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Automated Log Counting: Proof of Concept Algorithm

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EXECUTIVE SUMMARY

Improvement log inventory is a key area where the New Zealand forestry industry could significant improve its supply chain performance. Although the process of counting logs seems relatively simple; in reality it is actually a difficult and labour intensive job. This is particularly significant to the New Zealand log export industry which is required to count and barcode every log (excluding pulp) that is exported. The fluctuating nature of export markets means that automated methods of counting logs hold significant potential.

FFR has a programme of work (Objective 4 of the Intensive Forest System) looking at the improvement of resource monitoring systems. This programme investigates technologies to improve the collection and use of forestry data. The technology ranges from satellite imagery for forest health monitoring to the use of system dynamics to determine the impact of improved inventory on the forestry supply chain.

As part of Objective 4 of the Intensive Forest System FFR research programme a relatively small project was setup to investigate the potential of the accuracy of counting logs in pile/stacks using 3-dimensional (3D) point cloud data obtained from a ground based LiDAR scanner. In the past there have been a number of attempts to develop an automatic log counting system, the majority of these have used 2-dimensional photographic images. It was hypothesised that using 3D point data would overcome some of the problem that the approaches in the past have encountered.

The validation study carried out on the algorithm showed that logs can be accurately count and measure log diameters. Further work would be required to develop the algorithm into a commercial product. Additional work would be needed to determine the most cost effective hardware required to collect the 3-dimensional data required by the algorithm.

As part of this project, a business case was carried out by Seltec Advisory Ltd on log stack scanning showing that in its current form the algorithm has limited commercial markets in New Zealand until systems are priced at under $(NZ)5000 per unit. The study highlighted that if the algorithm could be extended to be able to carry out log scaling in accordance to New Zealand domestic and export scaling rules then potentially the application of such an algorithm would be commercial viable.

INTRODUCTION

Background

Exact log counts are required at marshalling points and at shipside. Present systems rely on truck drivers and stevedores to accurately count the number of logs both on truck and in piles (bunks) on the ground at the wharf prior to loading. Incorrect log counts incur a cost through additional labour to correct mistakes identified at a later stage, or from shipping unticketed logs where errors are not identified. New approaches are being considered to improve on the current manual system.

Automated log counting using standard photography and digital image processing has been trialed in the past however accuracy levels were not high enough for this combination to be considered practical. There is one example of stereo photography being used, sScale$^{(TM)}$ developed by Danish Company (Dralle Ltd, www.dralle.dk, Accessed on 3 July 2009) have commercialised a system to both count and measure the volume of logs. To overcome some of the problems of standard photography in this application, ground based LIDAR has been suggested. A Chilean company has developed Logmeter^{4000} (www.woodtechms.com, Accessed on 3 July 2009) that uses LiDAR (Light Detection and Range) to measure and scale volume of logs on a truck.

Whether using standard, stereo photography or LiDAR to capture the data, processing algorithm are required to automatically extract the information. LiDAR produces a dataset of 3D points where the x,y and z coordinates are known for each point on the object that the laser strikes. This sort of data has some potential advantage for counting objects in an image over standard photography. There are at least two general approaches that could be used in this application:

- The point data is turned into an image which is then used in a traditional image processing algorithms (thresholding and watershed) to count the logs.
- Use the point data and develop object recognition algorithm (subject of this report).

Project Objectives

The objective of this project was to develop and test a prototype log counting algorithm that uses solely the 3D point cloud dataset generated by a ground-based LiDAR scanner. This report details the methodology behind the algorithm and two validation exercises that were design to establish proof of concept.

METHODS

Algorithm Development

The LiDAR Log Counting algorithm is made up of three basic components: searching, filtering and stopping. This algorithm has been developed only to use the x, y, and z data. The number of user inputs into the algorithm has been kept to a minimum. The users only have to enter an estimation of the allowable maximum and minimum diameters of the logs in the pile\stack. This is as simple as entering the maximum LED (large end diameter) and minimum SED (small end diameter) for the log grade being counted. Figure 3 gives an overview of the algorithm.

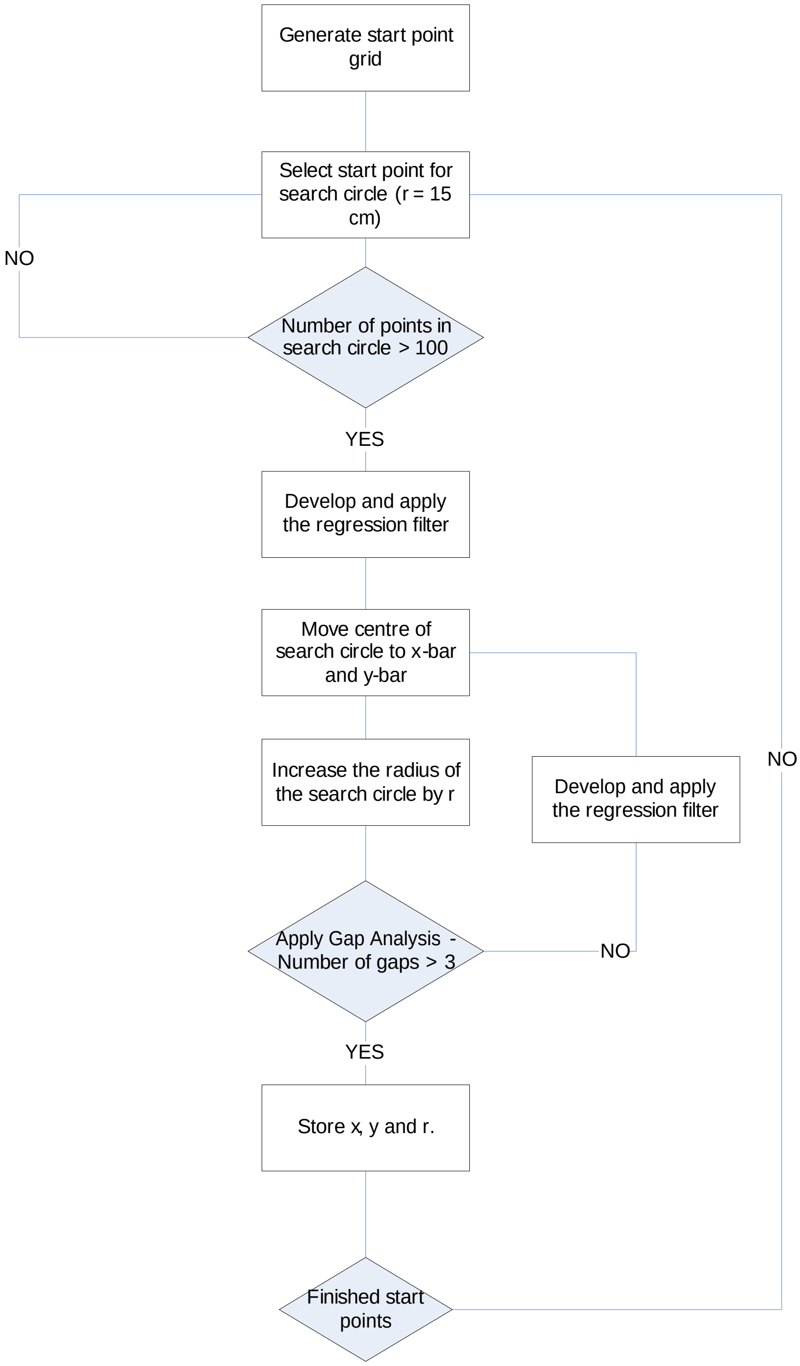


Figure 1. A flow chart of the LiDAR Logging Counting (LLC) algorithm

Searching Components

The searching component of the algorithm uses a systematic grid of starting points to find good locations to start the localised search. A "GOOD" search start point is defined as having at least 100 points within a search circle of 150 mm. Once a "GOOD" start point is found the search circle centre is moved so that it is centred on the mean x, y co-ordinates from the old circle's location (Figure 2).

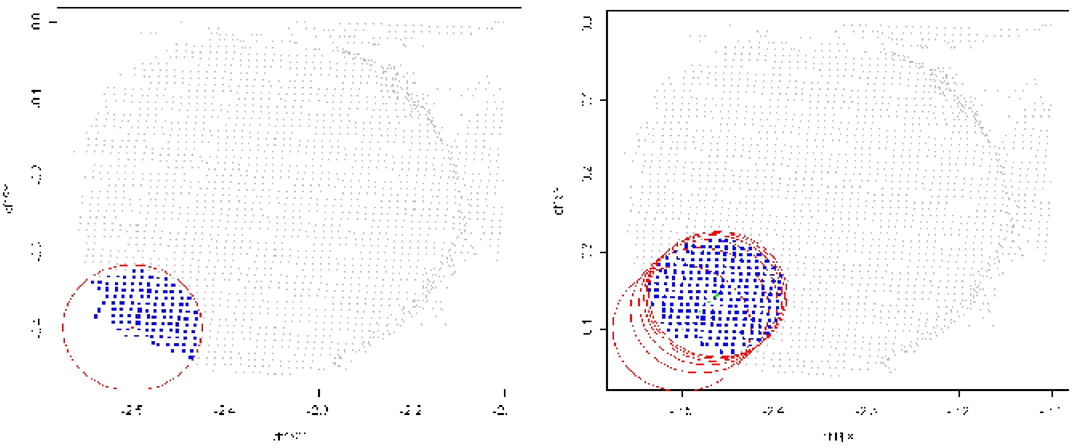


Figure 2. The demonstration of how the search circle is moved.

The search circle centre is continually shifted until the distance that the search circle moves is less than 1 mm. Once this point is reached the radius of the search circle is increased is a linear fashion. The radius of the search circle grows at a constant 1 cm each iteration (Figure 3).

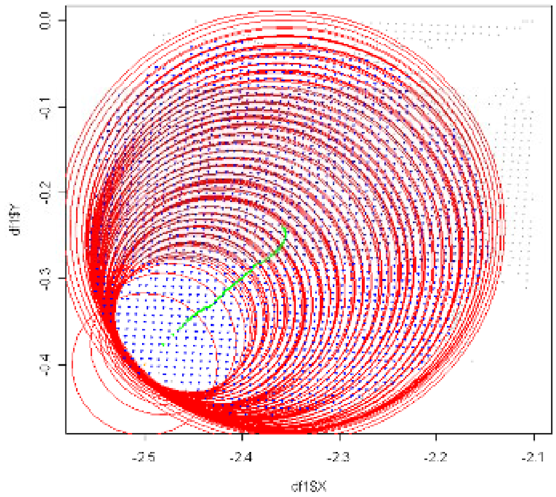


Figure 3. The search pattern of the algorithm

Filtering Components

This algorithm is primarily looking for flat circular surfaces of points that have reflected off the log ends. However the raw LiDAR dataset contains points that not only have reflected off the log end but also off other objects and the sides of the logs. The algorithm uses an adaptive filter to eliminate as many points that have not reflected off the current log end that is being searched. The algorithm utilises multiple linear regression to develop a model of the log end surface. This relies on the following characteristics of the LiDAR dataset:

- The log ends are normally cut with a straight face and hence can be modelled using a linear regression.
- Neighbouring logs are really on the same plane.

The points within the search circle are used to develop a linear function relating the x and y values to the z values. This function is then applied to the whole LiDAR dataset any point with a residual value (|actual – predicted|) less than 0.0075 is removed from the dataset until the current log has been isolated.

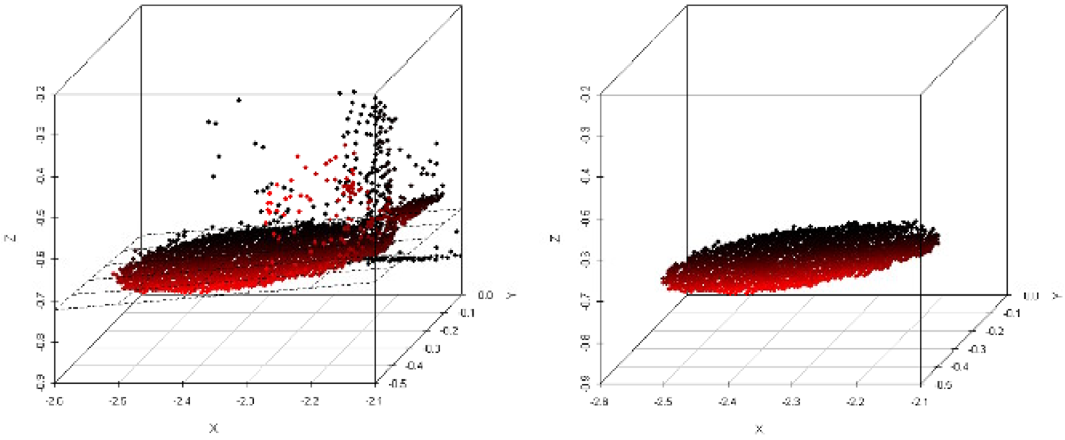


Figure 4. The effects of the regression filter.

Figure 4 shows the impact of the filter in eliminating points within the dataset that do not represent part of the log surface.

Stopping Components

Each time the diameter increases the stopping criteria is calculated, the criteria simply looks at the number of gaps in the outer 20 mm of the search circle. The angle from a horizontal axis is calculated for each of the points in this outer circle. The points are then sorted according to this angle. For the stopping criteria to be met there has to be at least three valid gaps. The rules that are used to count the number of gaps are as follows:

- Gaps in the direction that the search circle is moving are not counted.
- If the angle (radians) is greater than 0.6 a gap is counted.
- If there is only one point between two gaps then the two gaps are considered to be only one.
- If the gap has angle that is greater than 2 radians, then that is considered to be made up of 3 gaps.

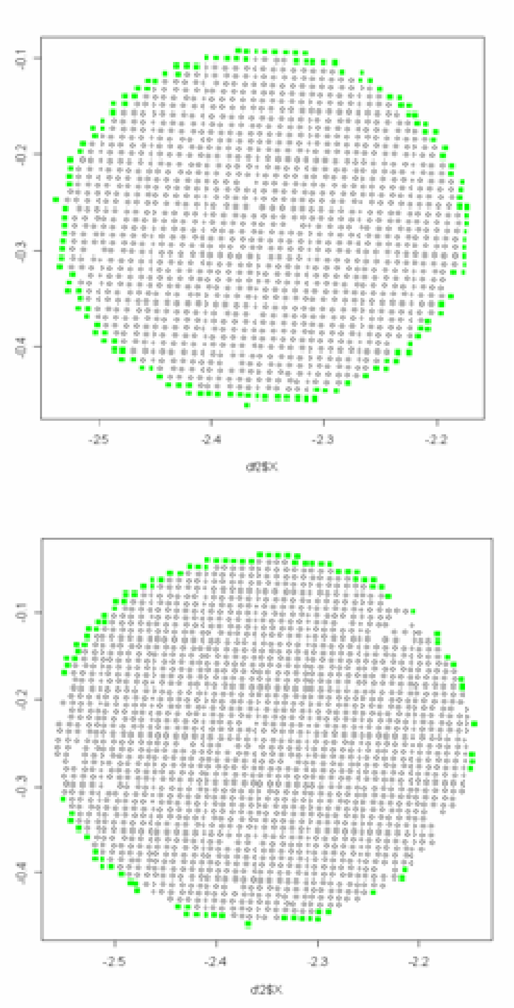


Figure 5. An illustration of the stopping criterion.

Once the stopping criterion is reached the search circle diameter (an approximation of the log diameter) is checked against the maximum and minimum allowable diameters for the log pile\stack. If the target diameter is outside the allowable diameter range it is rejected as a log and not added to the count. If the log is inside the allowable diameter range it is added to the count and the points in the image that made up that log are removed.

For testing purposes the algorithm has been implemented in the R statistical programming language. The algorithm has been ported across to C# to understand any improved performance from implementing with a compiled language.

Data Collection

The general methodology for collecting the source data for this project was to scan the end of the log pile with a ground-based LiDAR scanner. The LiDAR scanner collects a 3 dimensional point dataset of the log faces. The scanner used in this trial was capable of 4000 points per second, with a maximum intensity of 1 per mm^2. For this application, it seems that a scanning intensity of 1 per cm^2 (measured at maximum range) seems most suitable. On average, a scan at this intensity took no more than 5 minutes to scan a bunk of logs. The LEICA Scan Station (www.leica-geosystems.com) used in this trial was also capable of collecting the intensity of the reflected laser beam as well as the RGB (red, green blue) value for each point. These were not used in the algorithm to assist in the counting as they are not collected by cheaper LiDAR scanners.

Figure 6 gives an example of data collected during the scanning of the end of a bunk of logs. This dataset can be filtered to remove unwanted data such as returns from the log bunk and other objects in the background.

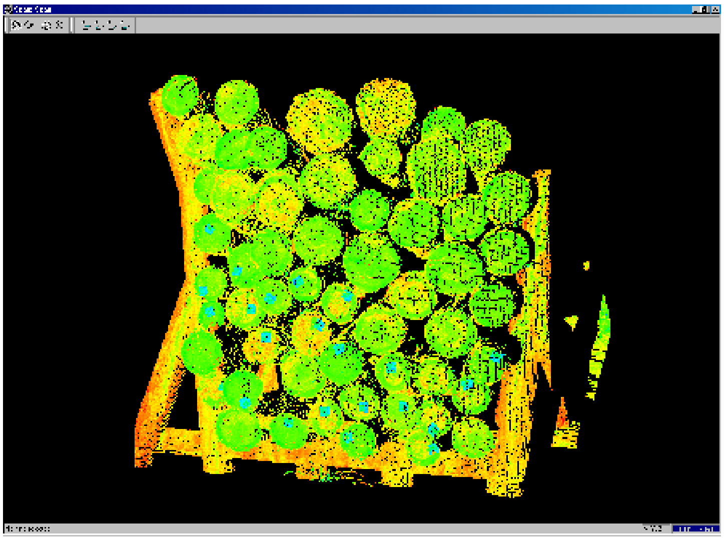


Figure 6. A view of the raw LiDAR data

Validation

A validation dataset was collected at the Port of Tauranga using the LIECA Scan Station. In total 16 scans were collected. It would have been beneficial to take a more systematic to collecting these scans to cover a wider range of different log piles, log diameters and scanning locations. However the relatively low project budget combined with the high cost of hiring the scanning equipment ($2500 per day + operator costs) meant that these scans were largely taken in largely an advantageous matter. Of the 16 scans; 6 were log piles in bunks with the remainder being log piles on the ground. Figure 7. Three examples of the range of the log stacks included in the validation dataset.

Figure 7. Three examples of the range of the log stacks included in the validation dataset.

In this study the scanner location was largely left to the third party scan operator. In most cases the location was no less than 2 metres away and not greater than 10 metres way from the pile/stack. The scanner was also placed directly in front of log pile and as close to the centre of the pile as possible.

Log Count Validation

The algorithm was run over each of the scans. For each of the scan the algorithm user input variables; minimum diameter, maximum diameter were changed to match the grade of logs in the pile.

The algorithm log counts were compared to human counts taken off the images. The human count was done several times to verify that the manual counts were accurate.

Log Diameter Validation

When the original scans were taken there was insufficient time to measure diameters in the field. However given the 6 millimetre positional accuracy of the LiDAR scanner it was decided that measuring the diameters manually from the images would give an equally accurate representation of the true log diameters as field measurement. A small R script was written to allow a human to measure the log diameter from the LIDAR scans.

Figure 8 shows how the R script allowed the manual measurement to be made from the LiDAR scans on a computer screen. Figure 8 was created from the LiDAR; the LIECA Scanning Station used to collect this data collects not only returns the x,y and z position but also the red, green and blue value and the laser return intensity.

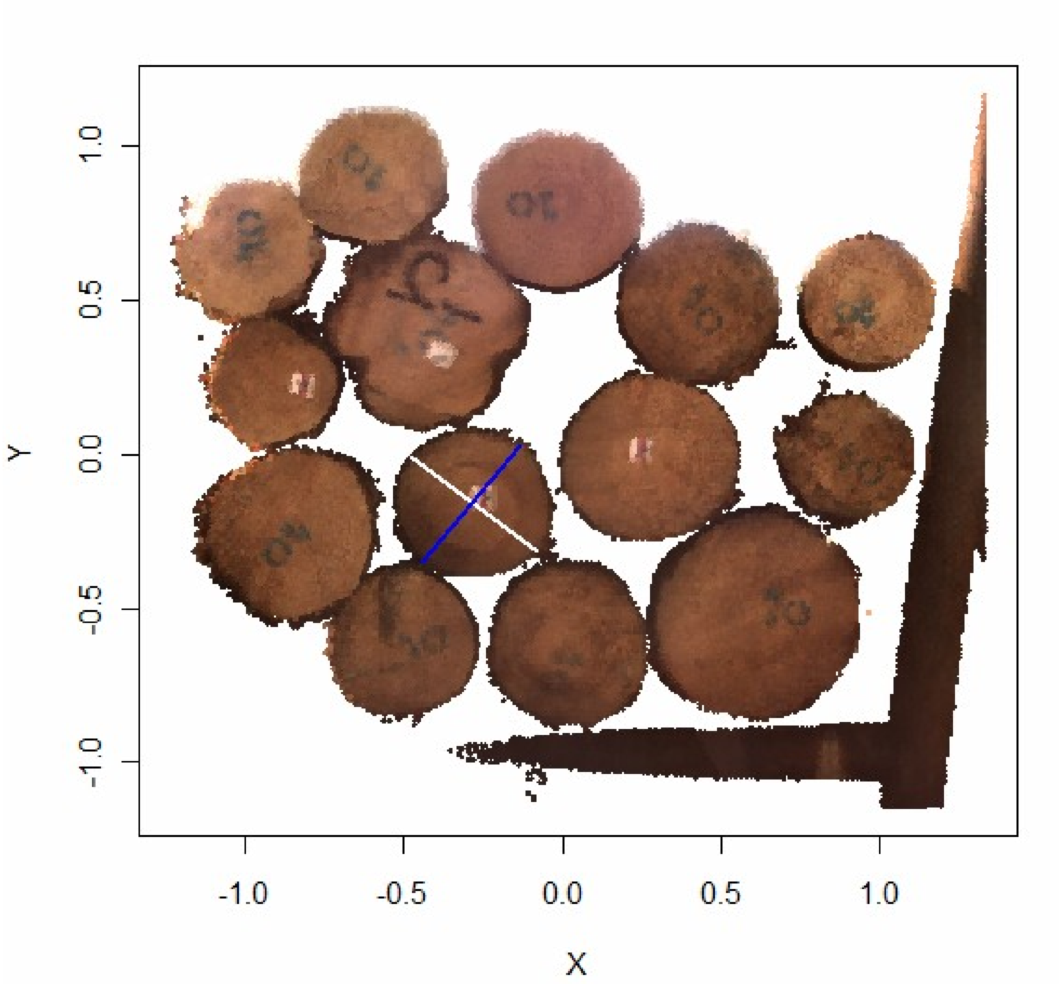


Figure 8. A typical image used to manually measure the diameters of the logs. The white and blue lines demonstrate how the diameters of log were measured from the image.

Both the largest diameter (diameter 1) as well as the diameter (diameter 2) at right angles to that diameter was measured on each log. These diameter measurements were all carried out by a technician with practical scaling experience. No scaling log diameter reductions were done to either the manual or algorithm measured diameters.

The irregular shape of most log ends mean that the exact diameter measurement of a log is always somewhat subjective. This makes comparing the accuracy of diameter measurements made by different measurement techniques difficult.

RESULTS

Pilot Log Count Validation Study

Table 1. Manual vs Algorithm Log CountTable 1 shows the actual (manual) log counts compared to the counts produced by the algorithm. In Scan O only an approximately count could be carried out due to poor image quality.

Table 1. Manual vs Algorithm Log Count

Scan	Actual Count	Algorithm Count	Percentage Accuracy
A (Bunk)	14	14	100 %
B (Bunk)	35	35	100 %
C (Pile)	31	30	96.6 %
D (Bunk)	64	64	100 %
E (Pile)	209	204	96 %
F (Bunk)	24	24	100 %
G (Bunk)	24	23	96 %
H (Pile)	14	14	100 %
I (Pile)	31	31	100 %
J (Pile)	44	45	97 %
K (Pile)	58	56	96.6 %
L (Pile)	75	75	100 %
M (Pile)	79	81	97.5
N (Pile)	~ 101	101	100 %
O (Pile)	181	175	96.7

The least accurate counts were all from log pile such as those in the centre and left images in Figure 7. It seems that algorithm performs better when the edges of the log piles are well defined rather than those which formed part of a larger log stack.

The LEICA Scan Station scanner used in this study uses a whisk broom scanner; a mirror scans across and reflects light into a single detector which collects one data point at a time. In this application the disadvantage of this type of scanner is that the laser only hits the log ends perpendicular to the exact centre of the scan. Logs further away from the location of the scanner get scanned at increasingly acute angle, this leads to increased chance of shadowing that can affect the accuracy of the counts. Another type of scanner called push broom maybe more suitable for this application and could lead to more accurate counts even on log piles that are not in bunks as the laser beam hit the log perpendicular more often (Figure 9).

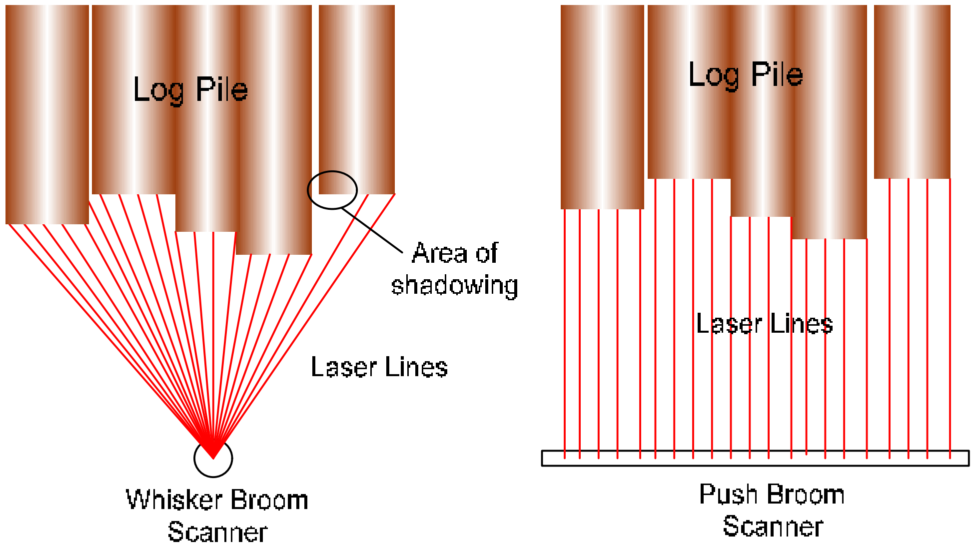


Figure 9. Different scanning options and their impact on counting accuracy.

Appendix 1 contains graphic illustration of the count of each scan.

Pilot Diameter Determination Validation Study

It should be noted that this algorithm was not developed to measure the diameter of the log. As part of the methodological approach of the algorithm the diameter of each log is estimated. However the algorithm is not optimised to accurately measure the diameter of the logs in a pile. In total 397 log diameters (measured vs predicted) were compared. The diameters in the validation set ranged from 165 mm to 760 mm.

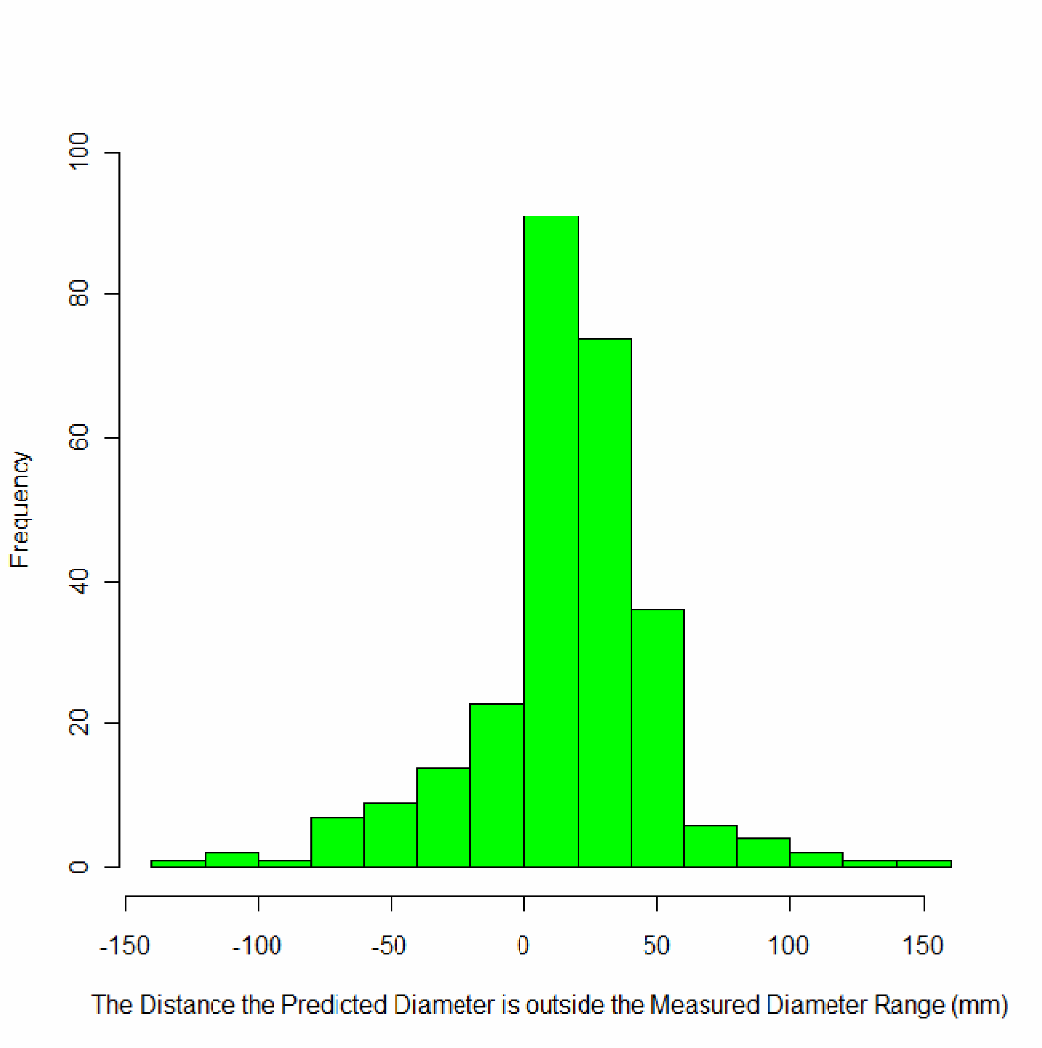


Figure 10. Distribution of the algorithm predicted diameters that are outside the measured diameter range.

Figure 10 shows the distribution of the residuals of the algorithm predicted diameters and the measured diameters. This graph does not include the 124 algorithm predicted diameters that were inside the manually measured diameter range. This means that 69% of the algorithm diameters were outside the manually measured range. In the majority of the cases the algorithm slightly over predicts the diameter as compared to manually measured diameter.

Paired t-tests were used to determine whether there is a statistical difference between the measured and algorithm predicted diameters. The tests showed that there was no statistical significant difference (p-value = 0.2258) between the algorithm predicted diameter and the maximum manually measured diameter (diameter 1). However there was a statistical significantly difference (p-value < 0.000) between the algorithm predicted diameter and the minimum manually measured diameter (diameter 2).

Performance

Table 2 shows the time it takes to process the different scans using the algorithm described in this paper. It compares the processing time for the algorithm implemented in R Script and C#.

Table 2. Algorithm Processing Times

Scan	R Script Implementation (s)	C# Implementation (s)
A (Bunk)	65.5	5.8
C (Pile)	139.0	20
D (Bunk)	450.3	47
E (Pile)	1059.5	185
F (Bunk)	73.1	5.4
G (Bunk)	55.2	4.1
I (Pile)	118.7	17.58
J (Pile)	372.6	53.55
K (Pile)	307.7	39.38
L (Pile)	887.1	40.12
M (Pile)	325.4	47.94
N (Pile)	898.7	155.14
O (Pile)	1039.7	136.16

On average there is 88 percentage improvements through using a complied language such as C#. It should be noted that the actually counts may differ between the two implementations.

DISCUSSION

The original idea for the development of this algorithm came from the need to accurately count logs in pile/stacks particularly at the port before export. Past attempts have been made in New Zealand including one that was used commercially in the early 1990s. A Danish company (Dralle Ltd) currently markets a system called sScale(TM) used for both counting log in piles and measuring volume (www.dralle.dk). Dralle Ltd's website claims that the accuracy of their system in measure volume is within 2 % at a cost of €0.5 per cubic metre (~$(NZ) 1.04). Using standard photography has some advantages in term of capital cost of equipment but has a disadvantage in terms of lighting requirements.

The goal of this project was to investigate and proof the concept that a 3d point cloud of x,y, and z co-ordinates could be used to count logs in a pile\stack. Ground-based LiDAR scans are being used in a number of industries, including mining and film making to collect 3d point clouds of objects. By using a 3d point cloud to count logs in pile/stack, issues around lighting are no longer an problematic; in fact the images could be taken at night in complete darkness. The Logmeter developed in Chile uses LiDAR to scan a whole truck from a above to estimate diameter, length, volume and a range quality characteristics (http://www.woodtechms.com , Accessed on 3 July 2009).

This report outlines the methodology used to proof the concept that number logs in a pile can count using a 3d point cloud representation of the end of the pile of logs. A small validation study showed that the algorithm can routinely produce counting accuracy of greater than 96%. The accuracy improves to 100% if the logs are contained in a log bunk such as the image on the far right of Figure 7. It is likely further work on the algorithm such as implementing improved segmentation techniques could improve the counting accuracy of the algorithm. The target has to be to obtain 100 % accuracy 100 % of the time for this algorithm to be a commercial success.

The algorithm outlined in this study was not designed to measure the diameter of the logs that were being counted. However as part of the counting methodology an estimate of the diameter is obtained. Due to the irregular nature of the log diameter it is different to accurately qualify the accuracy of one diameter measurement against another measured using a different methodologies. In this study 31 % of the algorithm measured logs were within manually measurement range (two manually measurement were made per log).

In operational situation performance (time to count a pile of logs) of the algorithm will be important. The original prototype was developed in the R statistical language, porting it across to C# showed that significant improvements in the processing performance can be achieved. Further performance improvements are likely to be able to be made both improving the design of the algorithm as well as utilising programming technologies such as multi-threading and parallel processing.

The research covered in this report did not cover hardware. LiDAR scanners are expensive, the LIECA Scan Station costs approximately $(US) 150,000 however it has numerous features that are not utilised in this application. There are other cheaper LiDAR options such as those manufactured by SICK (a Swedish company) that cost around $(US) 10,000. 3D point cloud data of objects can be generated from stereo photography, which simply requires two high quality cameras such as used by Dralle Ltd in the sScale(TM) product.

A report on the commercialisation of log counting technology was commissioned by SCION and conducted by Seltec Advisory Limited (Anderson 2009). The report talked to a number of potential customers in the market. The finding of this report found that simply carrying out log counts on piles/stacks would not be enough to create a commercially successful product. It seems that the original demand for this log counting seems to have disappeared as export demand has shifted from K grade to A grade, meaning that less logs need to be counted per cubic metre of volume. The report indicated that if the concept could be extended to automatic scaling to export and domestic scaling rules then there may be a market for such technologies. To turn the current algorithm into a product would require additional development work and due to the qualitative nature of some scaling rules that development work would be non trivial.

CONCLUSION

This report outlines a proof of concept log counting algorithm using 3D point cloud data generated from a LiDAR of the end of a pile logs. The algorithm accuracy for counting logs in a pile is upwards of 96% on the data sets collected. Although not originally designed to measure diameter of the log, a validation study carried as part of this project showed that the algorithm described in this report has could be improved to accurately measure the diameter of all the logs in a pile/stack.

To be fully commercialised this algorithm would need further work to improve its accuracy both in terms of log counting and diameter measurements. There are numerous image processing techniques as well as computer programming techniques that could be investigated to improve overall performance. In terms of new functionality, any additional work on this project should focus on developing automated methods for identifying defects that affect the scaled volume of logs. Additional research into the optimal hardware to capture the 3D point cloud would also need to be undertaken before a cost effective tool could be released.

It seems that based on a business case carried out by Seltec Advisory Limited on the market size for log stack scanning concluded that the market is relatively small. The study did identify some niche markets that would benefit from the concept of log counting. This market would dramatically increase if the algorithm could automatically scale logs based on New Zealand’s scaling rules however from algorithm development point of way this is a non trivial matter.

From a research perspective, this project has highlighted the potential of using ground based LiDAR scanning technology and 3d point cloud data for determining log characteristics. The lessons learnt and techniques developed as part of this will hopefully be utilised in further research and development into this or other applications.

ACKNOWLEDGEMENTS

John Threadgill (ATLAS Technology, SCION) for re-implementing the algorithm into C#.

Bruce Robinson (Geosurvey) for assisting in the scanning.

James Anderson (Seltec Advisory Limited) for providing commercialisation insights.

REFERENCES

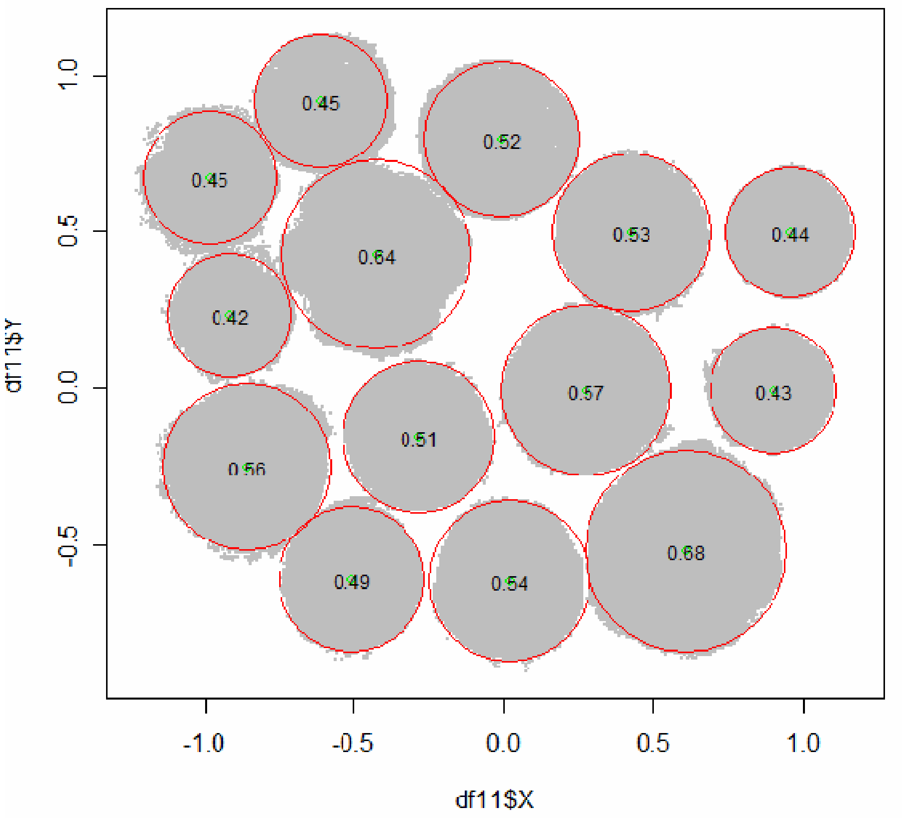
Anderson J. 2009. Log Stack Scanning: Business Case. Prepared for Scion and Future Forests Research. Seltec Advisory Limited. Confidential Report. Seltec Advisory Limited.

LogMeter^{4000} http://www.woodtechms.com/logmeter1.php, Accessed on 3 July 2009.

sScale$^{(TM)}$ www.dralle.dk, Accessed on 3 July 2009.

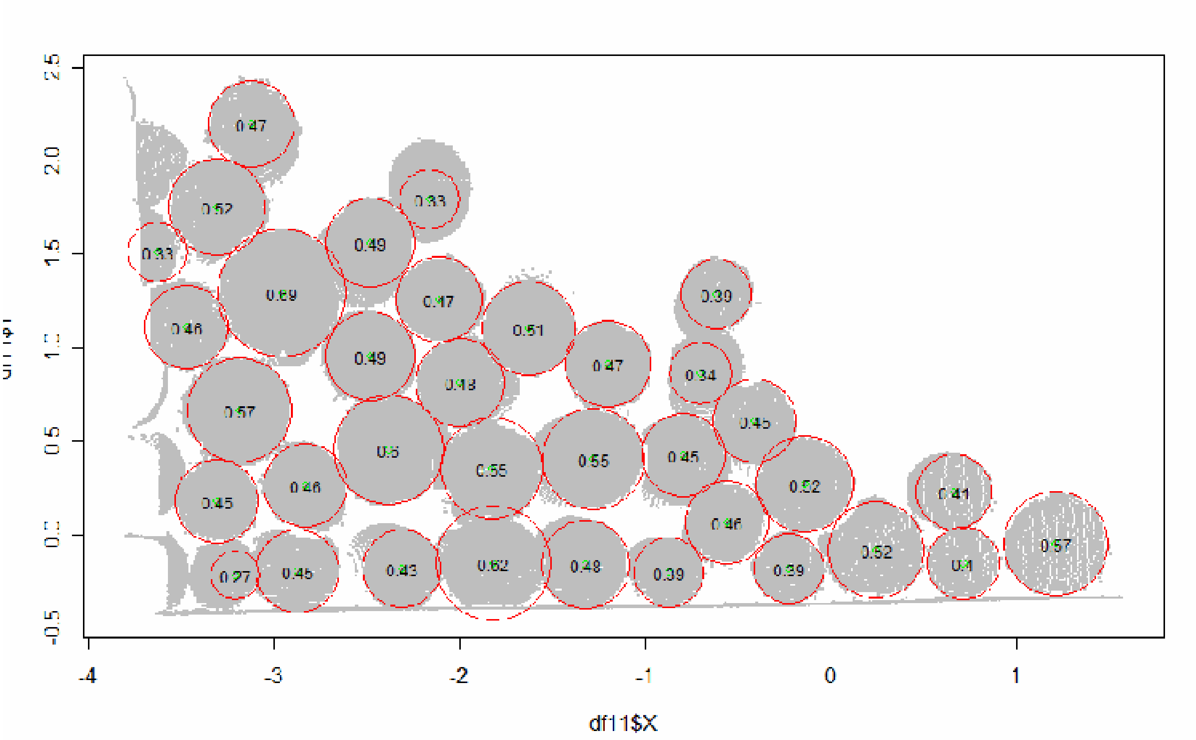
APPENDICES

Scan A
Actual Count = 14.
Algorithm Count = 14 (100%)
Counting Time (R Code) = 65.46 seconds (4.7 seconds)



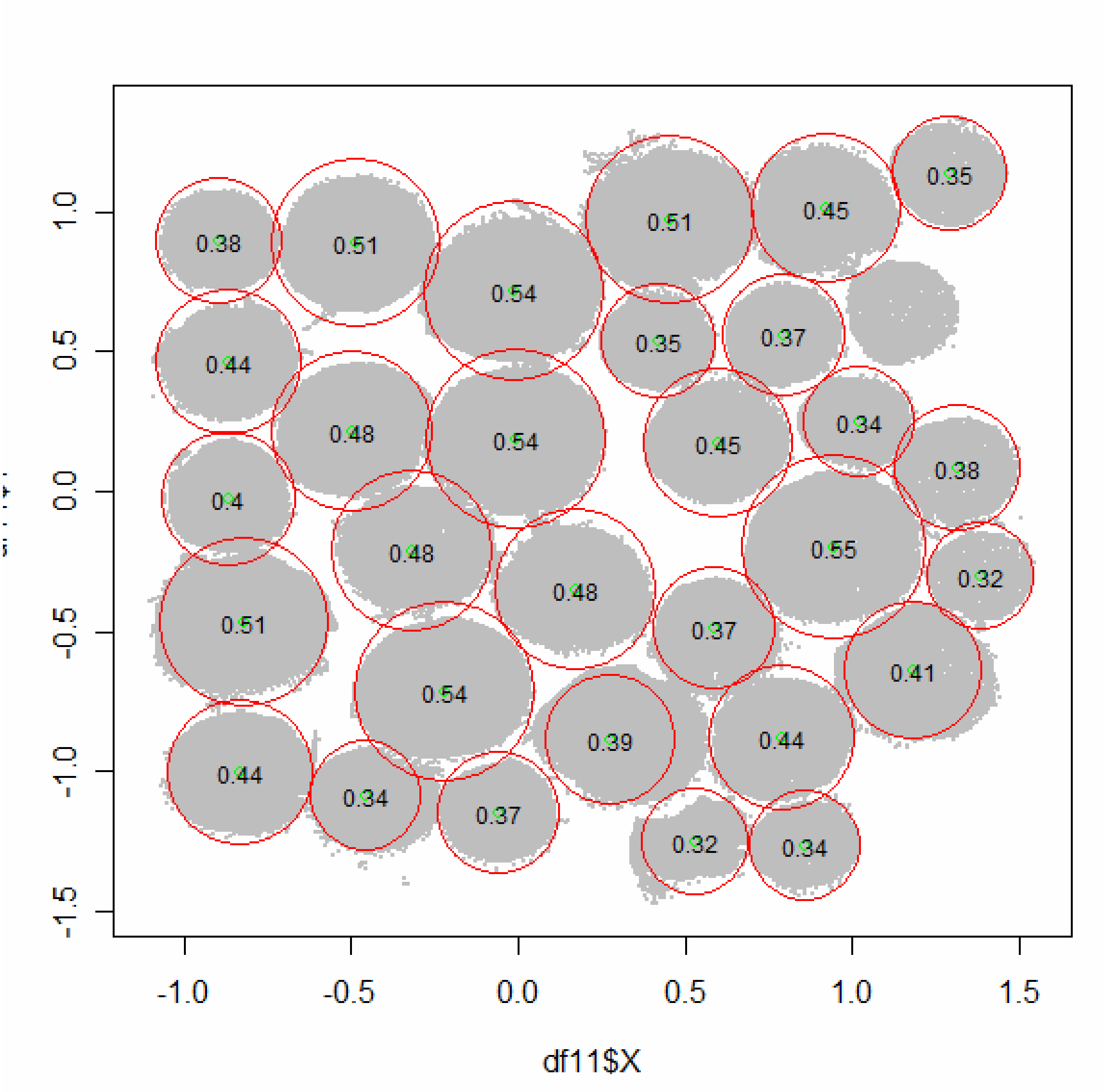
Scan B

Actual Count = 35.
Algorithm Count = 35 (100%)
Counting Time (R Code) = 119.61 seconds (3.4 seconds)



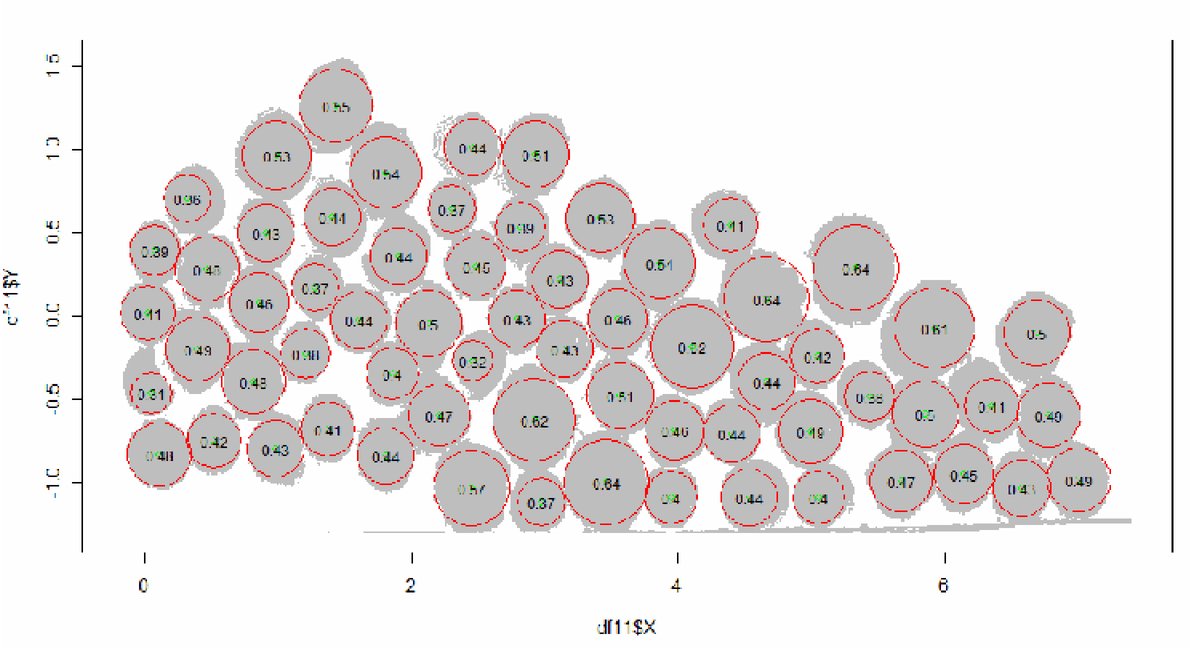
Scan C

Actual Count = 31.
Algorithm Count = 30 (96.666%)
Counting Time (R Code) = 139.01 seconds (4.6 seconds)



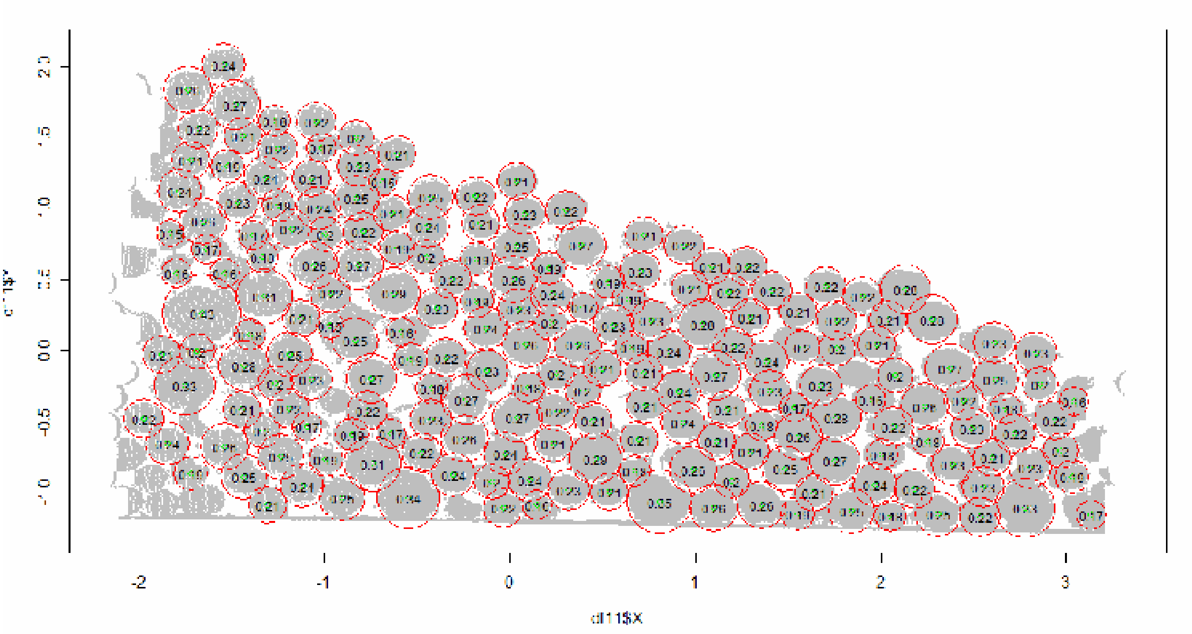
Scan D

Actual Count = 64.
Algorithm Count = 64 (100 %)
Counting Time (R Code) = 450.26 seconds (7.1 seconds per log) **–** 7 mins for total count
Comments: Speed improvement when the minimum allowable shift distance was reduced from 0.001 to 0.01 was (450.26 – 439.33 = 10.67)



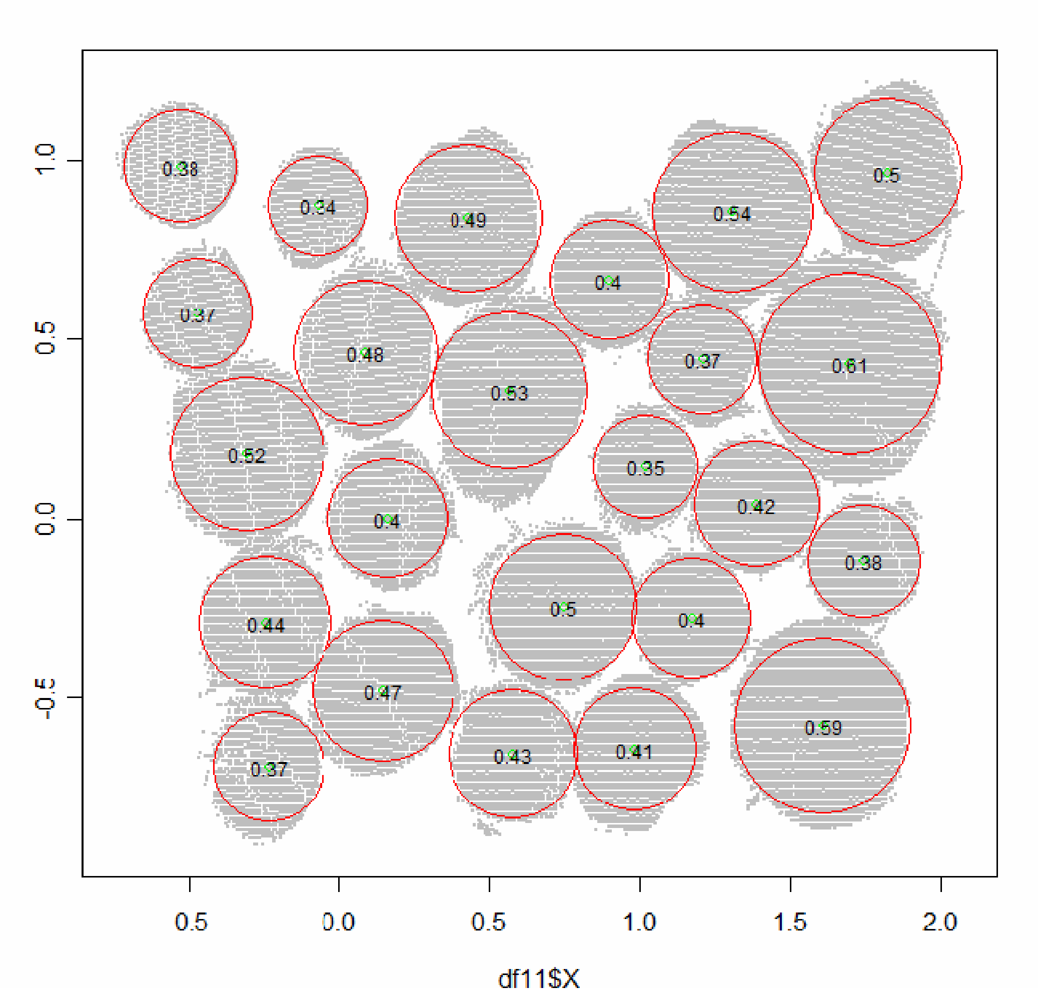
Scan E

Actual Count = 209.
Algorithm Count = 204. (~96 %)
Counting Time (R Code) = 1059.48 seconds or 17.65 mins (5.19 seconds per log)
Comments: This is by far the most difficult of all the log piles due to the small diameter of the logs. A number of logs were missed by the algorithm.



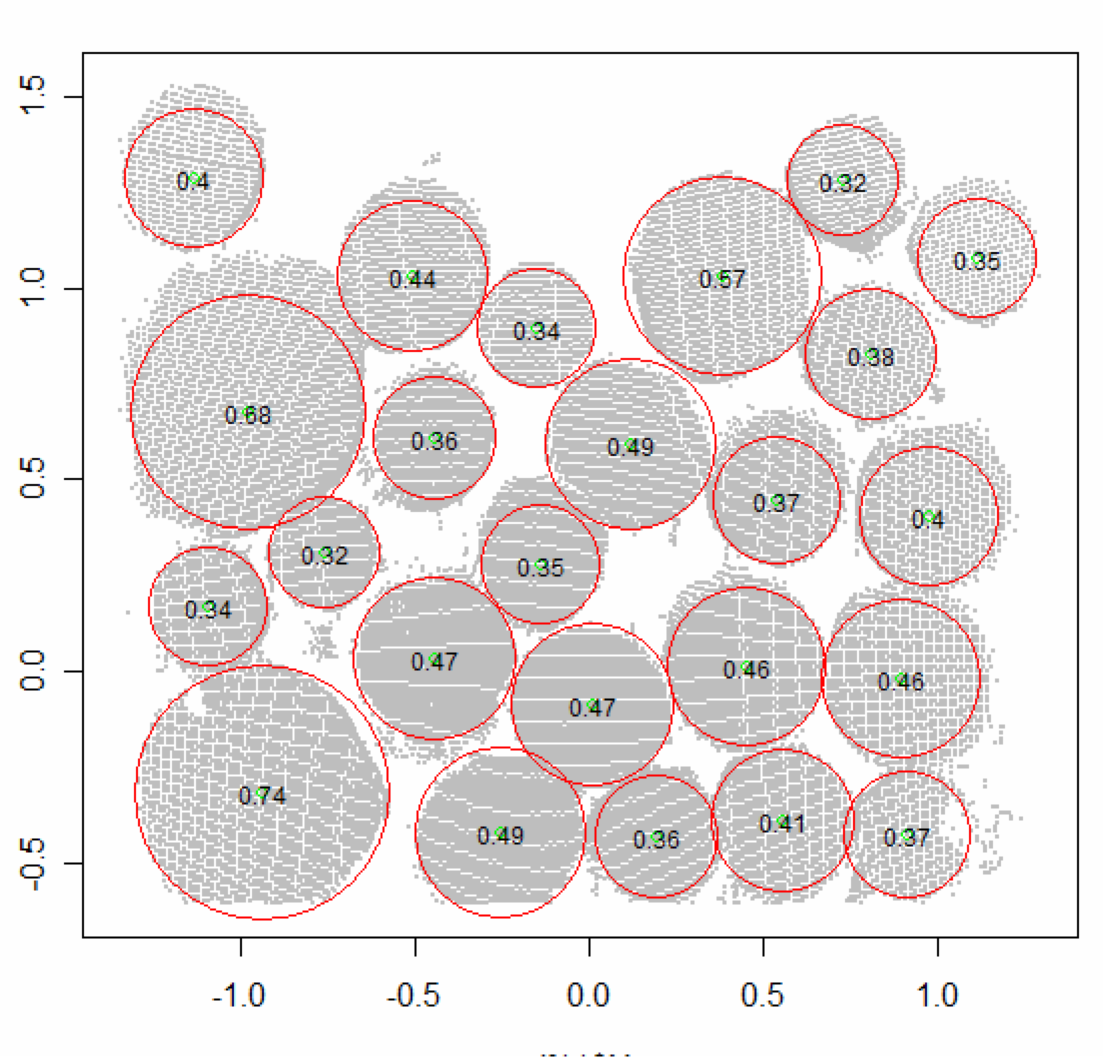
Scan F

Actual Count = 24.
Algorithm Count = 24. (100 %)
Counting Time (R Code) = 73.14 seconds (3.04 seconds per log)
Comments: Speed improvement when the minimum allowable shift distance was reduced form 0.001 to 0.01 was (73.14 – 64.97 = 8.17)



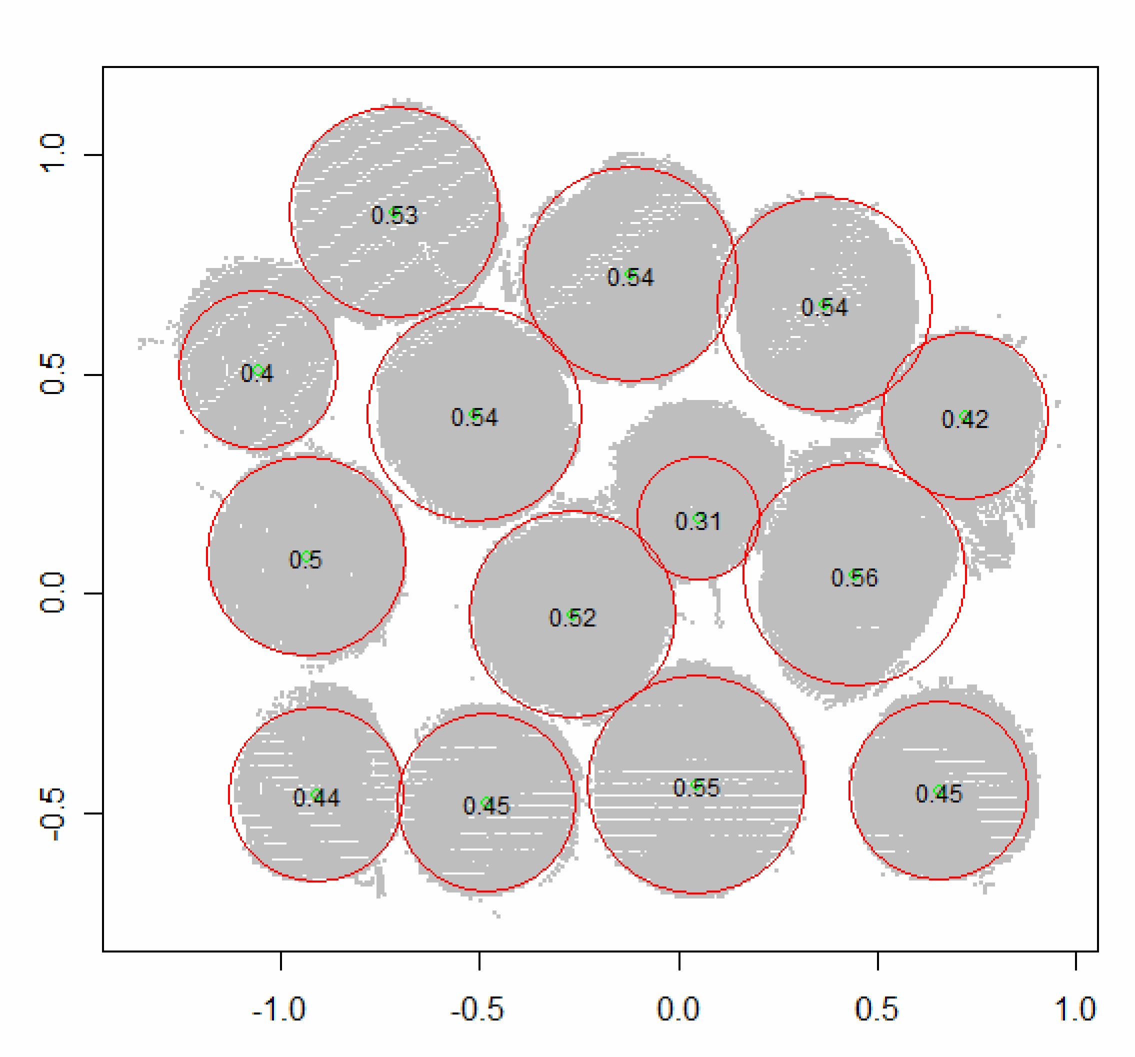
Scan G

Actual Count = 24.
Algorithm Count = 23. (96 %)
Counting Time (R Code) = 55.17 seconds (2.40 seconds per log)
Comments: This count is missing 1 log after further investigation found that if the maximum allowable shift was increased to 0.01 the count increased to 24.



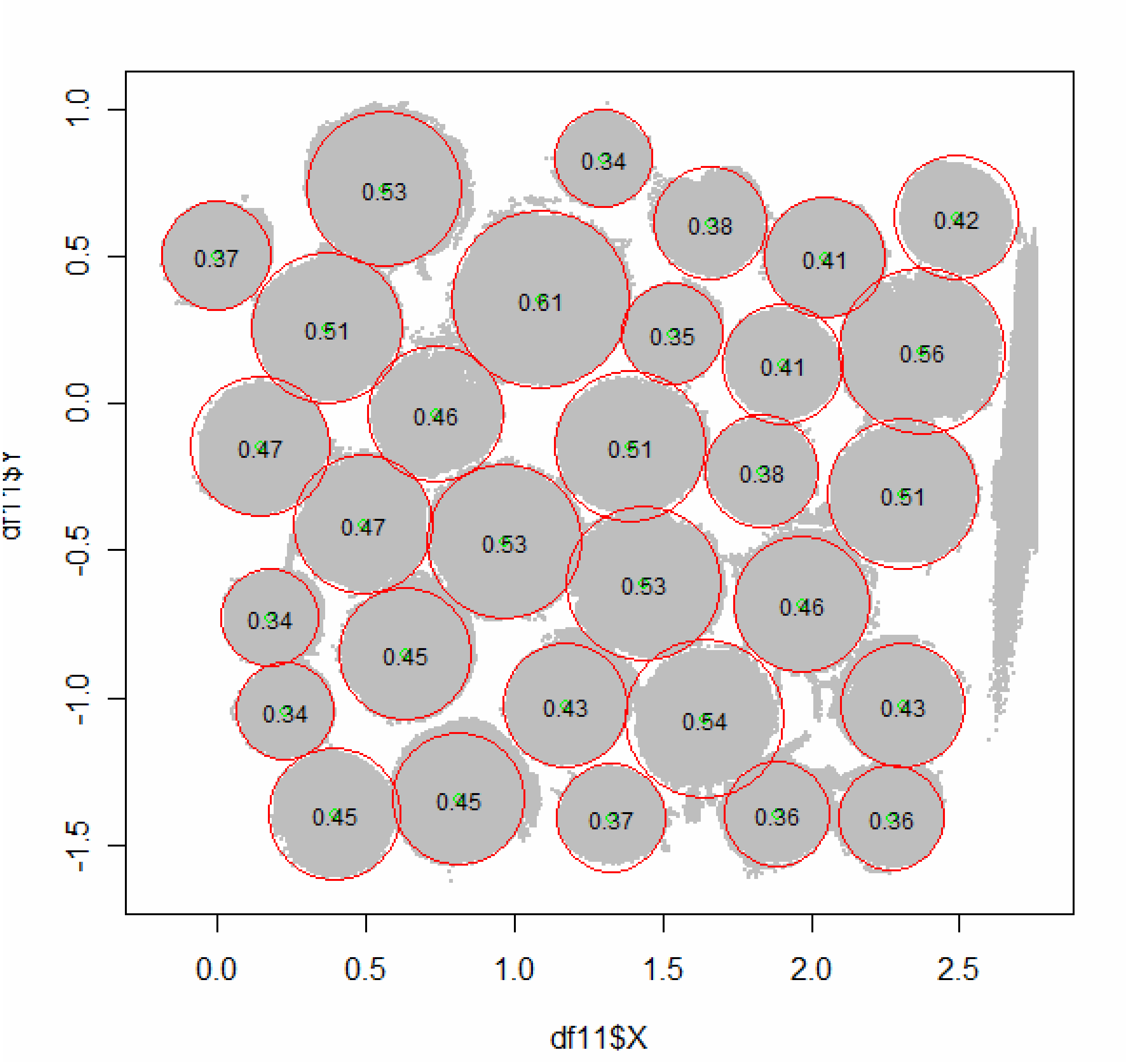
Scan H

Actual Count = 14.
Algorithm Count = 14. (100 %)
Counting Time (R Code) = 32.31 seconds (2.30 seconds per log)
Comments:



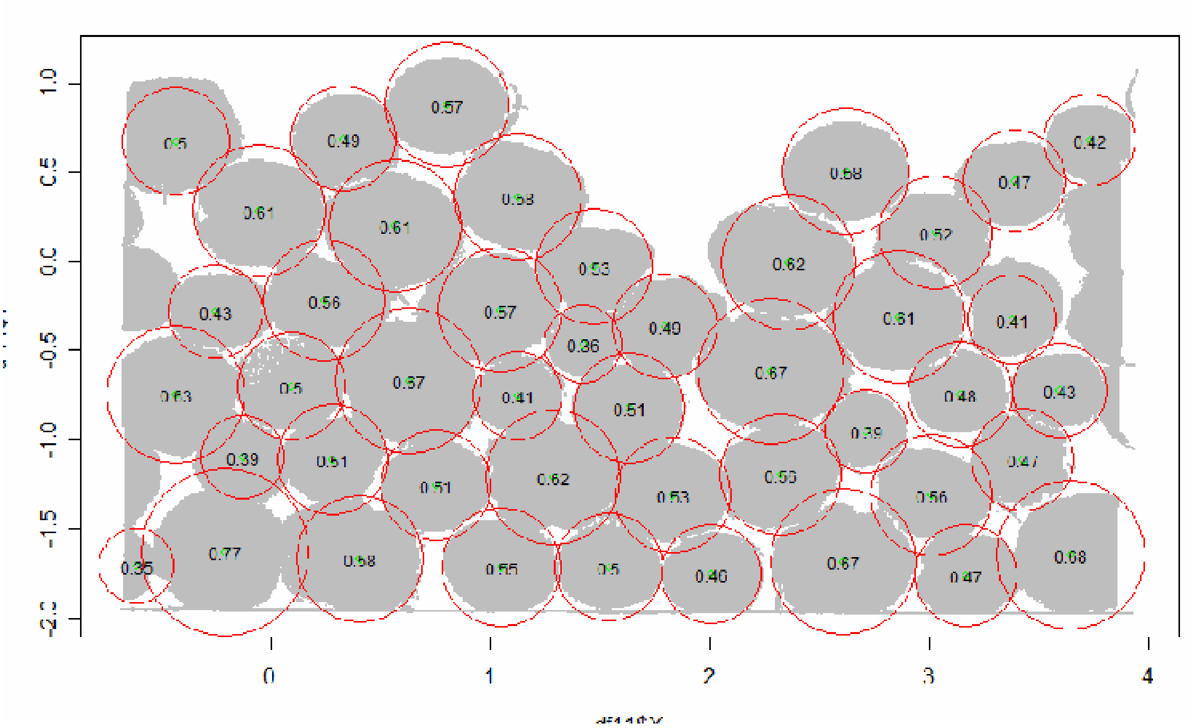
Scan I

Actual Count = 31.
Algorithm Count = 31. (97.5 %)
Counting Time (R Code) = 118.67 seconds (3.8 sec per tree)
Comments:



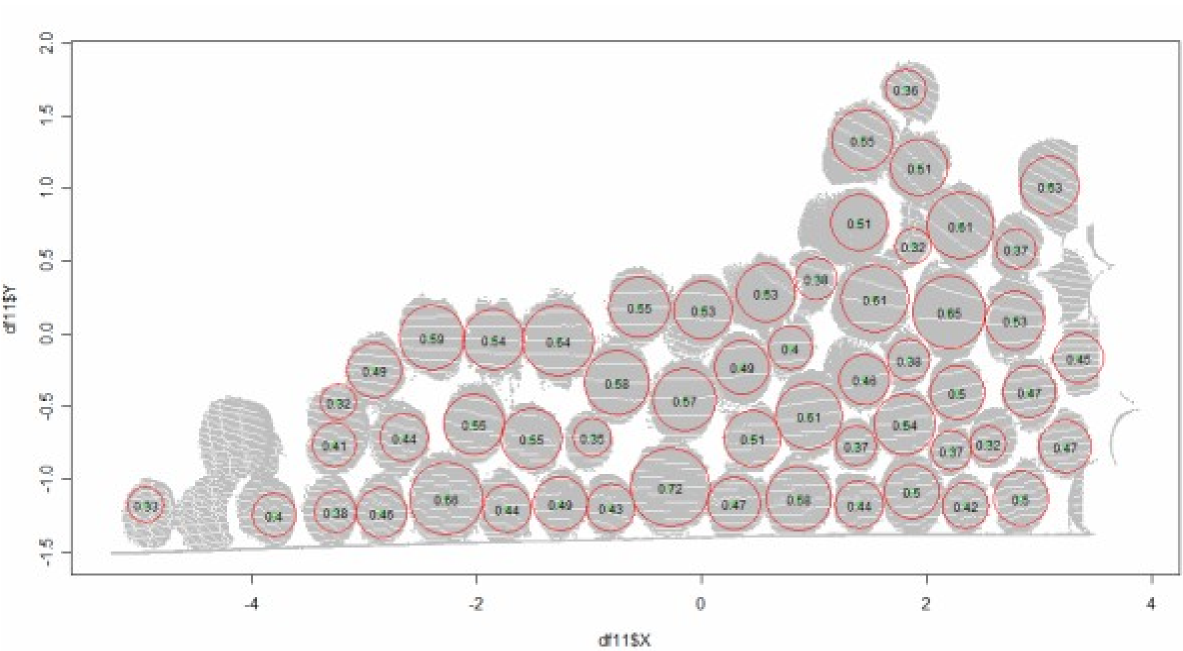
Scan J

Actual Count = 44.
Algorithm Count = 45. (97 %)
Counting Time (R Code) = 372.64 seconds (8.4 sec per tree)
Comments: The additional log that was half in the scan and half out of the scan was counted.



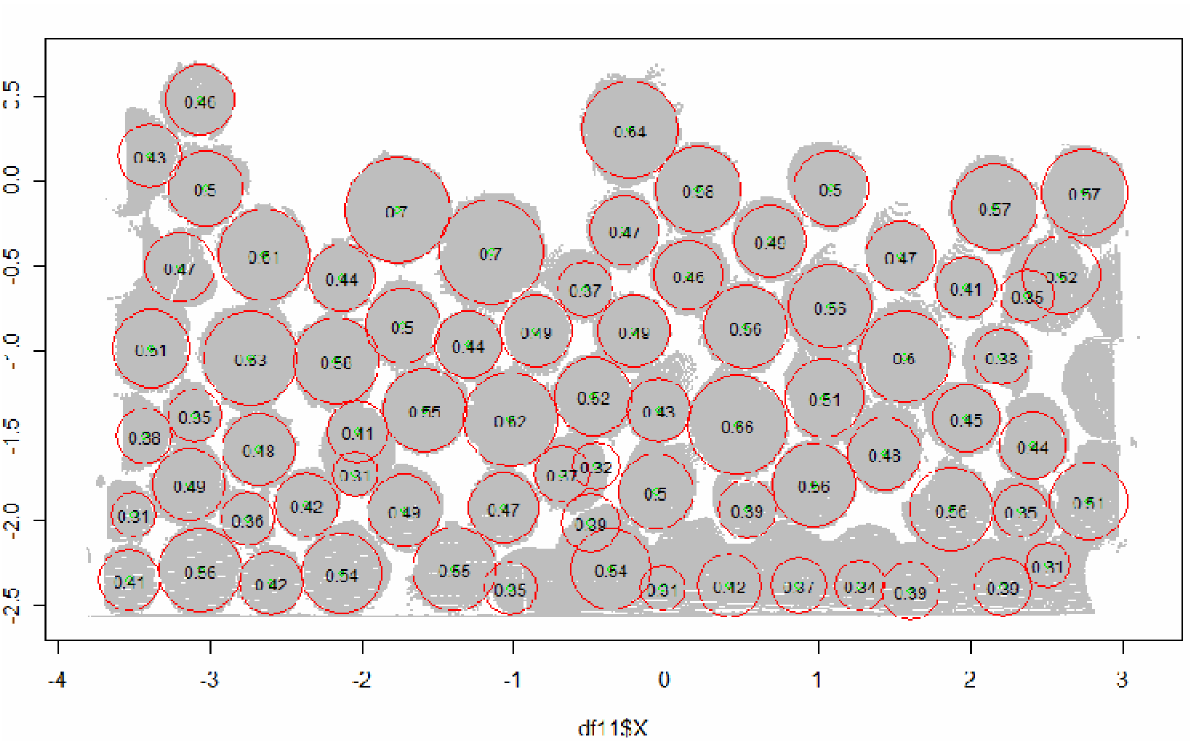
Scan K

Actual Count = 58.
Algorithm Count = 56. (Missed 2 logs – 96.6 %)
Counting Time (R Code) = 307.72 seconds (5.495 sec/tree)
Comments:



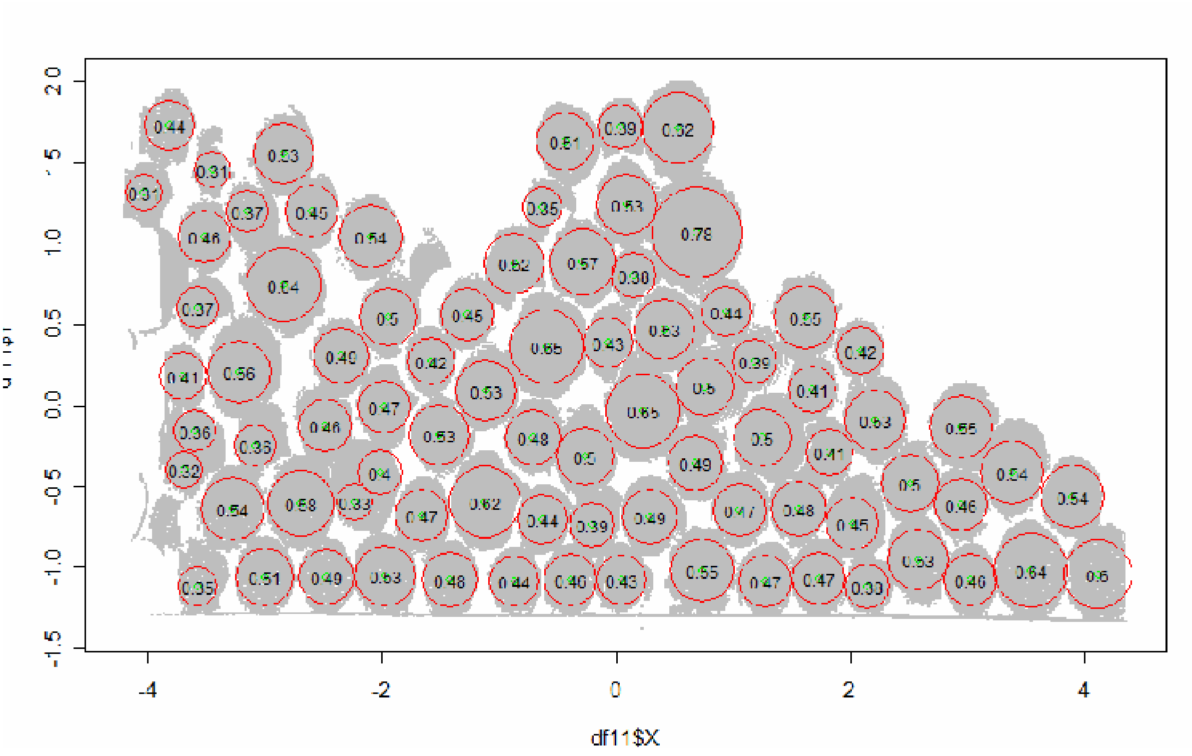
Scan L

Actual Count = 75.
Algorithm Count = 75. (97.5 %) – 10 Addition False Logs, 3 Logs were double counted
Counting Time (R Code) = 877.08 seconds (7.4 sec)
Comment: This scan had a log sitting in front of the pile (which can be seen in the scan) , this lead to 10 additional false logs being counted along this log.



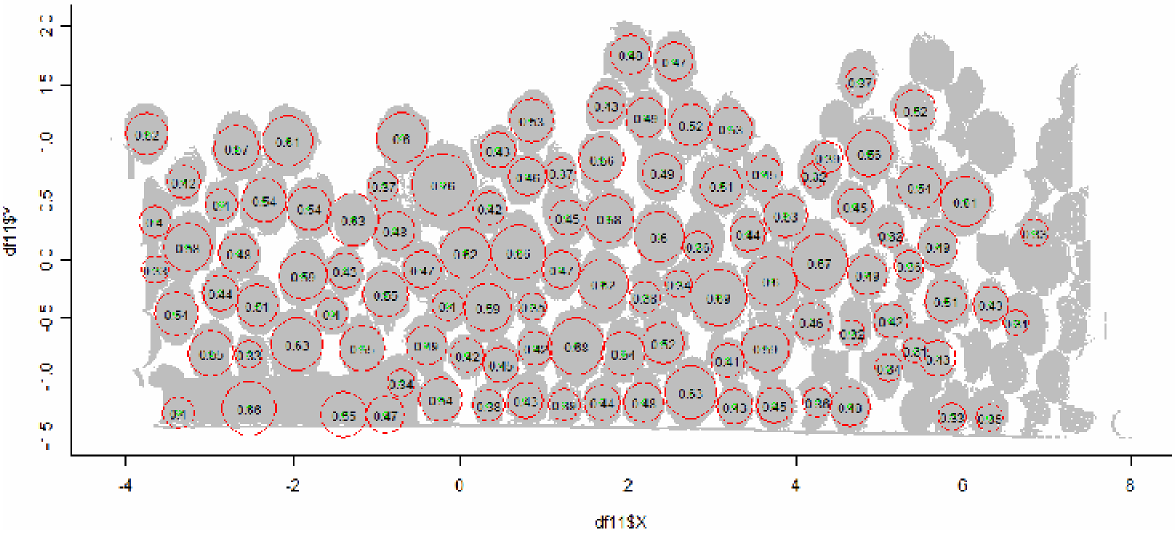
Scan M

Actual Count = 79.
Algorithm Count = 81. (97.5 %)
Counting Time (R Code) = 325.43 seconds
Comments:



Scan N

Actual Count = ~ 101.
Algorithm Count = 101. (see picture)
Counting Time (R Code) = 898.74 seconds
Comments:



Scan O

Actual Count = 181.
Algorithm Count = 175. (see picture – missed 10 logs – double counted 4 logs)
Counting Time (R Code) = 1039.65 seconds
Comments: