A Complete Building Extraction System from Elevation Data

Chris Finlayson
Visual Learning Systems, Inc.
PO Box 8226
Missoula, MT 59807
cfinlayson@vls-inc.com

David W. Opitz
University of Montana
Computer Science Department
Missoula, MT 59812
opitz@cs.umt.edu

Abstract

Buildings are one of the most important geospatial features for spatial analysis and mapping; however, the collection and maintenance of these features in a GIS database is a slow, expensive, and manually intensive process. Previous attempts at automating the building extraction process from images has met with limited success due to (1) spectral similarities between building rooftops and roads, (2) lack of spatial processing parameters for building geometry and (3) the failure of these systems to incorporate auto-editing tools for vectors such as building squaring. Feature Analyst® extracts building footprints automatically using digital elevation models obtained from LIDAR, stereo, or radar sources and also provides tools for post-extraction clean up including automated building square-up. Buildings can subsequently be analyzed in either 2 or 3 dimensions using ArcMap or 3D Analyst to support modeling and simulation planning efforts.

Introduction

A good building extraction system should be easy to use and provide tools for end-to-end data processing including extraction of buildings, vector editing of features, and attribution. Feature Analyst, developed as an ArcGIS extension by Visual Learning Systems, Inc., uses inductive learning algorithms and data fusion to extract buildings from high-resolution elevation and image datasets. Feature Analyst provides the user with:

- A simple interface and integrated workflow process with ArcGIS
- The ability to take into account spatial context (contextual classification),
- Clutter mitigation using a hierarchical machine learning approach, and
- The ability to learn disjunctive concepts i.e. residential houses and industrial buildings.

Feature Analyst is available as an extension to ArcGIS, ERDAS IMAGINE and SOCET SET. Feature Analyst works by having an analyst provide samples of buildings in an image set, and then it learns from these examples to automatically detect buildings in the fused elevation and image set. This workflow process is illustrated in Figure 1. Feature Analyst also provides a set of manual and auto-editing tools to assist the user in cleaning up and attributing the results. These tools assist the user to remedy common problems in the building extraction process such as squaring building corners or adding pieces of buildings obscured by overhanging trees.

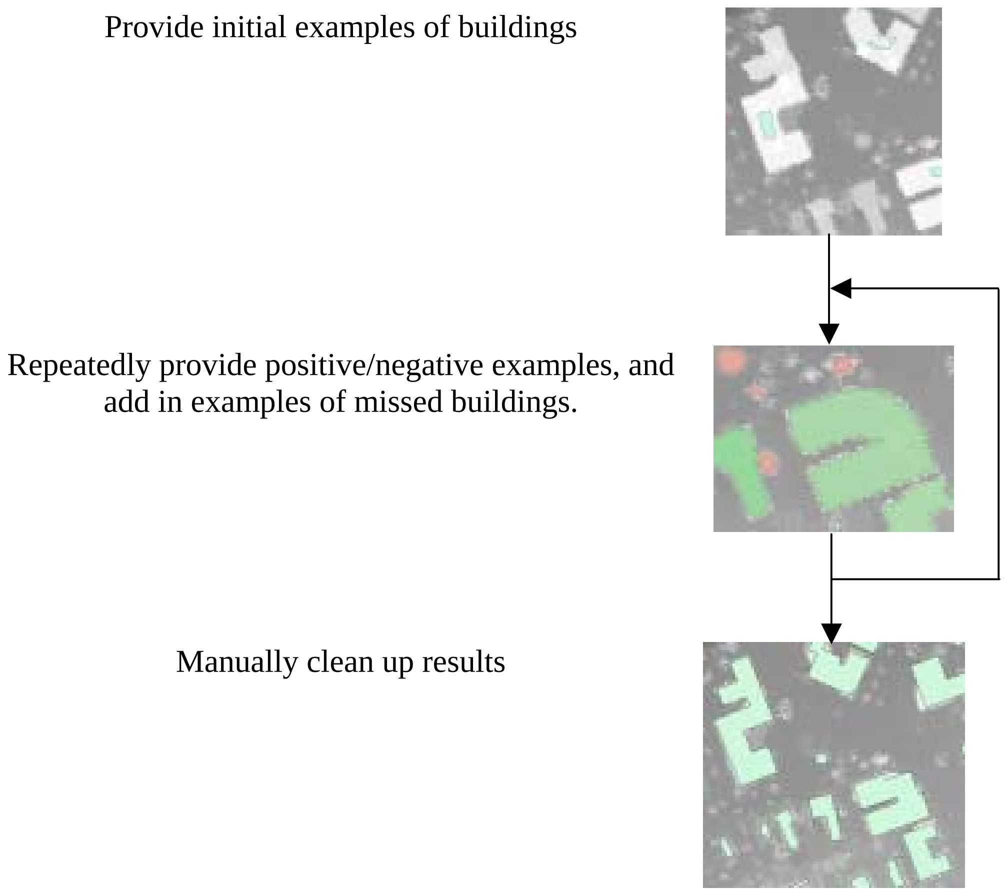

Figure 1: Building Extraction Workflow

Building Extraction Approaches

As described above, the Feature Analyst approach uses digitized building examples provided by the user to extract target features; however, Feature Analyst also provides a completely automated building extraction process when the inputs are first return and second return LIDAR DEMs. In the assisted approach, Feature Analyst "learns" to find buildings from the user-provided examples, provides an initial set of extracted building features (first pass results), and then provides tools for the user to repetitively refine these result by selecting positive and negative results. A benefit to this partially assisted or supervised approach is that the user is not required to be an expert image analyst to obtain good results.

The completely automated approach requires the user to define the location of the LIDAR DEMs and then set building extraction parameters including the option for auto-squaring of building corners. In Figures 2-4 we show examples of processed LIDAR images including filtered results to show the removal of trees and the application of a bare-earth filter.

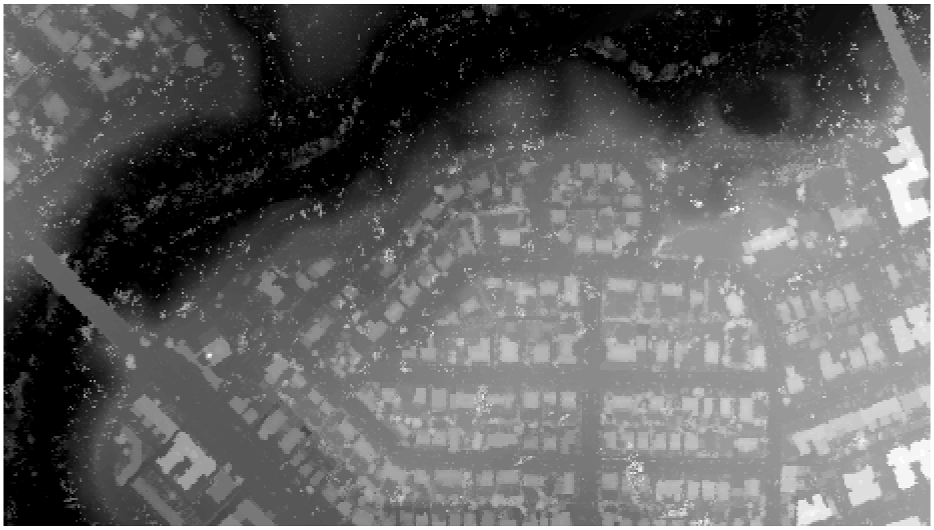

Figure 2: Original elevation data (last return LIDAR shown here)

Figure 3: Filtered data (ground flattened; trees removed)

Figure 4: Close-up of original last return LIDAR data

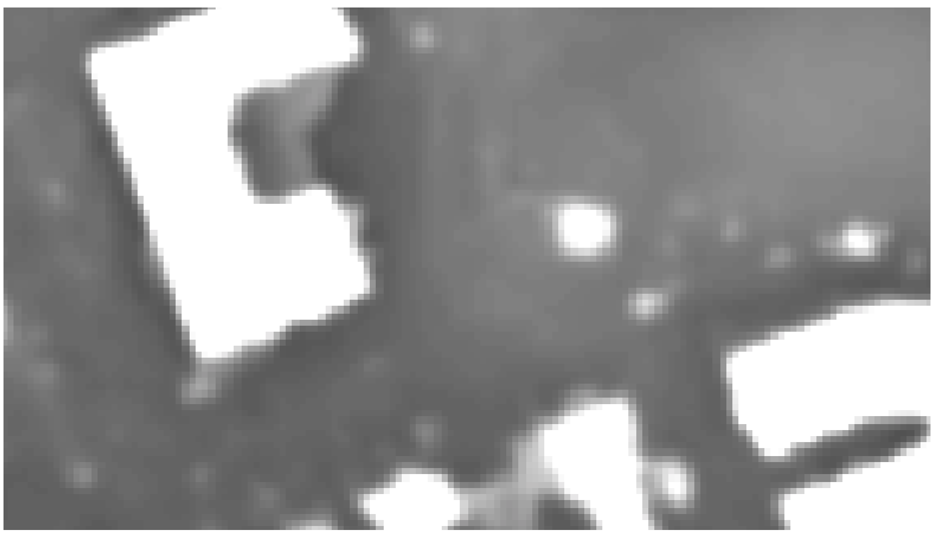

Figure 5: Close-up of filtered data

Unless the user specifies otherwise, the processing of the data described above happens automatically when Feature Analyst is provided the first and last return LIDAR data. Feature Analyst uses this processed data as the inputs (behind the scenes) in the supervised classification workflow.

Results

The results of the automated extraction process on 1-meter resolution LIDAR data over an urban/suburban area resulted in 20 false negatives out of 385 buildings (5.2%) and 12 false positives (3.1%). We obtained similar results on other LIDAR datasets that included suburban and rural areas for building extraction. A frequently overlooked factor in the speed of the extraction process is the quality and integration of vector clean-up tools assist the user in finalizing building results.

Clean-Up Tools

Clean-up tools to handle common edits are imperative for a successful building-extraction system. Based on our experience, we've developed a clean-up tool that reduces the time of hand editing drastically by performing common tasks in an automated fashion.

Polygon Edit tool

The polygon clean-up tool (Feature Analyst's Polygon Reshape Deluxe) addresses the necessity of having to enter into different editing modes in the GIS platform in order to edit polygons. Most of the problems with building extraction are as follows: 1) buildings "bleeding" into one another; i.e. two buildings so close together that they are extracted as one, 2) buildings with "holes" where there should be none, 3) adding missed parts to buildings, 4) trimming off pieces of the extracted building that do not represent a building, and 5) adding buildings that were missed entirely. Many GIS platforms, such as ArcGIS, support this editing capability. The problem is that one must enter into distinctly different edit modes to complete these tasks. This is not a problem *prima facie*, but when working with large datasets, it is very time-consuming. A rather small 3% error rate over a region with 5000 buildings means having to edit 150 buildings manually. Keyboard shortcuts allowing one to enter different edit modes greatly reduce this editing time. These shortcuts are illustrated in Figure 6~~Figure 6~~ through Figure 11~~Figure 11~~ below.

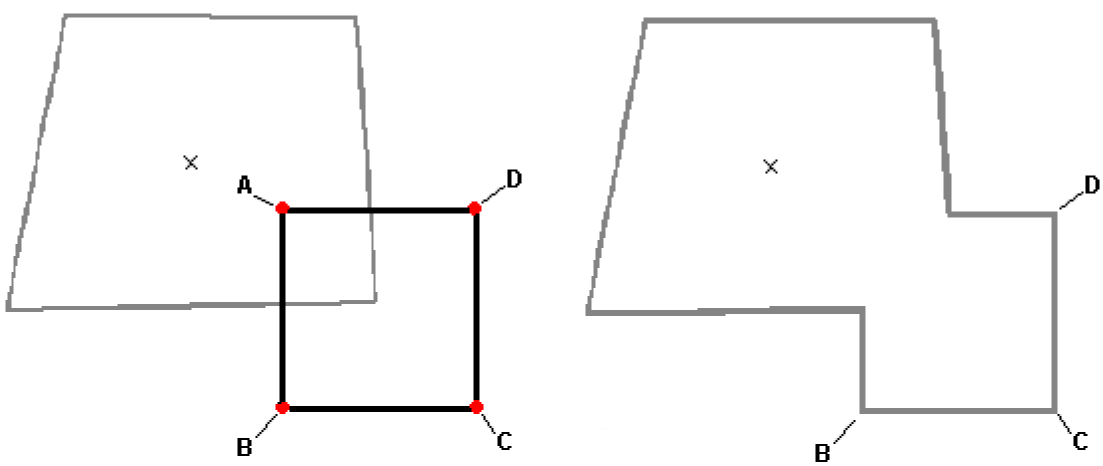

Figure 6: Extending a polygon feature. Clicking on points A through D extends the polygon as shown.

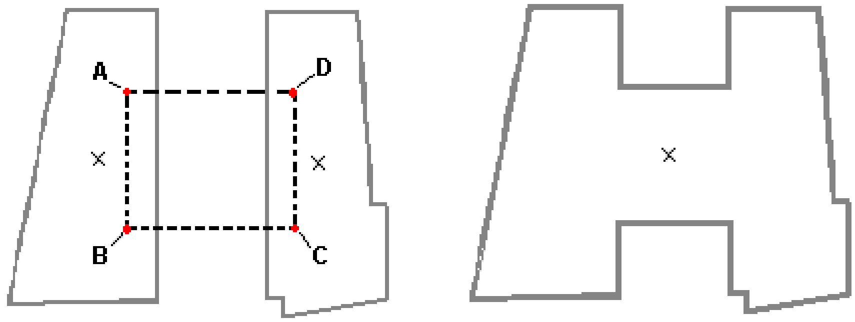

Figure 7: Merging polygon features. Clicking points A through D merges the two polygons automatically.

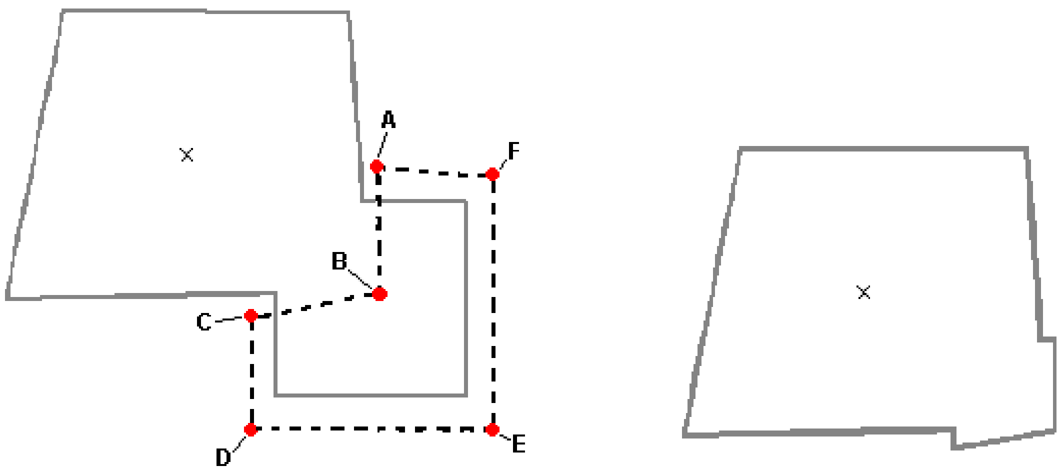

Figure 8: Trimming feature. While holding the shift key down, clicking on points A through E trims the polygon as shown.

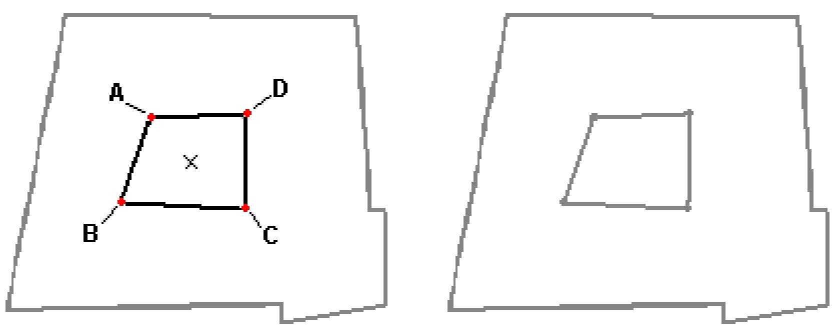

Figure 9: Cutting a hole in the middle. Clicking on points A through D while holding the shift key down cuts a hole in the middle of the polygon as shown.

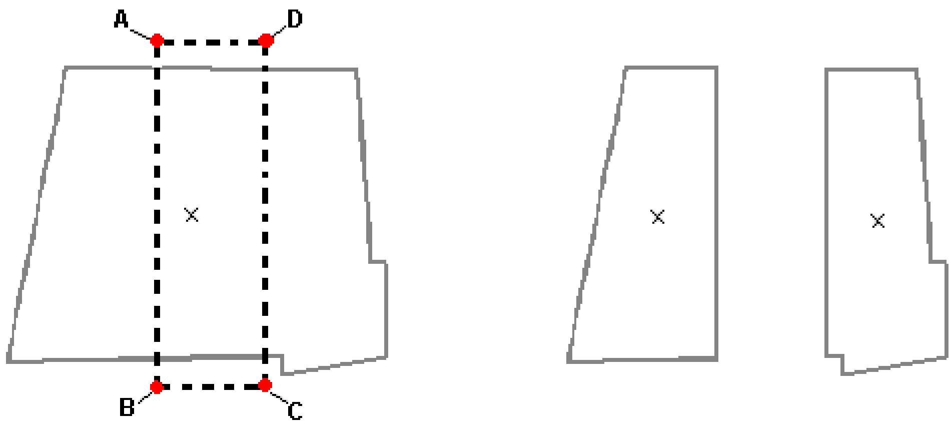

Figure 10: Splitting a polygon. Clicking on points A through D while holding the shift key down splits the polygon as shown.

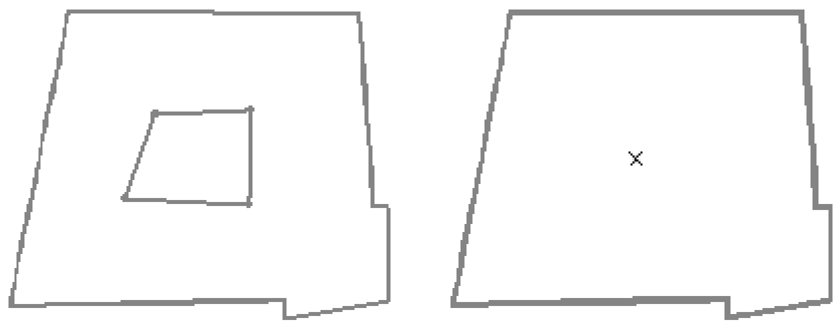

Figure 11: Closing hole in polygon. Holding the ctrl-key down and double-clicking clicking on a hole in a polygon will close the hole.

Edge-snapping tool

Most buildings have straight walls as opposed to curved features. For visually appealing results, an edge-snapping tool was created to create sharp edges from a building shape. See Figure 12~~Figure 12~~.

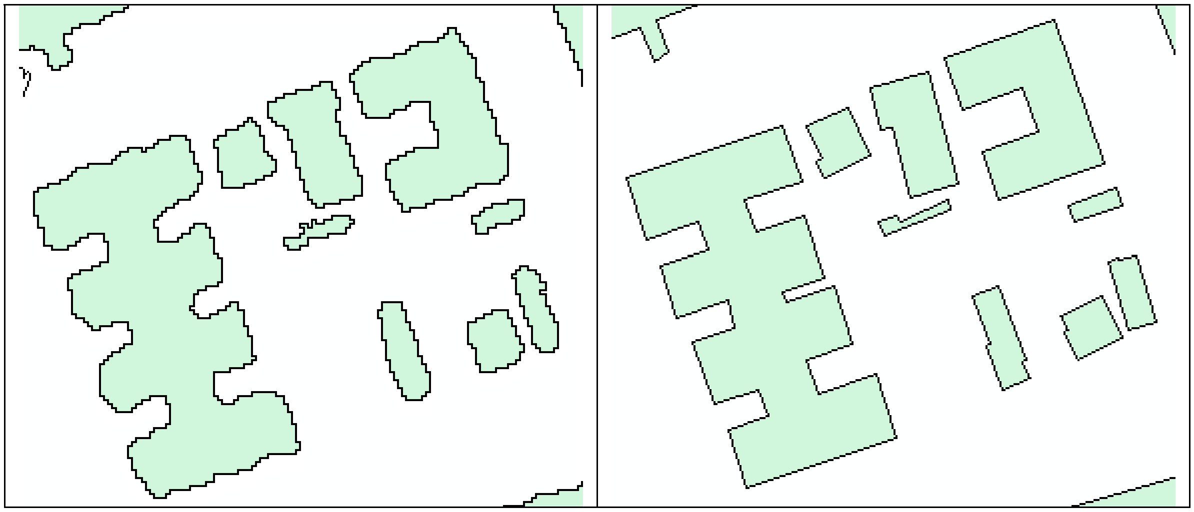

Figure 12: Before and after edge snapping

The edge-snapping tool attempts to find a prevalent direction among a series of connected edges, and snaps these connected edges together in a straight line. The general manner in which this is done is:

1. The user defines the number of major axes to fit shapes to. One works for most areas, since many buildings are square or "L" shaped. Areas where buildings have wings at odd angles require increasing the number of major axes so the algorithm can make a truer fit.

2. Lines are distributions of contiguous vertices using a least-squares fit. Contiguous vertices fitting to a side of the building have a lower mean squared error than contiguous lines crossing around a building corner. Lines are selected that have a good combination of length and small root mean squared error.

3. All selected lines are then snapped to an appropriate angle, given the major axes setting in step 1. For example, if the major axes are set to one, then adjacent lines will be snapped to 90 degrees.

4. After snapping, lines will not necessary touch, so they are extended so they reach one another.

5. The final shapes are simplified to remove certain artifacts. For example, the process can sometimes produce a short line in between two long lines, all parallel with one another. These are replaced by a weighted average of the two lines.

Conclusions

The manual collection of building features from high-resolution elevation and image datasets is a time-consuming and expensive process. Previous attempts at automating this process have failed due to poor elevation data processing algorithms, confusing spectral signatures for building rooftops and roads, and incomplete tools for cleaning and attributing features. Feature Analyst overcomes these shortcomings by providing assisted and automated workflow approaches for building collection in ArcGIS. Feature Analyst fully utilizes both high-resolution elevation data, such as LIDAR, as well as imagery to extract building features. Furthermore, Feature Analyst provides a complete end-to-end workflow for extracting building features, editing vector results with manual and automated approaches, and providing an interface for attribution.