NASA Earth Science Enterprise
Commercial Remote Sensing Program
Affiliated Research Center
University of South Carolina

Final Report:

Extraction of Airport Features from High Resolution Satellite Imagery for Design and Risk Assessment

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Table of Contents

Tables

Figures

Executive Summary

The LPA Group, consisting of 17 offices located throughout the eastern and central United States is an architectural, engineering and planning firm specializing in the development of Airports, Roads and Bridges. The primary focus of this ARC project is concerned with assisting their aviation specialists who work in the areas of Airport Planning, Airfield Design, Landside Design, Terminal Building Planning and design, and various other construction services.

The LPA Group wanted to test the utility of high-resolution commercial satellite imagery for the purpose of extracting airport elevation features in the glide path areas surrounding the Columbia Metropolitan Airport. By incorporating remote sensing techniques into their airport planning process, LPA wanted to investigate whether or not it is possible to save time and money while achieving the equivalent accuracy as traditional planning methods.

The Affiliate Research Center (ARC) at the University of South Carolina investigated the use of remotely sensed imagery for the extraction of feature elevations in the glide path zone. A stereo pair of IKONOS panchromatic satellite images, which has a spatial resolution of 1 x 1 m, was used to determine elevations of aviation obstructions such as buildings, trees, towers and fence-lines. A validation dataset was provided by the LPA Group to assess the accuracy of the measurements derived from the IKONOS imagery.

The initial goal of this project was to test the utility of IKONOS imagery in feature extraction using ERDAS Stereo Analyst. This goal was never achieved due to problems with ERDAS software support of the IKONOS sensor model and the unavailability of imperative sensor model information from Space Imaging. The obstacles encountered in this project pertaining to ERDAS Stereo Analyst and IKONOS imagery will be reviewed in more detail later in this report.

As a result of the technical difficulties with Stereo Analyst, ERDAS OrthoBASE was used to derive aviation obstruction measurements for this project. After collecting ancillary data such as GPS locations, South Carolina Geodetic Survey and Aero Dynamics ground survey points to set up the OrthoBASE Block File, measurements were taken of the various glide path obstructions and compared to the validation dataset. This process yielded the following conclusions: The IKONOS stereo model in conjunction with Imagine OrthoBASE can provide The LPA Group with a fast and cost efficient method for assessing aviation obstructions. Also, by creating our own stereo model we achieved any accuracy better currently available commercial products.

1.0 Introduction

1.1 Company Background and ARC Project

Founded in 1981 and headquartered in Columbia, South Carolina, The LPA Group Incorporated is a multi-disciplinary planning/engineering/architectural firm providing a variety of professional consulting services. The company employs over 190 professional personnel in regional offices throughout fourteen cities and offers a wide variety of professional services. These services include airport planning, design and construction, roadway planning, design and inspection, environmental planning and design; bridge planning and design, structural design, building planning and design, water and sewer system planning and design, and industrial site planning and layout.

The identification of potential obstructions to air navigation both on and off-airport is a significant concern to the several stakeholders in airport development, namely: the Federal Aviation Administration, airport owners, operators, tenants, and users. The vast majority of critical obstructions consist of tall structures such as buildings, towers, antenna, and signs. The structures and properties receiving primary focus include those, which lie in close proximity to an airport and are found in the approach areas to each runway end. For these close-in locations, vegetation is often also a key concern. The goal of all stakeholders is to ultimately eliminate or greatly diminish the adverse impacts that these obstructions may pose to airport operations as well as possible expansion plans.

The engineering community currently and has historically relied upon traditional field and aerial survey methods to identify and evaluate potential obstructions in the vicinity of airports. Both methods often require considerable time and money to execute. Oftentimes for planning purposes, the initial screening for potential obstructions needs to occur quickly and with little cost, recognizing a sacrifice in the level of accuracy. For these reasons, we strongly believe that remote sensing technology combined with pre-existing computer applications, may afford the airport stakeholder and engineering communities with cutting-edge applications that will revolutionize and enhance the ability to identify potential obstructions and more importantly work to provide safer airport environs.

The LPA Group Inc. and the University of South Carolina's NASA Affiliated Research Center (ARC) formed a partnership to investigate whether digital photogrammetric techniques and high-resolution commercial satellite imagery can produce a more time efficient and less expensive method for the extraction of airport feature elevations. Acquisition of a stereo pair of IKONOS panchromatic imagery and ERDAS software modules provided us with an opportunity to investigate whether digital photogrammetrically derived elevations were comparable to those derived from traditional aerial and ground survey methods.

1.2 Columbia Metropolitan Airport

The study area is located approximately 15 miles southwest of Columbia in Lexington County, South Carolina. The Columbia Metropolitan Airport is a modestly sized airport consisting of two runways servicing flights along the eastern seaboard. The predominant landcover types surrounding the airport consist of forest, residential areas and industrial. With all these features in such close proximity to the airport it is crucial to have accurate and timely data when planning additions to existing airport infrastructure. Figure 1 shows an IKONOS image of the study area.

Figure 1: Study Area – Columbia Metropolitan Airport (IKONOS Panchromatic)

2.0 Project Implementation

2.1 Project Objectives

The primary purpose of this research was to investigate the utility of panchromatic IKONOS imagery in conjunction with ERDAS digital photogrammetry modules to derive 3D features to assist the LPA group in their planning process.

The steps required to conduct this research included the following:

- The acquisition of a stereo pair of panchromatic IKONOS images of the Columbia Metropolitan Airport
- The acquisition of horizontal and vertical ground control to set up the ERDAS Imagine Block file
- The application of image processing techniques to extract elevation data from the images
- The comparison of digitally derived elevation values to those derived from traditional methods

2.2 Schedule

Event	Date
Kick off Meeting	May 17, 2000
Proposal Submitted to NASA	June 2, 2000
NASA Approves Proposal	June 13, 2000
Memorandum of Agreement Reached	June 21, 2000
IKONOS Data received	November 30, 2000
Final Report Delivered to NASA	April 21,2000

3.0 Data Acquisition and Processing

3.1 IKONOS Imagery

Imagery used for this research was IKONOS panchromatic imagery, which was provided by Space Imaging. The panchromatic band of the IKONOS satellite has a spatial resolution of 1m x 1m. This resolution is superior to any of the current commercial satellites in operation such as Landsat ETM (30m) and SPOT (Pan 10m). Specifications for the IKONOS satellite are listed in Table 1.

Table 1: IKONOS Satellite Specifications

	Multispectral	Panchromatic
Spatial Resolution (m)	4	1
Radiometric Resolution	11 bit	11 bit
Spectral Resolution (μm)	1 Blue 0.45 - 0.52	0.45 - 0.90
	2 Green 0.52 - 0.60	
	3 Red 0.63 - 0.69	
	4 NIR 0.76 - 0.90	
Swath Width (km)	11	11

3.2 ERDAS Software Modules

Stereo Analyst

The initial proposal for this project suggested the use of ERDAS Stereo Analyst for 3D-feature extraction from the IKONOS imagery. Stereo Analyst is equipped with capabilities such as stereo compilation, 3D-feature measurement and 3D GIS data extraction. To use this software, a stereo pair of images is required. A stereo pair consists of two images of the same area that are acquired from different orbits with one taken East of the other with 60% overlap. This requires significant differences in the angle of inclination of the sensor. Another crucial requirement for the creation of a Stereo Model is to define the sensor model. The sensor model describes the information associated with a sensor as it existed when the imagery was captured.

Internal Sensor model information relates to the internal geometry of the sensor as it exists when the imagery is acquired. This is usually derived from a sensor calibration report. This includes information such as pixel size and flying height of the sensor. Internal sensor information is generally easy to obtain.

External Sensor model information pertains to the position and orientation of each image as they existed at the time of capture. The position of the image is defined using 3D coordinates. The orientation of an image at the time of capture is defined by it's rotation about three axes: Omega (ω), Phi (φ), and Kappa (κ) (ERDAS, 2000). This information is vital if one plans to create an Image Block for use in Stereo Analyst. If this information is not available it can be modeled through the use of Ground Control Points (GPC's) in OrthoBASE.

OrthoBASE

Since the information for the IKONOS stereo model was not available, we incorporated ERDAS Imagine OrthoBASE into our research. ERDAS Imagine OrthoBASE is another digital photogrammetry package that can perform sensor modeling of IKONOS imagery through the use of a Rational Polynomial Coefficient (RPC) model and ground control points. The RPC model also known as Rapid Positioning Capability relates the object space coordinates of the real world (latitude, longitude, and elevation) to the image space coordinates (line & sample) (Grodecki, 2001).

This allowed us to establish a mathematical relationship between the images, the ground and the IKONOS sensor through the process of triangulation (ERDAS, 1999). Usually for frame cameras, digital cameras and other sensors such as SPOT HRV, the post triangulation report normally provides the user with the coefficients needed to define the Interior and Exterior Sensor parameters. In the case of the IKONOS sensor, ERDAS OrthoBASE did not report this information. ERDAS Inc. representatives informed us that Space Imaging has decided to encrypt this information making stereo compilation in ERDAS Stereo Analyst impossible at the present time.

The primary feature utilized in this research is ERDAS Imagine OrthoBASE's ability to automatically measure the image positions (X, Y, Z) of ground features that appear in both of the stereo images. This procedure allowed us to derive the heights of possible aviation obstructions. ERDAS OrthoBASE also automates the collection of tie points by utilizing digital image matching techniques (ERDAS, 1999). For our purposes this was not useful because it eliminates the user's control over where the tie points are placed.

3.2.1 Other Software Modules and IKONOS Support

Autometric

- Does not support IKONOS stereo at this time

BAE/LH

- Has IKONOS IGM import module for Socet Set. This module can read the TIFF+text IGM format but not NITF. It permits stereo and mono import for terrain extraction, orthorectification and stereo compilation. It does not permit block adjustment. The required modules are available at no cost to Socet Set version 4.2 users on NT and Sun Solaris systems.

PCI

- PCI OrthoEngine has the ability to import IKONOS stereo imagery with IGM data in TIFF or NITF format. Can perform visualization, terrain extraction and orthorectification. Block adjustment of IKONOS imagery is not recommended for general use.

Z/I Imaging

- ZI ImageStation and SSK software can import IKONOS stereo pairs with IGM data in TIFF or NITF format. It allows stereo and mono import for terrain extraction, orthorectification, and stereo compilation. The software does not permit block adjustment. These modules are part of the base ImageStation and SSK distribution packages.

3.3 Ground Control Data Acquisition

RPC information can be used alone to construct the ERDAS Block file but to improve the accuracy, horizontal and vertical control points were gathered. Accuracy of stereo products produced from IKONOS imagery are highly dependent on ground control points (Grodecki, 2000). To accomplish this task, three different approaches were executed, each exhibiting unique complications. The RMS errors produced by each of the models is summarized in Table 2.

Table 2: Summary of Stereo Model Accuracy (* Could not be used)

	GPS	SCGS	Aero Dynamics
RMS Error	7.3278	1.3378*	5.1864

1) *In situ* data in the form of GPS points were collected. For a period of two days, we collected GPS points at the Columbia Metropolitan Airport and neighboring areas that were in the IKONOS image. The points were collected at ground features that were visible on the image so they could be used accurately in ERDAS OrthoBASE. X, Y and Z values were collected at each of the 30 locations. Also, to ensure maximum accuracy 100 positions were taken at each location. This model could not be used due to the inaccuracy of GPS elevation measurements.

2) Ground Survey data in the form of ArcView shapefiles was acquired from the South Carolina Geodetic Survey. These points represented Survey Benchmarks locations in the vicinity of Lexington County. This data did improve the RMS error of the Blockfile but the sparse arrays of points were extremely difficult to locate on in the stereo scene. This resulted in an inadequate number of ground control points making our measurements inaccurate and unreliable.

3) Planimetric data of the Columbia Metropolitan Airport was acquired from the LPA group. This data was to be used for validation purposes but one of the data layers consisted of ground survey points collected by the land surveying crew of Aero Dynamics in Charlotte, NC. This data consisted of 6,200 points with X, Y and Z values. The high density of survey points made it much easier to select points that could be found on the IKONOS imagery.

3.4 Comparison of Terrain and Obstruction Elevations

To assess the accuracy of the IKONOS model, the elevations of terrain and aviation obstructions were measured. The model created using the Aero Dynamics survey data was used for these purposes since it exhibited the lowest RMS error (5.579 pixels). Due to the absence of orbital information for the IKONOS imagery it is impossible to achieve sub-pixel accuracy (Toutin and Cheng, 2000). Using the ERDAS OrthoBASE Point Measurement Tool, tie points were created at the locations of numerous aviation obstructions and ground features. Tie points are locations that can be found in both images for which coordinates can be derived through triangulation. To ensure maximum accuracy of measurements, locations of features must be chosen exactly in both images of the stereo pair.

By using the triangulation function, Imagine OrthoBASE determines the X, Y, and Z coordinates for each of the tie points from the IKONOS model. The values for the elevations of the 52 tie points were then compared to the values found in the aerial mapping dataset provided by the LPA Group. The measured features were classified as one of five categories: Buildings, Trees, Road, Runway and Ground. Figure 2 shows how the major aviation obstruction features (Buildings and Trees) appear on the IKONOS image and in the Imagine OrthoBASE point measurement tool.

Figure 2: point #109- tree measurement

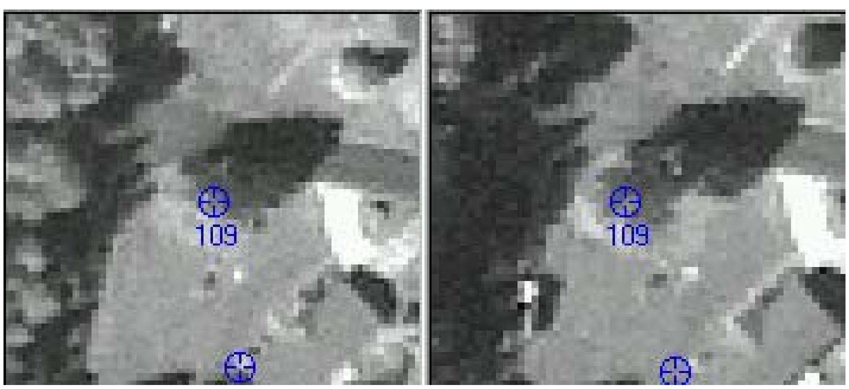
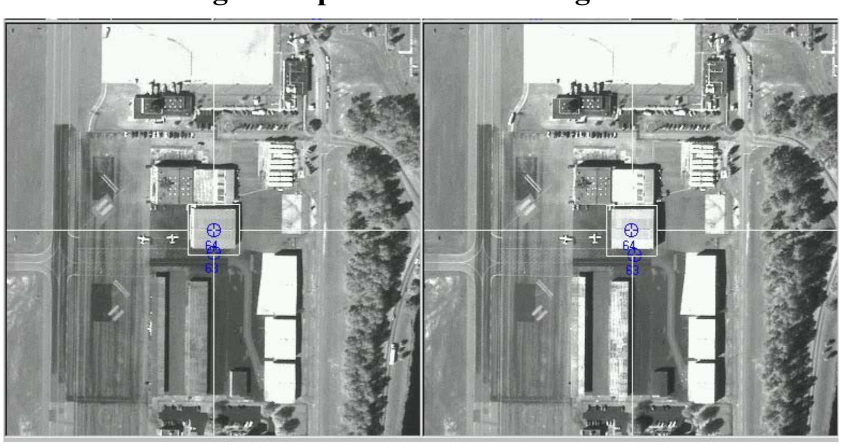


Figure 3: point #64 – building measurement



Other procedures were employed to access how well OrthoBASE recognized differences between the ground and aviation obstructions such as buildings and trees. This involved placing tie points on top of buildings and trees and points directly beside them on the ground. The differences of the values were calculated after triangulation was performed. Figure 3 shows the placement of these points to accomplish this task.

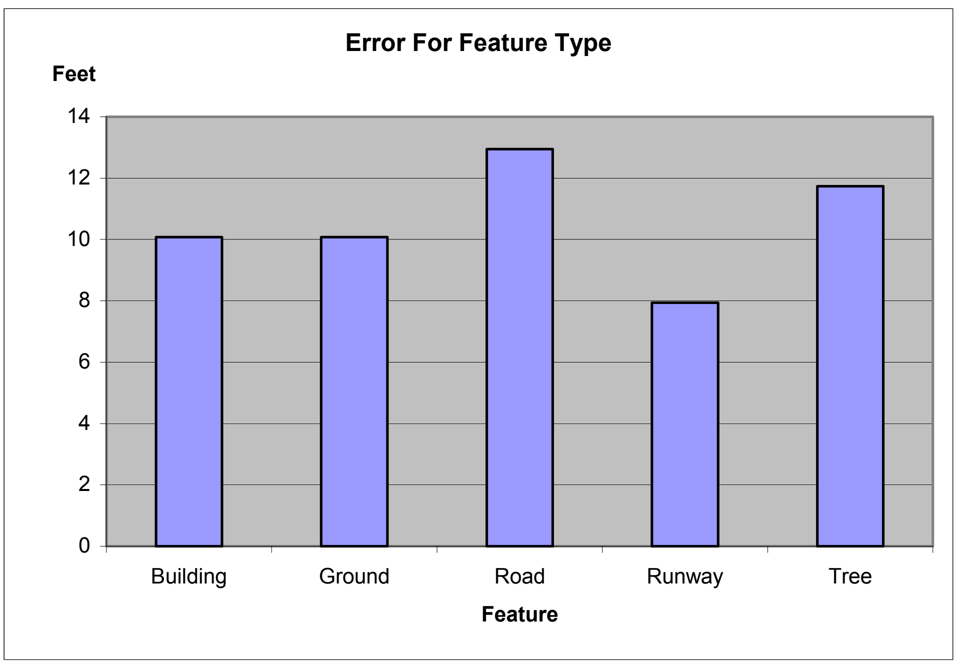
4.0 Results and Metrics

4.1 Results and Discussion

The results of all the measurements located in Appendix A show that the IKONOS model yielded an average vertical error of 10.729ft (3.271m) overall. This finding is important because Space Imaging produces stereo models with a vertical accuracy of 7.0 meters. Space Imaging customers have the option of purchasing the Precision product with the 7.0 meter accuracy which requires customers to provide Space Imaging with GCP's and a digital elevation or they can purchase the Geo-product and perform their own processing. The data presented here proves you can obtain a more accurate stereo model by processing the data yourself.

The data was also separated by feature type as well to see if there were differences in error between different types of ground features and aviation obstructions. This approach did reveal some terrain related features. Figure 3 shows the results of this analysis.

Figure 4: Error for Feature Types



Roads and trees seemed to be the two types of features that standout as having the most error. One reason for this is due to the spatial extent of the validation dataset we received, which did not cover the entire image. This resulted in a small number of observations for both of these classes. The lowest amount of error was exhibited by the Runway measurements. This can be attributed to the fact that the terrain is extremely flat for runways. Building obstructions, which are a major concern when assessing the glide path zone of runway, had an average error of 10.797 ft. Table 3 shows the results of the analysis involving differences between the buildings, trees and the ground.

The accuracy of these measurements could have also been improved with a ground control data source specific to this project. Deriving data from other sources created many obstacles throughout the duration of this research. The most even distribution of control points was acquired through the use of Global Positioning Systems but inferior accuracy of the vertical coordinates made it unsuitable. One suggestion would be to strategically plan a ground survey using a total station for the sole purpose of acquiring horizontal and vertical ground control for the images in the stereo pair.

Table 3: Obstruction Measurements (Units: Feet)

Points ID's	Object	True Elevation	Measurement	Error	Absolute Error
64-63	Building 1	9.288	4.939	-4.349	4.349
66-65	Building 2	17.273	16.567	-0.706	0.706
72-73	Building 3	21.071	4.695	-16.376	16.376
76-75	Building 4	7.638	6.459	-1.179	1.179
78-77	Building 5	12.93	1.409	-11.521	11.521
93-98	Building 6	10.326	5.003	-5.323	5.323
99-100	Building 7	11.163	7.12	-4.043	4.043
101-100	Building 8	9.123	2.552	-6.571	6.571
107-108	Building 9	4.604	8.038	3.434	3.434
110-112	Building 10	8.335	5.22	-3.115	3.115
113-114	Building 11	15.526	6.32	-9.206	9.206
79-77	Tree 1	7.857	-0.173	-8.03	8.03
102-103	Tree 2	3.98	4.836	0.856	0.856
104-105	Tree 3	6.361	3.698	-2.663	2.663
106-98	Tree 4	2.147	0.67	-1.477	1.477
109-108	Tree 5	35.075	10.681	-24.394	24.394
111-112	Tree 6	1.97	2.842	0.872	0.872
115-114	Tree 7	3.034	1.234	-1.8	1.8

4.2 Metrics

This ARC partnership allowed for the investigation of utility of high-resolution satellite imagery for Airport planning procedures. This project may have a more cost-effective method and timely method for deriving elevations of aviation obstructions. Other advantages include a new data source that is easier to update than the traditional methods used to map airport features.

4.2.1 Enhanced Market

Faster Data Acquisition

One advantage of the use of IKONOS imagery as opposed to traditional aerial survey methods is that faster data acquisition can be provided. The LPA group will not have to wait for current information concerning airport infrastructure and possible obstructions in the surrounding areas. Aerial and ground survey methods can take several months to complete especially for an international airport. This is an absolute benefit of using satellite imagery.

4.2.2 Costs

Elevation Data Savings

LPA Traditional Data Acquisition Method:

- Typical aerial survey for a single runway end may cost $3,000-5,000. Columbia Metropolitan Airport consists of two runways.
- Ensuing engineering analysis (largely a manual process) to complete the effort is equivalent, resulting in a total cost of $6,000-10,000 per runway end
- For a two-runway facility, such as the Columbia Metropolitan Airport in Columbia, SC, the total cost to provide obstruction analysis may reach **$25,000-40,000**

IKONOS/ ERDAS OrthoBASE Method:

- IKONOS stereo pair for this project: $ 9,800 (approx. $100 per Square Km)
- Computer Processing and Analysis: (50 hrs @ $25/hr = $1,250)
- Personnel Resources: (50 hrs @ $50/hr = $2,500)

Total = $13,550

5.0 Conclusion

It seems the utilization of IKONOS imagery with ERDAS Imagine OrthoBASE could benefit the LPA Group. Improvements include faster data acquisition, easier updating capabilities and a more cost-effective methodology for planning. More benefits of the imagery could have been explored if more input on the project was received from the LPA Group. The stereo product created for this research using IKONOS imagery has a superior accuracy to the precision product offered by Space Imaging and could benefit the LPA Group when planning construction in the glide path zone. The research here only scratches the surface of what benefits the Aviation planning community can receive from remote sensing technology.

Given that on average, each of the 50 states has approximately 75-150 public-use airports that are maintained and utilized by the general population, benefits realized by automating the identification/quantification process is significant. Certainly for individual airports with multiple runways, automation becomes a key factor to reducing costs. By reducing the costs associated with analysis, oftentimes stakeholders are more inclined to keep data more current on far more airports, thus allowing their constrained budgets to stretch farther and provide a higher level of safety.

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Appendix A

Table A-1: Summary of Point Measurements (Units: Feet)

Point ID	True Elevation	Measurement	Error	Absolute Error	Feature
54	231.1	246.091	14.991	14.991	Runway
55	227.9	250.98	23.08	23.08	Runway
56	213.5	210.973	-2.527	2.527	Runway
57	211.15	209.915	-1.235	1.235	Runway
58	239.636	237.804	-1.832	1.832	Runway
59	284.845	288.566	3.721	3.721	Building
60	183.389	203.177	19.788	19.788	Road
61	273.406	269.805	-3.601	3.601	Building
62	210.968	212.37	1.402	1.402	Runway
63	233.418	237.768	4.35	4.35	Building
65	244.6	245.306	0.706	0.706	Building
69	210.74	217.648	6.908	6.908	Ground
70	177.769	196.981	19.212	19.212	Road
71	177.7	173.901	-3.799	3.799	Ground
72	290.28	272.207	-18.073	18.073	Building
73	269.209	267.511	-1.698	1.698	Ground
75	322.8	306.677	-16.123	16.123	Ground
76	330.438	313.136	-17.302	17.302	Building
77	323.3	308.146	-15.154	15.154	Ground
80	283.29	275.705	-7.585	7.585	Ground
81	216	232.618	16.618	16.618	Road
82	231.1	247.125	16.025	16.025	Runway
83	218	238.777	20.777	20.777	Road
84	200	225.285	25.285	25.285	Building
85	288	280	-8	8	Road
86	166.293	190.984	24.691	24.691	Building
87	264	258.296	-5.704	5.704	Ground
88	252	228.997	-23.003	23.003	Ground
89	200	204.128	4.128	4.128	Road
90	216	233.462	17.462	17.462	Ground
91	217	209.721	-7.279	7.279	Runway
92	217	209.312	-7.688	7.688	Runway
95	210	206.631	-3.369	3.369	Runway
96	194	196.101	2.101	2.101	Road
97	200	205.882	5.882	5.882	Ground
93	169.426	188.945	19.519	19.519	Building
98	159.1	183.941	24.841	24.841	Ground
99	216.263	212.749	-3.514	3.514	Building
100	205.1	205.629	0.529	0.529	Ground
101	214.223	208.181	-6.042	6.042	Building

102	195.98	203.132	7.152	7.152	Tree
103	192	198.295	6.295	6.295	Ground
107	265.244	277.096	11.852	11.852	Building
108	260.64	269.058	8.418	8.418	Ground
109	295.715	279.739	-15.976	15.976	Tree
110	281.088	287.064	5.976	5.976	Building
111	274.723	284.686	9.963	9.963	Tree
112	272.753	281.844	9.091	9.091	Ground
113	301.621	308.14	6.519	6.519	Building
114	286.095	301.82	15.725	15.725	Ground
115	289.129	303.054	13.925	13.925	Tree
				Average 10.729	

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