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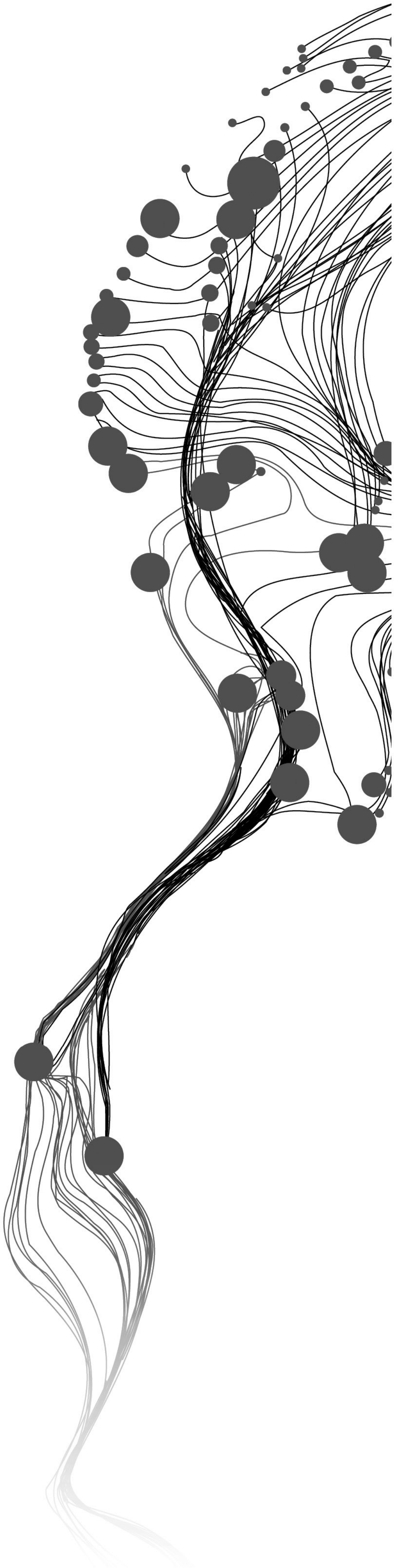

MANUAL AND AUTOMATED TREE EXTRACTION FROM OBLIQUE AIRBORNE IMAGES

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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
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ABSTRACT

Trees are the essential components of urban greenness. Tree mapping has been a major concern of municipalities for estimation of urban greenness. Different remote sensing data are being used for mapping trees. Nadir view images and Airborne laser data (ALS) lack detailed information about tree profile whereas terrestrial/mobile laser scanning data, though provides sufficient information on profile of features, has limited coverage area to be used for mapping tress in urban context.

Oblique aerial images provide much detailed information about profile of trees due to its oblique viewing angle and have larger coverage area compared to terrestrial equipment. The profile information of unfoliaged deciduous trees from oblique images is exploited in this research to estimate different tree parameters. Features such as geometric location, its Diameter at breast height (DBH), height are extracted manually from images with mono-plotting approach. Then an ellipse is fit to a tree crown based on its widths at different height levels. Quality of measurements in oblique imagery with this method is also assessed by GCP points and LiDAR data. These parameters are analysed to approximate threshold value to be used for automatic detection.

For automatic detection of trees in oblique images, vertical lines are extracted from tree stems from multiple images of the same or different viewing directions. Base coordinates of these lines are computed by mono-plotting in object space. These coordinates are then projected into each image to identify reliable matching lines. Forward plane intersection is conducted on matched lines to generate 3D vertical lines in object space. The foot position of each 3D line is compared with mean tree coordinate measured from images. The quality of tree detection of tree is assessed manually for test site. This method is able to detect 28 out of 42 trees in the test site.

The detection algorithm developed in this research shows its ability to detect most of the free standing trees, but it was unable to detect trees grouped in cluster. This is mainly due to poor extraction of lines from these trees in multiple images. Tree heights from proposed method vary much from manually extracted heights. This may due to the low contrast between a tree top and its surroundings.

The result of automatic detection algorithm shows satisfactory detection of vertical lines. But the separation of vertical line from trees has not been conducted yet. Further study in this direction is expected in future.

Keywords
Oblique image, Mono-plotting, Multi-view, plane intersection, line extraction

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1. INTRODUCTION

1.1. Motivation and problem statement

Urbanization is increasing rapidly ((UNDESA-Population Division, 2005) in (UNFPA, 2007)). This drives the focus of authorities on urban life quality, which includes urban greenness as one key element. Greenness in city mitigates the loss of natural space and allows direct access, physical and visual, to its dwellers (Imam, 2006). Trees are the essential components of urban greenness. They provide balance between urban infrastructure and green spaces, connect urban dwellers with nature (Ardila Lopez et al., 2010).

Quantification and monitoring of individual trees is one of the major concerns of municipalities for the estimation of urban greenness of cities. Traditional field based mapping in this context is time consuming and expensive. Different remote sensing data are being used as an alternative data source for this type of mapping. Studies have shown automation is possible in detection of trees and their parameters from those datasets (Ardila Lopez, et al., 2010; Bacher & Mayer, 2000; Gerke et al., 2001; Hirschmugl et al., 2007; Rutzinger et al., 2010; Wolf & Heipke, 2007).

Different remote sensing datasets have their own pros and cons in tree detection. Automatic tree detection by traditional classification techniques in urban area using high resolution satellite images is quite cumbersome due to high spectral variability and complex urban pattern (Ardila Lopez, et al., 2010). Another major deficit with single view nadir ortho images is that these do not have profile information of the object. The stereo pair of nadir images can only give height information up to 2.5 D. Airborne LiDAR technology can also give accurate height information of tree but still detail information on vertical structure of feature like stem depend on angle of incident and penetration property of laser(Reitberger et al., 2009). Terrestrial Laser Scan technology is one good alternative but technology is comparatively more costly (Rutzinger, et al., 2010) Mobile laser scanning technology is relatively expensive as well and can only captures object in the vicinity of (public and accessible) roads. Aerial image and laser point cloud are used in combination for individual tree crown volume estimation (Hyyppä et al., 2005). Though a result from it is promising, availability or use of two dataset of the same time from application perspective is not always possible. Terrestrial image are also being used in tree crown determination (Pyysalo, 2004). But acquisition of images of all trees with terrestrial camera in an urban area is practically very cumbersome.

The systematic approach of acquisition of oblique imagery has shown the potential to overcome limitation of all these dataset. Oblique airborne images are captured by an aircraft flying at low altitude. The coverage area is significantly greater than that of terrestrial equipment used in-situ for tree mapping. These aircrafts are equipped with cameras that capture oblique views of the feature from four directions additional to nadir view. The oblique view adds supplement information regarding height of feature and its surrounding environment. Acquisition of 3D information is possible from these images (Gerke, 2009). These properties of oblique images shows its potentiality in application for tree mapping in urban area and in extracting parameters for greenness volume estimation, biomass estimation and 3D modelling of city.

Aiming at such demands and potentiality, commercial companies like BLOM Aerofilms (Pictometry), Fugro Aerial Mapping B.V, (FLI-MAP) are investing in oblique image acquisition. BLOM has already captured oblique images of every city where population is 50,000 or more in Western Europe (BLOM, 2011; Karbo & Schroth, 2009). However, self-occlusion and occlusion of object is quite significant in these images due to its oblique angle of incidence. Self-occlusion occurs in rear part of elevated object due to obstruction of viewing ray by its front part and occlusion of object occurs due to obstruction of incidence viewing ray by nearby elevated object (Panday & Gerke, 2011). Thus visibility of one object in all oblique images is not always possible.

Hence, considering need of tree mapping and also potential of oblique images for photogrammetric purpose, with its advantages over other remote sensing dataset such as nadir aerial images, LiDAR, TLS/MLS and terrestrial image, this research aims at automatic detection of trees and extraction of tree parameters in urban area.

1.2. Research identifications

This research focuses on exploiting tree profile information from features presented in oblique images to detect individual tree and extract its key parameters.

Many image acquisition projects are conducted in leaf-off season to get much detail on urban structure and to minimize occlusion on underlying object by tree canopy. Previous work on mapping trees from images concentrates either on leaf-on or leaf-off season, but not on both, as methodology for detecting leaf-on tree can differ from that for leaf-off tree. This study will focus on the study of mapping of leaf –off trees. Figure 1 shows an unfoliage deciduous tree in one oblique image. This study will further assess quality of algorithm developed on detection of tree as well as on extracted parameter.

Figure 1 Unfoliage deciduous tree in oblique image

1.2.1. Research objective

The main objective of this research is to automatically detect single trees and estimate individual tree parameters such as tree height, diameter of stem at breast height, crown height and crown width from oblique airborne images of an urban area for unfoliage deciduous trees.

The main objective can be achieved by the following sub-objectives.

- To identify manually most common parameters that characterize individual tree in oblique airborne images
- To estimate parameters of trees from oblique airborne images
- To detect individual trees automatically from oblique airborne images

1.2.2. Research questions

The research scope is defined by formulating following research questions for each sub-objective presented above.

Identifying manually most common parameters to characterize tree in oblique airborne images

1. Which parameters are most suitable to characterize tree in oblique image?
2. What parameters of tree can be extracted from these images?
3. What is the accuracy of these manually extracted parameters?

Extracting parameters of detected trees from oblique airborne images

1. How to extract parameters of tree from oblique airborne images?
2. What are factors that influence quality of these extracted parameters?
3. How to evaluate quality of extracted parameters?

Automatically detect individual trees in oblique airborne images

1. Which physical parameters can be used to detect individual tree automatically from these images?
2. How to detect these parameters in these images?
3. What is the accuracy of detection?

1.2.3. Innovations

This research aims at following innovations:

- Detection of individual tree of an urban area from oblique images
- Identification of physical parameters of individual tree in oblique airborne images.
- Design of an algorithm for automatic detection of individual tree and to develop a method for extracting its parameters.

1.3. Thesis Structure

Chapter 1: Introduction

This chapter includes motivation and problem statement, research identifications. Research identification is subdivided into objective, research questions and innovation aims of the research

Chapter 2: Literature review and introduction to some basic techniques used in the research

This chapter provide the theoretical concepts on the basis of which this research is conducted. The existing method of tree detection from different remote sensing data is reviewed with the focus on most suitable method for this research. It also includes the review of different tools to be used in the research. The work done in the field of oblique images are also included in this chapter

Chapter 3: Research methodology

This chapter is mainly divided into two parts. The first part consists of Manual analysis. This include tree parameter identification for oblique images, method used for manual extraction of measurement in oblique imagery by mono-plotting and quality assessment of these measurement is presented. The second part consists of methodology developed for automatic detection. This includes method for line extraction from trees its processing and 3D line generation by plane intersection using reliable match points.

Chapter 4 Experimental results and discussion

This chapter introduce the study area and dataset used. Results obtain from different analysis conducted in the research are presented in this chapter discussion on them are presented.

Chapter 5 Conclusion and recommendations

It presents final conclusion, answers to research question and future recommendation.

2. LITERATURE REVIEW AND INTRODUCTION TO SOME BASIC TECHNIQUES USED IN THE RESEARCH

This chapter present theoretical base needed for this research. First, methods used for detection of the trees from different remote sensing data are reviewed with the focus on potential method in 2.1 and tools used in those methods in 2.1.1 and 2.1.2. Section 2.2 includes outline of works conducted in oblique images and properties of these images and key factors that will influence measurement tree in oblique images. Section 2.2.1 describes mono-plotting method of measurement in oblique images and lastly ellipse fitting approach of set of points is discussed to be used for generalizing crown into elliptical shape.

2.1. Tree extraction from remote sensing data

Field base mapping of tree is very time consuming and expensive. Several researchers have been working in (semi-) automatic detection of tree from variety of aerial imagery data. Most of them are concentrated on forestry application. One of the methods used in this application domain to detect trees from very high resolution (VHR) aerial imagery is to delineate tree crown by segmentation process initiated with seed pixel(Hirschmugl, et al., 2007). In urban area, Object based image analysis (OBlA) technique is used by Ardila Lopez et al. (2010) to detect individual tree crown from VHR satellite images considering spatial, contextual and spectral characteristic of urban tree object. His approach is limited only to nadir view ortho-images. Urban trees are detected from aerial colour infrared (CIR) ortho images and normalized digital surface models (NDSM) based on morphological approach considering shape of tree crown as circular in (Gerke, et al., 2001). Aerial LiDAR and image data are used to detect urban tree by two step method in (Secord & Zakhor, 2007). In first step region, growing segmentation is a done based on weight of different feature obtain from image and LiDAR. In the second step, trees are classified using weighted support vector machines (SVM). Trees and other urban structures such as buildings are extracted by co-registration of NDSM generated from laser altimetry data with CIR imagery in (Haala & Brenner, 1999). The algorithm simultaneous uses height information from NDSM and radiometric information from image to classify these features.

All above method of tree detection uses crown characteristics for its detection. Automatic extraction of leaf-off deciduous tree in urban area from high resolution aerial image is presented by Bacher & Mayer (2000). In contrast to above mention method, this approach detect trees' stem. It uses shadow casted by tree and verticality of stem for its detection. The vertical stem in real world appears as straight line in image, pointing towards nadir direction and shadow appears as straight line in the direction of sun. This method models the leafless deciduous tree and shadow casted by it in an aerial image with 2-5 cm ground pixel size as semantic network. Figure 2 presents the model of leafless deciduous tree in urban environment. Beside, tree it also model surrounding objects to make detection robust. The model has three different levels having strong connection with each other. Top level represents real world. It assumes deciduous tree as rotational symmetric, such that every tree consist of trunk, connected to crown. Crown consists of branches, which hierarchically connected with each other and becomes thinner and thinner to end up in twig. The base of trunk represents position of trunk in ground. At this level disturbing object/ surrounding structure such as car are model as medium sized volume and poles as vertical linear object. The second level defines material and geometry of each component. This level is independent to sensor. At this level, base is represented as 3D point. This point can be determined by stereo pair image or DTM of area. The trunk is thick vertical wooden cylinder. Twigs are extremely thin and branches are thin wooden cylinder. The disturbing vertical linear objects also appear as having geometry of vertical cylinder. The third level is the appearance of these material and geometry in image. Besides their direct projection, shadow projection also appears at this level. Shadow of vertical trunk and vertical linear object from disturbing object appear as long distinct dark line in sun direction, Branches appear as short, distinct dark line. Extremely thin twigs appear as blurred edge. The direct projection of trunk as well as those from vertical disturbing object appears as straight line in nadir direction. Branches appear as short line.

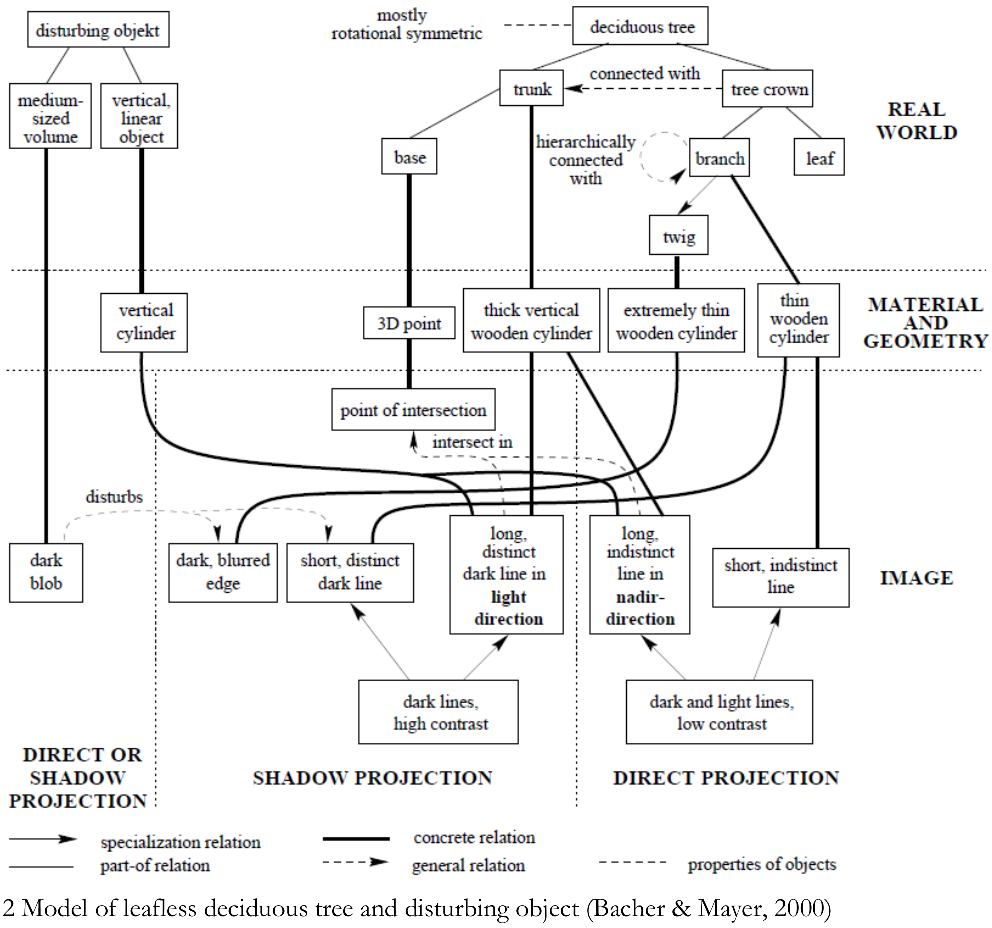


Figure 2 Model of leafless deciduous tree and disturbing object (Bacher & Mayer, 2000)

Hypothesize and verify strategy is adopted to extract different parts of tree from images. Tree stem is hypothesized as vertical. The shadows of these are extracted first with a line extraction tool(Steger, 1998) as they appear dark in image in the direction of sun. This method applied Hough transform to detect straight lines in a sun direction. The detected lines are connected by morphological closing and thinned to their medial axes. Linear regression is performed to connect un-joined lines. The result presented showed that algorithm still needs to be improved for joining lines. Hypothesis of trunk is verified by extracting lines from stem in nadir direction and using it as evidence. The position of tree is determined by intersecting these lines in image space. Lines from branches shadow are then extracted by defining the search area around extracted lines from shadow. The extracted lines from branches are also used as further verification of tree trunk based on knowledge that branches emerge out of trunk. Beside detection of tree by this approach, it further outlines the crown using endpoints of extracted line from branches using snake based approach. Crown parameters are calculated based on extracted outline. The end points of branches are used to outline shape of the crown. The method presented in this paper shows the promising result for detecting tree in urban environment. The implementation of method is done for single image. This paper points out the extension of the method for generation of 3D line by using stereo pair images. The tool used for extraction of line in this paper and other possible option are studied and presented in sub section. The possibility of generation of 3D line as pointed out by the paper is also reviewed in consecutive sub section.

2.1.1. Line extraction from images

Many algorithms are present in computer vision to extract line from images. Line extraction from images considering gray value difference of the feature is presented by Fischler et al (1981). Line detection by nonlinear combination of edge detection filter applied perpendicular to locally determined line is presented in (Koller et al., 1995). Line extraction from bar shaped line model is presented by Steger (1998). This algorithm is based on differential-geometry and Gaussian scale-space principle and can extract line with sub-pixel accuracy. This algorithm assume lines as function and extract a line point based on magnitude of second derivative at the place where its first derivative becomes zero. First and second derivative of the function is estimated by convolving derivative of the Gaussian smoothing kernel. Thus the factor that influences line detection from this algorithm depends on Gaussian smoothing kernel. The amount of smoothing by Gaussian kernel depends on standard deviation of the Gaussian kernel. It is also known as Sigma, σ value. For the extraction of line of width w, sigma value should be greater than the value given by the relation **7**.

$$\sigma \geq \frac{w}{\sqrt{3}} \qquad (7)$$

High value of sigma largely smoothen image resulting worse localization of line(Steger, 1998). Line point extracted for parameter sigma is then linked to another line point. Linking of this line point depends on second derivative value. Line point with its second derivative lager than upper threshold define (High value) are accepted and those with second derivate less than lower threshold (Low value) are rejected(Steger, 1998). For the line points between upper and lower threshold, all points are accepted if they are connected. The High and Low threshold parameter which accounts second directional derivative depends on the amplitude and width of the line and sigma value. Larger the sigma value, smoothing in image will be lager thus smaller should be upper and lower threshold value. This algorithm can also detect width of line based on maximum gradient value on both side of extracted line point. The algorithm searches maximum gradient value with the range of 2.5σ. However, for highly asymmetrical bar shaped line, algorithm fails to extract edge lines.

2.1.2. Generation of 3D line from multiple images

A line in one image and its projection centre forms a plane. If same line is viewed from other images, plane formed by it with its corresponding projection centre will intersect to give infinite 3D line in object space due to homographies between

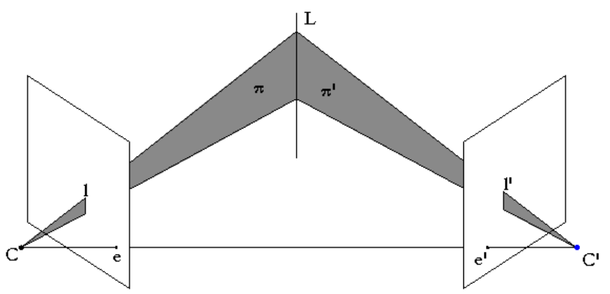


Figure 3 Plane induced homographies given F and image correspondences

the images. In the Figure 3 line l and its projection centre C forms a plane π intersect with plane π' formed by l' and C' and defines line L in 3-space (Hartley & Zisserman, 2003).

Homography between different view oblique images is used to generate 3D edge of roof by intersecting plane define by lines of same feature in different images (Xiao et al., 2011). Building edges are reconstructed from video image sequence by this plane intersection method in Tian et al. (2008) base on reliable match points. Generation 3D line with reliable match point reduces the search space for corresponding 2d lines in image and is quite faster compared to forward ray intersection of endpoints to find candidates from stereo pair images (Tian, et al., 2008).

2.2. Potential of tree mapping from oblique images

Most of the method used to detect tree presented in 2.1 used tree crown as parameter for its detection. Limitation of several remote sensing data for tree detection is also discussed in 1.1. These provide a necessity to explore other dataset for tree detection. Potentiality of photogrammetric measurement from oblique images as well as generation of 3D information from these images is briefly discussed in 1.1. Several studies had already used oblique images for production of geo-spatial data. Automatic detection of flat roof building with oblique image is presented in (Xiao et al., 2010). Edge extraction from multi-view oblique images is shown in (Xiao et al., 2009). Application of oblique images in damage assessment of building is presented (Gerke & Kerle, 2010). Texture mapping for 3D city model from oblique images are presented in (Frueh et al., 2004). Plane sweeping method is presented for rectangular flat roof building detection from oblique image in (Xiao, et al., 2011). These images are quite intuitive as feature appear similar to human perspective and has wide range of application field (Grenzdorffer et al., 2008). Mono-plotting method is used to measure feature in oblique imagery (Hoehle, 2008). The detail method of mono-plotting is presented in 2.2.1.

2.2.1. Measurement in Oblique images

Mono-plotting approach of measurement in oblique images from Pictomerty is describe in (Hoehle, 2008). The approximate height of elevated feature from oblique images is calculated by measuring radial displacement of this feature in images and computing viewing ray between base point of feature in image plane and projection centre. The formula for computing height of feature by measuring its radial displacement is given below and terms used in it are depicted in Figure 4 from (Hoehle, 2008)

$$dh \approx dr' m_T \frac{1}{cost\ tan\beta} \qquad (1)$$

dh = height of feature in object space
dr' = radial displacement of elevated object
m_T = The scale number of bottom of the elevated object

$$\beta = t + \tau \qquad (2)$$

β= angle between viewing ray between base of elevated feature to camera centre
t= tilt of camera axis

$$\tau = \tan^{-1}\frac{r'}{c} \qquad (3)$$

c= camera constant

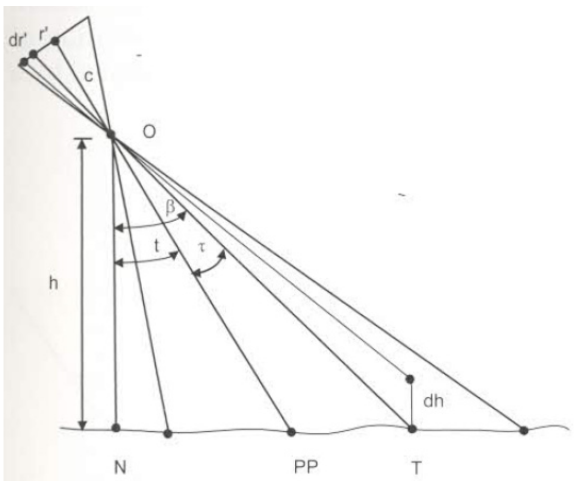


Figure 4 Determination of heights of elevated objects (Hoehle, 2008)

The object coordinate of feature can be calculated with the aid of DTM. For calculating ground coordinate of feature, a horizontal distance between image centre and projection centre is estimated in object space with known projection centre coordinate and azimuth angle of camera axis then pixel coordinate of the feature is used to identify region of DTM. Initially 4 corner point of DTM is selected around this point based on tilt and elevation of identified DTM region. A viewing ray between pixel coordinate and projection centre is intersected with identified DTM region to get the plane coordinates of feature. The z-coordinate of the feature is calculated by bilinear interpolation of corner point of DTM. The precise coordinate is estimated by iterating the selection of another set of corner point from DTM region till the projected image coordinate of calculated point are within threshold value of measured pixel coordinate.

The length of feature in the ground plane is measured by calculating the coordinate of starting and end points in similar way. The coordinate of end points are used to calculate distance between these points using distance formula. Since, DTM is essential for coordinate calculation, this method can only measure the distance of feature located in ground plane. Measurement of feature above ground plane is done by raising the virtual plane parallel to ground plane (Pictometry, 2007).

This accuracy of this method depends on DTM and projection centre coordinate. However, commercial companies involved in acquisition of these images either do not usually provide these information or information are not reliable as these system uses non-metric camera for which long term stability is not guaranteed. (Grenzdorffer, et al., 2008). Indirect sensor orientation method is used to orient these images to get reliable information of orientation of images (Gerke, 2011).

The profile information of the trees present in these images provides potential to detect trees stem from the images and its multi view platform can be exploited for its 3D generation. For the natural feature like trees, when viewed from different direction, it won't correspond to the same point of the tree. Beside, error in orientation of images, DTM and variation of scale with in oblique images will also influence the extracted measurement. Thus, this should be analyzed to extract the tree parameters from these images and to generate 3D line.

2.2.2. Ellipse fitting

Shape of tree crown is quite complex in nature. Studies related to tree mapping has generalized shape of crown to simple geometric shapes. Coder (2005) has proposed different geometric model for modelling crown and determining its volume. Crown shape is model based on the distribution pattern of laser points and its volume is calculated by Pokharel(2008). Rutzinger, et al. (2010) classified the crown shape into different geometrical shape by comparing diameter of enclosed circle at different level of crown part for terrestrial laser data. Pyysalo (2004) also measured crown width at different level along crown height to estimate its parameter in terrestrial images. Crown shape is model as rotational ellipsoid by Pollock (1994). In this study also crown points are obtain by measuring width of crown at different level and crown shape is assumed as elliptical. As discussed in 2.2.1 same tree when seen from different images will appear different. This motivate to study on different approach of ellipse fitting to a set of crown point obtain from different direction.

Fitting ellipse of data is a nonlinear least square problem. There are mainly two approaches to fit ellipse to a set points by least square approach. Geometric fit approach minimize the sum of square of distance to the given point $\sum_{i=1}^{m} f_i(u)^2 = min.$ whereas algebraic fit approach determines parameter of algebraic equation $F(X) = 0$ in least square sense(Gander et al., 1996).

The conic section is represented by second order polynomial equation:

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0 \quad (\mathbf{4})$$

Where, A, B, C,D, E and F are coefficient and x, y are the points on the section
The conic section represent ellipse when $B^2 - 4AC < 0$

The quadratic form can be derive to the standard form of ellipse with its centre at origin is given by

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \quad (\mathbf{5})$$

Where, a & b are major and minor axis of ellipse and x and y are the points on the ellipse. For the centre of ellipse other than origin standard form of equation is given by

$$\frac{(x - x_0)^2}{a^2} + \frac{(y - y_0)^2}{b^2} = 1 \quad (\mathbf{6})$$

Where x_0 and y_0 is the coordinate of the centre of ellipse.

Algebraic fit approach is used to for ellipse represented by equation **4** requires normalization of coefficient to prevent trivia solution. The characteristics of normalizing by either A+C=1 or F=1 is studied by Paul(1993). He showed that normalizing F parameter give rise to singularities and transformational invariance(Paul L, 1993) and proposed the solution of shifting data to its origin and fitting ellipse at this origin. Geometric fit approach can be used to fit the ellipse define by function **5** and **6**.

3. RESEARCH METHODOLOGY

This chapter describes in detail the methodology applied in the research. Subsections of the chapter are arranged to reflect research question. Manual analysis of tree parameter is presented in 3.1 as per discussion in 2.2.1 and Automatic detection is presented in 3.2. Sub-section of manual analysis presents the methodology adopted in this phase of research. 3.1.1 presents identified parameters for a tree. 3.1.2 presents a methodology to extract these parameter from oblique images 3.1.3 presents methodology to assess quality of measurement from oblique image and last part of this section 3.1.4 presents methodology to fitting ellipse to the crown. The subsection of automatic detection part starts with methodology of line extraction from oblique images. 3.2. 2 and 3.2.3 presents method to filter these line extracted in oblique images to generate vertical line and 3.2.4 presents mono-plotting approach of calculating coordinates of base of the vertical line. 3.2.5 presents the methodology to identify reliable match points between lines from different image and finally 3.2.7 presents approach of calculating end points of 3D line.

3.1. Manual Analysis

The importance of manual analysis for measurement in oblique images is discussed in 2.2.1. Beside these analysis is essential to approximate threshold value for automatic detection as well as for assessment of automatic detection result. Mono-plotting method of measurement in oblique images is exploited to extract different parameters of the tree. The parameters which can be extracted from oblique images are identified based on the concept of model presented in 2.1. Basic difference occurs at third level for oblique images. Vertical deciduous tree appears vertical in image space as oblique images are acquired with oblique angle with respect to horizon. These modes of measurement are then assessed for its quality and finally ellipse fitting is done to the measurement obtain from Crown Point -

- Tree parameter identification
- Manual extraction of parameters
- Quality assessment of extracted parameter
- Fitting ellipse to tree crown.

3.1.1. Tree parameter identification

An Oblique image contains profile information of the elevated feature due to its oblique viewing angle. The trunk as well as crown of an individual tree is distinctly visible in these images, if not occluded by nearby elevated feature. Thus, different tree parameters can be visualized in an oblique image. In oblique image tree is visualized as shown in Figure 1. The parameter of tree can either be directly extracted or computed via monocular measurement from oblique images manually.

Figure 2 shows different parameters of a tree that can be manually extracted or computed from oblique images.

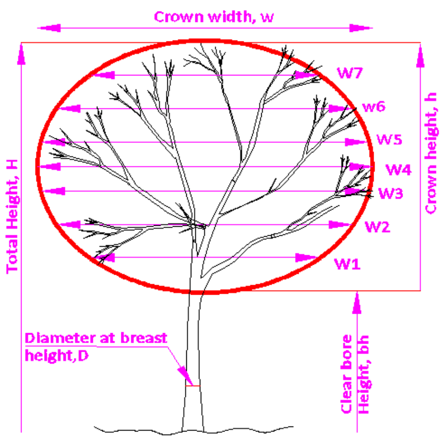


Figure 5 Parameters of tree

Position of tree is marked by intersection of trunk with the ground. This intersection point is measured as 3D point.

Diameter at Brest Height (DBH) of tree trunk which is defined as the diameter of the trunk at normal breast height of the human is measured as width of tree trunk at 1.37 m height from ground level.

The width of a tree crown is the maximum width extent of tree canopy by its branches. The height of a tree crown is the height from lower most branches to the top of the tree. In the Figure 5, h represents crown height. Tree canopy has a complex shape in nature so first its shape will be generalized to elliptical shape. Many literatures has model the tree canopy as elliptical. (Pokharel, 2008; Rutzinger, et al., 2010) The geometric parameter of this shape will yield the dimension of the tree crown.

Height of the tree is its vertical extent from base of tree to its top most branches. This is also computed from known 3D coordinate of base of tree and calculated geometric parameter of tree canopy. The difference of elevation value between calculated highest point of canopy geometry and known ground point gives the height of the tree. These measured heights will be compared with derived height during quality assessment.
Clear bore height of tree is also the vertical extent from base to its lower most branches. This is computed as the difference between z-coordinate of the base and the z-coordinate of lowermost branch of the tree.
Beside these there are also other parameters but for this research only the above-mentioned geometric parameters of tree are considered. These are also enlisted below.

- Location of tree
- DBH of tree trunk
- Width of tree crown
- Length of tree crown
- Height of tree
- Clear bore height of tree

3.1.2. Manual extraction of Parameters

The parameters of tree defined in 3.1.1 are extracted manually from oblique airborne images. The theoretical concept of measurement in oblique images is reviewed in 2.2.1. Implementation of extraction of parameters is done in Electronic field survey (EFS) software. EFS software application uses mono-plotting method to extract coordinate, elevation, height and length of the feature. The functionality for each of these measurements is supplemented by different tool present in the application. Location tool extract 2D geographic coordinate at the point clicked in image by intersecting viewing ray computed between unique projection centre and clicked pixel position with DTM (Hoehle, 2008). Elevation tool works similar as location tool but only extract ground elevation of the clicked position in image. Height tool extract vertical height of the feature using formula (**1)** between two clicked points in image. Distance tool extract the length of the feature between two clicked points in image. This height and distance tool of EFS can also extract its measurement for feature above ground plane. To extract the measurement of feature above ground level ground plane offset option has to be enabled. This offset option raises ground plane up by the offset height inputted to application platform by moving mouse crosshair, thus enabling measurement at that raised plane.

Figure 6 Shows extraction of parameters of tree in oblique image in EFS software. The blue line in Figure 6 represent the DBH measurement, green line represent height measurement and yellow line represent crown width measurement at different crown level.

The positions of individual tree are marked with Location tool and elevation tool in EFS to extracted 3D coordinate of the base of tree. Beside geographic coordinate pixel coordinate of the feature is noted manually which is used as input for coordinate calculation by mono-plotting in images oriented with indirect sensor orientation method and using DTM extracted from LiDAR data.

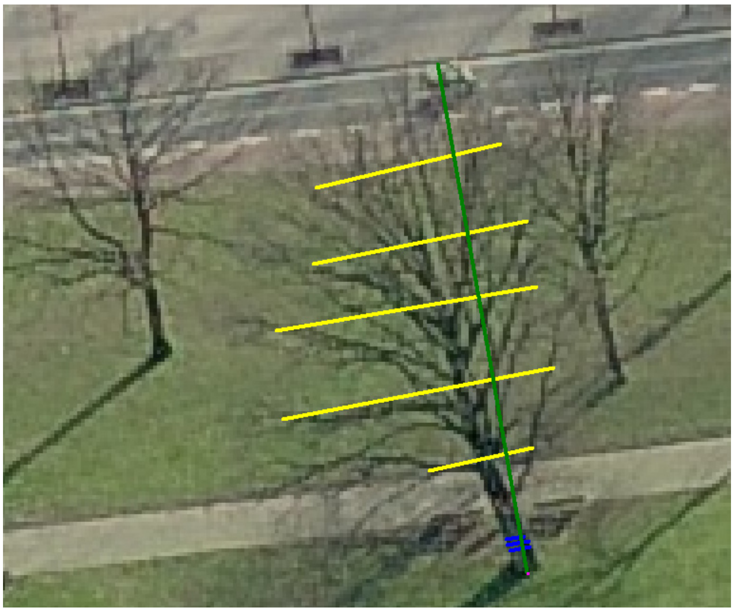


Figure 6 Parameter digitization in EFS

DBH of tree is measured using "Distance tool" by activating offset option in EFS. First, a offset distance of about 1.37 m from ground is measured and then the width of tree trunk is measured at that offset. In EFS, it is quite cumbersome to take a offset exactly at 1.37m so for DBH measurement, three measurement are taken near this height and later the averaged per tree per view.

The height of tree is obtained from two methods. First one directly measuring height by the use of "Height tool" of EFS software and the second by computing height as described above in parameter estimation.

The width of tree canopy is measured at different height from ground level along its canopy length using "Distance tool". Offset from ground to different level is inputted via mouse crosshair movement.

Manual measurements of parameters of individual tree are conducted in multiple images of same viewing direction and of different viewing direction. A unique identity number is given to all trees of the study area. Every measurement from all images are then referenced to this identity number. All the measurements are store in ESRI shapefile format except pixel coordinate of location of tree which is stored manually.

3.1.3. Quality assessment of measurement in EFS

The motivation behind this comparison is to check how accurately measurement can be done with mono-plotting method. The reference data is used to compare EFS measurement as the accuracy of orientation of images and DTM used by EFS software is not known. Coordinate measurement obtain from EFS is compared with Ground control points (GCP) and reference dataset (Gerke, 2011) which uses indirect sensor orientation method to orient the same set of images and DTM extracted from LiDAR data. The accuracy of measurement from other tool in EFS used for extraction of different tree parameters, height and distance tool, are assessed with reference to available dataset. Height and length measurement is compared with reference to LiDAR data. All the parameter defined in 3.1.1 for a tree is extracted from multiple images of same viewing direction as well as of different viewing direction. All these measurement of single tree from different images are compared to estimate threshold value to be used in automatic detection phase of this research.

3.1.4. Crown parameter estimation

As stated in 3.1.1 tree crown has very complex shape and it is modelled to as ellipsoid in this research. The different method of fitting ellipse by least square approach for segmented data is reviewed in chapter 2.2.2. In this research, ellipse is fitted by algebraic fit method. The function for ellipse is defined using equation (4)..

Input data for fitting ellipse to crown is generated from measurement of width of crown at different level from ground. In figure 5, w1, w2, w3, w4, w5, w6 and w7 are different widths of crown measured at different level of from ground. The geographic coordinate of end point of this line is calculated and its offset from ground plane is manually noted. As the ellipse to is to be fitted in vertical plane, only x-coordinate and it's offset from ground is used as input data for its fitting for North and South view images whereas y- coordinate and offset height is used for East and West viewing images. Ellipse is fitted independently from the measurement obtained from all images for a tree. The height of tree is also calculated with parameter obtain from ellipse and compared with the height obtain from direct measurement.

The clear bore height of the tree is calculated based on estimated elliptical geometry. First lowermost level of extracted crown is calculated, if this level is above the base of tree by 1.37m, clear bore height is taken as this lower lever. In the case where this level exceeds above mention threshold, clear bore height is taken as height of lower branch from the ground.

3.2. Automatic detection of trees in oblique images

An algorithm is developed to detect urban trees from oblique images in this research. The methodology of

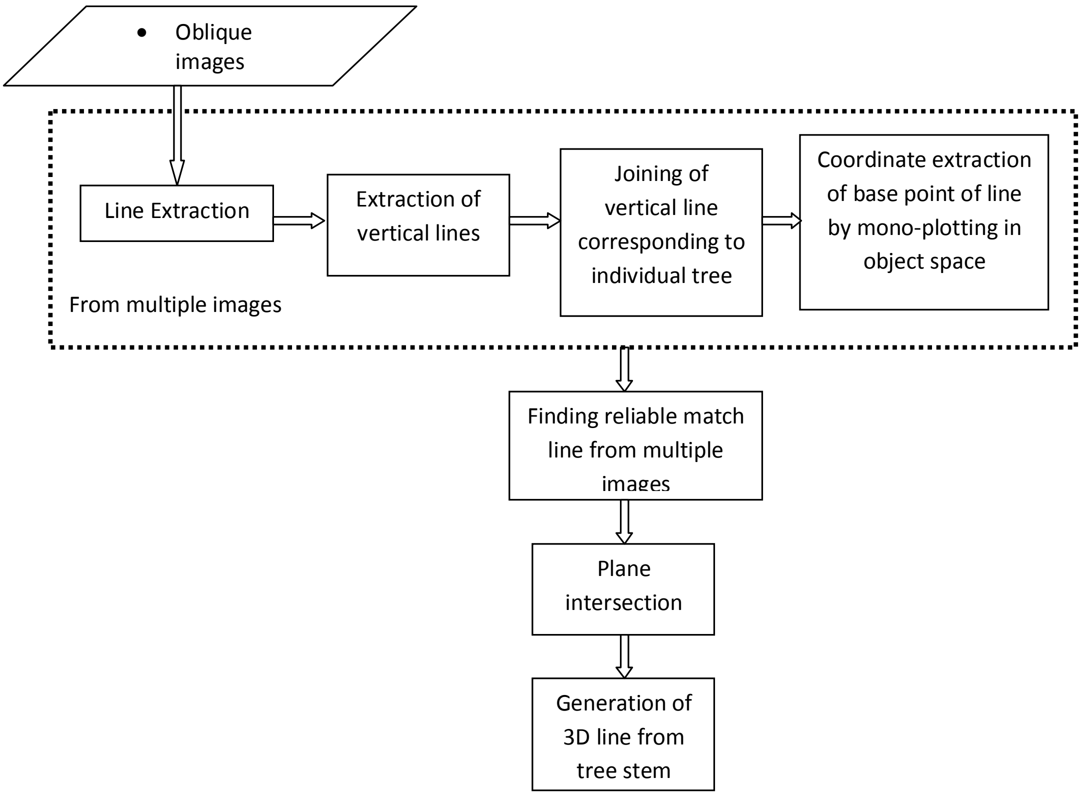


Figure 7 Flowchart for automatic detection of tree from oblique images

this detection mainly consists of extraction of lines from oblique images. Vertical lines are firstly extracted. Vertical lines corresponding to individual tree are joined together. Mono-plotting method is used to calculate object space coordinate of base point of these lines and reliable match lines from different images are identified on the basis of object coordinate of the line. The obtained reliable match lines are then used to generate 3D lines by plane intersection method. Finally, an approach to estimate end points of the vertical line is presented. The following sections describe the methods in detail.

3.2.1. Extraction of line from oblique image

The stem of tree appears as distinct line having certain width in oblique images. Steger(1998) bar-shaped line extractor tool is used to extract lines from oblique images. Theoretical concept behind this line extraction tool is reviewed in 2.4. Implementation of line extraction was conducted in HDevelop software application. The threshold value used in this algorithm is determined based on average DBH of tree obtain from manual analysis and analyzing contrast difference between tree stem with its background.

3.2.2. Extraction of vertical line

Bar shaped line extracted as explained in section 3.2.1 delineate features like tree stem, roof edge, windows in the building, cars, electric pole and other similar feature. These extractions other than tree trunk have to be filtered out. These unwanted extractions are removed by assuming tree trunk as vertical. As the oblique images are acquired with oblique angle with respect to horizon only vertical objects in the scene appear vertical in the images. An algorithm is developed in python to separate vertical lines from extracted lines. Lines extracted in 3.2.1 contains multiple instance of vertical lines in the single segment so Least Square based line separation or RANSAC based method does not work here. These algorithms take in to account single instances of line orientation per segment. Least square method will generate best fit line based on all the points while RANSAC will generate lines considering most number of inliers. Since the extracted lines contains multiple horizontal as well as vertical segment, fitted line will shift from original detected position with least square while RANSAC will remove outlier point (which may even be from the tree stem), ultimately resulting in poor detection of tree.

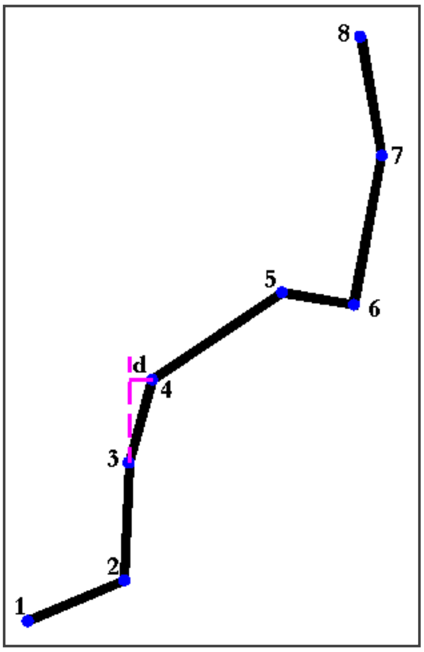


Figure 8 Separation of Vertical line

The algorithm to separate vertical line is developed in such a way that it can extract multiple vertical lines from single line segment. The algorithm is described with reference to the Figure 8. Figure 8 shows a typical line segment extracted having two vertical segments. The numerical value in the Figure indicate node of the line segment. Vertical segment in the Figure is formed by node 2, 3 4 and another segment formed by 6, 7 and 8.

The algorithm reads first three nodes of the line segment, node 1, 2 and 3. It the checks the slope of line formed by node 1 and 2. If the slope of line is more than threshold value with respect to vertical, it rejects node 1 and consider node 2, 3 and 4. It does the similar checking for line defined by node 2 and 3, if slope of line is within threshold value; it keeps both nodes and checks node 4, whether its lies in the same line segment. For this check it calculates the perpendicular distance between lines projected from node 4 to the extension of line from node 2 and 3. The algorithm accepts the node 4 if the distance "d" as shown in

Figure 3 is within some threshold. Thus the new line segment will contain node 2, 3 and 4. This process continues again considering node 4 and 5 and check slope between them. If the slope between them is greater than threshold it rejects node 5. This means that vertical line segments define by node 2, 3 and 4 will be separated from its original segment. This process continues till the final node of the line.

This algorithm actually breaks a single line into a number of vertical segments and considers the slope of line in its first step which helps to filter out lines other than vertical define by the threshold. If the line is horizontal or have slope more than define threshold, algorithm just require calculating the slope between nodes to reject the initial node.

3.2.3. Connecting vertical line segment per feature

The output from algorithm as described above results in a number of vertical segment. This vertical segment has to be joined so that it represents a complete feature. For joining this broken line, an additional algorithm is developed in python. The new algorithm is based on the relation of end points of vertical segment with another vertical segment, c.f. Figure 9.

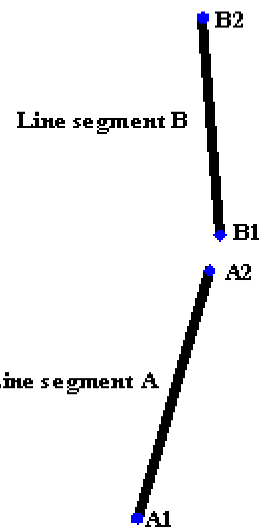


Figure 9 Connecting vertical lines

Figure 4 shows two line segment "A" and "B" to be joined. "A1" and "A2" are the end points of line segment "A" and "B1" and "B2" are the corresponding end points of line segment "B". The algorithm joins these line based on threshold value set as horizontal separation between end points "A2" and "B1" and vertical separation between these points.

The search technique used in this algorithm is computationally very expensive. So to reduce computational time of algorithm, search spaced was narrowed. This was done by tiling line segment into rectangular grid of 500 by 500 and executing the algorithm per tile. Additionally, lines in each tile are arranged in vertical order. This means the first line of each tile is top most line of that tile and last line is the lowermost line in that tile. This helps to find the corresponding line segment to be joined more quickly. After completing this type of searching for each line, algorithm computes the length of line segments either joined or not. If the length of segment is within threshold defined (length greater than 25 pixel and less than 100 pixel) it keeps the line segment. This is done to remove very tinny vertical segment as well as very large segment extracted from road edges and building edges. This threshold value is also chosen by inspecting delineated line of tree stem in the image.

Joining of all line from individual tree is very important as these lines will be used to calculate object coordinate of feature by mono-plotting. If the lines are broken, mono-plotting algorithm will calculate coordinates considering individual line. This may result in false identification of reliable match point. It will also result in poor extraction of tree parameter.

3.2.4. Finding reliable match line in multiple images

Reliable candidate of match line is obtained by analyzing object coordinate of the base of vertical line in object space. Threshold used for searching match point is obtained from manual analysis of coordinate of tree. The algorithm developed to find reliable match point in object space is illustrated with Figure 10 below. This algorithm is implemented in python.

Figure 10 shows working methodology of finding reliable match point from 4 different viewing images. In figure "Img 1", "Img 2", "Img 3" and "Img 4" are object coordinates of all the line from 4 different images. Corresponding line between two images are searched at a time. This is similar to combination problem. Mathematically combination of "n" object considering "r" at a time is given by the relation:

$$C(n,r) = \frac{n!}{r!\,(n-r)!} \qquad (7)$$

Where n is the total number of on objects and r is the number of object considered at time.
So as shown in Figure 10, in first stage it checks the match points between two image pairs. This is denoted as "Mpt 1-2" in figure. The numbers in label indicates that it is the combination between input "Img 1" and "Img 2".

As there are four inputs and we are considering only two at time, as per combination principle, there will be six different combinations. The reliable match is identified by calculating their coordinate difference which should be within some threshold value. This threshold value for this is interpreted from manual analysis. The algorithm stores the identity of both the point matched and also compute mean coordinate between these points. If there are multiple match points between line from first image to multiple lines

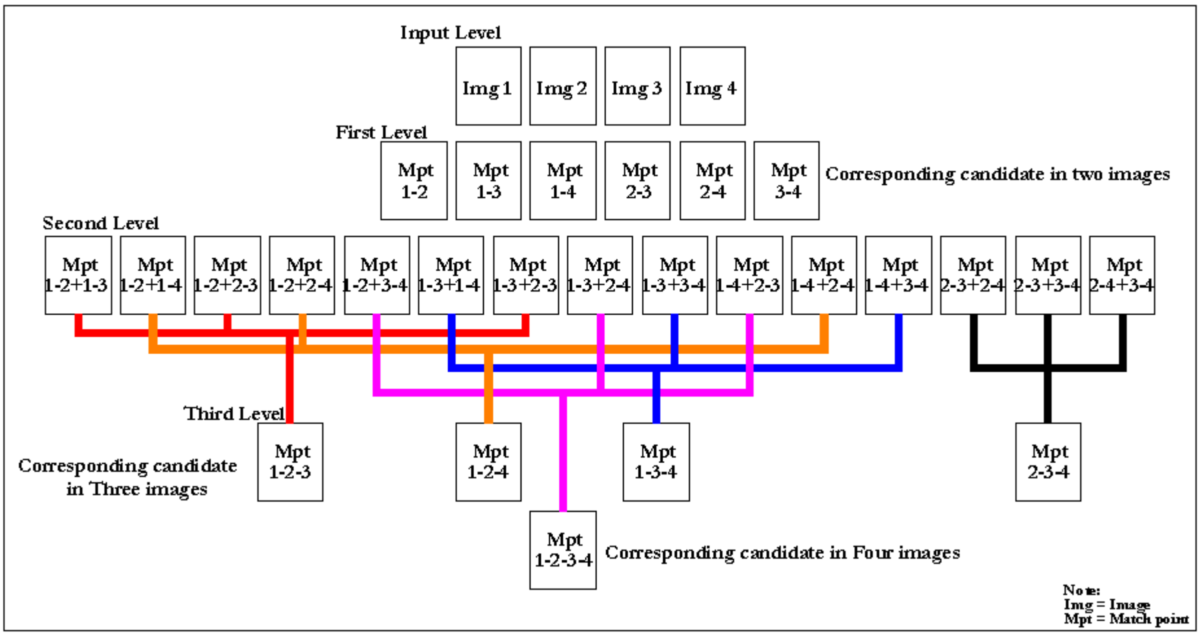


Figure 10 Searching matching line between images

from second stage, a closet match between them is only considered. In the second stage, it takes the obtained six combinations as input and checks two at a time. The criteria of finding match points are again the coordinate difference between the point and its correspondence with threshold. Only difference at this level compared to earlier one is that it uses the mean coordinate of the match point of first stage in place of actual coordinate. As per combination relation, it will results in 15 combinations.

If we consider only four inputs, then we can obtain all possible combination with in this level. It is clear from description above that the total number of level one should repeat the process depends on the number of inputs given. This can be generalized by the relation:

$$Number\ of\ level, (\mathrm{L}) = \begin{cases} 0.5 + \dfrac{n}{2} & \text{for n = odd numbers} \\ \dfrac{n}{2} & \text{for n = even numbers} \end{cases} \quad (8)$$

For all the combination thus obtains, the combination having match lines are considered first for 3D generation. For successive set, lines used earlier are not considered.

3.2.5. Extraction of finite 3D line

The match point between multiple image are traced back to obtain corresponding line per image plane with reference of line identity. The pixel coordinate of the base and top of these match lines per image is extracted. The line in image plane and its respective projection centre forms a plane. Intersection of these planes defines by respective projection centre and reliably matched line from corresponding multiple images define an infinite 3D line as describe in section 2.2.2. The theoretical concept behind this 3D line generation from stereo or multiple pair is presented in chapter 2.5. The plane intersection method here computes the 3D line from each stereo pair of images and the final 3D line is generated using least square fitting between the 3D line obtain from each stereo pair intersection. The infinite 3D line thus obtain after this least square fitting is then converted to a finite length by analyzing the projection of end points from each participating 2D line.

Selection of image is another key parameter in obtaining good 3D line. As from literature (Gerke, 2009) that if the baseline between two stereo pair images is small , intersection geometry between images will be weak, Thus, resulting in mismatch of feature during forward plane intersection. Thus, to obtain the maximum baseline between the images, images from different viewing direction is only considered in this research.

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

This chapter present the analyses of results obtain from manual analysis and automatic detection. It subsequently discusses these results. This chapter stars with the description of study area, used datasets in the research in section 4.1. Section 4.2 presents the analysis of measurement in EFS. The results of these will be discussed in relation to the various factors that influence it. Section 4.3 presents analysis of measurement of extracted tree parameters. Analysis of measurement of each parameter is presented in sub section. Section 4.4 presents the results of automatic detection of trees. This section is arranged in subsection to present intermediate results.

4.1. Study area and datasets

The study area is selected at eastern part of Enschede, The Netherlands. The study area is comprised of open area and road corridor. Open area is along the side of "Boulevard 1945" road and road corridor is along "Hogelandsingel" road. Figure 11 shows the location of study area in google map and in oblique images. The study area consists of around 100 free standing and clustered trees. These trees are of different species and of different ages. The only dataset used in the research is airborne oblique imagery. However, LiDAR data was used to compute the input DTM for mono-plotting measurement from oblique imagery. DBH measurement of tree is verified by field measurement. The 3D line extracted is assessed visually with airborne laser scanning data.

Figure 11 Study area image (left map is obtain from ©Google Map 2012

4.1.1. Airborne oblique images

Oblique imagery dataset of Enschede is acquired from Pictometry Inc. (Blom Aerofilms). This data is acquired in February 2007. The pictometry system consist of small frame camera, four capturing images in forward, backward, left and right direction with oblique view and one in nadir direction(Hoehle, 2008). The flight lines during image acquisition are designed in a way that an area is visible in multiple overlapping images of same and different viewing direction. In this research only images with oblique view are used. In manual analysis part of this research 15 images (3-South, 4-East, 4-North and 4-West) of the study area are used while for automatic detection only 12 images (3-South, 2-East, 3-North and 4-West) of the study area are used. Specification of oblique images are presented in the Table 1- is taken from(Gerke, 2011). The manual measurement in oblique images is conducted in Electronic Field Survey (EFS) software. This software application from Pictometery consist of geo-referenced oblique and ortho-rectified vertical images(BLOM, 2011). It also facilitates monocular measurement in oblique images. However, the accuracy of orientation of images and Digital Terrain Model (DTM) used in this application is not known to the user. For automatic detection part of this research as well as for analyzing some of measurement from EFS, images are orientated using Gerke(2011).

Table 1 Parameters of Pictometry system, estimated accuracies (based on baseline of 400m, stereo intersection), (Cited to(Gerke, 2009) in (Gerke, 2011)

Parameter	
Flying height	920 m
Baseline	30 – 2600 m
Tilt angle	50 degree
Focal length	85 mm
Pixel size	9 μm
Sensor size	36 mm x 24 mm
Image size (Column x Row)	4008 pixels x 2672 pixels
GSD and theoretic accuracies from fore-to background	
Ground sampling distance (cm)	10 -16
s_z across track base (cm)	22 -44
$s_{x,y}$ across track base (cm)	18 -37
$s_{x,y}$ along track base (cm)	22 -42
s_z along track base (cm)	19 -35

4.1.2. Airborne laser scanning data

Airborne laser data is used to analyse quality of measurement from EFS software in manual analysis part of the research and also to visualize quality of 3D line extracted from automatic detection. Airborne laser scanning data of Enschede was acquired in 2007 by FLI-MAP 400 system with the average point density of 20 pts/m^2(Vosselman, 2008). This dataset has the planimetric accuracy of 2 cm and height accuracy of 10 cm(Vosselman, 2008).

4.2. Analyzing accuracy of measurement

The different type of measurement conducted in EFS software is assessed for its accuracy. The motivation behind this analysis is presented in 3.1.3. First the accuracy in measurement is conducted for the point distinctly visible in multiple images. The 3D coordinate extracted with EFS and mono-plotting measurement in the same set of images orientated with method in (Gerke, 2011) are compared with available GCP of area. These GCP are acquired from RTK-GPS in previous study (Gerke, 2011) of the area. Only three GCP were used in calculation as these are only available in the study area. Two GCP are visible in only two set of images and one GCP is visible in seven set images of same and different viewing direction. The pixel coordinate extracted from EFS and undistorted images are taken as input for obtaining geographic coordinate from images oriented by Gerke (2011). Here, undistorted images are referred to those images in which lens distortion are corrected in the figure and table below. The figure 12 shows the graph of error in X-coordinate and Y-coordinate for GCP-310 for multiple images of same and different viewing direction for the coordinate obtain from distortion corrected image and using image orientation parameters obtained with the method from (Gerke, 2011) and coordinate extracted from EFS. The figure 13 shows the error in z coordinate for same GCP. The Table 2 shows the Root Mean Square Error (RMSE) in for all GCP. The GCP used in the measurement has nominal standard deviation below 3cm (Gerke, 2011).

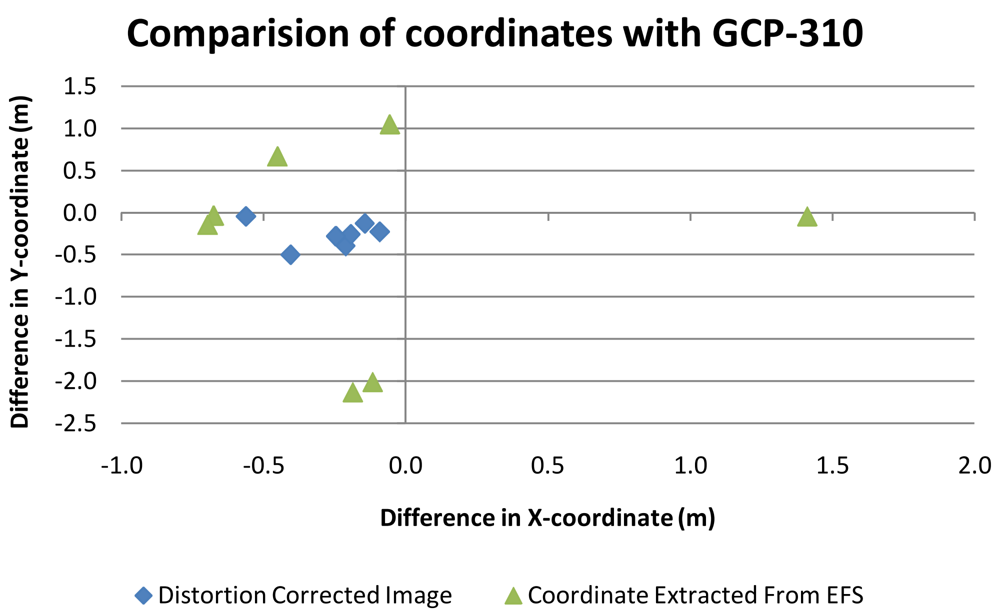


Figure 12 Comparison of X and Y coordinates with GCP 310

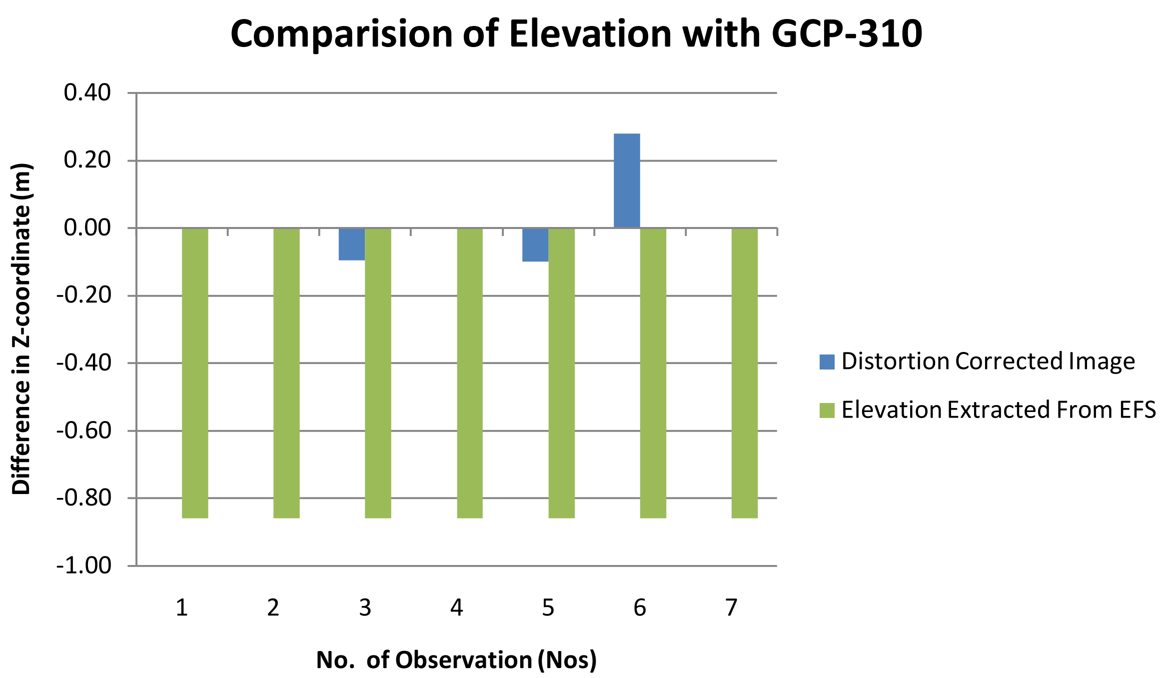


Figure 13 Z- Coordinate comparison with GCP 310

Table 2 Root Mean Square Error (RMSE) for all GCP

Source	Along X-axis (m)	Along Y-axis (m)	Along Z-axis (m)	Total (m)
Distortion Corrected Image	0.42	0.47	0.33	0.71
Coordinate From EFS	0.75	1.09	0.92	1.61

These graphs in figures 12 and 13 shows that difference in x and y coordinate from all images for the GCP-310 has high variation in coordinate extracted directly from EFS compared to that obtain from distortion corrected images. The elevation between distortion corrected images with respect to GCP elevation differed by 0.861 m for coordinate obtain from EFS directly. The Table 2 of RMSE for all GCP of the area shows high RMSE for coordinate obtain directly from EFS compared to those calculated from distortion corrected images.

The coordinate calculated from distortion corrected image uses DTM from LiDAR of the area whereas coordinate extracted from EFS uses different DTM of unknown accuracy. So RMSE along Z-axis for distortion corrected images is higher than that of EFS. Analyzing these figures and table revealed that deviation of coordinate is influence by shift in DTM. The Z- value difference for all the point for EFS is same but the distribution of the points is not even which indicate that there is some orientation error in images of EFS.

The influence of viewing ray computation and DTM on coordinate calculation is also analyzed by using some check point in all these three data set. Five distinct points are selected in the images (mainly zebra crossing mark and road median mark) and its coordinate are calculated from every images of same and different viewing direction where these are visible. The mean coordinate for every check points are calculated from the coordinate obtain from multiple images of same and different viewing direction. Individual coordinate are deducted from these mean value and standard deviation of these difference is calculated. This calculation is conducted for coordinate obtain from EFS and those from distortion corrected images. The Table 3 below shows the standard deviation with respect to mean coordinate of individual check point for all three image sequence.

Table 3 Standard deviation in check point

Check Point	Distortion Corrected Image			EFS		
	ST Dev in X (m)	ST Dev in Y (m)	ST Dev in Z (m)	ST Dev in X (m)	ST Dev in Y (m)	ST Dev in Z (m)
1	0.36	0.45	0.10	0.19	0.47	0.00
2	0.55	0.38	0.12	0.39	0.88	0.00
3	0.77	1.25	0.12	0.26	0.65	0.00
4	0.74	0.94	0.11	0.39	0.65	0.00
5	0.73	0.75	0.09	0.31	0.57	0.00

Note : ST Dev = Standard deviation

The table 2 shows that Standard deviation of individual z-coordinate from its mean coordinate is 0 from EFS where as it is around 0.1 m for other two image sequence. The DTM used in these two image sequence is derived from LiDAR data of point density 20 pts/m^2 with height accuracy of 10 cm. But we don't have any information regarding DTM used in EFS application. The accuracy of coordinate calculation by mono-plotting depends on DTM. Mono-plotting approach use iterative procedure to calculate coordinates of the point. If DTM used in calculation is of coarse resolution, it converge the iteration procedure before a precise coordinate of point is calculated, as in every iteration, it will yield same value. Thus, these values suggest that DTM used in EFS are of coarse resolution than those obtain from LiDAR points. Although these check points are taken on flat surface but still it will be quite pessimistic to assume no variation in z value in these natural surface. This coarse resolution of DTM in EFS resulted in low Standard deviation in x and y coordinates value influencing accuracy in measurement as well as presenting false impression about the precision of measurement. Also comparing to GCP analysis, standard deviation in distortion corrected image seems to contradict. So with this observation it is not clear what the reason behind it. However, this analysis on GCP and CP shows that the coordinate extracted from mono-plotting is influence by DTM and viewing ray computed between image pixel and projection centre.

The length and height measurement of permanent physical structure is compared with LiDAR data of the area. Here, permanent physical structures are referred to structure for example buildings whose dimensions are assumed to remain constant between image acquisition time and field survey or referenced dataset acquisition time. The lengths of outer edge of roof of buildings are measured in EFS using length tool from multiple images. This building is identified in LiDAR data and point cloud corresponding roof edge line strip is then extracted manually using PCM software. The coordinate of extreme point of these line strips is used to calculated length. The mean length from EFS is compared with calculated length from LiDAR. The result shows that mean difference from two data source is 0.84 m with standard deviation 1.02 m. similar process is conducted for height measurement in EFS. Height of corresponding feature in LiDAR is obtained by deducting average height of measured height to average ground height. The result shows the mean difference of 0.36 m with standard deviation of 0.42. The LiDAR data used here have planimetric and height accuracy of 2cm and 10cm respectively. The mean difference and standard deviation between these value suggest that height measurement from oblique images is more accurate compared to the distance measurement. This is basically due to the influence of DTM as distance measurement require multiple coordinate calculation.

4.3. Quality assessment of manually extracted tree parameter

The tree parameter defined in 3.1.1 is extracted from oblique imagery using mono-plotting method described in 3.1.1.

4.3.1. Tree position

3D tree location is extracted from multiple images of same and different viewing direction. Additionally, pixel coordinate of this location is also extracted and used as input for calculating geographic coordinate from images oriented with Gerke (2011). The motivation behind this analysis is to assess factors influencing coordinate of tree when viewed from different direction with mono-plotting method. The mean coordinate of individual tree obtained from different viewing images for both sets are calculated and individual coordinate are deducted from the mean coordinate for individual tree. The Figure 14 below shows the distribution trend of these difference along x and y axis for four tree and for all the trees. The

Blue diamond shape in the graph refers to the measurement extracted from EFS and Red square shape refers to the measurement extracted from Gerke (2011).

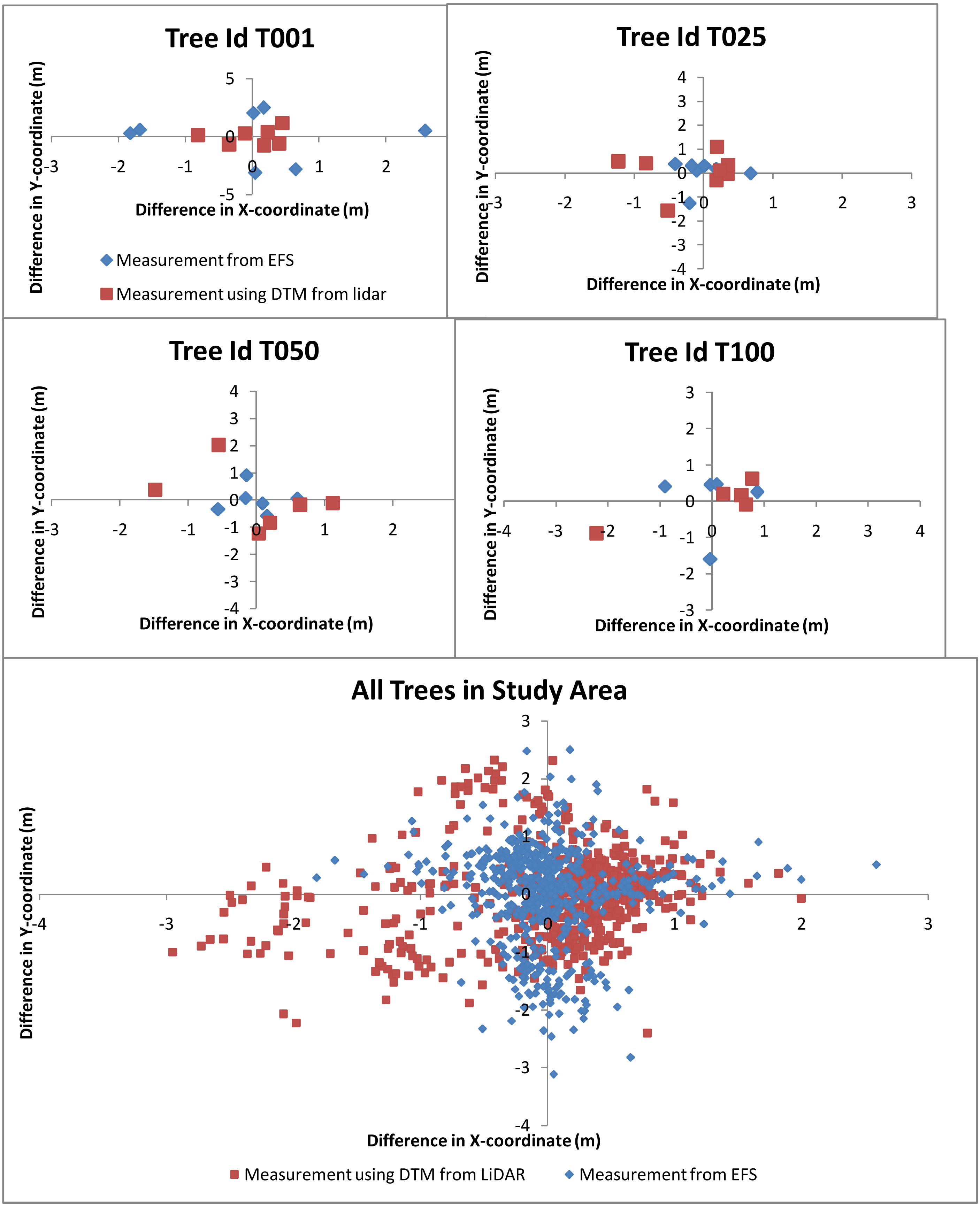


Figure 14 Distribution pattern of difference in position of tree from its mean position

The distribution pattern of clustering of points around origin revelled in the graph is mainly due to shift in DTM between two approaches. This is also seen during the analysis of GCP and CP. The Figure 15 below shows the variation in z-coordinate from its mean for all observation from different images of individual tree. Red line represents the z-coordinate differences obtained by using DTM extracted from dense LiDAR point cloud. The Z-coordinate difference for EFS measurement is 0. So it is not shown in graph. The difference in z-coordinate in EFS for all observation from different images is 0 which indicate that DTM used in EFS is of coarse resolution than the DTM obtain from LiDAR data.

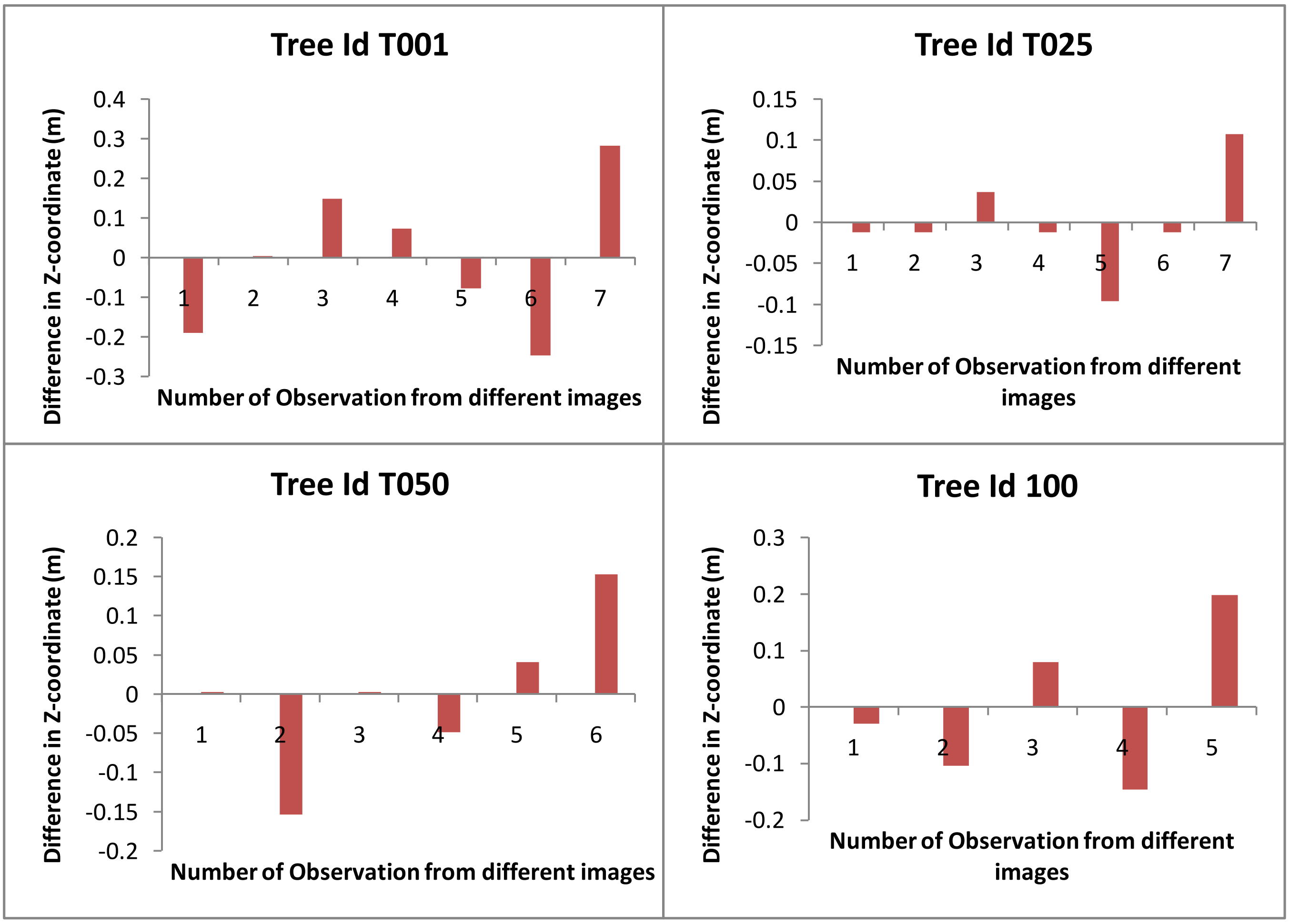


Figure 15 Variation of Z- coordinate from its mean value for all observation

4.3.2. DBH measurement

The width of tree trunk is extracted with "Distance tool" of EFS software from different images. The Table 4 below shows the mean difference and its variation in different viewing images for all 103 trees measured during manual analysis.

Table 4 Variation of DBH per viewing direction

View Direction	Mean Difference (m)	Standard Deviation
East	0.078	0.061
North	0.107	0.073
South	0.087	0.063
West	0.086	0.060

DBH of are also measured in field. For DBH measurement the circumference of the tree trunk is measured using measuring tape and then diameter of trunk is calculated using geometric circle formula. The comparison of DBH measurement from oblique images in EFS software with its field measurement shows that average error in measurement is 0.08 m with standard deviation 0.08. Stem of tree is cylindrical in nature and it appears almost of same width in images from different viewing direction. The very low error in DBH as compared to other measurement doesn't reflect that accuracy of DBH measurement is high in oblique images. Average DBH of trees in study area is very thin with average width of 5 pixels. The reason behind this low mean and standard deviation is also due to limitation in sub pixel precision level measurement in EFS.

4.3.3. Tree Height measurement

"Height tool" of EFS is used to measure the total height of the tree from different images. The Table 5 below shows the mean difference and its standard deviation in different viewing images. Average difference between mean height and height obtain per direction variation is quite high compared to that measurement of DBH. The top branches of deciduous tree are very hard to identify when they are at the back of image than when they are at the front side of the image.

Table 5 Variation of tree height per viewing direction

View Direction	Mean difference (m)	Standard Deviation
East	2.040	1.587
North	1.302	1.059
South	1.904	1.481
West	1.809	1.472

4.3.4. Tree Crown Estimation

Least square fitting method describe in 3.1.4 is used for fitting ellipse. Matlab software was used for this fitting. The highest point of the ellipse where slope is zero is taken as the height of tree by calculating the derivative of the function. This height is compared with directly measured height in EFS of corresponding tree. The comparison shows that mean difference in height is 1.64m with standard deviation 1.12 for 20 trees The widths of ellipse is calculated per view as it doesn't make sense to compare width per view by this approach.

Geometric fit method is also tested for 20 trees. In this approach ellispse describe by (6) is used to fit the crown point. The crown parameter is used to calculate height and width of the tree. The height obtain from this approach shows mean difference of 2.03m with standard deviation 2.5 with directly measured height. The difference in crown width from different direction is direction is 0.54m with standard deviation of 0.277. The Figure 16 below shows fitting of ellipse with algebraic fit methods to crown points for a single tree from different viewing direction. Figure 17 is from fitting algorithm which minimizes the sum of squares distance to the function.

It is seen from the figure 16 and 17 that algebraic fit approach fits the crown points well but it fails to locate lower point of the crown. The fitted ellipse in most case is elongated. Also rotation of ellipse depends on distribution of Crown Point. The direct fitting of crown assuming it to be rotationally symmetric overestimate crow shape In all cases, fitting of ellipse is different and depends on viewing direction.

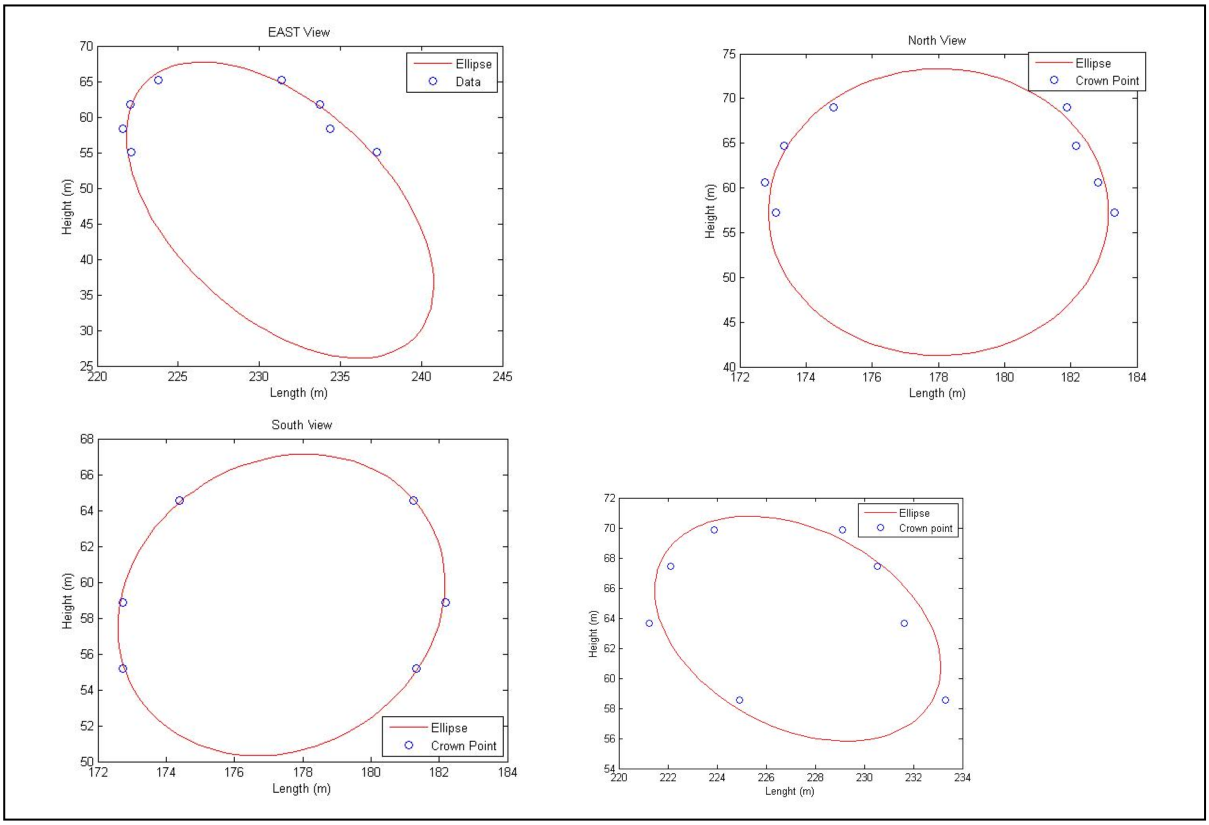
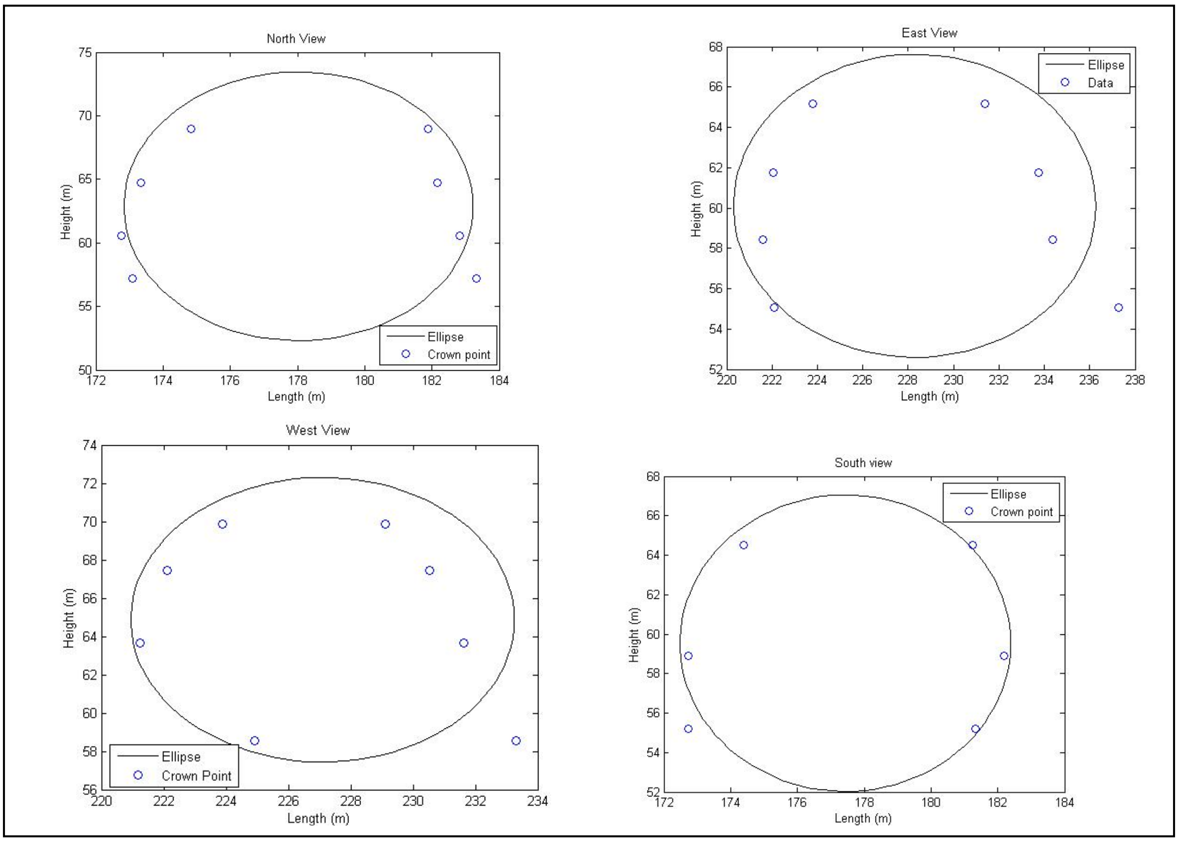


Figure 16 Ellipse fitting to crown by Algebraic fit method


North View
Height (m)
Length (m)
Ellipse
Crown point
East View
Ellipse
Data
West View
Ellipse
Crown Point
South view
Ellipse
Crown point

4.4. Automatic detection of tree in oblique images

Profile information of the vertical structure of tree present in oblique image is used for its detection. The stem of tree is distinctly visible in these images, if not occluded by neighbouring structure. Hypothesis and verification strategy approach is used to extract tree stem from oblique images. The implementation of algorithm described in 3.2 for automatic detection of tree is presented in following section.

4.4.1. Line extraction from oblique images

Steger (1998) line extraction tool is used to extract lines from oblique images. The parameters that influences lines extraction with this tool mainly dependent on contrast between background and line feature and amount of smoothing done by Gaussian smoothing kernel, sigma. The sigma value in turn depends on number of pixel contain in the width of line. So to extract enough lines from tree stem, contrast difference between tree stem and its background is checked for number of trees and number of pixel contain by tree stem is approximated from average DBH measurement done in manual analysis. These values are used to estimate sigma. The upper threshold, high value and lower threshold, low value is estimated by calculating second derivate perpendicular to the line direction. These thresholds are used to determine whether line point extracted should be accepted or rejected to be linked with extracted line. The parameters used for extraction of line are given in Table 6.

Table 6 Threshold values used for line extraction

Parameter	value
Number of pixel contain in line width, 2w	5
Contrast difference/amplitude, h	10
Sigma, σ	1.5
Upper threshold / high value	1.5
Lower threshold /Low Value	0

These parameters are used for all images. The contrast difference/amplitude value is taken only 10 to extract the line from the upper portion of the tree as well, where gradient between tree stem pixel and its surrounding is quite low. This low value of amplitude also incorporate less gradient occurred due to the presence of similar background for example road. This also helps to extract lines from the tree located at the background of the image. Tree at the background of oblique image have comparatively less contrast difference between its surrounding due to

Figure 18 Left: Tree in study area Right: Line extracted by line extraction tool

lager ground sampling distance. The lower threshold is set to 0 to join even the faint line extracted at top of tree. Figure below shows the tree in oblique image and extracted line with this tool.

Beside above mention parameters, another key parameter that effect delineation of tree stem is extraction of dark line on light background or light line on dark background. In oblique images tree stem may appear as dark or bright line depending upon direction of image acquisition and position of sun at that moment. If sun position is on the same side as of image acquisition direction tree stem will appear light as compared to its surrounding where as if sun is on the opposite side, stem will appear dark. In this images used in this research, tree stem in images from north direction appear dark as sun position is on the opposite side. This is not a problem for extracting line from tree stem but it's become critical when position of tree in image, the position of sun during its acquisition and viewing ray direction of camera aligned in such geometry that part of the stem appears light and part of it appear dark. This will induced a error during extraction as line will be extracted either from lighter part or a dark part based on parameter defined as shown in Figure 18 below. It is seen that at such case extracting line from light part will give

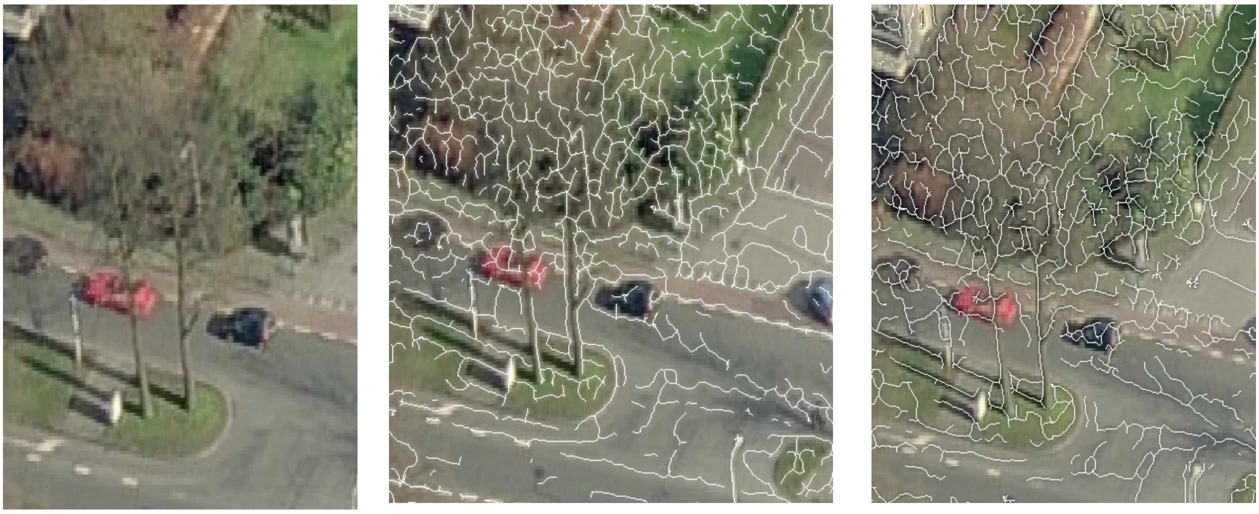


Figure 19 Position Position of tree in image where portion of stem appear dark and remaining portion appear light

lots of broken lines segments which eventually effect its detection.

The parameter used here are able to delineate most of the tree of the study area as most of the tree in study area have width within the range of 5 pixel but for trees whose width are around twice more than parametric value it fails to delineate the stem of tree at its centre. The main motivation besides using these parametric values is to extract enough lines from tree stem, even from thin stem having very low contrast with background. Visual inspection of extracted lines shows that it does hold for many cases but with this it also produces major disadvantages of having long line due to the use of very low upper threshold and lower threshold value. In some cases a single line segment delineates more than one tree stem. The next section focuses on separating these lines.

4.4.2. Separating lines of tree stems

Tree stems are hypothesized as being vertical. Vertical lines from the from extracted line segment are extracted using the methodology describe in 3.2.2. Two parameters are used to define verticality of the line, slope between two points and perpendicular distance between line defined by two points and third point. The threshold valued used in algorithm for these two parameter is given in Table 7

Table 7 Parameters value used to extract vertical lines

Parameter	Slope
Slope	≤10º with vertical
Distance, d	<1.5 pixel

Figure 20 Extracted Vertical lines

Figure 19 shows the separated vertical lines from the extracted lines in Figure 17 In the figure colour line represents different line segment. It is clear from the figure that the algorithm is able to separate vertical lines within defined threshold and also able to extract multiple instances of vertical line represented by the single line segment extracted in 4.5.1. However line representing tree stream are broken as it is from different line segment or from same line segment with removed horizontal line. Since the algorithm consider slope between two points, it is quite sensitive in removing lines having greater slope than the given threshold. Moreover the distance threshold of only 1 pixel is considered because when inspecting extracted line of tree stem, it is seen that nodes of line from stem is staggered within one pixel for most of tree. This is also because average width of tree stem is only 5 pixel i.e., centre line extracted is within 2.5 pixels from either of the edge. This parameter holds good for most of the tree but for the trees having lager width this parameter breaks the line giving rise to multiple broken line within the delineated line from tree stream. In this algorithm slope is key parameter which separate vertical line with the given threshold from other line if only distance is used as the parameter it will only be able to define weather the checked point is the part of line being considered which may be horizontal or vertical.

4.4.3. Connecting broken lines

Vertical line separating algorithms of 4.5.3 though extract vertical lines from extracted line from 4.5.2, it will delineate tree stream with broken line which have to be joined. The algorithm describe in 3.2.3 is used to join these broken line. This algorithm considers end points of two lines and joins them based on horizontal and vertical separation threshold value. The threshold used for these parameter are given in Table 8 and figure 20 shows the output from these algorithm for the broken vertical line of figure 19

Tabel 8 Threshold value used in algorithm to joining vertical line

Parameters	Threshold value
Horizontal separation	≤1.5 pixel
Vertical separation	≤10 pixel

Figure 20 Joined vertical line

The small cut-out of the Figure 20 presented here which shows that the algorithm is able to join most of the broken line within the profile of tree stem with reference to figure the threshold value is selected by inspecting the nature of broken line in profile of the tree.

The completeness and correctness analysis is conducted to define quality of extraction. Completeness is the ratio of found trees against all existing ones and correctness gives ratios of correctly detected trees against all detected trees. True Positive (TP), False Positive (FP) and False negative (FN) values are calculated for this analysis. A test site is selected within study area, This site contains 42 trees along the median of road. The extracted lines are visualized against the images of the area. The total number of lines delineating trees are taken as TP, the lines those do not corresponds to tree are FP and Trees without any line delineation is taken as FN. Then correctness is computed as

$$Correctness = \frac{TP}{TP+FP} \quad (9)$$

And ,

$$Completeness = \frac{TP}{TP+FN} \quad (10)$$

This value is calculated for 4 images, Correctness obtain are 0.82, 0.76, 0.3 and 0.83 and completeness obtain are 0.86, 0.67, 0.52 and 0.83. The completeness and correctness value for those images in which tree are located in foreground and low values are observed in the images in which trees are located at background.

Visual inspection of joined line overlaid in image shows that in most of the cases, though it was able to delineate tree stem, start and end point of the line is rarely the intersection of ground and tree stem at bottom and top most level of the tree. Failure in extracting exact base and top induces certain uncertainty in the position and height of the tree. This uncertainty is quite random and has the influence of contrast between background feature, width of stem extracted and presence of sun position.

4.4.4. Extracting ground coordinate of extracted lines in object space

The ground coordinates of the extracted lines were calculated by mono-plotting method described in 3.2.4. The pixel coordinate of the base of vertical line from 4.5.4 is extracted. This pixel coordinate is use as input to compute viewing ray between pixel coordinate and image projection centre per image and its coordinate in object space is calculated by intersecting viewing ray with the DTM. Thus obtain coordinate are stored in the text file along with the identity number of line and image in text files. The object coordinate thus extracted is plotted against the manually extracted trees of the site. Here also completeness and correctness index calculated. If an automatic tree is within the surrounding of an manually extracted one, it is count as TP, otherwise FP. If there are no any extracted trees around manual one it is taken as FN. This yield completeness of 0.68, 0.83, 0.75 and 0.84 for respective image and 0.62, 0.69, 0.36 and 0.62 as correctness value. For the first image this value decreased but fo5r the third image it increased from 0.3 to 0.75. This indicates that the lines are extracted close to ground for third image. As mono-plotting is done here decreasing value indicate that the lines extracted in these images may be shifted.

4.4.5. Finding reliable match points from different images

The object space coordinate of the base point of the line extracted in 4.5.4 from four different viewing direction images are used to find matching line between these images. The algorithms for finding this match point are described in 3.2.3. This algorithm mainly uses two parameters to find the reliable match point, x-coordinate and y-coordinate difference in object space between two points. The threshold values used for these parameters are approximated from the manual analysis of the coordinate of location of tree from multi view images. As describe in 3.2.3, two level of search is conducted by the algorithm first using base coordinate and in second stage using mean coordinate of the matched point from two images. The threshold value used in both level of search is presented in Table 9 below.

Table 9 Threshold value used in reliable match line

Parameters	Threshold for 1st level	Threshold for 2nd level
x-coordinate difference	5.0 m	3.0 m
y-coordinate difference	5.0 m	3.0 m

The z-coordinate difference is not considered in this algorithm as maximum z-coordinate variation for a tree from different viewing direction is within 0.5m as obtain from manual analysis. The threshold value used in this algorithm is much larger than that actually obtain in manual analysis. During manual analysis base of the tree is manually identified at intersection point between ground and tree stem in different viewing images whereas the extraction of line from stem rarely starts from this point and it was seen that the position of this base point in different viewing direction has high variation. In some case, the base point in one image is 4 to 6 pixel above the actual pixel which represents the intersection point on ground and in another image base point extends below the intersection pixel by 2 to 8 pixel. So, to compensate the effect of this variation as well as to obtain general threshold value, the threshold value shown in Table... is used in the algorithm. Appendix A presents the average difference in coordinates of trees in the study area between images from different viewing direction. The coordinates of the trees for individual direction are obtained from two images of same viewing direction by mono-plotting in EFS software. Using such a large value of threshold compared to that obtain from manual analysis will lead to multiple matches. Therefore algorithm considers only the closest matched lines among the multiple matches.

The correctness and completeness is also calculated here, the base coordinate of 3D line is again plotted against the manually extracted tree. The correctness value of 0.77 is obtained and completeness value of 0.57 was obtained. All these correctness and completeness index calculated at different stages shows quality of detection. Higher the correctness value indicate higher rate of detection and higher completeness value indicate higher accuracy of the value.

4.4.6. Extraction of 3D line

The line identity number of reliable match lines obtain from 4.5.6 is used to extract the ends point pixel coordinate of the line from all the images. The infinite 3D line in object space is then generated by forward plane intersection method describe in 3.2.6. The matching algorithm used here produces duplication a match of same combination of line from different images as matching is done between different pair of images independently. So 3D intersection of match line is done for the highest set of matches obtain from 3.2.5 and for next set it uses only those matched lines combination which is not used earlier. This 3D line is generated only to those match lines obtain from the combination of either from 3 images or 4 images. The residual error between generated 3D line and each line contributing in its generation is also computed. The end points of individual lines is also projected on the estimated 3D line by the method describe in 3.2.6.

4.4.7. Estimation of End points of the 3D line

The end points corresponding to each line on 3D line is analyzed to estimate the end point generated 3D line. The 3D line corresponding to tree stem of the study area is manually selected in PCM software by visualizing it with reference to LIDAR data. The z coordinate of base of individual line segment is compared with ground elevation of tree obtain in manual analysis. Beside this, height of the tree calculated in manual analysis is also compared. The Table 10 shows that average difference in ground elevation of tree extracted during manual analysis and coordinate of the base point of the line from different images used for 3D line generation.

Table 10 Difference between in ground elevation between manually extracted tree and base point of the line from 3D line generated

	Average difference (m)	Standard Deviation	Maximum difference (m)	Minimum difference (m)
Ground Elevation	2.57m	4.79	27.61	0.01

The manual analysis of ground elevation of tree from different images of same viewing direction yield the average difference of 0.1m with standard deviation 0.09. The values in table above are quite high compared to that obtain from manual analysis. The reason behind this is extraction of line rarely starts at the intersection of ground and tree stem. The height of tree obtain in manual analysis when compared with height obtain by projection ends point of individual segment on to 3D line gave average difference of 5.48m with standard deviation 4.26. These value are larger compared to that obtain from manual analysis Table.5. The reason behind this is the line extracted from the tree seldom able to extract whole profile of the tree. Thus the endpoints of 3D line representing base and top of the tree is not possible with this. So in this research, the base end points of 3D line is estimated by taking the projected end point of line having lest residual error. The top end point of the 3D line is taken by calculating the maximum height obtained by deducting each top end point from the base end point with least residual error.

4.5. Quality Assessment of automatic detection

The base coordinate of 3D line generated is compared with tree coordinates obtain from manual analysis. The test site in the study area is selected and 3D line extracted is visualized against LIDAR data of the area in PCM. The identity of tree (used during manual analysis) identified manually. The difference in mean coordinate of tree from multiple images of same and different viewing direction with the base coordinate of the 3D line generated is 0.57m (in x-direction) and 0.48 m (in y direction) with respective standard deviation of 0.59 and 0.47. Thus, for the test area, it is seen that the algorithm can extract the tree position within average value mention above within the variation shown by standard deviation.

The numerical evaluation of tree detection by the algorithm is done by manually checking total number of tree detected in the test site of study area against the total number of tree identified. The test area contains 42 trees. Only 7 trees are identified from combination of 4 images but when combinations from 3 images are also considered detection rate increases to 28 trees. This can be mathematically expressed as Correctness value(Agouris et al., 2004). According to Agouris (2004) Correctness is the measure of correctly extracted feature with respect to reference data set. Correctness is expressed as

$$Correctness = \frac{TP}{TP + FP}$$

Where, True positive(TP) is the number of extracted feature present in reference dataset and False positive (FP) is the number of extracted reference feature not extracted.

The calculation gives the correctness of 66.6%. Other measure of quality for extraction is not calculated as till this stage 3D line from trees are not yet separated from other detection like Electric pole, building roof.

The test site used here consists of mostly free standing trees. It also contains some clustered tree. The algorithm used here was not able to detect any tree of the clustered area. The reason behind this is also extraction of line from these trees. Though line is extracted in upper portion of tree, the base portion is not delineated due to occlusion from neighbouring tree. Thus base coordinate of the line in object space shifted from the point where it should be and match point algorithm fails to generate reliable match point.

In some closely spaced tree it is seen that the matching algorithm giving false matching line i.e, line from one tree is matched with lines from other tree. This is because the match point algorithm uses large threshold value. Though algorithm considers only closet match among multiple match, it will give this kind of false matching when there is no any line extracted from another view fro same tree and algorithm considers this line from another tree as the matched lines. This kind of false matching is removed during 3D line generation as there also it uses threshold value for stereo intersection.

Analyzing detection of tree in study area it is seen that, the tree stem in some images appear dark at some portion of the image and appears light (both dark and light with reference to background) at another portion of the same image. So when lines are extracted considering light lines only, it fails to extract the lines from this dark appearing tree stem. Also in these images, at some position in images same trees stem partly seen dark and partly seen light along the profile of tree stem. Considering dark or light line for extraction doesn't seems to affect much on extracted coordinate values of the 3D line. However it is seen in the test site that extraction considering light lines yield lots of widely spaced broken line. The main reason for this is that the contrast between background and light lines, especially in these positions is very low. In these situation other part of tree mainly branches will act as the barrier for extracting a continuous lines.

Another major factor influencing detection is the occlusion from the neighbouring elevated feature. In the test site considered here, the block of trees are occluded by the trees from the neighbouring park area in one of the images which also contributed to only 7 trees detection of the study site.

Figure 21 below shows the 3D lines of tree in test area are visualized against LiDAR data.

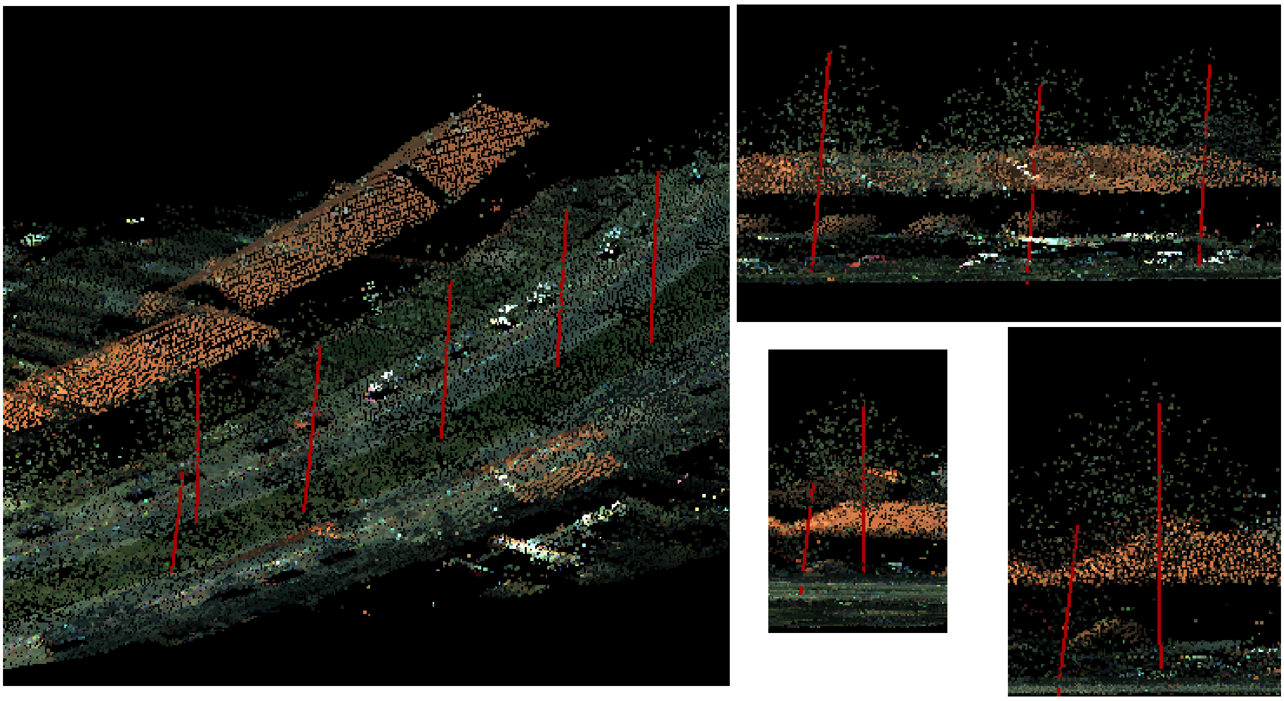


Figure 21 3D line extracted visualized against LIDAR Data

5. CONCLUSIONS AND RECOMMENDATION

5.1. Conclusions

The main objective of the research is to analyze the use of oblique imagery for the extraction of tree and its parameter and develop a method to automatically detect trees in these images for an urban area. This research concentrated only on unfoliaged deciduous tree. The research mainly consist two part:- 1) Manual analysis for extraction of tree parameter and 2) Automatic detection of tree in oblique images. Different geometric parameters of the tree which can be measured or can be computed from oblique images are identified based on mode of available measurement available in these images and the way tree is visualized in these oblique images. These include tree position, DBH, tree height, crown shape parameter and clear bore height.

Mono-plotting method is applied for measurement in oblique images. The accuracy of measurement extracted from oblique images is also conducted with different reference data set and field measurement. EFS Software is used to conduct mono-plotting operation. However, accuracy of orientation of images and DTM used in this software is unknown to its user. These are checked first by conducting measurement on known GCP point. Also some distinctly identifiable points are selected as check points and measurement are also conducted on these points. These measurements are then compared with the same measurement extracted from images oriented by indirect sensor orientation method which uses DTM extracted from LiDAR data. The result revelled that there is the shift between the DTM used by EFS and DTM extracted from LiDAR. Moreover, EFS DTM is coarser compared to that from LiDAR.

In this research, mainly three type of measurements in object space is conducted in EFS: - coordinate extraction, height measurement and distance measurement. Different parameter of trees is measured with different tools which enable these mode of measurement. Location of tree is extracted with coordinate extraction tool. Height of tree is measured with height tool. DBH is measured with distance tool. For crown shape parameter, width of canopy is measured at multiple levels from ground. The coordinate of the end points of these measured line and its height from ground level are used to fit ellipse to generalize the crown shape. Different method of fitting ellipse to the crown is studied. In this method, least square fitting approach of minimizing algebraic distance is used to fit ellipse to these Crown Point. This method is quite sensitive towards distribution of crown points. It fails to fit ellipse to crown when crown points resemble hyperbolic or parabolic shape. Also it fails to locate bottom point of the crown in most of the cases. In these cases, the lowest crown width measured is taken as clear bore height of the tree. Different crown parameters, such as crown centre, transverse radius and longitudinal radius are derived from the geometry of fitted ellipse. Tree height is also computed from the derived parameter of ellipse. Accuracy of all the parameters measured from oblique imagery is not conducted as there was no reference data set of image acquisition time was available. The accuracy of measurement is conducted for permanent static object done with same tool. Height and length of different building are measured in EFS and its measurement is compared with LIDAR dataset. The location measurements of tree are compared with similar measurement in same images oriented with indirect sensor orientation method. Tree parameter extracted in this phase also used to estimate different threshold during its automatic detection in oblique images.

The second part of the research concentrates on automatic detection of trees from oblique images. The profile information of tree available on these oblique images is used as key parameter to detect tree. Bar shaped line extraction algorithm by Steger(1998) is used to extract tree stem. Tree stem are assumed as vertical in the research. Thus vertical line extracted from this tool is extracted with the algorithm which is based on slope of line and perpendicular distance of the point from the line. The vertical line separated by the algorithm contains lots of broken lines which were joined using the algorithm which considers horizontal and vertical separation of end points between lines. The base coordinate of these vertical lines are calculated with mono-plotting method. These coordinate is used to find the reliable match points in object space between vertical lines extraction from different viewing images. The threshold value used to find these match points are approximated from manual analysis of base coordinate of tree for multi-view images. The reliable match point is used to obtain 3D line by forward plane intersection method. This method use stereo intersection between image lines and it generate infinite 3D line from multiple stereo pair by least square adjustment method. The end point projection of individual line contributing in generation of these 3D lines is also estimated by backward projection method. The projection points of these end points from individual line from different images are then compared with location and height measurement obtained in manual analysis. The bottom endpoints of 3D line are then selected base on residual error obtained during least square adjustment of this 3D line and top end point for this line is selected from individual top point which yields maximum height. The 3D lines from tree stem are manually selected for a test site by visualizing it against LIDAR data.

The base coordinates of these lines are compared with the mean coordinate of the tree obtain from multi-view images in manual analysis. The mean difference in coordinate of tree and vertical line is 0.57m along x-axis and 0.48m along y-axis with the standard deviation of 0.59 and 0.47 respectively. Out of 42 trees of test site, the method is able to detect 28 trees. This research is able to extract 3D vertical line of vertical structure. However, the separation of line of tree is still to be done. One of the approaches for this could be hypothesis and verification strategy. The relational hypothesis that number of branches emerge out of tree trunk might be helpful to separate trees from other elevated object. As branches are also delineated during line extraction in 3.2.1 as horizontal and incline line, distribution of these horizontal and incline line around the vertical line per image, separate trees from other elevated vertical object. The main difficulty during this is to separate horizontal/incline line extracted from neighbouring trees and surrounding feature. One of the solutions for this problem is checking distribution in every viewing direction image used to obtain 3D line.

5.2. Answers to research question

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The research is conducted by setting a research question to fullfil the objective of the research. The answers to these are presented in following paragraph.

1. Which parameters are most common to characterize tree in oblique image?

The oblique images provide profile information of tree due to their oblique viewing property. Dimension of most of the tree parts are visible in these images. The most suitable parameters that characterize tree in oblique images are its position in ground, DBH, tree height, canopy width, canopy height, clear bore height.

2. What parameters of tree can be extracted from these images?

Coordinate, height and length measurement is possible in oblique image with mono-plotting method. All the parameters mention in question 1 can be either extracted or computed with the mono-plotting method from oblique images.

3. What is the accuracy of these manually extracted parameters?

The images used in the research are of 2007 and the natural feature like trees grows in time. Also in urban context, trees are periodically trimmed. Other reference dataset of same time period was also not available. Thus accuracy assessments of tree parameter extracted from oblique images are not checked for its accuracy. In the research accuracy of different mode of measurement used to extract parameter are checked by measuring static permanent feature like building roof length its height. Coordinate measurement is checked with GCP. Total RMSE of 1.61m (for measurement in EFS) and 0.71m (for images oriented with indirect senor orientation approach) was obtained for 3 GCP available at the study area. For assessment of distance and height measurement, physical static object like roof length and building height were measured and compared with LIDAR data of the area. The result shows that mean difference from two dataset is 0.84 m with standard deviation 1.02 m. Similarly, mean difference of 0.36 m with standard deviation of 0.42 was obtained for height measurement. The only parameter measured in the field is DBH. Its comparison with measurement in image yield average error in measurement is 0.08 m with standard deviation 0.08. The very low error in DBH as compared to other measurement doesn't reflect that its accuracy of measurement is high in oblique images. DBH of trees in study area are very thin with average width of 5 pixels. So the reason behind this low mean and standard deviation is due to limitation the limitation in sub pixel precision level measurement.

4. How to extract parameters of tree from oblique airborne images?

The mono-plotting approach is used to extract different parameters of the tree. The coordinate measurement is used to extract location of tree, distance measurement is used to measure DBH and crown width of the tree and Height measurement is used to measure height of the tree. Beside these other parameters are computed from these measurements. Ellipse is fitted on the crown using least square estimation method by extracting coordinate of end points of crown measured at different level. Similarly clear bore height of the tree is measured by deducting lower level of crown.

5. How to evaluate quality of extracted parameters?

The accuracy of measurement with mono-plotting depends on DTM, internal orientation and external orientation of camera (Hoehle, 2008). Orientation parameter influences viewing ray computation while DTM influences coordinate extraction. So the accuracy of extracted parameters is evaluated on basis of these parameter used during measurement. In this research, Measurement from EFS when compared with (Gerke, 2011) shows that DTM used in them are shifted and have different spatial resolution resulting different measurement of the same feature. Beside quality estimation of extracted parameter can be compared with reference dataset or field measurement. For natural feature like tree, direct assessment is not possible if the data set is of past time, when there is not any availability of reference dataset. In this case evaluation can be done as describe in question 3

6. Which physical parameter can be used to detect individual tree automatically from these images?

In oblique images, tree stem is visible distinctly. Also tree are assumed vertical. So stem of tree can be used to detect tree automatically.

7. How to detect this parameter in these images?

Steger (1998) bar shaped line extraction tool is used to extract lines from tree stem. Vertical lines are separated from all extraction assuming tree to be vertical. Mono-plotting method is used to extract object space coordinate of base of these vertical line. These coordinate are used to find reliable match line from different images. Thus obtain matched lines are used to generate 3D line by plane intersection method. The ends point of these lines are selected based on residual error obtain during fitting and also with the effort to obtain maximum height of the tree.

8. What is the accuracy of detection?

For the test area with 42 trees, detection rate was 66.6%. However, in this research separation of trees from other vertical object are not conducted. Research is only limited to extraction of vertical line and its accuracy estimation. The detection rate presented here is presented by selecting manually vertical lines representing tree for test area considered. The separations of tree from other vertical objects require further study. However, detection of tree directly depends on the extraction of line from tree stem. This extraction depend on various factor like width of line to be extracted, contrast available between its background, the shadow of the tree itself and shadow of surrounding object. Also, height of tree will be extracted well if line can be extracted from at least 3 images for whole profile length of the tree.

5.3. Recommendations

Some of the recommendations for future work are enlisted here,

The separation of trees from other vertical object is not investigated yet. This can be done with hypothesis and verification approach or other advance approach.

Automatics parameter estimation is another field which is to be investigated. The major hurdle for automatic detection is the separation of lines of individual tree from surrounding. The line extraction tool used in this research is not able to extract line width for highly asymmetrical bar shaped line represented by tree stem. So it is recommended exploit another approach to extract tree width.

The elevation of base point of tree is quite obtain in this research is quite inaccurate, the further work can be in the direction of obtaining precise base point of tree. This can be done by intersecting line from shadow and tree stem. This is result in using lower threshold for reliable search algorithm and increases robustness of the algorithm

The line extraction tool used in research is very much affected with appearance of feature in images, i.e either dark or light, so it is recommended to search for similar extraction tool having less or no influence for such condition. Also method to cope with such problem should be studied.

The algorithm used in the research for joining broken separated line is computationally very expensive. So improvement on this algorithm is also highly recommended.

Finally, the method to minimize influence of occlusion effect should be studied.

Appendix A presents the average difference in coordinates of trees in the study area between images from different viewing direction

Direction	South-East			South-North			South-West			East-North			East-West			North-West		
	Delta X (m)	Delta Y (m)	Delta Z (m)	Delta X (m)	Delta Y (m)	Delta Z (m)	Delta X (m)	Delta Y (m)	Delta Z (m)	Delta X (m)	Delta Y (m)	Delta Z (m)	Delta X (m)	Delta Y (m)	Delta Z (m)	Delta X (m)	Delta Y (m)	Delta Z (m)
Mean Difference	1.30	0.56	0.18	0.60	2.72	0.16	0.91	1.19	0.13	0.74	3.07	0.13	2.22	1.49	0.14	1.49	1.53	0.17
	Difference wrt South-East Mean			0.70	2.16	0.01	0.39	0.63	0.05	0.56	2.50	0.04	0.92	0.93	0.04	0.19	0.97	0.01
				Difference wrt South-North Mean			0.31	1.53	0.03	0.14	0.35	0.03	1.62	1.23	0.02	0.89	1.19	0.00
							Difference wrt South-West Mean			0.16	1.87	0.00	1.31	0.30	0.01	0.58	0.34	0.04
										Difference wrt East-North Mean			1.48	1.58	0.01	0.75	1.53	0.03
													Difference wrt East-West Mean			0.73	0.04	0.03

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