**Machine Learning Engineer Nanodegree**

**Capstone Project**

**Classification of Objects in 3D Point Cloud Data**

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March 8, 2017

**I. Definition**

**Project Overview**

Images of things are no longer restricted to 2D pictures. Three dimensional images are becoming more available because of low cost commercial and industrial sensors. Sensors like the Microsoft Kinect allow anyone to create a 3D image of anything [Figure 1].

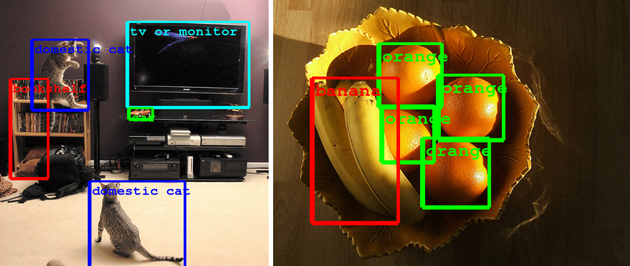


Figure : (left)3D Point cloud collected using a Microsoft Kinect (ref. <http://123kinect.com/wp-content/uploads/2012/08/Kinect-1-point-cloud-example.jpg>) (right) Google’s object recognition algorithm (ref. https://www.engadget.com/2014/09/08/google-details-object-recognition-tech/)

Just like with 2D images, it is now possible to do object recognition on 3D structures. Google, Microsoft and other tech companies have long had the ability to take a picture of a scene and identify the objects it contains [Figure 1]. It is now possible to do the same thing with these new 3D images. This has applications to things like gesture recognition for next generation user interfaces or industrial applications such as identifying structures from 3D survey data.

One application of 3D object recognition is the automatic identification of structures in a building survey. Surveys are no longer limited to measuring distances to single points on a job site. It is now possible to capture highly accurate 3D structural data [Figure 2]. The data collected during one of these surveys is what is termed a point cloud. A structure is represented as a dense collection of points in (x,y,z) possibly with brightness and color information. However, just as with images, there is no label attached to each point. The point cloud by itself does not identify walls, chairs, roofs, etc. It would be very useful to have these objects automatically identified within a point cloud. That is the goal of this project, to train a classifier to recognize a 3-dimensional object within a point cloud.

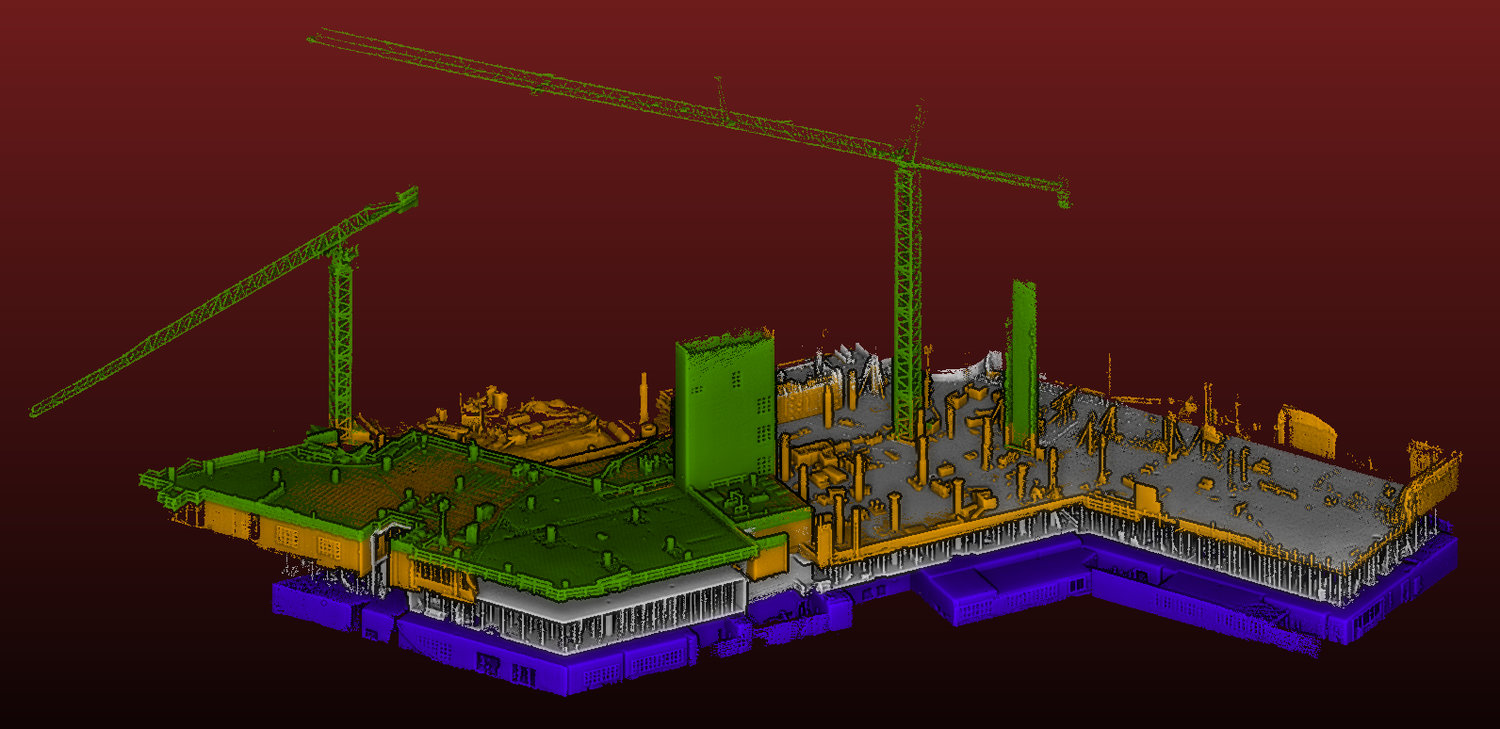


Figure : 3D Survey of a building under construction. The data is a 3 dimensional point cloud. In a point cloud, the building is represented by a dense cloud of (x,y,z) points, possibly with color or brightness information (Ref. kaarta.com/gallery)

In this section, look to provide a high-level overview of the project in layman’s terms. Questions to ask yourself when writing this section:

* *Has an overview of the project been provided, such as the problem domain, project origin, and related datasets or input data?*
* *Has enough background information been given so that an uninformed reader would understand the problem domain and following problem statement?*

**Problem Statement**

The purpose of this project is to create a supervised learning classifier to identify and locate an object within a 3D point cloud. Because this project uses supervised learning, a hand labeled data set must be created. The overall process used is the following:

1. Create point clouds of a prototypical scene
2. Hand label a training set
3. Define a set of features to train on
4. Investigate the data to ensure the defined features have the discriminating power necessary to separate the target object from others
5. Using cross validation, split the data in to a test and train set
6. Evaluate a variety of supervised learning algorithms,
7. Select the best performing algorithm
8. Tune the selected algorithm using grid search to optimize its parameters
9. Test the optimized algorithm on other point clouds to see if it can detect the object in untrained data

In this section, you will want to clearly define the problem that you are trying to solve, including the strategy (outline of tasks) you will use to achieve the desired solution. You should also thoroughly discuss what the intended solution will be for this problem. Questions to ask yourself when writing this section:

* *Is the problem statement clearly defined? Will the reader understand what you are expecting to solve?*
* *Have you thoroughly discussed how you will attempt to solve the problem?*
* *Is an anticipated solution clearly defined? Will the reader understand what results you are looking for?*

**Metrics**

To measure the performance of the classifier, the F1 score is used. The classifier we are going to create is binary. A set of features either represents the target object or it does not. The F1 score measures the accuracy of a test with binary results. With a test, there are four possible outcomes: true positive, false positive, true negative and false negative. Given the rate of true positives, true negatives, etc. the precision, recall and F1 score of a test are defined as:

Figure 3: Possible test results are True positive, false positive, false negative and true negative

True Positive

Test Result

False Negative

True Result

True

False

False Positive

True Negative

True

False

The F1 score has a maximum value of 1 if the test results match the true results and a minimum value of 0 if the test is always wrong.

In this section, you will need to clearly define the metrics or calculations you will use to measure performance of a model or result in your project. These calculations and metrics should be justified based on the characteristics of the problem and problem domain. Questions to ask yourself when writing this section:

* *Are the metrics you’ve chosen to measure the performance of your models clearly discussed and defined?*
* *Have you provided reasonable justification for the metrics chosen based on the problem and solution?*

**II. Analysis**

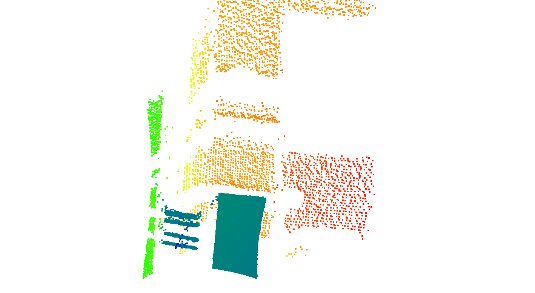
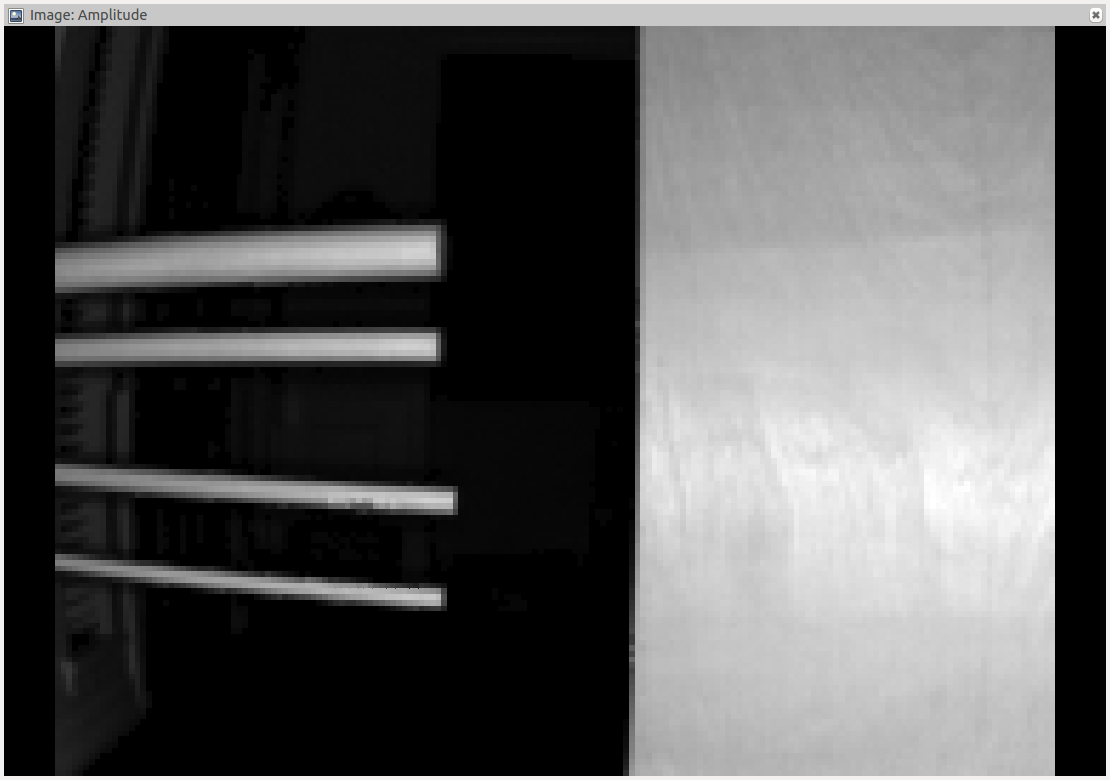
*(approx. 2-4 pages)*

**Data Exploration**

The purpose of this project is to create a classifier which can identify pipe-like structures within a 3D point cloud. Towards this end, I created a prototypical scene with a series of pipes, surrounded by walls and other objects [Figure 4]. The 3D scene was imaged by an IFM 03D303 flash lidar from several different angles. The flash lidar generates a 3D point cloud of the scene. Each pixel in the 3D point cloud has a value (x ,y, z, intensity) [Figure 5]. This raw data cannot be used by the classifier because a single point does not contain enough information to describe what it is a point of. Instead, the features describing a point must come from a region of the point cloud. Given the size of object being classified and the resolution of the flash lidar, a 6cm cube is an appropriate volume. However, because points within the point cloud are not evenly distributed, the size of the cube must be adapted especially in areas of low point density (Zakhor, 2011). In the case where insufficient points are located in a 6cm cube, the size of the cube is increased until a minimum number of points (15) are included. This is to ensure that a sufficient number of points are used to generate accurate statistics of the volume.

Figure : 3D Scene with pipes, walls and other objects

Figure : Flash Lidar Output. (a) Intensity image, (b), (c) point cloud as viewed from different angles. Points colored by distance from the sensor



(a)

(b)

(c)

Once a representative group of points is gathered, features describing the local geometry are calculated. The features used are common in analysis of point clouds. They use the eigen values and vectors of the covariance matrix in the region around a point. Given the eigen values of the covariance matrix, the geometric features are , the geometric features represent point-ness, surface-ness and linear-ness of the region. In addition, directional features using the local tangent and normal vectors. The tangent and normal vectors are estimated using the eigen vectors of the largest and smallest eigen values. The sine and cosine of these vectors with respect to the horizontal plane are used, giving a total of 4 directional features. To estimate the confidence in these features, the features are scaled according to the strengths of their corresponding eigen values: .

In this section, you will be expected to analyze the data you are using for the problem. This data can either be in the form of a dataset (or datasets), input data (or input files), or even an environment. The type of data should be thoroughly described and, if possible, have basic statistics and information presented (such as discussion of input features or defining characteristics about the input or environment). Any abnormalities or interesting qualities about the data that may need to be addressed have been identified (such as features that need to be transformed or the possibility of outliers). Questions to ask yourself when writing this section:

* *If a dataset is present for this problem, have you thoroughly discussed certain features about the dataset? Has a data sample been provided to the reader?*
* *If a dataset is present for this problem, are statistics about the dataset calculated and reported? Have any relevant results from this calculation been discussed?*
* *If a dataset is* ***not*** *present for this problem, has discussion been made about the input space or input data for your problem?*
* *Are there any abnormalities or characteristics about the input space or dataset that need to be addressed? (categorical variables, missing values, outliers, etc.)*

**Exploratory Visualization**

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In this section, you will need to provide some form of visualization that summarizes or extracts a relevant characteristic or feature about the data. The visualization should adequately support the data being used. Discuss why this visualization was chosen and how it is relevant. Questions to ask yourself when writing this section:

* *Have you visualized a relevant characteristic or feature about the dataset or input data?*
* *Is the visualization thoroughly analyzed and discussed?*
* *If a plot is provided, are the axes, title, and datum clearly defined?*

**Algorithms and Techniques**

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In this section, you will need to discuss the algorithms and techniques you intend to use for solving the problem. You should justify the use of each one based on the characteristics of the problem and the problem domain. Questions to ask yourself when writing this section:

* *Are the algorithms you will use, including any default variables/parameters in the project clearly defined?*
* *Are the techniques to be used thoroughly discussed and justified?*
* *Is it made clear how the input data or datasets will be handled by the algorithms and techniques chosen?*

**Benchmark**

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In this section, you will need to provide a clearly defined benchmark result or threshold for comparing across performances obtained by your solution. The reasoning behind the benchmark (in the case where it is not an established result) should be discussed. Questions to ask yourself when writing this section:

* *Has some result or value been provided that acts as a benchmark for measuring performance?*
* *Is it clear how this result or value was obtained (whether by data or by hypothesis)?*

**III. Methodology**

*(approx. 3-5 pages)*

**Data Preprocessing**

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In this section, all of your preprocessing steps will need to be clearly documented, if any were necessary. From the previous section, any of the abnormalities or characteristics that you identified about the dataset will be addressed and corrected here. Questions to ask yourself when writing this section:

* *If the algorithms chosen require preprocessing steps like feature selection or feature transformations, have they been properly documented?*
* *Based on the* ***Data Exploration*** *section, if there were abnormalities or characteristics that needed to be addressed, have they been properly corrected?*
* *If no preprocessing is needed, has it been made clear why?*

**Implementation**

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In this section, the process for which metrics, algorithms, and techniques that you implemented for the given data will need to be clearly documented. It should be abundantly clear how the implementation was carried out, and discussion should be made regarding any complications that occurred during this process. Questions to ask yourself when writing this section:

* *Is it made clear how the algorithms and techniques were implemented with the given datasets or input data?*
* *Were there any complications with the original metrics or techniques that required changing prior to acquiring a solution?*
* *Was there any part of the coding process (e.g., writing complicated functions) that should be documented?*

**Refinement**

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In this section, you will need to discuss the process of improvement you made upon the algorithms and techniques you used in your implementation. For example, adjusting parameters for certain models to acquire improved solutions would fall under the refinement category. Your initial and final solutions should be reported, as well as any significant intermediate results as necessary. Questions to ask yourself when writing this section:

* *Has an initial solution been found and clearly reported?*
* *Is the process of improvement clearly documented, such as what techniques were used?*
* *Are intermediate and final solutions clearly reported as the process is improved?*

**IV. Results**

*(approx. 2-3 pages)*

**Model Evaluation and Validation**

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In this section, the final model and any supporting qualities should be evaluated in detail. It should be clear how the final model was derived and why this model was chosen. In addition, some type of analysis should be used to validate the robustness of this model and its solution, such as manipulating the input data or environment to see how the model’s solution is affected (this is called sensitivity analysis). Questions to ask yourself when writing this section:

* *Is the final model reasonable and aligning with solution expectations? Are the final parameters of the model appropriate?*
* *Has the final model been tested with various inputs to evaluate whether the model generalizes well to unseen data?*
* *Is the model robust enough for the problem? Do small perturbations (changes) in training data or the input space greatly affect the results?*
* *Can results found from the model be trusted?*

**Justification**

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In this section, your model’s final solution and its results should be compared to the benchmark you established earlier in the project using some type of statistical analysis. You should also justify whether these results and the solution are significant enough to have solved the problem posed in the project. Questions to ask yourself when writing this section:

* *Are the final results found stronger than the benchmark result reported earlier?*
* *Have you thoroughly analyzed and discussed the final solution?*
* *Is the final solution significant enough to have solved the problem?*

**V. Conclusion**

*(approx. 1-2 pages)*

**Free-Form Visualization**

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In this section, you will need to provide some form of visualization that emphasizes an important quality about the project. It is much more free-form, but should reasonably support a significant result or characteristic about the problem that you want to discuss. Questions to ask yourself when writing this section:

* *Have you visualized a relevant or important quality about the problem, dataset, input data, or results?*
* *Is the visualization thoroughly analyzed and discussed?*
* *If a plot is provided, are the axes, title, and datum clearly defined?*

**Reflection**

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In this section, you will summarize the entire end-to-end problem solution and discuss one or two particular aspects of the project you found interesting or difficult. You are expected to reflect on the project as a whole to show that you have a firm understanding of the entire process employed in your work. Questions to ask yourself when writing this section:

* *Have you thoroughly summarized the entire process you used for this project?*
* *Were there any interesting aspects of the project?*
* *Were there any difficult aspects of the project?*
* *Does the final model and solution fit your expectations for the problem, and should it be used in a general setting to solve these types of problems?*

**Improvement**

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In this section, you will need to provide discussion as to how one aspect of the implementation you designed could be improved. As an example, consider ways your implementation can be made more general, and what would need to be modified. You do not need to make this improvement, but the potential solutions resulting from these changes are considered and compared/contrasted to your current solution. Questions to ask yourself when writing this section:

* *Are there further improvements that could be made on the algorithms or techniques you used in this project?*
* *Were there algorithms or techniques you researched that you did not know how to implement, but would consider using if you knew how?*
* *If you used your final solution as the new benchmark, do you think an even better solution exists?*

**Before submitting, ask yourself. . .**

* Does the project report you’ve written follow a well-organized structure similar to that of the project template?
* Is each section (particularly **Analysis** and **Methodology**) written in a clear, concise and specific fashion? Are there any ambiguous terms or phrases that need clarification?
* Would the intended audience of your project be able to understand your analysis, methods, and results?
* Have you properly proof-read your project report to assure there are minimal grammatical and spelling mistakes?
* Are all the resources used for this project correctly cited and referenced?
* Is the code that implements your solution easily readable and properly commented?
* Does the code execute without error and produce results similar to those reported?

# References

Zakhor, X. S. (2011). Fast approximation for geometric classification of LiDAR returns. *18th IEEE International Conference on Image Processing* (pp. 2925-2928). Brussels: IEEE.