3D intersection calculation algorithms on point clouds for mid-air haptic systems

End of studies project of **DELFOSSE Charlotte**

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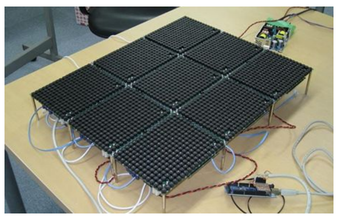
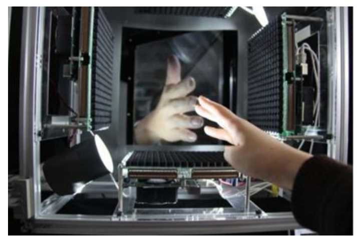
Introduction to Mid-air Haptic Systems

Mid-air haptic systems are systems in which users can **interact** with an interface and have a **haptic feedback**. The haptic feedback is a pressure on the skin of hands and fingertips. It is created by ultrasound wave interference and enables to feel and move virtual objects in **real-time**.
Two components are required to create a mid-air haptic system:



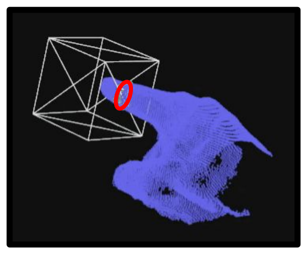
While Infrared sensor (left) enables to capture the data of moving hands in real time, Airborne Ultrasound Transducer Arrays (AUTDs, right) enable to produce the haptic feedback somewhere on the hand which data has been captured.

Intersection Calculation in Previous Mid-air Haptic Systems[1,2]



With mid-air haptic systems, users can touch and move virtual objects. A virtual object is defined by a set of points in 3D space. Its existence is simulated by haptic feedback at the **intersection** of the finger with the object.

Haptic feedback has been provided previously at the cross-section intersection of the hand and the virtual object. This research aims at finding algorithms to enable the inner sensing of virtual objects.

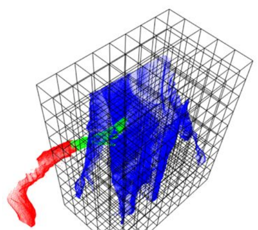


Problem Statement

How to enable the inner sensing of virtual objects in real time ?

The goal is to find a real-time 3D intersection algorithm on point clouds.

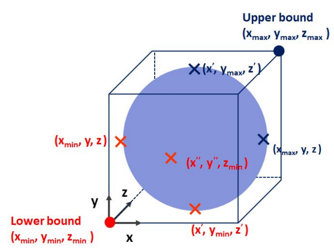
Voxel algorithm



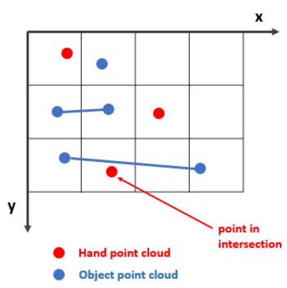
The voxel algorithm consists in calculating intersection of two point clouds directly without any surface reconstruction. A voxel is the unit element of a 3D grid.

For testing if points of a hand are inside a virtual object, the algorithm consists of :

1. Creating a **minimal bounding box** encompassing the **virtual object**
2. Traversing the bounding box to find points **within the interval formed by two points of the object**



Step 1.



Step 2.

Results

number of voxels	1150	3375	8100	27050
number of points in result	139	156	147	144
number of missing points	80	54	61	58
number of extra points	23	14	12	6
accuracy	0.529	0.676	0.649	0.683
running time (ms)	11	30	80	220

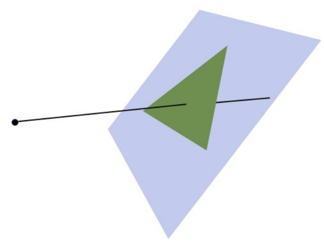
The voxel algorithm was tested on the point cloud of a hand and a sphere each containing 1000 points. The accuracy is relatively low, which can be explained by changes in the density of either or both point cloud. Running time can be lowered by using an accelerating structure for the virtual object.

Crop Hull Algorithm

The Crop Hull algorithm enables to calculate intersection of a hand point cloud and virtual object by **reconstructing the surface of the object**[3].

The method is based on **ray tracing**[3] for checking if a point is inside the object.

Reconstructing the surface consists in generating a **triangular mesh** out of the object's point cloud. The mesh is a **concave hull**.



Ray tracing consists in finding intersections between a ray casted from points of the hand and triangles of the mesh. The **number of intersections** found finally indicates if the point is inside the mesh or not.

The performances of the algorithms can be improved by using a **KD-tree structure**. The tree partitions the triangles of the mesh and drastically reduces the number of intersection tests.

Results

number of points in result	number of missing points	number of extra points	accuracy	number of ray-triangle tests	time for building kd-tree (ms)	time for intersection finding (ms)
196	1	0	0.995	9965	2.7	1.7

The Crop Hull algorithm with KD-tree was tested on the point cloud of a hand and a sphere each containing 1000 points. It gives quality output and runs in real time for the given data. The algorithm can thus be integrated into a mid-air haptic system.

Publications

1. Yasutoshi Makino, Yoshikazu Furuyama, Seki Inoue, and Hiroyuki Shinoda. 2016. Haptoclone (haptic-optical clone) for mutual tele-environment by real-time 3d image transfer with midair force feedback. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, pages 1980–1990.
2. Atsushi Matsubayashi, Hiroki Oikawa, Saya Mizutani, Yasutoshi Makino, and Hiroyuki Shinoda. 2019. Display of haptic shape using ultrasound pressure distribution forming cross-sectional shape. In *2019 IEEE World Haptics Conference (WHC)*, pages 419–424. IEEE.
3. R.B. Rusu and S. Cousins. 2011. 3d is here: Point cloud library (pcl). In *Robotics and Automation (ICRA), 2011 IEEE International Conference on*, pages 1 –4.