DETERMINATION OF URBAN VEGETATION VOLUME ON THE BASIS OF LASER SCAN DATA AT NON-LEAF AERIAL FLIGHT TIMES

G. Meinel [a,] R. Hecht [b]

[a] Leibniz Institute of Ecological and Regional Development, 01217 Dresden, Weberplatz 1, Germany, G.Meinel@ioer.de
[b] Technical University, Institute for Cartography, Helmholtzstr. 10, Germany, Robert.Hecht@mailbox.tu-dresden.de

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ABSTRACT

The determination of urban vegetation volume is getting more and more important within the frame of an ecologically orientated city planning. Conventional methods like the height categorization of typical kinds of vegetation followed by multiplication with the area are costly and complicated during survey but remain exact. Since there are several cities which already have laser scanner data for creating 3-D city models the idea emerges of using this data for the determination of urban vegetation volume. It is a problem that the date of survey of Digital Elevation Models (DEM) is not within the vegetation period and therefore interferes considerably with the survey of the vegetation volume. That’s why this paper deals with the question whether laser scanner data that has not been taken during the vegetation period allows a determination of vegetation volume with sufficient accuracy.
Therefore laser scanner data has been compared to photogrammetrically determined vegetation height measurements. Despite a relatively high laser point density of one point per m² it has to be considered that almost 80 % of the measurement points in the vegetation stock have been classified as ground points because the non-leaf tree branches have led to insufficient reflections. Even with the measurement data classified as non-ground points, the vegetation height has been underestimated by approximately 50 % on average.
Thus the subtraction of the laser-based Elevation Model (DEM) and Surface Model (DSM) in vegetation areas leads to a sufficient underestimation of vegetation volume of up to 85 %. By applying correcting methods this error is to be corrected and might lead to a sufficiently exact and efficient determination of vegetation volume on the basis of laser scanner data of aerial flight times during non-vegetation periods. The necessary separation of a vegetation-covered area and an area with no vegetation can be carried out with the urban geo-basis data or from the color infrared film with the NDVI.

1. PROBLEM

1.1 General Instructions

Urban vegetation is an elementary need for the population of a city. Trees cause bioclimatic effects, reduce the warming-up of areas (heat island effect) by their shadowing and evaporation and filter dust and harmful substances from the air. Parks are an oasis of silence and relaxation. But also the aesthetic effect of vegetation on townscape in terms of town building should not be underestimated.

On the part of urban planning indicators are used for a quantitative description of the vegetation because of the importance of the urban vegetation. The indicators related to the vegetation like the biotope area index and soil function index or the vegetation volume index with its ecological statement are counterparts to the indicators for the structural use of land like the site occupancy index and the floor-space index. While the biotope area index and the soil function index can be recorded two-dimensionally; for the calculation of the vegetation volume a three-dimensional survey is essentially necessary. The vegetation can also be simply determined by ideal geometric figures like cuboids, spheres, cylinders or cones adapted to single vegetation objects (shrubs, trees). Since this method is also very costly and complicated usually the vegetation volume is expressed by a vegetation volume index referring to a reference area. The vegetation volume index is defined as a product of the area with vegetation and vegetation height. The reference areas can be planned units like blocks, parcels of land and land use types. For development planning the vegetation volume is often estimated in simplified terms in dependency on the type of constructional use of the reference area.
The planner often lack all-covering up to date information about green areas and especially vegetation volume. Even, in the meantime, if Green Departments of cities partly have tree cadastre it only applies to areas and trees in property of the city (private gardens and parks a.s.o. are not recorded). In addition the vegetation doesn’t only change seasonal but also because of the highly dynamic urban development (succession of fallow ground, the changing of green areas, cutting and felling of trees). At present most cities are lacking detailed information about their urban vegetation.
That is the basis for the purpose of an all-covering survey of urban vegetation including the determination of the vegetation volume with an efficient method. In only few cases where it had been recorded, the determination was based on the mapping of vegetation areas including the capturing of a medium vegetation height on these areas. This determination is very complicated and costly, rather inaccurate and gives an acceptable value only for larger area units like blocks, statistical districts or parts of the city.

Height measurements of the vegetation stock on the basis of laser scanner data have been tested many times and have proved to be worthwhile in praxis (e. g. Holgren, 2003). Like for example the measuring of forest stocks with regard to their structure (e. g. tree height, canopy, crown surface shell and crown radius) (Hese 2002). While the aerial flight for measuring forest stocks takes place during the vegetation period, the optimal aerial flight times for most of the other methods like surveying, flood modelling and the creation of 3-D city models are during the non-leaf period. The emphasis hereby is mainly on the exact recording of the Digital Elevation Model (DEM) as well as the substance of buildings but less on the vegetation. Especially in cities there are often only laser scanner data from aerial flight times during non-vegetation periods available. Therefore it seems useful to apply this data for determination of urban vegetation volume as well. It's the purpose of this paper to survey whether the non-leaf tree branches and shrubs show reflections in the first-pulse of the laser scanner data at a high laser point density (1 reference point per m²) in order to calculate the vegetation volume sufficiently.

2. METHOD

A large area of interest (520*514 m) in a wide park in Dresden (Großer Garten) with a great variety of vegetation (deciduous tree and conifer stocks, shrubs and meadow areas) was chosen to test the suitability of laser scanner data for determination of urban vegetation volume. To get exact reference data regarding the vegetation height, a pair of aerial images during the vegetation period with a ground resolution of 10 cm was scanned, orthorectified and stereoscopically analyzed. The applied data material is shown in Table 1.

Technical data laser scan material	
Type of scanner	ALTM1225 (Topscan)
Flying height	1000 m
Swath width and overlap	425 m/225 m
Scan angle	12 deg
Point density	1,1 points/m²
Date of survey	12/2002
Position accuracy	±50 cm
Height accuracy	±15 cm
Technical data aerial image material	
Type of aerial frame camera	RMK A 15/23
Image scale	1 : 6368
Flying height	973 m
Focal length	152.786 mm
Date of survey	19.8.2002
Three-dimensional resolution (Scan)	0,1 m

Table 1. Technical data of the used data material

An automatic area based image matching method (Fuchs 2003 p. 36-39) for extracting the Digital Surface Model (DSM) led to an insufficient result at the stereo image pair because of the urban situation. That's why the recording of the height measurement was carried out visually and supported by a Stereo Analyst for ArcGIS 8.3. Here about 40 000 different vegetation heights were measured. There were only few problems at the classification of measurement points because of the perspective inclination which covered the vegetation areas as well as the small-leaf vegetation which form a homogeneous area in the image. Clear-cut reference points at the vegetation objects have been chosen for height measuring. The medium measurement point density of the vegetation stock is 0.4 points/m². For receiving a complete Digital Surface Model it had to be completed by ground points. For this a regular point raster with laser height was created in unsurveyed areas (areas without vegetation and grass areas). For determining deviations of dimensional accuracy the variance was captured for measuring the heights on the screen. The multiple measurement of a tree height had a standard deviation with ±0.25 m, determined at 20 measurement points.

To get the unavoidable measuring variance through the referring choice of useful measurement points a single representative tree (height 24.4 m) was surveyed with 110 measurement points and captured five times. The calculated volume was between 8173 und 9785 m³ (mean value: 9088 m³, standard deviation: 545 m³).

A vector-based mass point model as well as a raster with a ground solution of 0.5 x 0.5 m was created from the surveyed vegetation heights and the ground points taken from the laser scan. This model serves as a reference DSM of the vegetation.

Parallel to this, the data of the airborne laser scanning has been processed. Approximately 240 000 measurement points (1.1 points/m²) were present in x,y,z-coordinates and as classified non-ground points (First-Pulse) or ground points (Last-Pulse). The mean height error of this data is according to the facts of the data provider <15 cm; position error <50 cm. From the non-ground and ground points a DSM and from the ground points a DEM was triangulated. Further for each of them a raster with a mesh size of 1 m was created. As a result there are two comparable models each as a mass point model and as a raster DSM available, one laser scan based model and one photogrammetrically determined reference model.

3. RESULTS

The mass point data as well as the raster-based DSMs created from this were now subject to analysis and visualization. The results of the point-based measurement in comparison are shown in Table 2. The reference heights on the position of the laser points at homogeneous area as a stereo image pair are not measurable. Therefore only the medium vegetation height can be given

	Reference model	Laser scan model
Non-ground points (total)	40 379	57 890
Ground points (total)	189 971	239 483
Average point density (total) [per m²]	0,9	1,1
Measurement points in vegetation stock	40 379	27 790 non-ground points 100 481 ground points
Average point density in vegetation stock [per m²]	0,4	0,25 non-ground points 0,92 ground points
Medium vegetation height [cm]	11.1	5.2 (only non-ground points) 1.1 (all points)
Standard deviation of the height [cm]	6.5	5.4 (only non-ground points) 3.3 (all points)

Table 2. Laser and photogrammetrically determined vegetation heights in comparison

Striking is the large number of 78.3 % of the laser measurement points in the vegetation stock which have been classified as ground points. Most of the laser beams came fully through the wintry tree branches and were than reflected by the ground. Only 21.7 % of the laser beams, which have been recognized as non-ground points, are reflected by the tree branches. But this reflection is average only at half of the height between ground and the summer foliage as you can see from the comparison of the medium vegetation heights. Thus, an underestimation of the vegetation volume by approximately 50 % could be possible, even at generating Digital Surface Models (DSM). Since ground points are often used for the generating of surface models, an underestimation of the vegetation volume by 90 % could be the result as well.

Figure 2a, 2b, 3a and 3b show clearly that especially high deciduous tree stocks are very thinned out and too small. Even more precise is this shown with difference of the height models (fig.4a and 4b).

The reason for this large difference of the vegetation heights is the low component of reflections of the non-leaf tree stock. The tree branches are obviously insufficiently dense in order to cause a reflection. In this context the different distribution of laser points in dependency of the vegetation height is also remarkable. At the photogrammetrical capturing of the vegetation, the attention was paid to a uniformly three-dimensional distribution (i.e. shrub and tree stocks were surveyed recording to their proportionate part of the area). In contrary at the laser measurement in the low (dense) vegetation stock considerably more measurement points have been classified than non-ground points in the high (thinned out) deciduous tree stock (Figure 1).

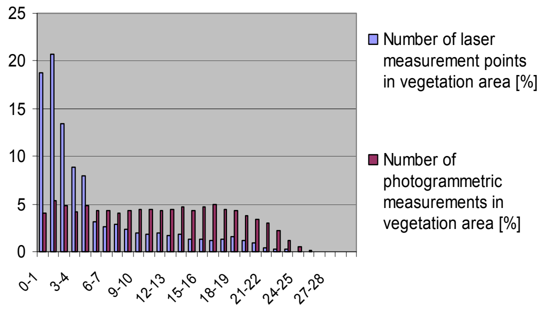

Figure 1. Number of measurement points in dependency of the vegetation height

Since different types of vegetation have dissimilar reactions to the reflection each has been analyzed in a differentiated way. (Table 3):

Vegetation type	Num-ber of test areas	Refe-rence height	Laser scan height		Part non-ground points
			Total points	Non-ground points	
Shrub (2.5-8m)	29	2.5 (1.1)	1.0 (0.6)	2.3 (0.9)	52.0 % (23.6%)
Deciduous tree (3-30m)	36	14.1 (4.0)	0.4 (0.4)	7.9 (2.4)	5.5 % (4.3%)
Conifer (3-30m)	25	12.3 (3.7)	10.9 (3.1)	12.3 (3.8)	89.4 % (7.5%)

Table 3. Reference and laser scanning differentiated according to vegetation types in comparison (both medium height and standard deviation in m [in brackets]).

Grass area (0 – 0.1 m) can not be captured with laser scanning outside the vegetation period. Because of their low height they are classified as ground points.

Herbs and grasses (0.1 – 2.5 m) are just little lignified and die at the end of the vegetation period. Therefore a survey with laser scan outside the vegetation period is not possible.

Non-seasonal low-growing plants/shrubs (0.1m – 2.5m) can be well captured with laser scanning even during the non-vegetation period because of their high and dense lignifications. Here the problem is rather the photogrammetrically capturing of these plants resulting from the limited object shape. The high density and number of non-ground points (80-100 % of all laser measurements in this stock) and the high correspondence with the reference heights (average underestimation is about 15 cm because of the lacking foliage) indicate a high accuracy of the laser scanner data.

Shrubs (2.5 – 8 m) are strongly branched and therefore easily captured with laser scanning during the non-vegetation period. But it varies a lot between very dense hedges and less dense shrubs.

Conifers (> 3 m) are almost always evergreen and therefore can very easily be captured with laser scanning during the non-vegetation period as the comparison with the reference measurements shows. The determination of the vegetation volume with laser scanning is often more precise than a photogrammetric determination because of a better recording of the shape and a higher point density (80-100 % of the laser scan data is reflected by the conifer's branches)

Deciduous trees (> 3 m) have, depending on their height and the tree species, rather open branches and therefore let through more of the laser scan during the non-vegetation period. So the part of the laser measurements classified as non-ground points is only 0 – 10 % of all measurement points in this vegetation stock. These non-ground points are not reflected by the tree crown but in average more or less at about half the tree height. Sometimes single trees on the road haven't been recorded at all. That's why it seems that the vegetation determination of deciduous trees outside the vegetation period just on the basis of non-ground points with an uncorrected (non-filtered) laser model is not possible.

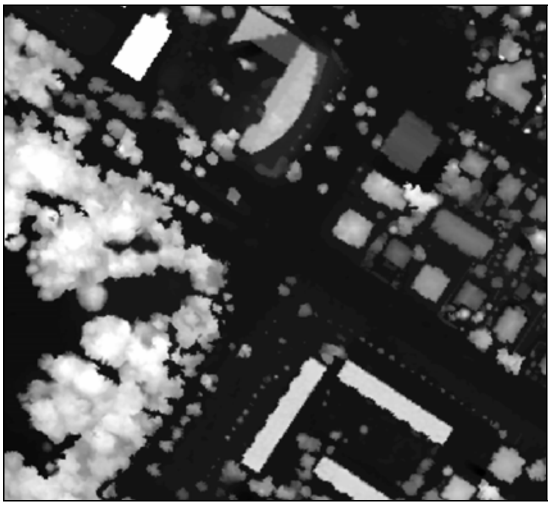

Figure 2a. Reference-DSM.

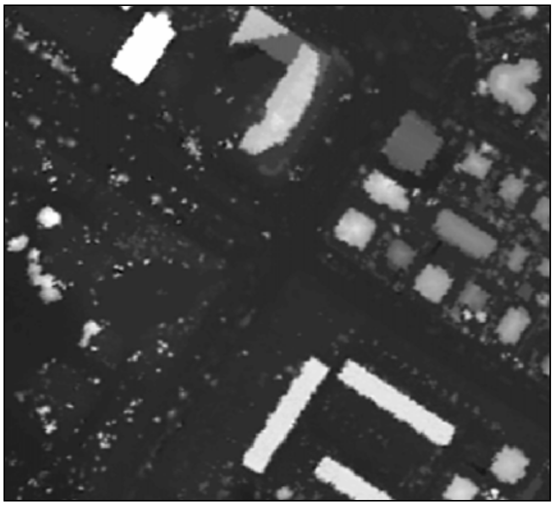

Figure 2b. Laserscan-DSM.

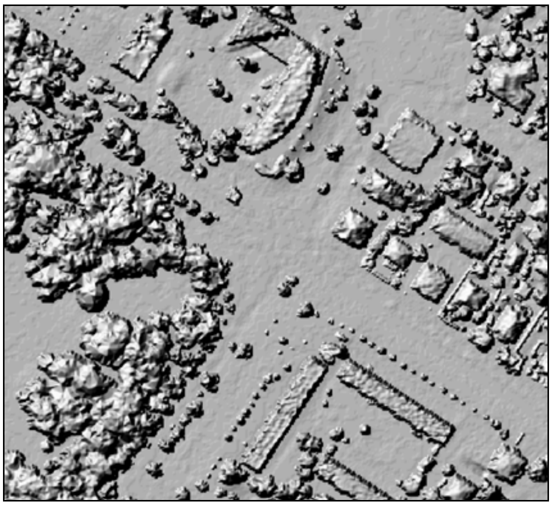

Figure 3a. Hillshade of Reference-DSM.

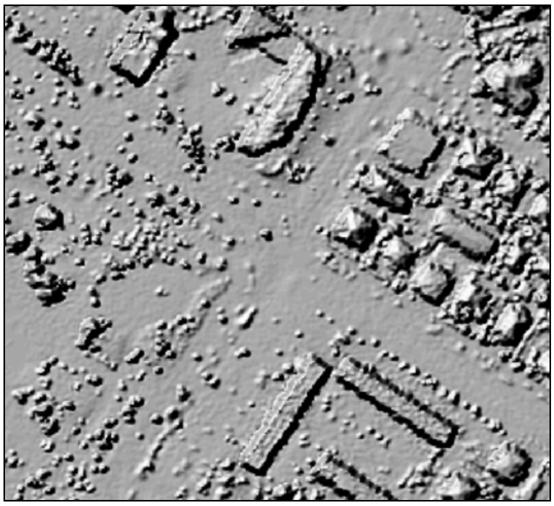

Figure 3b. Hillshade of Laserscan-DSM.

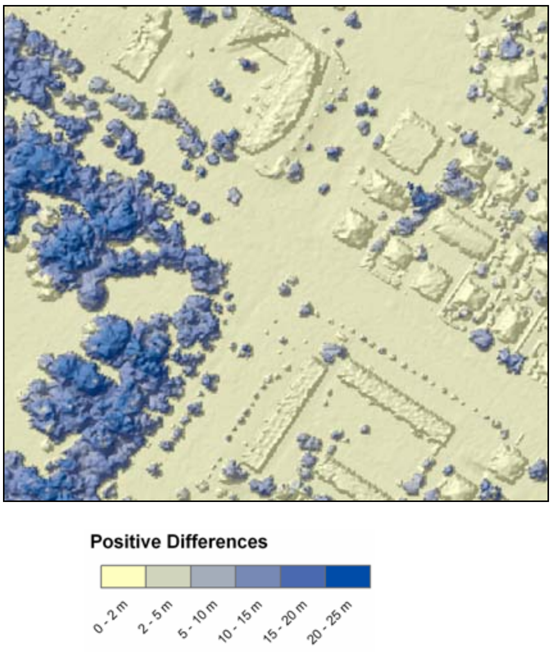

Figure 4a. Positive Differences of Difference Model (Reference Model subtracted by Laser Model).

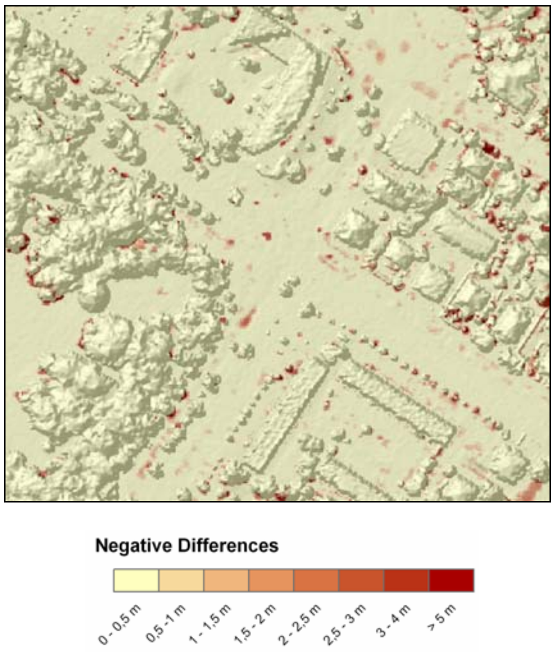

Figure 4b. Negative Differences of Difference Model (Reference Model subtracted by Laser Model).

Figure 5 and 6 show the representative test areas combined with examples of the three compared vegetation types

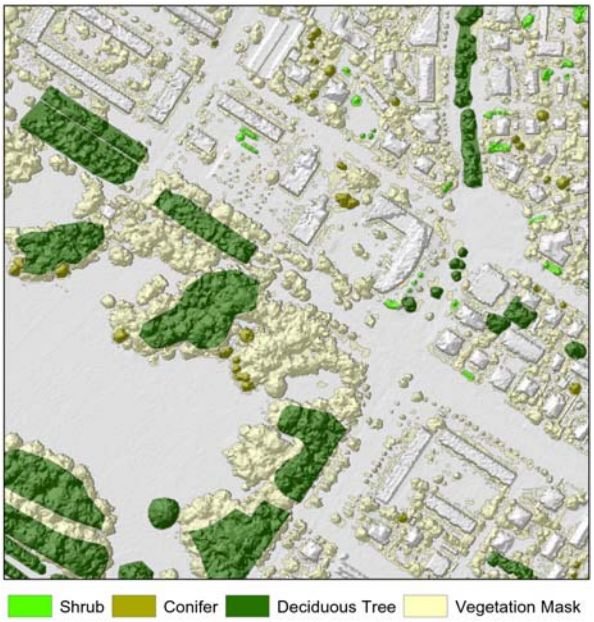

Figure 5. Applied test areas of the vegetation types

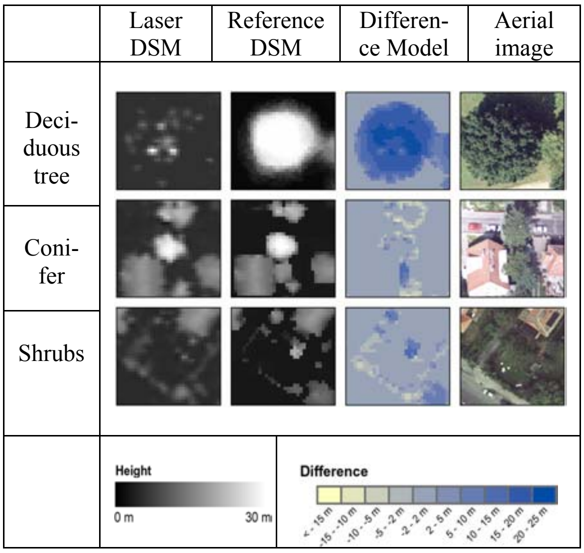

Figure 6. Comparison of the vegetation types and their modelling

On the basis of the difference between DSM and DEM the vegetation volume has been calculated for the laser scan model as well as for the reference model. (Table 4) The raster-based calculation of the volume has been compiled with the language AML for ArcInfo. For this the polygons of interest are intersected with the surface models. The cell values within every polygon are cumulated, multiplied with the corresponding area and added to the polygon as an attribute.

	Photogram-metric reference	Laser scan	Difference Reference-laser scan
Shrub	1.6 (2,0)	1.5 (2.6)	-4.1 %
Deci-duous tree	10.9 (5.0)	0.8 (0.6)	91.7 %
Conifer	10.1 (4,1)	9.9 (4.2)	-6.5 %
Total area	*3.9*	*0.5*	*86.3 %*

Table 4. Comparison of the vegetation volume [m³/m²]

The strong underestimation of the vegetation volume, captured by laser scanning in a height of 86.2 %, can mainly be due to the underestimation of the deciduous tree vegetation stock. But on the other hand compared to a conventional survey there is an overestimation of the vegetation volume opposed to the photogrammetric survey.

4. CONCLUSIONS AND PROSPECT

The results lead to the conclusion that the reproduction of vegetation stocks during the non-vegetation period (a typical period for airborne laser scanning) is only insufficiently successful although there was a relatively high laser point density. There are measurement deviations especially with deciduous trees because of their less dense tree branches which hardly reflect any impulses. Here almost 80% of the laser impulses reach through the tree crown to the ground. Reflections by the branches are rather seldom. Thus the determination of the vegetation volume for deciduous trees on the basis of laser scanning without a correction causes an underestimation of almost the factor 10, whereas evergreen conifers as well as shrubs and bushes can be easily captured because of their dense branches.

In view of the survey results the following correcting method are possible. Since almost 80 % of the laser scan measurements in the non-leaf vegetation stock were classified as ground points, an underestimation of the vegetation volume can be reduced if these ground points are eliminated and only the classified non-ground points are applied. Furthermore the laser points are in average reflected at half of the tree height of the deciduous tree stock which forms the main part of the vegetation volume. If the non-ground points with maximum height are extracted in a defined searching window the results could be even more improved. (Andersen et. al., 2001)

A further improvement is possible by including point density and height measurement data. A high point density stands for a dense vegetation stock that can be easily measured with laser scan and doesn't need to be filtered. Great heights together with a less dense point density stand for a deciduous tree stock that can only be reconstructed in a large searching window by considering just the maximum of the non-ground points. A requirement for all correcting methods is a vegetation mask that contains all vegetation areas except grass and meadow areas. This kind of digital geometric data is often available for urban areas or can be derived from infrared images on the basis of the vegetation index NDVI. Extracting of these data via GIS from urban habitat maps is also possible.

The correcting methods regarding of their results are to be implemented, tested and compared within the following research work.

5. LITERATURE

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