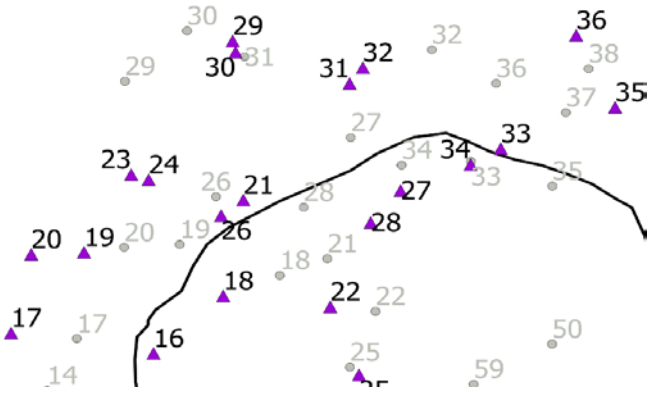
The positioning accuracy of trees based on harvester location and harvester head position measurements – a computational algorithm for improving the estimate for harvester head position



Metsätehon tuloskalvosarja 9b/2017

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Summary

- Improving the location accuracy of harvester data is essential, if tree-wise data is going to be used in updating the forest inventory data and as ground reference for remote sensing data.
- The objective of this study was to determine the positioning accuracy of single harvested trees within the harvested stand, when position parameters of the harvester boom are recorded while cutting the tree.
- Using merely the recorded boom parameters as such, the tree-wise accuracy improves 1.3m from 7.9m to 6.6m in contrast to using the harvester location.
- Using the filtering algorithm developed in this study, the improvement in tree-wise accuracy is in average 3.1m. The positioning accuracy of 4.9m is obtained within the whole dataset.
- To further improve the accuracy, harvesters should use such GNSS receivers which interact with different satellite systems (GPS, Glonass, Galileo etc.) and which would allow the VRS (virtual reference station) correction either in real time, or as post-processing. Using these techniques would result in sub-meter level of accuracy.

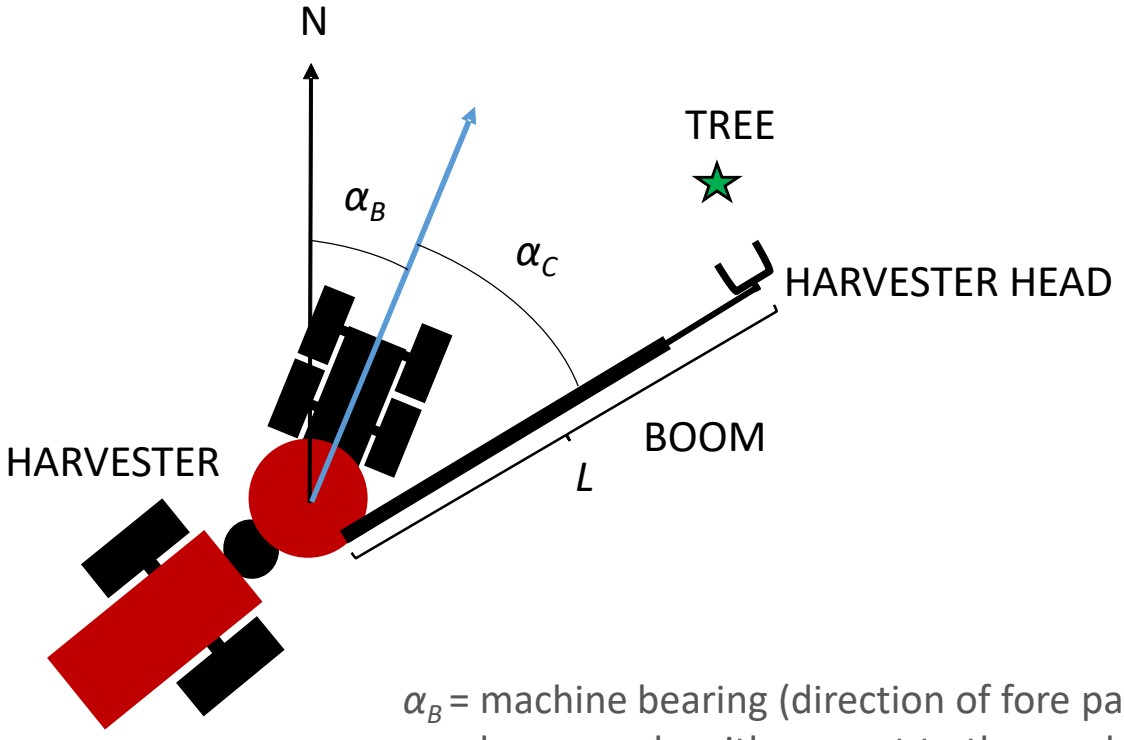
Objective and data

- Improving the location accuracy of harvester data is essential, if tree-wise data is going to be used in the updating of forest inventory data and as ground reference for remote sensing data.
- The objective was to examine and improve the tree-wise positioning accuracy from harvester measurements.
- The data was collected from eight sampling plots at the Evo research site, Finland, in co-operation with the University of Helsinki (A. Saukkola's Master's thesis), HAMK Polytechnic school, Komatsu Forest Ltd, and Metsäteho and its shareholders.
- The harvester was Komatsu 931.1, using the MaxiExplorer operating system.
  - 6 sampling plots were harvested in a normal manner (n_{trees} = 440).
  - 2 sampling plots (IDs 1091, 2019) were harvested without using the last extention of the boom (n_{trees} = 93).
- To find the position of the harvester head with respect to the harvester, the angle and length of the boom were recorded, excluding the length of the last extensible part of the boom.

The starting point of study

- Based on earlier studies, the distance of the harvester and real location of trees has been 8.6m – 9.7m on average (Melkas et al., 2014). In this study, the distance was on average 7.9m.
  - The positioning accuracy was determined by comparing the location of the harvester to the real locations of trees.
- According to the University of Helsinki (private comm., Saukkola and Vastaranta 24.2.2017), accuracy was improved roughly 1.2m by using the boom parameters as harvester head position, in contrast to using only the harvester location to represent the location of the tree.
- The crucial question turned out to be whether the position estimate of harvester head (based on harvester data) can be improved computationally – for example by filtering the harvester location or the direction?
- Metsäteho developed a computational algorithm to estimate the harvester head position more accurately and the results were compared to the real locations of the trees.
- The input data included parameters from hpr file:
  - the raw location of harvester for each harvested tree while cutting
  - machine bearing recorded by harvester
  - the boom angle with respect to the harvester (cabin position with respect to harvester)
  - the distance of the harvester head from the harvester (length of the boom).

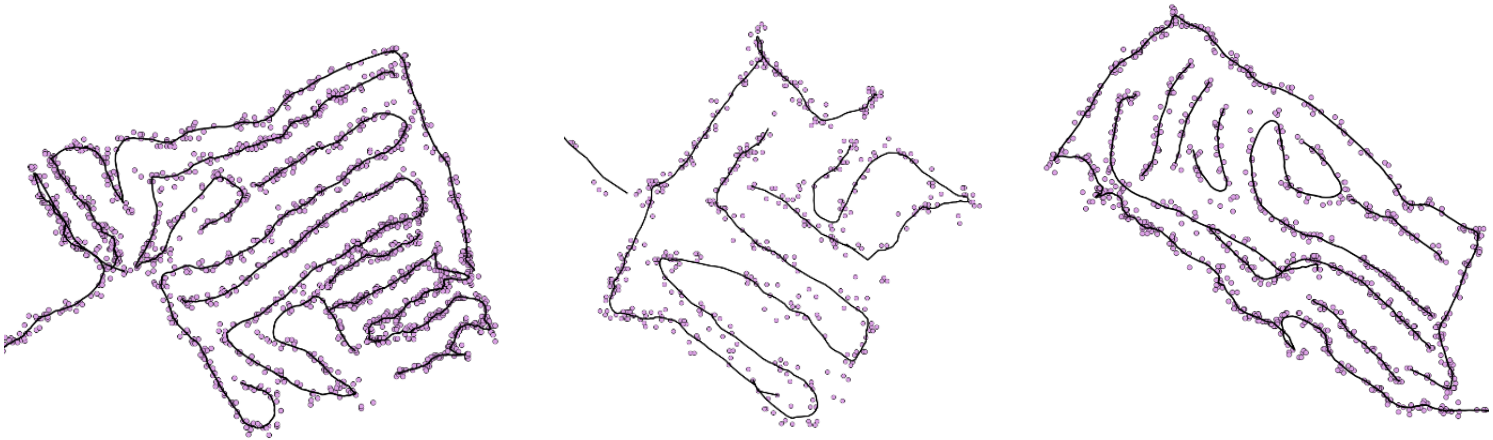
The geometry of harvester and harvester head position



α_B = machine bearing (direction of fore part of machine)
α_C = boom angle with respect to the machine bearing
L = length of the boom

Preprocessing of data

- Harvester locations were transfered from WGS84 coordinate system to ETRS FIN35TM coordinates.
- The strip road was generated from the GNSS positions by averaging.



Improving machine bearing

- According to StanForD 2010 standard, the variable ”MachineBearing” is the bearing orthogonal to the front axle of harvester, while the boom angle is recorded.
- Based on the current dataset, the bearing values in hpr file seem to be the direction of movements of the harvester.
  - Sometimes several following trees have similar bearing values, but then suddenly the value changes notably (opposite directions at consequent trees).
  - However, the harvester typically cannot change a bearing of the front axle by roughly 180° between harvesting consequent trees from locations close to each other.
  - There is no detailed information available on how the bearing is produced into the hpr file.
- To obtain more accurate bearing, the values were determined from the generated strip road.

Filtering of machine bearing

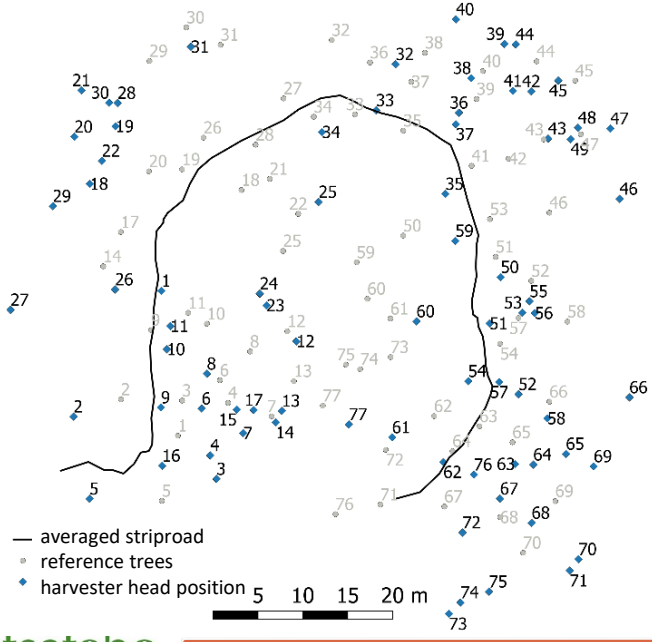
- The averaged strip roads were observed to have been ”bouncing” back and forth.
  - The averaging works typically rather well, but it cannot remove all of the GNSS positioning error.
  - This causes the computational bearing to bounce as well.

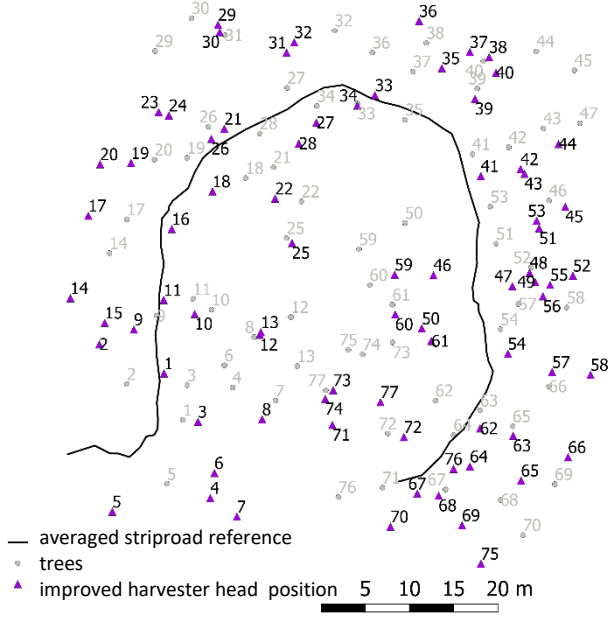
  → Computational filtering of direction is needed.
- Based on the dataset, at the starting and ending points of the strip roads, the filtered bearing values differ clearly from bearing values recorded by harvester.
  - The averaging and filtering could not be done fully.

  → The averaging is expected to fail at these stages of harvesting.
- Therefore the bearing values recorded by harvester were used for the starting and ending points of the strip roads.
  - The variation in distance between harvester head and tree is large anyway.
  - The bearing recorded by harvester is found to be the best available value.

Improved harvester head position while tree cut

- The improved position of the harvester head was obtained by
  - moving the harvester into the averaged strip road
  - using the filtered machine bearing values
  - adding the boom (cabin) angle and the boom length.





Results

- The computationally improved harvester head positions were compared to real locations of the trees as follows:
  - By comparing all real locations of trees to the improved harvester head positions.
  - By excluding the strip road starting and ending observations and comparing the rest of the real locations of trees to the improved harvester head position.
  - By categorizing the sampling plots by the use of last extension of boom during harvesting (using the extension or not) and comparing the real locations of trees to the improved harvester head position.

- The following slides contain the positioning accuracy results for the computationally improved harvester head position based on harvester data.
  - The location of harvester and real location of trees – distance 7.86m
  - The harvester head position parameters recorded by harvester and real location of trees – distance 6.56m / 6.53m
  - Improved harvester head position and real location of trees (filtering of location and direction, considering the net extension of boom) – distance 4.93m / 4.77m

The improved positioning accuracy

- The positioning accuracy is determined by using the real locations of the reference trees from field measurements that are compared to the harvester locations, harvester head positions from harvester data and to improved harvester head positions.
  - At sampling plots 1091 and 2019 (last extension of boom not used), the average length of the last extension of boom was subtracted from boom length.

All observations (including beginnings and endings of strip roads)

		Positioning accuracy, m			Improvement, m		
Sampling plot	Number of stems	Harvester – reference (A)	Harvester head – reference (B)	Algorithm – reference (C)	Boom position (A-B)	Algorithm (B-C)	Improved position (A-C)
1018	69	7,09	5,77	3,79	1,32	1,98	3,30
1024	67	7,58	5,37	4,08	2,22	1,29	3,50
1036	107	9,78	6,84	6,06	2,93	0,78	3,72
1038	90	7,27	6,42	4,93	0,85	1,49	2,34
1091*	96	6,83	7,07	4,30	-0,23	2,77	2,53
2019*	97	7,41	6,27	4,15	1,14	2,12	3,25
2083	53	8,00	6,16	5,97	1,84	0,19	2,03
2110	54	8,90	8,84	6,80	0,06	2,04	2,10
All together	**633**	**7,86**	**6,56**	**4,93**	**1,30**	**1,63**	**2,93**

*Last extension of boom not used

The improved positioning accuracy

- The positioning accuracy for those trees for which the full averaging could be done.
- Determined by excluding the starting and ending trees of strip roads.

Mid -strip road observations

	Positioning accuracy, m			Improvement, m		
Sampling plot	Harvester – reference (A)	Harvester head – reference (B)	Algorithm – reference (C)	Boom position (A-B)	Algorithm (B-C)	Improved position (A-C)
1018	6,93	5,33	3,52	1,60	1,81	3,41
1024	7,65	5,23	3,52	2,42	1,72	4,13
1036	9,79	7,09	6,19	2,70	0,90	3,60
1038	7,25	6,55	4,88	0,70	1,66	2,36
1091*	6,89	7,39	4,36	-0,50	3,03	2,53
2019*	7,36	6,23	3,95	1,13	2,28	3,41
2083	7,95	5,62	5,44	2,33	0,18	2,51
2110	9,47	8,48	6,55	0,99	1,93	2,92
All together	**7,89**	**6,53**	**4,77**	**1,36**	**1,77**	**3,13**

*Last extension of boom not used

Effect of the last extensible part of the boom

All observations (including beginnings and endings of strip roads)

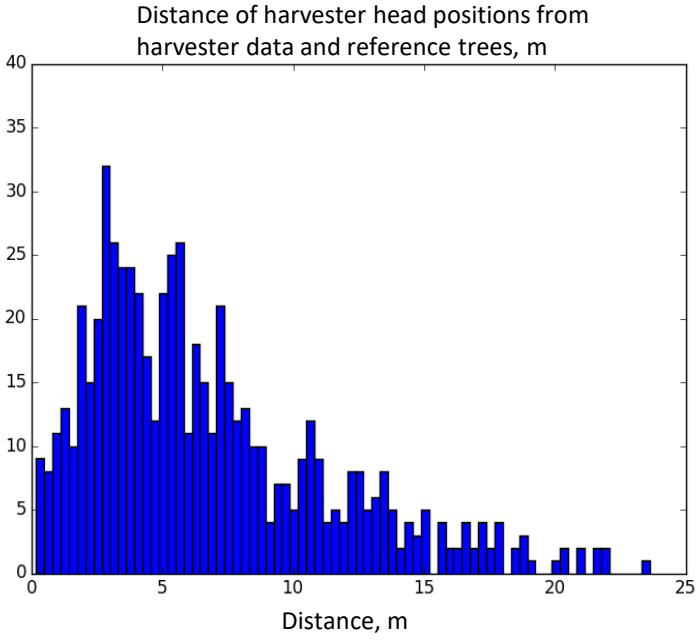
Sampling plot	Number of stems	Positioning accuracy, m			Improvement, m		
		Harvester – reference (A)	Harvester head – reference (B)	Algorithm – reference (C)	Boom position (A-B)	Algorithm (B-C)	Improved position (A-C)
Boom extension used (n = 6)	440	8,18	6,52	5,24	1,66	1,28	2,94
Boom extension not used (n= 2)	193	7,12	6,66	4,23	0,46	2,44	2,90

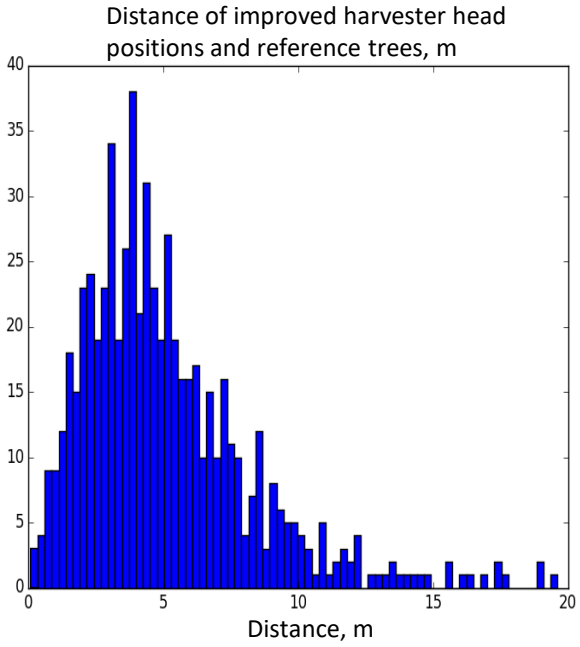
Mid -strip road observations

Sampling plot	Positioning accuracy, m			Improvement, m		
	Harvester – reference (A)	Harvester head – reference (B)	Algorithm – reference (C)	Boom position (A-B)	Algorithm (B-C)	Improved position (A-C)
Boom extension used (n = 6)	8,24	6,41	5,04	1,83	1,37	3,19
Boom extension not used (n= 2)	7,13	6,80	4,15	0,33	2,65	2,98

Results – distance distributions

- Comparison of harvester head positions and real locations of reference trees:
  - harvester head positions from harvester data (left)
  - improved harvester head positions (right).





Error analysis

- The total error of location ΔS was estimated using the error propagation law:

$$\Delta S = \sqrt{(\Delta S_{GNSS})^2 + (\Delta L)^2 + L^2[(\Delta\alpha_B)^2 + (\Delta\alpha_C)^2]}$$

Where

ΔS_{GNSS} = error of GNSS-positioning (in both x and y -directions)
L = boom length
ΔL = error of boom length
$\Delta\alpha_B$ = error of machine bearing (in radians)
$\Delta\alpha_C$ = error of boom angle (in radians)

Error analysis, examples

- Here is assumed that boom length L = 8m (average value) and error of boom angle $\Delta\alpha_C$ = 1° = 0,017 rad.
- If assumed in ”basic case” that
  - ΔS_{GNSS} = 6m
  - ΔL = 0.5m (the range of last extensible boom part movements is between 0,8m … 2,5m, in addition to boom length measurement error 0.1m)
  - $\Delta\alpha_B$ = 20° = 0,349 rad

  → total error of location is approx. **ΔS = 6.64m for raw data without filtering**

- If assumed in ”bad case” that
  - ΔS_{GNSS} = 7m
  - ΔL = 1m
  - $\Delta\alpha_B$ = 50° = 0,873 rad

  → total error of location is approx. **ΔS = 9,93m**

ΔS_{GNSS} = error of GNSS location (in both x and y -directions)

L = boom length

ΔL = error of boom length

$\Delta\alpha_B$ = error of machine bearing (in radians)

$\Delta\alpha_C$ = error of boom angle (in radians)

Error analysis, interpretation

- If a high-accuracy GNSS was available and machine bearing known with good accuracy:
  - ΔS_{GNSS} = 1m
  - L = 8m
  - ΔL = 0,5m
  - $\Delta\alpha_B$ = 5° = 0,087 rad
  - $\Delta\alpha_C$ = 1° = 0,017 rad

  → total error of location is approx. ***ΔS* = 1.33m for raw data without filtering**

- If a high-accuracy GNSS was available and machine bearing known as currently:
  - ΔS_{GNSS} = 1m
  - L = 8m
  - ΔL = 0,5m
  - $\Delta\alpha_B$ = 20° = 0,349 rad
  - $\Delta\alpha_C$ = 1° = 0,017 rad

  → total error of location is approx. ***ΔS* = 3.01m for raw data without filtering**

Error analysis, interpretation

- In this dataset, the error of the harvester head position from harvester data was estimated to be roughly 6.7 m (the error of ”basic case” from page 16).
  - The average positioning accuracy of single trees was found to be approx. 6.6m (harvester head – reference).

- The computational algorithm improves the average positioning accuracy approx. 1.8m – GNSS error being the most significant source of error, limiting the amount of improvement.
  - Average is obtained from trees where the averaging and filtering of strip roads was possible.

Conclusions

- The harvester head position measurements of harvester by Komatsu Forest improve the positioning accuracy by 1.3m, resulting the level of accuracy of 6.6m instead of the 7.9m accuracy of only harvester location data.
- By computationally filtering the location and direction data of harvester, additional improvement of 1.8m is achieved.
  - At best, the improved harvester head position results in an even 3.6m level of positioning accuracy for certain sampling plots. The average positioning accuracy is 4.9m in the whole dataset.
  - It is worth noting that the sampling plots were rather small compared to typical harvested stands which implies that the level of accuracy is expected to be better in a typical harvest since the relative proportion of strip road startings and endings is lower.
- The harvester data stored in hpr file is raw data and it requires filtering of both location and direction to obtain the highest possible level of tree-wise positioning accuracy.
- During the work it was observed that the improvement of Komatsu's harvester head position measurements was clearly smaller (0.33m) for the sampling plots (1091, 2019) which were harvested without using the last extension of boom than for the other sampling plots (1.83m). From this was deduced that the harvester data contains an additional constant length (1.65m) representing the average length of the last extension of the boom, assuming that this part of the boom would be in middle position of its range (0.8m … 2.5m).

Conclusions

- Significant approach to improve the positioning accuracy would be to improve the measurement of harvester location by using satellite receivers which can interact with different GNSS systems (e.g. GPS, Glonass, Galileo etc.) resulting in better satellite geometry, and allowing the virtual station correction (VRS) either in real time or as postprocessing.
- If the aim is to improve the positioning accuracy further, the length of the last extensible boom should be included into the data and calculations.
- Removal of the error of boom length would thus require that the extension of the last part of the boom is somehow detected while cutting the tree. One possibility would be to detect the amount of oil fed into the cylinder of the last part of the boom.
- The information of the working point from which the tree was harvested would improve the single tree accuracy. This could be determined from the movements of the harvester.
- Based on this study, the numerical accuracy of location values recorded by harvester is worth considering to improve.
  - A proposal for enhancing the display accuracy of coordinate values from 5 to 7 digits was made for StanForD group. Accepting decision was made in StanForD meeting 21.11.2017.
  - In Komatsu Forest harvesters, 7-digit coordinate values have been in use since autumn 2017 (program version 3.12) .

This study has been conducted in co-operation with the University of Helsinki (A. Saukkola's Master's thesis), HAMK Polytechnic school, Komatsu Forest Ltd, and Metsäteho and its shareholders. The research is part of research program "Forest information and digital services" of the Ministry of Agriculture and Forestry in Finland.

Metsäteho has been responsible for collecting and processing of the harvester data, and of developing of the algorithms. University of Helsinki has been responsible for-collecting the reference tree data and combining the reference dataset into the harvester dataset. Measuring the reference data has been part of Atte Saukkola's Master's thesis.