.00	4,581.66	18,093.50	4,620.15	294.91%	0.84%
	45.00	4,581.66	18,219.28	2,605.36	297.66%	43.13%
Mug	0.00	46,941.40	95,572.11	45,555.86	103.60%	2.95%
	7.00	46,941.50	95,669.36	45,377.22	103.81%	3.33%
	45.00	46,941.60	96,368.45	45,565.43	105.29%	2.93%
Torus	0.00	10,846.60	28,223.36	10,768.54	160.20%	0.72%
	7.00	10,846.60	28,319.24	10,763.14	161.09%	0.77%
	45.00	10,846.60	28,389.51	10,763.63	161.74%	0.76%

Table 1. The results obtained from the 2 volume estimation approaches on the test set.

5. Conclusions

- In general, the mesh volume estimate performs better than the OBB volume estimate, in terms of the mean percent error.
- But performs worse than some other existing volume estimation methods, such as the method used in "Object Volume Estimation Based on 3D Point Cloud" [3].
- The test set used may be incompatible with the surfacing algorithm used.
- Further research should be conducted to verify the assumptions made.

References:
[1] Z. Zhang, “Microsoft kinect sensor and its effect,” IEEE Multimedia, vol. 19, pp. 4–10, 2 Feb. 2012, issn: 1070-986X. doi: 10.1109/MMUL.2012.24. [Online]. Available: http://ieeexplore.ieee.org/document/6190806/
[2] A. Makhal, F. Thomas, and A. P. Gracia, “Grasping unknown objects in clutter by superquadric representation,” Oct. 2017. [Online]. Available: http://arxiv.org/abs/1710.02121.
[3] W.-C. Chang, C.-H. Wu, Y.-H. Tsai, and W.-Y. Chiu, “Object volume estimation based on 3d point cloud,” in 2017 International Automatic Control Conference (CACS), pp. 1–5, IEEE, 2017.