View Planning for 3D Modeling of Outdoor Environments by Voxel Model with Object Existence Probability

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3D model of outdoor scenes

Useful for applications of ubiquitous networked media computing

- Virtual walk-through
- Site simulation
- Wearable AR
  (Human navigation)

These models are made manually with high cost.

Virtual walk-through

Automatic 3D modeling of outdoor scenes by using a laser rangefinder has been widely investigated.

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3D modeling using a rangefinder

A rangefinder can acquire 3D shape of object.

Acquired partial shape

Integrated model (10 data)

The whole model is generated by registering partial shapes.

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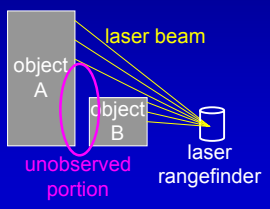
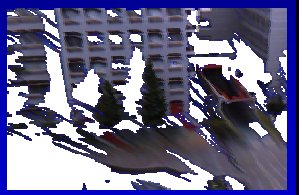
The modeling problem

Unobserved portions caused by occlusions become missing portions of a 3D model.





White portions are unobserved portions.

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View planning for 3D modeling

Search of the position where range data which reduce unobserved portions efficiently is acquired

- Motivation
  - Reduction of the number of times of data acquisition.
  - Reduction of unobserved portions.

Instruction of the NBV (Next Best View) from acquired range data

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3D model for calculation of NBV

"View Planning for automated 3D object reconstruction and inspection" [Scott et al. 2003]

- Surface-based method (polygon model)
  - Suitable for expression of detailed 3D shape.
  - Addition in range data causes increase of memory usage.
- Volumetric-based method (voxel model)
  - Shape accuracy depends on the voxel size.
    - Memory usage does not depends on the number of range data.
  - Compact method of encoding spatial occupancy.

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Application to the outdoor modeling

- Wide modeling area
  - Large memory requirement for 3D model
    - Use of voxel model with object existence probability.
  - Consideration of moving efficiency
    - Creation of the map which show the recommendation rate of acquisition.
- The necessity for registration of acquired range data
  - Acquisition of the overlapping portions required for registration.

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Objective

Support of the decision of next measurement position by using a recommendation rate map

Approach：

- Recommendation rate is calculated from voxel model.
- Creation of the map which show recommendation rate
  - The map is updated when range data are acquired.
  - Next acquisition position is decided by a sensor operator.
  - The contents of instruction require only position by using an omnidirectional rangefinder.
- Acquisition of the portions which overlap acquired range data for registration

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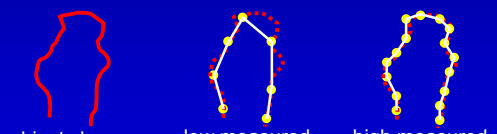
Recommendation rate of acquisition

The rate which raises reliability of object shapes in modeling area.

- Reliability of object shape = measured density by a rangefinder
  - Portions of low measured density : low reliability.
  - Unobserved portions : no reliability.



object shape　low measured density　high measured density

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Voxel model with object existence probability

Information of each voxel

- Object existence probability
  - The probability that a laser beam will reflect.
  - A ratio of the frequency of reflection and passage in the voxel.
- Maximum measured density
  - Reliability of object shape in the voxel.
  - Spatial resolution of laser beams in the voxel.
- Normal vector (when a plane exists in the voxel)
  - Registration is performed using plane based ICP algorithm.

In the initial state, object existence probability is 1 and maximum measurement density is 0

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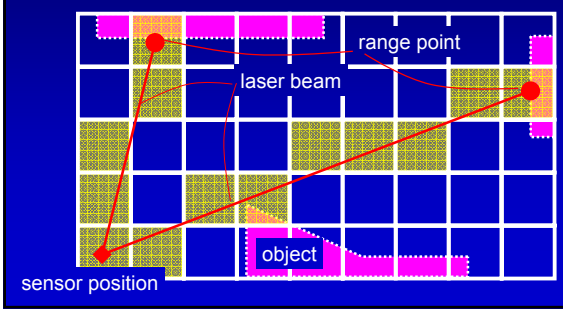
Construction of a voxel model

Object existence probability

Sensor position and range points are quantized to the voxel resolution.
Search of voxels which laser passed by Bresenham line-drawing algorithm.



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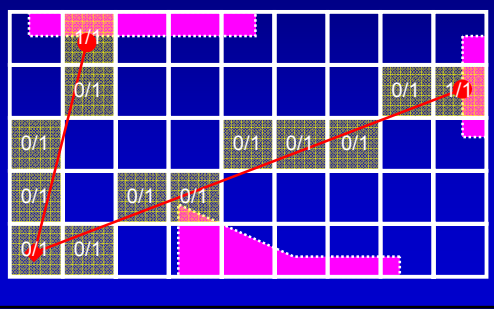
Construction of a voxel model

Object existence probability

Count of frequency of reflection and passage of laser beam.
Object existence probability = reflection / (reflection + passage)



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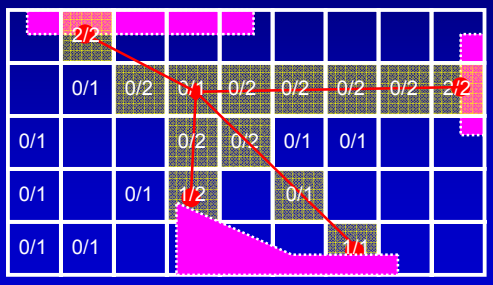
Construction of a voxel model

Object existence probability

When another range data is added.



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Calculation of recommendation rate

Sum of products of density difference and reflective probability at each voxel.

P_{In} , d_n : object existence probability and maximum measured density of V_{In}

d'_n :Density of V_{In} from the position where rate is calculated

D_{In} : Density difference at V_{In} { $d'_n - d_n$ $(d'_n > d_n)$; 0 $(d'_n \leqq d_n)$

Rate of the laser = $P_{I1} D_{I1} + P_{I2}(1-P_{I1}) D_{I2} + P_{I3}(1-P_{I2})(1-P_{I1}) D_{I3}$

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Preliminary experiment for our campus

- Use of omnidirectional laser rangefinder (Riegl Inc. LMS-Z360)
  - Angle : 360[deg]×90[deg]
  - Resolution : 1024×512.
  - Measurable range : 200m
- Voxel size is 1m.
- Calculation of recommendation rate is performed at intervals of 1m.
  - Acquisition height from the ground of rangefinder is known
  - workable area of range data acquisition is known.
- The recommended positions where the overlapping plane area can acquire 10% of all laser.

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Experimental result

First time　　Second time

Data acquisition position and recommendation rate map

× Data acquisition position

■ Area where plane portions cannot be acquired sufficiently

low ▬▬▬ high

recommendation rate

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Conclusion

- View planning by using voxel model with object existence probability.
  - Reduction of memory usage and calculation cost.
- Support of the decision of next measurement position by using a recommendation rate map.

Future work

- Evaluation of proposed method.
- Experiments in wide area urban environment.

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