Automatic Ground Modelling using Laser Radar Data

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Automatic Ground Modelling using Laser Radar Data

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Abstract

When building high resolution landscape models using laser radar information, it is desirable to get some kind of classification of the data. By separating the data from the objects in the landscape, it is possible to building up the model in layers, starting with the ground adding trees houses and other objects gradually.

In this Master Thesis we have implemented and evaluated an algorithm for ground segmentation based on the theories of Active Contours. The segmentation of the data is performed in two steps. The Active Contour estimates the ground and the laser radar data is then compared with this estimation. The Active Contour used for the estimation of the ground acts like a sticky rubber cloth being pushed up from underneath the surface. The contour sticks to the continuous ground surface.

The evaluation of the algorithm has been done on a data set from a laser radar surveillance done in 1998 with a TopEye™ system. The algorithm preforms well and the estimation of the ground has high accuracy compared with other methods.

Keywords
Laser radar, classification, segmentation, active contour
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Chapter 1

Introduction

This Report is a master thesis at the Department of Electrical Engineering at Linköping University, Sweden. The work was performed at the Defence Research Establishment in Linköping.

1.1 Background

A laser radar surveillance system is an excellent equipment for collecting high class topological information of an area. In the attempts of segmenting and classifying topologic laser radar data, numerous of ad hoc methods have been produced. The main reason, in this thesis, for wanting a segmented laser radar image, is to utilize it for building a high resolution Digital Terrain Model, DTM. This DTM can be used when creating a ground vehicle or a helicopter simulator. These types of simulators need a more detailed DTM than the more common flight simulators. The segmentation of the laser radar data makes it possible to give a more authentic view in the simulator with green ground, realistic trees and coloured roads and buildings etc. A ground surface could be build only using the ground points. Then a tree could be modelled using information of height or even species, obtained from the classed tree points, and then be put in the DTM. By achieving corner information from the buildings in the image, houses could be modelled and put on the ground.

If the material of the objects could be determined, it would be possible to implement more physical realism in the DTM. With information about the heat radiation from objects, a realistic night vision simulator can be built with a truthful infrared radiation image.
1.2 Problem Definition

The purpose of the work presented here is to design, implement and evaluate an active contour image segmentation algorithm for ground segmentation of laser range radar images. Further to make a comparison between this implementation and other methods.

1.3 The Laser Radar

The laser radar equipment used for the measurements in this thesis, is the TopEye™ system. The measurements in the following examples were performed 1998 by Saab Survey Systems AB. The facts are taken from [1], [2], [3] and [14] where more detailed information can be found.

Saab TopEye™ is a topographical survey system. The system is carried by a helicopter and contains a laser radar system measuring the distance to the ground. Knowing the position of the helicopter and the angle of the laser beam, the three dimensional coordinate of the measured point can be computed. The position is determined using a differential GPS and an inertial navigation system, INS.

The infrared laser beam is swept from side to side forming a zigzag pattern on the ground while the aircraft is moving forward, see Figure 1.1.

Figure 1.1: The laser radar scans the ground in a zigzag pattern.

In this thesis one line in the zigzag pattern will be noted as a sweep and several following sweeps will be called a strip. When mentioning footprint in this thesis, it is meant the area covered by the laser beam when reaching the ground.
1.3.1 Outputs from the TopEye\textsuperscript{TM} System

The collected range data and the position information of the system are processed giving the positions in WGS 84 coordinates. These positions are stored in the files referred to as \textit{raw data} in this thesis. WGS 84, \textit{World Geodetic System}, is based on an ellipsoidal surface of the Earth [7].

Besides the X, Y, Z values, time, reflectance and nadir angle are stored in the raw data files.

The time value simply tells when the pulse was sent. Since the sensor is able to detect several distances for every pulse sent, the time information is used to detect if following points come from the same pulse.

Reflectance is really the amplitude of the reflected laser pulse. The reflection data give a monochromatic infrared picture of the scanned area. From this information it is possible to separate materials from each others. For instance, asphalt and vegetation do not reflect the infrared laser beam in the same way.

The nadir angle is the angle between the normal of the surface and the direction of the laser pulse.

There are also two video-cameras mounted on the helicopter, one looking down and one mounted with a front view.

1.4 Terrain Data

Figure 1.2 and Figure 1.3 cover an area containing a road and a cycle way passing under the road in a tunnel. This area is flown over several times and contains several overlapping strips. In Figure 1.2 we see the topographic information, this is of course the most important information, from TopEye\textsuperscript{TM}, when building terrain models. Only this topographic information is used in the image segmentation models described in this thesis.

The intensity values are very useful when trying to determine what materials being measured in the terrain. Chlorophyll gives good reflectance of the infrared laser, asphalt does not reflect the laser well but the dashed lines on the road do, see Figure 1.3. Water gives a very high intensity-value when probing normally to the surface, if the laser falls in with a low angle against calm water nothing reflects back, then there is a \textit{drop out} meaning that there is not enough energy in the reflected pulse for the system to detect.
Double-echo points define another valuable information source in the image. With this we mean the case when two ranges have been detected in the return pulse due to the size of the footprint of the laser. This appears mainly in vegetation e.g. trees or on the edges of a roof on a house. In the area mentioned earlier the double-echoes are clearly seen in the trees, on the edges of the tunnel and on the street lamps, see Figure 1.4.

1.5 Problems with Irregular Sampled Images

One problem when processing an image from TopEye\textsuperscript{TM} is the irregular sampling in the spatial domain. The measured data are put in a long list in time order. Two near points in the terrain can be far apart in the list. Another difficulty is that there can be two or more points with the same XY coordinates but with different height.
value, see Figure 1.5. Objects can appear in several layers, one region does not just contain trees, there is ground under the trees both having the same coordinates. Even when looking on a single sweep, the measured point does not come in spatial order. Figure 1.6 contains real measurements from a wooded area. Since the laser beam falls in with an angle that is non orthogonal, the difference in height between the ground and the trees makes the laser beam run forward and back, seen in the XY coordinates.

It is possible to triangulate the area making an irregular mesh of the samples. This gives some spatial order between the points, as which points are neighbour-points. Still there is a problem with image processing when dealing with irregular sampled images, it is not possible to use a discrete convoluting kernel since the distances between the samples vary. When convolving such an image the kernel has to be continuous. During the convolution, the specific kernel has to be calculated in every image point.
Chapter 1 - Introduction

Figure 1.4: The image shows the locations of the points given double-echoes of the laser-pulse.

Figure 1.5: Two points with the same XY coordinates
Figure 1.6: A part of a sweep measured in a forest. The points do not come in order in XY coordinates.
Chapter 2

Ground Segmentation

In this chapter the active contour method for ground segmentation will be described. There are numerous ways to segment laser radar images and this chapter also contains an overview of other methods in brief.

When trying to segment the ground in a topographic image, one has to see to the typical qualities of the ground. The ground generally is continuous and has low variance compared to trees. When dealing with irregular sampled images as from a laser radar TopEye™-like system the highest of two measured points with the same coordinates could not belong to the ground. In the same manner the first echo on a double-echo is not a ground point, the ground is not transparent.

2.1 Using Active Contours for Ground Segmentation

The ground segmentation method based on active contours is rather an estimation of the ground done from the data than a direct segmentation. The segmentation of the data is done in a second step, comparing the data set with the ground estimation.

The contour used for estimating the ground acts like a sticky rubber cloth or a rubber band net being pushed up from underneath the surface. More details about active contours are given in section 3.2. The net is attracted by and sticks to the ground points. The elasticity forces in the rubber bands stop the mesh from reaching up to the points not belonging to the ground, see Figure 2.1. The net forms a continuous model of the ground. This is a robust method for ground estimation and it is possible to adjust the parameters to achieve the wanted behaviour of the net. If it is preferred that rocks in the terrain are classed as ground the net should be more elastic and sense a larger attraction from the measured points. If a more rough type of ground is preferred leaving rocks and small objects when classifying the ground, naturally a less elastic net is used.

The first thing done before running the segmentation algorithm is to resample the TopEye™ image to a regular image grid. This is done as a simplification to speed up the optimization step. It is straightforward to modify the segmentation algorithm...
to work on a triangulated irregular mesh obtained from the original data. The resampling is performed in the easiest way possible in a lowest neighbour kind of way. This means that the lowest point in the region around a sample is chosen. Since the ground points are the ones being of interest in this operation, there is no need to interpolate the samples in a more sophisticated manner. It would even be worse trying to make some kind of averaging. For example, if there is a tree point and a ground point equally distanced from the sample point it is better to let the sample have the ground point level rather than the average of the two. In a forest there are few measured ground points that belongs to a single echo. With an averaging algorithm there will be no or few true ground level values left after the resampling.

The next step in the algorithm is the optimization of the active contour surface. This is described in Chapter 3. From this process the ground mesh is achieved.

The segmentation of the ground points is made simply by comparing the original data with the estimated ground. If the estimation is good enough it is possible to decide if a measured point belongs to the ground or not from the residual, the distance between the point and the estimation. In Figure 2.2 a schematic view over the algorithm is shown.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure2.1.png}
\caption{The snake is not elastic enough to reach up to the tree points, it is held back by the ground points.}
\end{figure}
2.2 Other Methods

In [9] an iterative interpolation model for ground estimation in wooded areas is described. The idea behind this algorithm is that all points describe the ground surface only with different error. The residual, difference between the true ground surface and the measurements, goes from small negative up to large positive values. A measurement of the ground has a residual roughly of \( \pm 10^{-1} \) m, a measured tree point has a large residual due to the true ground of the size 10 m.

The first step is to interpolate a surface using all of the measured points. An average between ground and trees is then achieved in the wooded areas. Then the residual of the measurements due to the interpolated surface is computed. When this is done the measured points are weighted with a decreasing function that gives heavier weight on negative or small residual than large ones. In Figure 2.3 the principal appearance of the weight function is seen. A new surface is then interpolated by means of the weights, and a new residual is computed. The iterations are continued until the surfaces converge against a final solution.

This method need a large number of points to reach the ground. Over a building there are no measured points from the ground since the roof is not transparent. With no data from the ground the surface will adjust to the roof. Hence, this method
should work best in areas with quite sparse forest or open ground. In this kind of areas it is also reported to work well.

In [8] a one dimensional method is suggested. By processing one sweep at a time it is possible to segment the ground with low cost in computing. Of course in a sweep containing no or few ground points this approach will yield unsatisfactory results.

TerraScan is a commercial product for handling and segmenting of laser radar images. In TerraScan a maximum elevation routine is used for ground classification, according to [13]: “The routine classifies points which have another point close by and the other point is at a steep angle downwards. It basically classifies points which can not be ground points because the slope to another point is too steep. This routine will basically compare each point with every other point within a given xy distance. If the vertical angle from the other point to the centre point exceeds the given limit, the centre point will be classified”.

2.3 Summary

The methods for ground segmentation of laser range radar images covered in this chapter use different approaches. In this thesis only the one based on active contours is implemented and tested. Some tests have been performed with TerraScan, and the result is a more rough ground surface than the one from the active contour algorithm. By allowing a steeper ground surface it is possible to achieve a more detailed ground but at the cost of getting some of the tree points classed as ground.
Chapter 3
Active Contours

The theory of active contours is specially designed to be used in image processing. It is mainly used for detection of contours in images. The active contours are commonly referred to as snakes, especially when meaning two dimensional contours. In that case the snake is a continuous spline, opened with loose ends or closed in a loop. In the implementation done in this thesis a three dimensional active contour is used, it is a continuous open surface. For deeper studies of active contours, see the references [4], [5] and [6].

3.1 Theory

The shape of the active contour depends on its physical characteristics and the potential field from the image, surrounding it. The physical characteristics are material behaviour like elasticity and rigidity. The optimized contour is the solution that minimizes an energy function. The active contour may very well be drawn and stuck to a local minimum. In fact the wanted solution is probably not the global minimum.

3.1.1 Active contour spline in two dimensions

We review the original snake model as described in [4]. The snake position is given as a parametric function by \( v(s) = (x(s), y(s)) \), \( s \in [0, 1] \). The energy function can be written as

\[
E(v) = \int_0^1 (E_{\text{int}}(v(s)) + E_{\text{image}}(v(s)) + E_{\text{ext}}(v(s))) ds
\]

\( E_{\text{int}} \) is the internal energy, which gives the spline a smoothness, \( E_{\text{image}} \) comes from the potential of the image and \( E_{\text{ext}} \) comes from the external constraint forces.

The internal energy in the spline is derived from its elasticity and rigidity.

\[
E_{\text{int}}(v(s)) = w_e |v'(s)| + w_r |v''(s)|
\]
The first term is the elasticity and the second is the rigidity. The weight constants $w_e$ and $w_r$ control the relative importance of the elasticity and rigidity. If $w_e = 0$ the spline behaves like a rubber band, if $w_r \neq 0$ the spline behaves more like a strip of wood, preventing the snake from developing corners.

The image force functions control which type of contours we want to find in the image. If

$$E_{image} = -I(x, y)$$  \hspace{1cm} (3.3)

i.e. the energy is the negative image intensity, the snake will be attracted to light lines in the image. If the edges in the image should be detected, set

$$E_{image} = -|\nabla I(x, y)|^2$$  \hspace{1cm} (3.4)

Then the snake is attracted to contours in the image with large intensity gradient.

The external constraint forces are used to guide the snake towards the solution. Since the image forces often are quite local, for example the contour of an object, the snake has to get help to come near the edge. If a closed snake should find the edge of an object, the snake could be put inside and inflated to grow until it is drawn to the edge, see Figure 3.1. This force is weaker than the image forces, in other case the snake could be drawn past the wanted solution.

![Image](image.png)

**Figure 3.1:** The snake inside the object is inflated to grow out to find the edge. Compared to the image forces the force from the inflation is weak, making sure the snake stops at the edge.

### 3.2 Implementation for Ground Segmentation

In this thesis the active contour is used for ground segmentation. This is a very specific use and gives the opportunity to make several simplifications compared to regular three-dimensional active contours. The first thing done is to limit the
contour’s degrees of freedom by only letting the net move along the Z-axis. This simplifies the description of the contour to a regular image-matrix containing only the height information. Since the active contour is discrete Equation (3.1) can be written

\[ E(v) = \sum (E_{\text{int}}(v(k)) + E_{\text{image}}(v(k)) + E_{\text{ext}}(v(k))) \]  

(3.5)

The second simplification is to let the internal energy \( E_{\text{int}} \), that gives rise to the internal forces, only depend on the elasticity of the contour. The contour does not have any rigidity. The elasticity force influencing one point in the net depends on its eight connective neighbours, see Figure 3.2. This makes the contour act more like a rubber-band net rather than a rubber-membrane. The internal energy in a node \( v(i,j) \) in the net is a summation of the elasticity force between the node and its neighbours.

\[ E_{\text{int}}(i,j) = \sum F_{\text{elast}}(v(i + m, j + n) - v(i, j)) \]  

(3.6)

\[
\begin{align*}
&\{m = -1, n = (-1,0,1)\} \\
&\{m = 0, n = (-1,1)\} \\
&\{m = 1, n = (-1,0,1)\}
\end{align*}
\]

The elasticity force, \( F_{\text{elast}} \), between two neighbour points is a non linear function. To let the net bend down steep slopes and still stretch out under buildings, the \( \text{arc tan} \) function is used as the elastic force function in this thesis. The \( \text{arc tan} \) function rises linear around zero, but far from zero it is almost constant, see Figure 3.3.
To bend the net to the ground an energy function of the image is needed, \( E_{\text{image}} \). This is an attraction force from the image points. The force-field around one image point only exists on the Z-axis. This is a major simplification, due to this the image force affecting a point in the active net only derives from one image point. In a node \( v(i,j) \) in the net the image energy from the image \( I \) is written

\[
E_{\text{image}}(i,j) = F_{\text{attr}}(v(i,j) - I(i,j)) \tag{3.7}
\]

The attraction force, \( F_{\text{attr}} \), in an image point is a gauss function, see Figure 3.4. The tail of the gauss function is cut off at the lower side. Due to this the net is not drawn to points too far away upwards.

The start state of the net is a horizontal plane below the lowest measured point. To help the net raise towards the ground, a negative gravitation force is added as an external constraint force. This force is later turned off in order to preventing it from lifting the net from the surface.
3.3 The Optimization Algorithm

Here is a sketch of the simple algorithm used for the optimization in this thesis.

The force is calculated in each node in the net.

- The elasticity force is calculated. Besides the border points the nodes have eight neighbour nodes. The resulting force in the node is the sum of the values of the elasticity function over all neighbour connections. See Figure 3.3 for the non-linear elasticity function. The force is always pointing along the Z-axis, up or down.
- The attraction force is calculated. The distance between the net and the sampled raw data gives the force from the attraction force function, see Figure 3.4. The force is given a sign making it pointing towards the measured point.
- A negative gravitation force is added with the other forces to the resulting force. This force helps the net to rise in the beginning of the iterations.
- When the force has been calculated in every node in the net it is updated. The sign of the resulting force decides if the node in the net should move up or down. The attraction force controls the length of the step. Strong attraction force means a small step, this is to prevent the net to jump past the measured point.

Figure 3.4: The one dimensional attraction force function in an image point. The tail on the lower side is cut off at a maximum range value to prevent the net to be attracted to points too far away.
The calculation of the forces and the updating of the net are repeated. Finally when the net converges towards a solution, the gravitation force is turned off. The iterations are then continued until the net converges again.

### 3.4 Performance of the active contour

In Figure 3.5 we see a typical single sweep from the test area used in Section 2.2.

![Figure 3.5: A typical single sweep from the terrain. The line drawn among the circles is a section of the optimized active contour. The white line in the highest figure indicates the location of the sweep.](image-url)

The sweep runs from the roadway and over the ditch and a few trees growing on the...
side of the road. Note the plotted line among the points, this is a cut of the optimized active contour.

The result of the algorithm over the test area is seen in Figure 3.6. The small bumps come from thick shrubs, the larger bump in the left of the image close to the road is a rock. In Figure 3.7 the original image is seen.

The synthetic test images in Figure 3.8 and Figure 3.9, show two special cases of ground images. In Figure 3.8 the interesting part is the stretching of the net under the two buildings. The small ripples is the result of stopping the iterations of the optimization. This can be corrected by running the optimization iterations longer. Somewhere one has to settle with the result and in real terrain data the ripple of this size disappear in the noise of the data. The forest in the upper corner is made from uniform distributed data between 0 and 20m, 25 percent of the points in the area is ground points.

Figure 3.9 shows another interesting case, with a steep slope. The net’s ability to stretch out in the slope is the result from the non linear elasticity force function, see Figure 3.3. The net is stiff and the elasticity force increases linearly in small extension, in larger extension the force is almost constant. The elasticity force kind of reach a maximum value and there is no effort to stretch the net further.
Figure 3.7: Raw data image over the test area. The ripples on the road are from passing cars. Note the three cyclists coming from the tunnel on the cycle way and the lamp posts.

Figure 3.8: Test images with two buildings and a forest block. The forest contains 25 percent ground points and 75 percent tree points. The tree points is spread between 0 and 20 m uniformly. Left: the original image. Right: the result of the optimization step. Note the difference in the scaling of the axis.
Figure 3.9: Top left: the true ground image, a cut off gauss function, representing a hill with a steep slope. Bottom left: the result of the optimization of the active contour. Bottom right: the difference between the last two images.
Chapter 4

Segmentation of Objects

The next step after the ground being segmented is to segment the objects above. In this chapter we describe the objects and their characteristics. Some statistical methods are explained briefly.

4.1 Remaining Objects after Ground Segmentation

When the ground points are removed from the data set, the remaining data belong to the object above the ground such as trees, buildings and vehicles. In Figure 4.1 a histogram over the height data from an area with grown up mixed forest is presented. In the figure, a normal distribution curve with average 17m is plotted. It looks like the data can be estimated with a mixture of a few normal distributions.

Figure 4.1: The histogram from the object data in a mixed forest. The plotted curve is an ideal normal distribution. It looks like the data can be estimated with a mixture of a few normal distributions.
seems that a mixture between two normal distributions with averages 6m and 17m could be fitted to the data.

4.2 Statistical Methods

The best way of dealing with the remaining objects is probably with a statistical model. In the ground segmentation done by the active contour method, see Chapter 2, an estimation of the ground surface is done. Having this estimate, it is better to look at the difference between the ground surface and the objects than only the object data. This difference data is insensitive to the formations of the ground.

In [1] a Hidden Markov Model, HMM, for target detection is described. In a HMM model an unknown process is represented with a markov model with a limited number of states. A wooded area containing one building with a common two plane roof could be modelled with a three state HMM. With a stochastic process $Z_i, i = 1, 2, 3$ in each state. The variance of the data from the roof of the building

$$Z_1(x, y) \in N(m_1, \sigma_1)$$

$$Z_2(x, y) = a_x x + a_y y + \epsilon_2, \epsilon_2 \in N(m_2, \sigma_2)$$

$$Z_3(x, y) = b_x x + b_y y + \epsilon_3, \epsilon_3 \in N(m_3, \sigma_3)$$

is of course much less than the variance from the tree data.

The segmentation method is to optimize the parameters of the stochastic processes and the state sequence to give as high probability as possible.

Another approach is to model the data with a Mixture Model. This method is described in [11] and [12]. A Mixture Model is a stochastic process containing of a mixture of several stochastic processes.

$$Z(x, y) = p_1(x, y)Z_1(x, y) + p_2(x, y)Z_2(x, y) + p_3(x, y)Z_3(x, y)$$

$$p_1(x, y) + p_2(x, y) + p_3(x, y) = 1$$

With similar expectations as above

The Mixture process $Z(x, y)$ is a combination of $Z_i(x, y), i = 1, 2, 3$ weighted by $p_i(x, y), i = 1, 2, 3$. By optimizing the parameters and the weights, maximizing the probability a soft classification is obtained.
Chapter 5

Conclusions

The active contour method for ground segmentation performs very well. By modifying the parameters of the contour one can get a net behaving in a desired way. With a stiff net the estimated ground becomes rough. On the contrary, with a very elastic net the optimized net is crumpled when stretched out to reach every shrub. The gain is that it is easy to adjust the parameters to fit the specific application.

To make the classification of the remaining objects, the best strategy is probably to use a combination of several methods. Combining the results from traditional image processing, edge detection and pattern recognition, and the outcome from the statistical methods would probably result in a reliable and robust segmentation.

5.1 Future Work

The next step is to incorporate the data not used in the work in this thesis as reflectance, double echoes and nadir angle. These data contain a lot of information of the measured terrain. From the reflectance information it would be possible to detect objects with common image processing. Asphalt for instance has a quite small variation in reflectance. With this information it would be possible to detect roads acceptably with a simple threshold followed by a detection of lines.

One way to go further with the active contours is to drop a net from above, with a similar technique as in the ground segmentation. With the right settings of the parameters it would be possible to obtain the shape of the trees and buildings. With pattern recognition it would then be possible to separate individual trees and even determine tree species.

It would also be an improvement if a correction could be done of the static error of the data. The relative error within a sweep is about 5cm but the static error due to drifting of the inertial navigation system is about 15cm. By comparing overlapping strips, correction of the data could give higher precision.
References


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