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14. ABSTRACT

This STIR project focuses on the development of 3D shape matching and recognition techniques specially targeted for 3D modeling. The ultimate objective of our research is to develop effective methods for rapid creation of large-scale 3D models from 3D geospatial sensor data, and specifically LiDAR point clouds. Our technical approach is a novel alternative to traditional modeling approaches. The novelty arises from using the strategy of Modeling by Recognition (MBR) to rapidly identify objects from a 3D library of objects within point-cloud data.

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LiDAR, 3D modeling, Shape matching, Object recognition, Self-similarity

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Report Title

Rapid Creation of Large-scale 3D Models

ABSTRACT

This STIR project focuses on the development of 3D shape matching and recognition techniques specially targeted for 3D modeling. The ultimate objective of our research is to develop effective methods for rapid creation of large-scale 3D models from 3D geospatial sensor data, and specifically LiDAR point clouds. Our technical approach is a novel alternative to traditional modeling approaches. The novelty arises from using the strategy of Modeling by Recognition (MBR) to rapidly identify objects from a 3D library of objects within point-cloud data. The recognized-object point clouds are then replaced with library data, such as polygon surface models, thereby constructing accurate and complete 3D scene models.

Our research foci are the key components in the proposed modeling approach: the 3D shape matching algorithms that are used to detect objects of interest from point-cloud inputs and match them to model-library elements.

We pursued shape matching algorithms in two ways: (1) Global primitive analysis for automatically detecting and extracting primitive shape geometry such as planes, cylinders and cuboids from point-cloud data, and (2) Local-feature techniques for representation of point-cloud features to produce unique 3D geometric descriptions for general 3D shape matching. We designed and implemented the approaches, and then evaluated them extensively with various datasets. Ultimately, these methods can become the core of a unified framework for automatic matching of point cloud data to a library of model components for creating both 3D models and object recognition/labeling.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

05/01/2013 1.00 Jing Huang, Suya You, Jiaping Zhao, Ulrich Neumann. Multimodal Image Matching using Self Similarity, 2011 Applied Imagery Pattern Recognition Annual Workshop . 2011/10/11 03:00:00, . : ,

05/01/2013 2.00 J. Huang, S. You, U. Neumann. Point Cloud Matching based on 3D Self-Similarity, IEEE Conference on Computer Vision and Pattern Recognition . 2012/06/12 03:00:00, . : ,

TOTAL: **2**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Jing Huang	0.50	
FTE Equivalent:	**0.50**	
Total Number:	**1**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Ulrich Neumann	0.10	
Suya You	0.50	
FTE Equivalent:	**0.60**	
Total Number:	**2**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:......	0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:......	0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):......	0.00
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The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense	0.00
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Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:

Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

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Technology Transfer

Project Report
ARO project 61826-MA-II (W911NF-12-1-0118)
Rapid Creation of Large-scale 3D Models

Ulrich Neumann, Suya You
University of Southern California

1. Summary

This STIR project focuses on the development of 3D shape matching and recognition techniques specially targeted for 3D modeling. The ultimate objective of our research is to develop effective methods for rapid creation of large-scale 3D models from 3D geospatial sensor data, and specifically LiDAR point clouds. Our technical approach is a novel alternative to traditional modeling approaches. The novelty arises from using the strategy of **Modeling by Recognition** (MBR) to rapidly identify objects from a 3D library of objects within point-cloud data. The recognized-object point clouds are then replaced with library data, such as polygon surface models, thereby constructing accurate and complete 3D scene models.

Our research foci are the key components in the proposed modeling approach: the 3D shape matching algorithms that are used to detect objects of interest from point-cloud inputs and match them to model-library elements.

We pursued shape matching algorithms in two ways: (1) Global primitive analysis for automatically detecting and extracting primitive shape geometry such as planes, cylinders and cuboids from point-cloud data, and (2) Local-feature techniques for representation of point-cloud features to produce unique 3D geometric descriptions for general 3D shape matching. We designed and implemented the approaches, and then evaluated them extensively with various datasets. Ultimately, these methods can become the core of a unified framework for automatic matching of point cloud data to a library of model components for creating both 3D models and object recognition/labeling.

The STIR was pursued to flesh out some initial ideas in an earlier proposal. Reviewers expressed concerns about several issues that we addressed over the STIR term. These issues are summarized below.

Our initial proposal provided little detail about the efficiency of our proposed 3D matching methods. There was skepticism about the feasibility of doing 3D matching in a manner that is robust to noise and sparse data. Some specific methods and initial results were needed to claim feasibility and focus the effort.

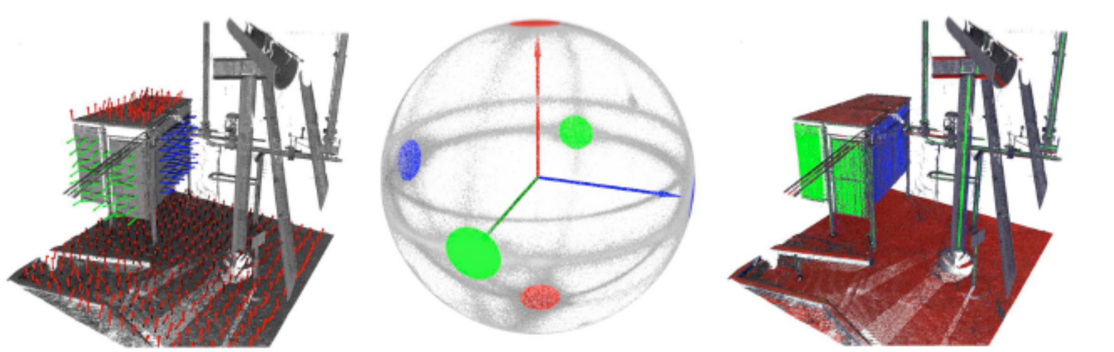
We believe that we've addressed these issues over the past months. We have developed and evaluated initial algorithms. We show results for real world data examples and provide measured performance. We believe the progress we made and the results of that effort are encouraging and make a compelling case that Modeling by Recognition (MBR) is in fact feasible and attractive as a new approach to the scene modeling and object labeling problems.

2. Description of research achievements

2.1 Techniques for detecting and modeling of primitive shapes

We focused on developing algorithms for automatic detection and extraction of primitive shapes and features such as planes, cylinders and cuboids from point-cloud data. We observe that a majority of urban man-made objects in existence are composed of primitives that often have planarity and regularity properties. This majority of object should be detected first and fitted to the raw data to form a simple and clean representation of the scene. The primitive shapes also serve as key backbones in further modeling process, providing additional constraints for the search for associated objects and propagate spatial relationships. For example, in aerial LiDAR of urban scenes, roofs and ground are often planar. In street-level LiDAR, facades and ground are often planar. Attempting to match planar surfaces is unlikely to succeed due to the lack of discriminating local features. Instead, our strategy is to extract the planar and cylinder shapes first using their global geometric properties. Modeling can proceed directly by replacing their point clouds with geometric surfaces. Labeling will require further analysis, which is beyond our scope in the STIR. However, we speculate that recognition based on a high-level description of planes and cylinders may be more tractable and successful than recognition based on low-level point-clouds,

An effective method for automatically detecting and modeling primitive shapes from point clouds is based on the concepts of the Gaussian sphere and global analysis derived from differential geometry. We employed two forms of global information: surface normals and axis-orientation to measure the regularity of surface. We adopt a statistical model based on normal analysis, which detects this global information automatically. Normals are computed for each data point using covariance analysis. The data points are converted to Hermite form or "oriented points", that is, 3D point positions with a normal vector. The Hermite points are then projected onto a Normal sphere (Gaussian sphere), which establishes distinctive patterns for feature detection and modeling (Figure 1). Circles indicate cylinders and point-clusters indicate planar surfaces are present. Figure 1 shows an example of a sphere map. The rings are distinctive signatures of Hermite scan data from cylinders of varied orientation. Color spots indicate aligned surface normals of



(a) (b) (c)

Figure 1: Illustration for plane detection: (a) Points on the parallel planes have similar normal, (b) Normals are projected onto a Gaussian sphere and clusters are detected; (c) Points are segmented based on locality of points within clusters.

planar surfaces. We process varied sizes of scan volumes to produce these spheres and then segment the scan points on a ring or at a spot. The sphere patterns are thus a representation of global object shape.

We have tested the approach with various point cloud datasets including ground-level LiDAR scans of industrial settings and complex urban scenes. Figure 1 shows a result of applying the method to detect and extract primitive shapes in a portion of an industrial scene. Figure 2 shows the modeled polygons for the primitives detected in the complete industrial scene. Figure 3 shows the results of applying the method to ground and aerial LiDAR of urban scenes (LA downtown area). The original LiDAR data of Figure 3 (a) and (b) contain 100.1M and 142.9M scanned points, respectively. Our approach detected and inferred 223 and 408 object clusters as primitive objects. The entire processing is completely automatic and the processing times are 410.7s and 482.5s, respectively.

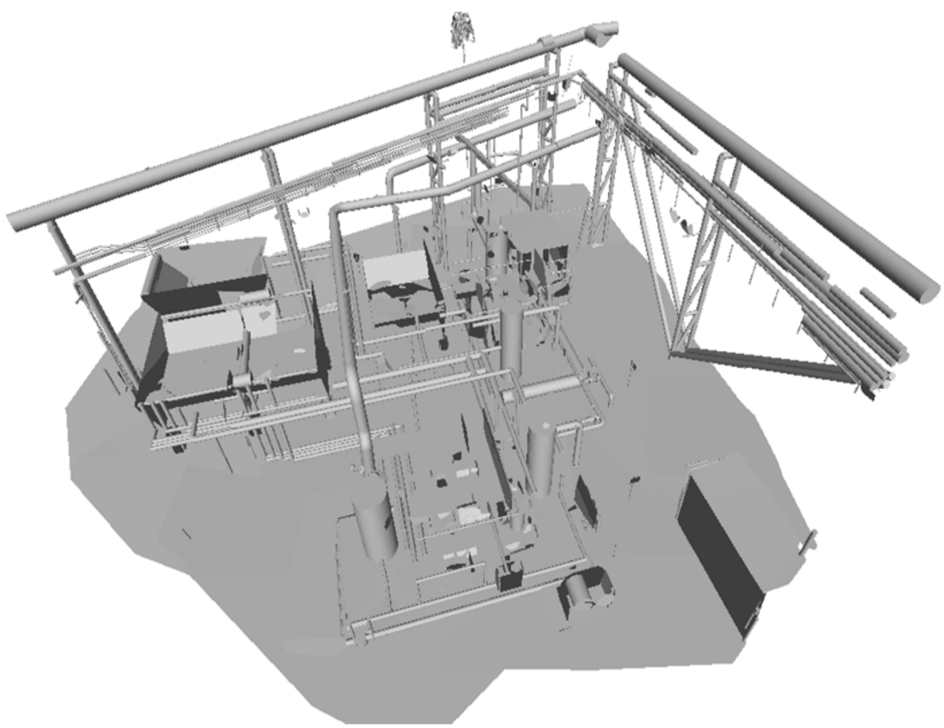
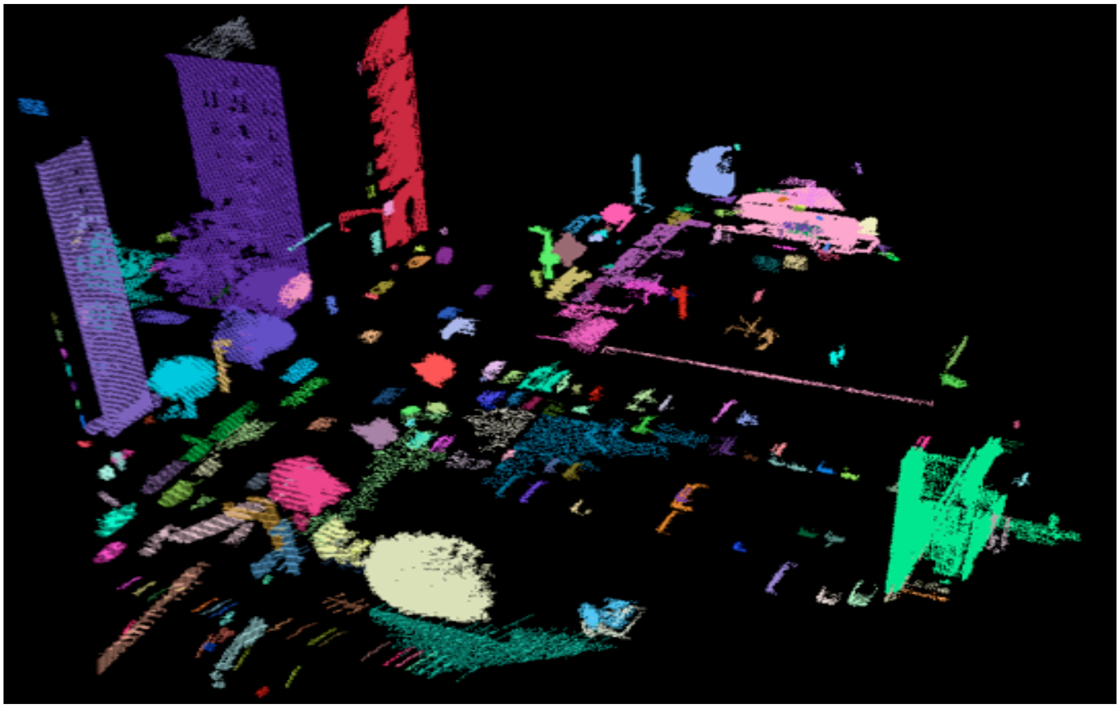
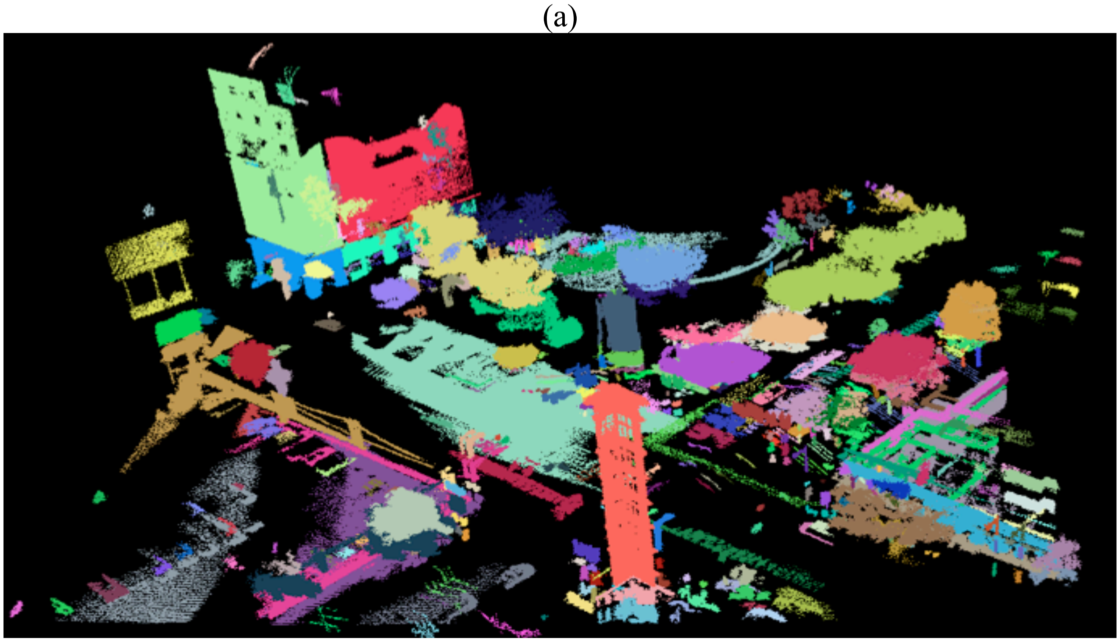


Figure 2: this industrial site scan model is automatically created from planar and cylinder primitives extracted and modeled by our algorithms.



(a)



(b)

Figure 3: Detected primitive shapes from point cloud data captured by ground and aerial LiDAR sensors (LA downtown area).

2.2 Techniques for feature-based scene description and shape matching

The second major focus is on algorithms for representing point-cloud features that encode unique local geometric properties for general 3D shape matching. Specially, we developed a novel representation and matching process based on the concept of *self-similarities*. Self-similarity is a unique property of fractals and topological geometry. It captures the internal geometric layout of local patterns in a level of abstraction. Locations in images with self-similarity structure of a local pattern are distinguishable from locations in their neighbors, which can greatly facilitate matching across images that appear substantially different at pixel level [Hua11].

We developed a unique 3D self-similarity feature descriptor and built a matching framework based on the descriptor for general shape matching. We define self-similarity as the property that is held by those parts of data that resemble themselves in comparison to other parts of the data. The resemblance can be photometric properties, geometric properties or their combinations. Photometric properties such as color, intensity or texture are useful for imagery, but they are unlikely to be useful on point clouds. We therefore turned to geometric properties as the essential information to use. Surface normals and curvatures characterize the geometric properties of a local surface; therefore we used these as self-similarity measurements to produce 3D feature descriptions for point matching. We can also considered photometric information in our descriptor and matching algorithms to generalize the problem.

The surface normal is an effective geometric property that enables human visual perception to distinguish local surfaces or shapes in point clouds. Normal similarity is robust to a wide range of variations that occur within disparate object classes. Furthermore, 3D point positions with normal vector (i.e. Hermite data) form a local cylindrical coordinate system that provides a view-independent description of a surface. Figure 3 shows corresponding descriptors based on surface normals for variations of point clouds obtained for similar surface shape.

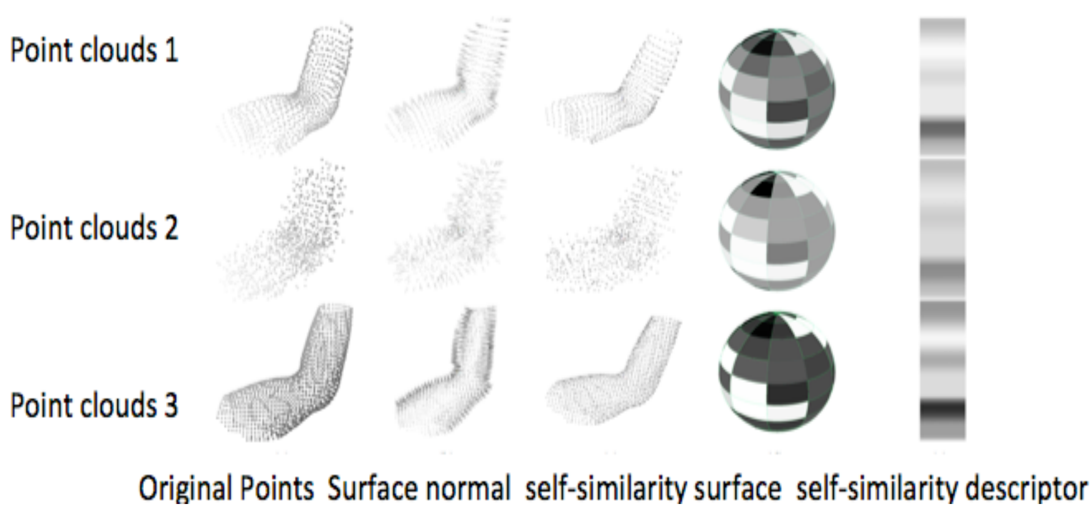


Figure 3: Illustration for using surface normals to produce a 3D self-similarity feature descriptor. The local internal layouts of self-similarities are shared by point cloud data with different geometric variations.

Curvature is another important geometric property we incorporated in similarity measurement. The curvature illustrates the changing rate of tangents. Curved surfaces always have varying normals, yet many natural shapes such as spheres and cylinders preserve curvature consistency. Since there are many possible directions of curvature in 3D, we used the direction in which the curvature is maximized, i.e. the principal curvature, to make it unique.

We extensively evaluated our 3D self-similarity descriptor and matching process in terms of robustness, accuracy and speed. Figure 4 shows some results of quantitative evaluation with SHREC benchmark datasets, and Table 1 shows the statistics of performance in terms of matching accuracy, robustness and computation time. Figure 5 shows the results on LiDAR point clouds, and Figure 6 shows the performance measures in precision-recall curves. More results and technical details of the method can be found in our recent publication [Hua12]. The results show that our 3D self-similarity algorithms efficiently capture distinctive geometric signatures embedded in point clouds. The resulting 3D self-similarity descriptor is compact and view/scale-independent, and hence can produce highly efficient feature representation and matching of point clouds.

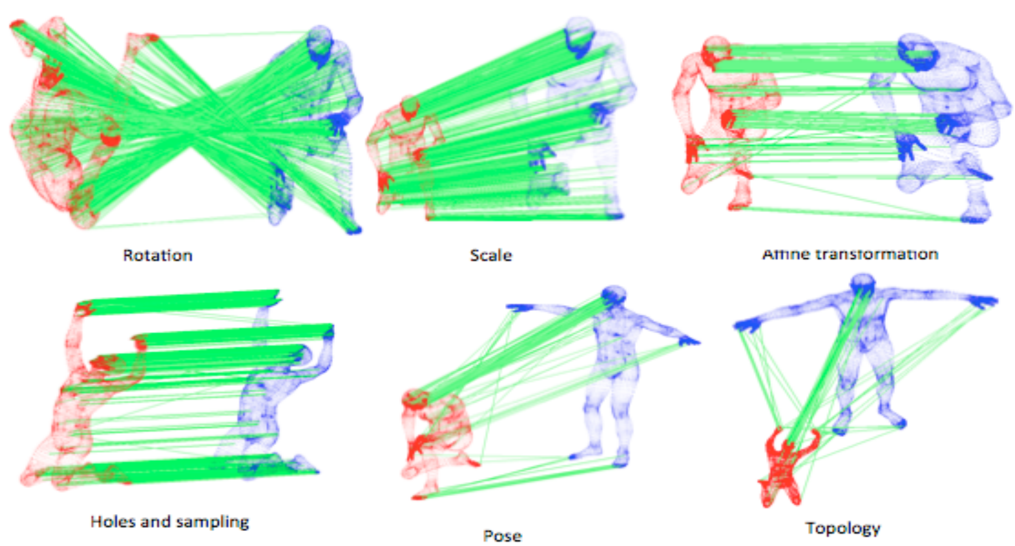


Figure 4: Quantitative evaluation results of our novel 3D self-similarity descriptor with SHREC benchmark datasets.

Table 1: Statistics of performance for SHREC datasets

Dataset	**Points #**	**Feature #**	**Match #**	**Time (s)**
Rotation	52,565 vs. 52,565	3,369 vs. 3,370	615	300.9
Scale	52,565 vs. 52,565	3,370 vs. 3,927	520	341.7
Affine	52,565 vs. 52,565	3,370 vs. 3,688	257	343.8
Hole	5,4410 vs. 5,2565	2,487 vs. 2,942	522	300.3
Pose	52,565 vs. 52,565	3,370 vs. 2,955	202	343.8
Topology	52,565 vs. 52,565	2,942 vs. 2,955	82	292.6

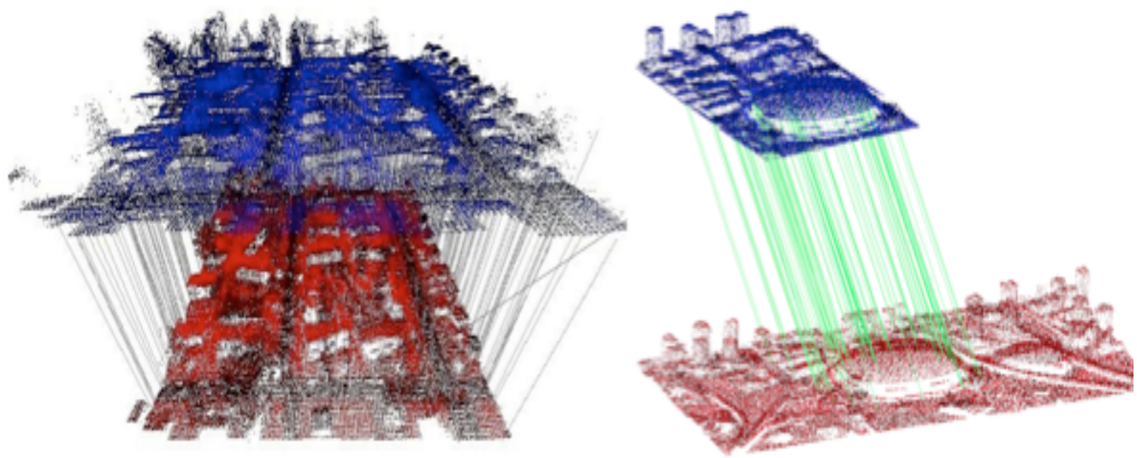


Figure 5: 3D self-similarity matching of aerial LiDAR point clouds (Vancouver area).

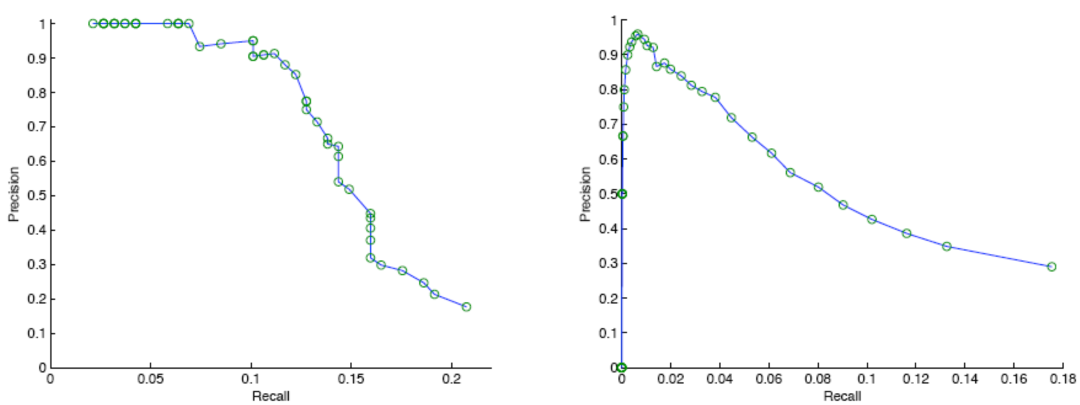


Figure 6: Precision-recall curves of matching on the LiDAR point data shown in Figure 5.

We developed an initial but complete matching system by combining the global primitive shape matching and the local self-similarity descriptor matching. The system is a focus-of-attention structure that first detects primitive objects to form key backbones, and then the local self-similarity matching is applied with the guide of the backbone objects. We applied the system for detection and recognition of commonly occurring objects in urban environments such as lamp posts, fire hydrants, street lights, mailboxes, chimneys, and vehicles. Figure 7 shows some sample results.

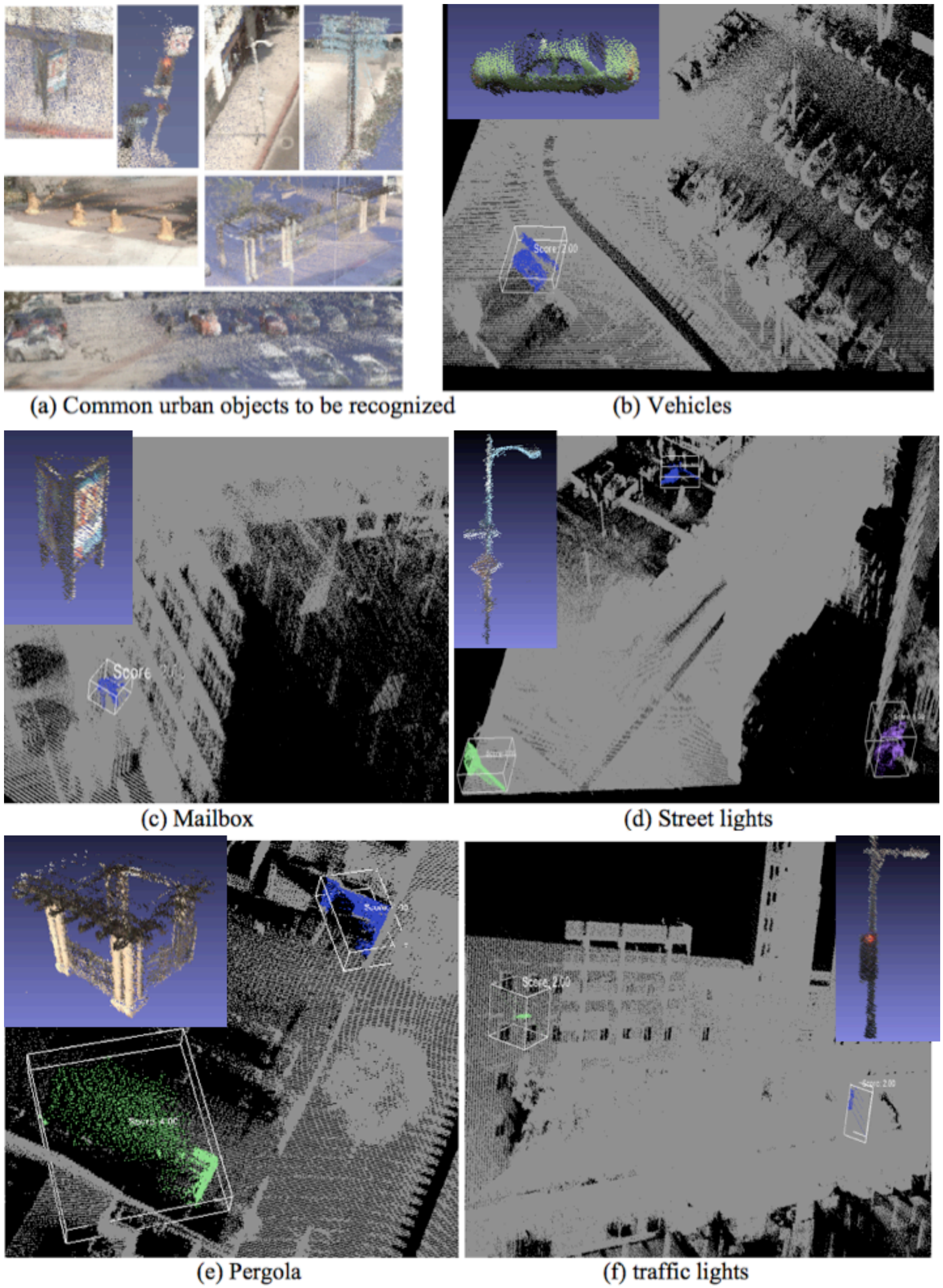


Figure 7: Applying the new matching approach for detection and recognition of commonly occurring urban objects from LiDAR point clouds (LA downtown area).

3. Conclusion

In conclusion, we feel that the issues raised by the earlier proposal reviews have been addressed. We feel the computation times are reasonable given the early stages of algorithm development and use of commodity PC computing systems.

We think that the feasibly of MBR has been shown. A combination of primitive recognition and general shape recognition has be applied to general LiDAR data with encouraging results. Robustness to noise and sparse data are difficult issues that require further work, but the results on real scan data indicate that MBR methods can work directly on commercial grade LiDAR without any special processing or considerations.

As for a specific research plan to pursue from here, we will elaborate in that in a full proposal.

4. References

1. [Hua11] J. Huang and S. You, "Multimodal Image Matching using Self Similarity," IEEE Applied Imagery Pattern Recognition Annual Workshop (AIPR), 2011
2. [Hua12] J. Huang, S. You and U. Neumann, "Point Cloud Matching based on 3D Self-Similarity," IEEE Conference on Computer Vision and Pattern Recognition (CVPR) 2012