Correction of Photogrammetrically Derived DSM's for Hydrodynamic Modelling Using Object Oriented Analysis

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March, 2010

Course Title:	Geo-Information Science and Earth Observation for Environmental Modelling and Management
Level:	Master of Science (Msc)
Course Duration:	September 2008 - March 2010
Consortium partners:	University of Southampton (UK) Lund University (Sweden) University of Warsaw (Poland) University of Twente (ITC) (The Netherlands)
GEM thesis number:	2010-26

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by

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Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation for Environmental Modelling and Management

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Abstract

Hydrodynamic models (HDM) have been widely used in predicting flood events. Digital elevation models (DEM) are important in HDM as they strongly control the water movement. As such, the topographic features represented in DEMs play vital role in accurate prediction of any flood event by HDMs.

Photogrammetrically derived digital surface models (DSM) represent earth's topography along with the elevated features on it. In HDM all the elevated features represented in DSM block the water flow although in reality only the features impermeable to water (e.g. house) block the water flow and permeable features (e.g. tree) allow the flow. As such, the impermeable features have to be present while the permeable features have to be removed from DSM. In addition, the artefacts due to shadow and occlusion also lead to erroneous terrain representation which have significant effect in HDM and have to be corrected for accurate prediction. Thus, use of corrected DSM for accurate prediction from HDM is necessary and is termed as 'Pseudo-DTM'.

This research describes a method that integrates Object oriented approach (OOA) with common tools available in remote sensing and GIS software to get Pseudo-DTM. OOA is used to identify and extract the features from orthophoto and DSM. The extracted features are used to selectively remove the terrain values from DSM. The removed terrain values are then predicted using the interpolated height values. Two approaches are used to remove the permeable features and artefacts from the DSM. The object based approach (OBA) uses shape of features to define the area to be removed from DSM, while the object based buffer (OBBA) approach considers formation of object based buffer (OBB) along with the features.

The features such as trees, humps, groynes, embankments were extracted with accuracies greater than 85% while houses were extracted at accuracy of 70%. The misidentification between trees and houses is most sensitive during removal process. The results from simple and compound cases showed that the OBA approach was able to remove the features leaving behind the artefacts while OBBA approach was able to remove the remaining artefacts. The applicability of the method however, has not been tested on areas where trees occur on slope, embankment and depressions.

The described approach shows the integration of OOA with GIS operation to get correct Pseudo-DTM for HDM. The correction procedure however, largely depends on proper identification of the features. The use of Pseudo-DTM thus should provide with reliable local and bulk flow prediction from HDM's.

Acknowledgements

I would like to express thanks to the European Union and Erasmus Mundus Consortium for awarding me opportunity to gain knowledge and invaluable experience in multinational and multicultural environment.

I would like to express my sincere gratitude to my first supervisor Dr. Norman Kerle for unlimited support, critical comments and constructive feedbacks, during the period of study. I am equally indebted to my second supervisor Dr. M.W. (Menno) Straatsma for his invaluable advice, comments and support in critical moments. The research in this form would not have been possible without their encouragement, advice and intellectual and professional comments.

I am grateful to Sokhon Phem, Shi Pu, Sander and Wan Bakx, for their advice and help during the research. I appreciate the help and support from Janak Raj Joshi. Special thanks to Diriba for his moral and technical support during hard times. I am grateful to Annika for reviewing my write-ups. Thanks to the entire GEM family for the support and love.

I would also like to thank all the staffs involved in the GEM consortium. Prof. Ted Milton, Prof. Petter Pilesjo, Prof Andrew Skidmore, Prof. Katarzyna Dobrowska, Dr. Andre Kooiman, Ms. Steff Webb and Ms. Jorein Terlouw for their support and hospitality during the entire course of my study.

I would like to thank all the friends of the Nepali community for providing me homely environment and support. I am also thankful to all of my friends back home for encouragement and support.

Above all I owe special debt of thanks to my family for endless moral support, encouragement and care.

Table of contents

1. Introduction 1
   1.1. Background and Significance 1
   1.2. Research Problem 4
   1.3. Research Objectives 5
   1.4. Research Questions 5
   1.5. Research Scope 6
   1.6. Thesis Structure 6
2. Literature Review 7
   2.1. Hydrodynamic Models and Flood Simulation 7
   2.2. Sources of DSM 7
   2.3. From DSM to DTM 8
      2.3.1. Filtering 8
      2.3.2. Selection of ground points in DSM 9
      2.3.3. Classification 9
      2.3.4. Segmentation 9
      2.3.5. Interpolation 10
   2.4. Errors and Effect on Flood modelling 10
      2.4.1. Error Source and Types 10
      2.4.2. Effect on Flood Modelling 11
   2.5. Information Extraction 12
      2.5.1. Object Oriented Analysis 12
         2.5.1.1. Image Segmentation 12
         2.5.1.2. Feature Identification, Classification and Extraction ... 14
   2.6. Accuracy Assessment 15
   2.7. Concluding Remark 15
3. Materials and Method 16
   3.1. Study Area 16
   3.2. Data 17
      3.2.1. Orthophoto and DSM 17
      3.2.2. Field Observation 17
   3.3. Proposed Method 17

3.3.1. Experimental Setup ... 17
3.3.2. Experimental Data ... 18
3.3.3. Feature Identification ... 19
3.3.3.1. Segmentation ... 20
3.3.4. Feature Delineation and Extraction ... 21
3.3.5. Quality Assessment ... 23
3.3.6. Feature Removal from DSM ... 24
3.3.6.1. Object Based Approach (OBA) ... 25
3.3.6.2. Object Based Buffer Approach (OBBA) ... 26
3.3.7. Accuracy Assessment ... 27
4. Implementation and Results ... 30
4.1. Feature Identification and Extraction ... 30
4.2. Quality Assessment ... 32
4.3. Object Based Buffer ... 33
4.4. Feature Representation and Removal ... 34
4.5. Accuracy Assessment ... 43
5. Discussion ... 51
5.1. Methodological Approach ... 51
5.1.1. Feature Identification and Extraction ... 51
5.1.2. Feature Representation and Removal ... 52
5.2. Significance in Hydrodynamic Models ... 54
5.3. Limitations ... 54
6. Conclusion and Recommendations ... 55
7. References ... 57
8. Appendix ... 63

List of figures

Figure 1.1: *Schematic drawing of features and their behaviour during flooding (a) feature resemblance in real world (side view), (b) feature representation as blobs in DSM (top view-generic),(c) representation in DSM where trees obstruct water flow behaving in the same way as house (d) actual situation during flooding whereby trees let water pass through it.* 4
Figure 1.2: *a) occlusion and shadow b) their representation in DSM* 5
Figure 3.1*: Location of Study area and experimental cases* 16
Figure 3.2*: The Schematic representation of features in photograph and profile in DSM (a) single tree (b) group of trees (c) single house (d) house surrounded with trees (e) embankment with grass (f) embankment with trees (g) hump covered with vegetation (h) depression with tree.* 18
Figure 3.3: *General description of the impermeable and permeable features* 19
Figure 3.4: *Iterative process of segmentation using orthophoto and DSM* 20
Figure 3.5: *Schematic representation of the feature removal by OBA approach; (a) tree along with shadow, (b) identified tree, (c) area in DSM defined by identified tree and (d) Pseudo-DTM.* 25
Figure 3.6: *Schematic representation of the feature removal by OBBA approach; (a) picture (b) identified tree and shadow (c)Identified tree with OBB (d)DSM representation of the tree (e)Pseudo-DTM after application of OBBA approach.* ... 26
Figure 3.8: *Schematic representation of features and their profile in DSM (a) photograph b) LIDAR DSM c) Pseudo-DTM d) standard deviation between the LIDAR and Pseudo-DTM.* 28
Figure 3.9*: Work flow of proposed method for identifying and removing features from DSM* 29
Figure 4.1: *Identification and delineation of individual houses (a) case I (b) case II.* 30
Figure 4.2*: Identification and delineation of trees in different context (a) single tree, group tree; (b) case I, (c)case II.* 30
Figure 4.3: *Identification and delineation of (a) groynes (b) major embankment (c) minor embankment.* 31
Figure 4.4: *Identification and delineation of compound case houses (a) case I (b) case II (c) case III.* 31
Figure 4.5: *Identified humps* 32
Figure 4.6 : *Application of normal buffer and OBB approach on data set I (a) orthophoto with embankment edge (b) DSM representation (c) result of OBB method (d) result of normal buffer method (e) expected area that would be removed with different buffer width (Table 3.3) from normal buffer method over laid on DSM (f) spatial profile along the transects seen in figures.* 34

Figure 4.7: *Application of the normal buffer and the OBB approach on data set II (a) orthophoto representation (b) result from OBB and normal buffer method (same result) (c) Extent of DSM that would be removed by different width of buffer (Table 3.3).* 34
Figure 4.8: *Single tree representation (a) orthophoto (b) DSM (c) Pseudo-DTM with OBA (d) Pseudo-DTM with OBBA (e) difference of OBA (f) with OBBA (g) spatial profile along the transects seen in pictures.* 35
Figure 4.9: *Single house and its representation (case I) (a) outline in orthophoto (b) DSM (c) Pseudo-DTM with OBA (d) Pseudo-DTM with OBBA(e) difference from OBA (f) difference from OBBA(g) spatial profile along the transects seen in pictures.* 36
Figure 4.10: *Single house and its representation (case II) (a) outline in orthophoto (b) DSM c) Pseudo-DTM with OBA (d) Pseudo-DTM with OBBA(e) difference from OBA (f) difference from OBBA(g) spatial profile along the transects seen in images.* 37
Figure 4.11: *Tree clump and its representation (Case I) (a) orthophoto (b) DSM (c) Pseudo-DTM with OBA (d)Pseudo-DTM with OBBA (e)difference from OBA (f) difference from OBBA (g) spatial profile along the transects seen on pictures.* 38
Figure 4.12: *Tree clump and its representation (a) orthophoto (b) DSM c) Pseudo-DTM with OBA (d) with OBBA (e) difference from OBA (f) difference from OBBA approach (g) spatial profile along the transects indicated in pictures.* 39
Figure 4.13: *Representation of house along with tree and shadow(a) outline of house in orthophoto (b) representation in DSM (c) Pseudo-DTM with OBA (d)Pseudo-DTM with OBBA (e)difference from OBA (f) difference from OBBA(g) spatial profile along the transects indicated in pictures.* 40
Figure 4.14*: Representation of house along with tree and shadow(a) outline of house in orthophoto (b) representation in DSM (c) Pseudo-DTM with OBA (d)Pseudo-DTM with OBBA (e)difference from OBA (f) difference from OBBA(g) spatial profile along the transects indicated in pictures.* 41
Figure 4.15: *Representation of house along with tree and shadow (a) outline of house in orthophoto (b) representation in DSM (c) Pseudo-DTM with OBA (d)Pseudo-DTM with OBBA (e)difference from OBA (f) difference from OBBA(g) spatial profile along the shadow as seen in a (h)Spatial profile along the transects seen in pictures.* 42
Figure 4.16: *Hill shade analysis (a) LIDAR DTM (b) photogrammetric DSM (c) Pseudo-DTM created with OBA (d) Pseudo-DTM with OBBA.* 44
Figure 4.17: *Accuracy assessment of single house (a) orthophoto (b) LIDAR DSM (c) Photogrammetric DSM (d) Pseudo-DTM with OBA (e) Pseudo-DTM with OBBA (f)spatial profile of height and standard deviation(with respect to L-DSM) along the transects seen in pictures* 46

Figure 4.18: *Profiles along the transects I and II on a) LIDAR DTM, (b) Photogrammetric DSM, (c) Pseudo-DTM with OBA, (d) Pseudo-DTM with OBBA, (e) Profile along transect I and (f) profile along transect II as seen in pictures.* 47
Figure 4.19: *Profiles along the transects I and II on (a) LIDAR DTM, (b) Photogrammetric DSM, (c) Pseudo-DTM with OBA, (d) Pseudo-DTM with OBBA (e) Profile along transect I and (f) profile along transect II as seen in pictures.* 48
Figure 4.20: *Accuracy assessment of compound case I, representation on (a) orthophoto (b) L DSM (c) P-DSM (d) Pseudo-DTM with OBA (e) Pseudo-DTM with OBBA (f) spatial profile of height and standard deviation(with respect to L-DSM) along the transects seen in pictures.* 49
Figure 4.21: *Accuracy assessment of compound case II, representation on (a) orthophoto (b) L DSM (c) P-DSM (d) Pseudo-DTM with OBA (e) Pseudo-DTM with OBBA (f) spatial profile of height values along with standard deviation with respect to L DSM along the transects as seen in pictures.* 50
Figure 8.1*: Single trees and their respective representation: case I-(a, b), case II-(c, d)*........ 63
Figure 8.2*: Single houses and their representation case I-(a, b), case II-(c, d)* 63
Figure 8.3: *Group tree representation; Case I-(a, b), Case II (b, c),* 64
Figure 8.4: *Groynes representation-(a, b), Embankment representation-(c, d) Hump representation-(e, f)* 64
Figure 8.5: *House representation in orthophoto and DSM; Case I (a, b), Case II (c, d) Case III (e, f)* 65
Figure 8.6: *An example on identification and delineation of features. Groynes are separated from the image using two different level of segmentation and rule set that combines various spectral and contextual properties of features.* 66
Figure 8.7: *Extracted image showing the objects that have been considerd under the study. Includes the features that are not removed from the DSM.* 67
Figure 8.8: *Pseudo-DTM with OBA approach* 68
Figure 8.9: *Pseudo-DTM with OBBA approach* 68

List of tables

Table1.1: *Sources of digital elevation models* 2
Table 2.1: *A classification of interpolation technique* 10
Table 3.1: *Experimental cases considered for the study* 19
Table 3.2: *Parameters and object properties used for segmentation and feature identification.* 21
Table 3.3: *Buffer width based on width of the features.* 26
Table 4.1: *Error matrix for assessing the quality of Houses.* 32
Table 4.2: *Error matrix for assessing the quality of Trees.* 32
Table 4.3: *Per-Object statistics for Groynes, Embankments and Humps.* 33
Table 4.4: *Statistics for the three cases in LIDAR DTM and Pseudo-DTM's. Unit are in meters* 44
Table 4.5: *Statistics for individual trees collected from field. Unit in meters* 45
Table 4.6: *Description of the abbreviation used in legend of profiles.* 45
Table 8.1: *Abbreviations* 69
Table 8.2: *Description of the feature Properties used for identification and delineation of features* 70

1. Introduction

1.1. Background and Significance

Flooding is one of the most common and damaging natural phenomena faced by humans caused by accelerating settlement on floodplains along with increasing extreme weather events in the wake of climate change The twofold increase in flood between 1950-1980 and fivefold between year 1996-2005 well explains the fact of increasing flooding events (Kron and Berz, 2007). The flooding events of Mississippi (1993), the Oder (1997), the Elbe and Danube (2002, 2006) are a few examples of catastrophic flood to mention.

A common way to understand the impact of flooding is the use of hydrodynamic models (HDM) to derive flood hazard maps. HDM's have been crucial in formulating strategies to prevent and cope with flooding. Strategies such as flood-plain building regulations, insurance, structural measures like reservoirs and levee projects and emergency preparedness all rely on model prediction (Sanders, 2007), and hence the effectiveness of these measures is linked to the quality of flood predictions. The quality of prediction by HDMs however, depends on the accuracy of the input data such as terrain elevation, roughness parameters and boundary conditions. Among these, elevation model is the most important because it provides the strongest control over the flow direction and distribution of water.

Elevation models used in flood modelling carry information either from earth's surface or terrain. When the earth's surface with elevated elements such as trees, houses, is used it is called as a digital surface model (DSM), while information about bare earth on the other hand is termed as digital terrain model (DTM). The generic term digital elevation model (DEM) is used to represent either the DTM or the DSM (Kasser and Egels, 2002; Maune, 2007). Elevation models can be obtained from various sources that determine their precision, spatial coverage and cost. Tachymeter and Global Positioning system (GPS) provide the highest accuracy DEM's at the expense of a low spatial extent (Nelson et al., 2008). Photogrammetry in contrast comes with decreased production costs for larger areas but at lower accuracy compared to differential global positioning system (DGPS). Interferometric synthetic aperture radar (IFSAR) exhibits high spatial resolution and lower accuracy, while LIDAR provides highly accurate data rapidly (Rayburg et al., 2009) but with high costs. The different source and their accuracy along with their specification are summarised in Table 1.1. The elevation information obtained gives either DSM or DTM depending upon the source and method of production. The elevation models however cannot be used directly in HDM as they either contain all the surface elements or none of them.

Table1.1: *Sources of digital elevation models*

Source	Spatial Resolution	Accuracy	Reference
DGPS	1-200m	< 1cm vertical, <1m horizontal	(Nelson et al., 2008; Rayburg et al., 2009)
LIDAR	1-5 m	0.15-11cm vertical	(Webster et al., 2006)
IFSAR (SRTM)	1-5m	Low to medium (m)	(Nelson et al., 2008)
SRTM C band	90m	16 m vertical, 20 m horizontal	(Nelson et al., 2008)
SRTM X band	30	16m vertical, 6m horizontal	(Nelson et al., 2008)
Aerial Photogrammetry	< 1 m	Medium to high (cm to m)	(Nelson et al., 2008)
Map Digitisation and scanning	scale and contour dependent	Relatively low (m)	(Nelson et al., 2008; Rayburg et al., 2009)

All of the methods have their own merits and demerits and their applicability and accuracy entirely depends on research interest. In this study the use of photogrammetry is considered due to wide availability of data and well proven and understood method. Photogrammetry can be used to derive DSM be stored in the form of regular grid (RG), triangulated irregular network (TIN) or contour models. The RG stores information in the form of square cell which determines the minimum size of terrain feature that can be stored in elevation models. DSM generation from aerial photography is a standard procedure whereby stereo pairs are geo-referenced, conjugate points are matched and interpolated. The DSM generated from photogrammetry thus contains all the elevated features represented as blobs. These blobs behave similarly by blocking water flow in any modelling environment unless defined or removed. For HDM blobs that obstruct the flow of water in real world have to be retained while others to be removed. The features that block the water flow are houses, embankments, elevated roads, groynes and dams (Mason et al., 2007), and termed as impermeable feature which are relevant in HDM. While features such as forests, shrubs and artefacts due to shadow or occlusion that do not block the water flow completely are called permeable features. Thus elevation model with the features that are relevant for HDM is termed as Pseudo-DTM, where pseudo means in between DSM and DTM. The use of pseudo-DTM is therefore suitable for deriving the accurate flood inundation extent, water velocity and depth from simulation models.

Various methods and approaches are applicable and available for constructing a Pseudo-DTM from a photogrammetric DSM. Most of the methods have similar premise of identifying and removing features from DSM to create DTM. The methods available are filters, classification, segmentation and ground point selection from DSM (Kasser and Egels, 2002). Filtering methods are able to identify and remove some specific features (Lu et al., 2006), from DSM, while classification approach is based on classifying and removing features based on spectral, textural, spatial and contextual information (Schiewe, 2003). Segmentation uses threshold and ancillary layer such as orthophoto to identify and remove segments from DSM (Kasser and Egels, 2002). Each approach has some limitations of their own which induce errors in DTM. The filtering methods that are specific to particular features and environment lacks transferability due to priori assumption of earth surface (James et al., 2006), while classification approach based on pixel fails to identify complex composition of features where a pixel contains more than one type of feature (Sarkar, 2009). As such, these methods are not generic enough to address all types of relevant features.

As DTM generation goes through multitude of processes, errors are inherited as early as from data source and post processing production methods. Fisher and Tate (2006) summarised the errors into three categories a) measurement and source data error, b) processing and DTM generation errors and c) terrain properties represented in DTM.. Studies have shown that these errors have significant effect on flood modelling. For example, Neelz and Pender (2006) used different DTMs derived from LIDAR with added error and found that the error significantly slows down the flow resulting in incorrect representation of flow dynamics. They also found that the error associated with LIDAR had significant impact on flow route, water level and velocities. Kenward et al. (2000) also showed that base flow predictions were lower and higher depending on the DTMs horizontal and vertical accuracy. Wise (2007) evaluated the DTM created by different methods other than photogrammetry in hydrological models and found the surface runoff predictions differed by over 200% and caused variation up to 25% in prediction of hourly variation. So for better prediction accuracy there is need for reducing error in DTM. Although the latter two studies conducted for hydrologic models the errors and their effect also carries significance in HDM. Most of the study in HDM either uses LIDAR DTM or DTM derived from other sources such as contours or IFSAR due to various errors associated with photogrammetric DTM. Along with the errors, the terrain properties represented is important. Sanders (2007) found that flood height increases by 30% while travel time increases by 50% when DSM (IFSAR) is used instead of DTM (national elevation grid-NED).

In order to create a Pseudo-DTM from photogrammetric DSM a method is needed that identifies and removes the permeable features from DSM. An approach would be to integrate object oriented approach (OOA) and GIS procedure. OOA is a knowledge based technique that considers group of pixels (objects) as basic entity of analysis rather than single pixel (Benz et al., 2004). As such various properties such as texture, context and spectra within or between the objects can be incorporated in the analysis helping to overcome limitations posed by single pixel based approaches (Blaschke et al., 2008). In addition, OOAs ability to integrate data of different dimension (e.g. height and spectra) (Baatz and Schape, 2000), makes it appropriate technique to consider in the research. A proper identification and delineation of features can then be linked with DSM for the removal procedure using GIS operation.

1.2. Research Problem

All the elevated features present in photogrammetric DSM are represented as blobs (Figure 1.1 b). These blobs have same functionality in HDM as all of them block the water flow (Figure 1.1 c). However, in reality only the features (e.g. houses or dams) that are impermeable to water block the flow while the features (e.g. trees) that are permeable barely block it (Figure 1.1 d). As such, having the permeable feature representation in DSM is erroneous and leads to inaccurate result from HDMs.

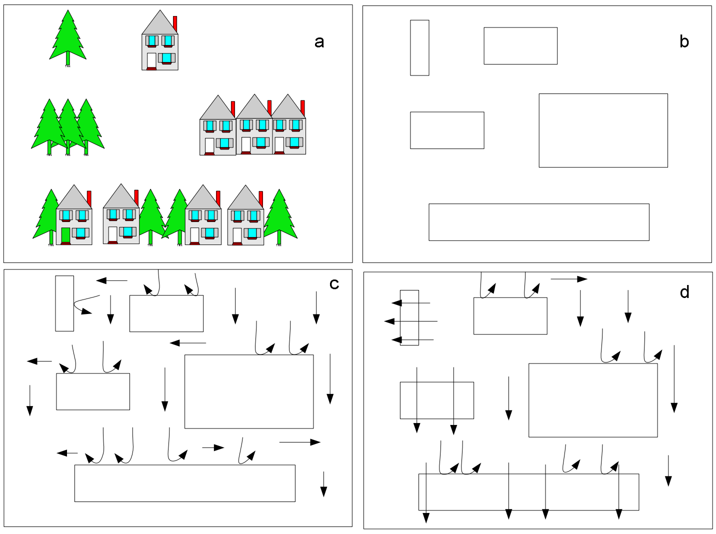


Figure 1.1: *Schematic drawing of features and their behaviour during flooding (a) feature resemblance in real world (side view), (b) feature representation as blobs in DSM (top view-generic),(c) representation in DSM where trees obstruct water flow behaving in the same way as house (d) actual situation during flooding whereby trees let water pass through it.*

In addition, photogrammetric DSM’s have been associated with errors due to failure of matching processes in areas with low contrast like shadows and occlusion (Figure 1.2). As such, interpolation of these areas leads in formation of spurious spikes or pits in the DSM. These artefacts along with the DSM blobs of permeable features are irrelevant in HDM and have to be removed from DSM, thus creating a corrected surface model called as Pseudo-DTM.

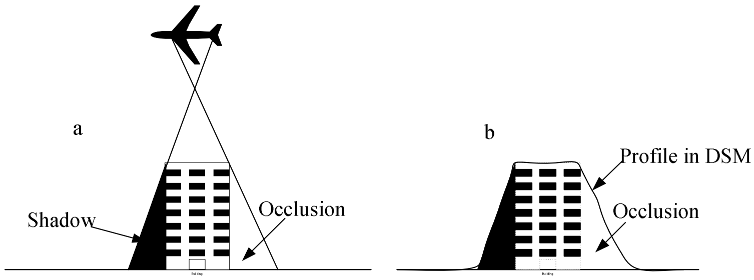


Figure 1.2: *a) occlusion and shadow b) their representation in DSM*

The use of Pseudo-DTM in HDM would therefore be logical for accurate simulation results. Yet, the methods available to generate Pseudo-DTM are not generic for features of various complexities and the artefacts present in photogrammetric DSM. Due to this, a method that can differentiate features along with the artefacts with integration of different form of information from photographs and DSM is needed to get the Pseudo-DTM for HDM.

1.3. Research Objectives

The main objective of the research is to use object oriented analysis for developing a method to generate Pseudo-DTM from photogrammetrically derived DSM for HDM. Specific objectives of the research are

- To identify and extract the permeable features and artefacts by integration of photograph and DSM using rule set
- To find the representation of feature in DSM automatically
- To link the features identified in photograph with DSM and to remove them automatically
- To assess the accuracy of the Pseudo-DTM

1.4. Research Questions

1. What are the features that permit water flow in HDM?
2. Is it possible to use the spectral and contextual characteristics of features from photograph and DSM to identify them?
3. What is the quality of the extracted features?

4. How are features represented in DSM?

5. How can we use the outline of, such as a group of trees, in the photo, to find the corresponding clump in the DSM, and to remove it?
6. Is it possible to identify artefacts created by shadows from photographs and their representation in DSM and to remove it?
7. How accurate is the created Pseudo-DTM in terms of reference LIDAR DSM and DTM or field data?
8. What is the significance of removing features from DSM in hydrodynamic modelling?

1.5. Research Scope

The research focuses on the correction of DSM for hydrodynamic models for rural areas. As such, the features relevancy for HDM is based on literature that considers obstacles present in rural areas. The correction procedure focuses on the identification of the features and the artefacts that are detrimental in HDM. These features include trees, shrubs and the artefacts of shadows and occlusion in DSM. The research does not involve validation of the Pseudo-DTM's by simulating flood event of different frequency.

1.6. Thesis Structure

The thesis is presented in 6 chapters. The first chapter gives preview on the background, problem, objectives, question and the scope of research. The second chapter provides a review of literature on HDM, DSM generation from photogrammetry, associated problems and errors and its significance in HDM will be discussed and the information extraction using OOA is described. The third chapter describes the materials and the method adopted for the feature identification and removal. Fourth chapter provides results while the fifth chapter discusses on the method employed and its significance in HDM. Conclusion and recommendation of the research are given in the last chapter.

2. Literature Review

The chapter starts by providing insight into HDM followed by the sources of DSM necessary for it. Then it provides review on methods to convert DSM to DTM. As the processing of DSM leads to errors it then describes the effect of errors in HDM. Information extraction techniques are reviewed followed by accuracy assessment and concluding remark.

2.1. Hydrodynamic Models and Flood Simulation

Hydrodynamic models have been used to simulate flood inundation in the floodplains. The approach of flood inundation simulation essentially involves the solution of one and two-dimensional Saint Venant equations using numerical methods (Merwade et al., 2008). These equations have been used to develop various numerical models for flood inundation and flow simulation. Based on the approximations used, the numerical models can be categorized into (a) one dimensional (1D) models, (b) two-dimensional (2D) models, (c) three dimensional (3D) models and (d) combination of one-dimensional river flow models with two-dimensional floodplain (1D–2D) models (Chatterjee et al., 2008; Merwade et al., 2008; Patro et al., 2009). 1D hydraulic models use cross-sections to represent river channel bathymetry and its surrounding topography while 2D and 3D hydrodynamic models require river channel bathymetry and its floodplain topography as a continuous surface elevation model integrated into finite element mesh (Merwade et al., 2008). As basic parameters for HDM, topographic representation has strong control over the accurate prediction of the simulation results. The required topographic information can be derived from various sources. This research however, focuses on the photogrammetric method as discussed in chapter1.

2.2. Sources of DSM

DSM generation from photogrammetry can be summarised into following steps (Schenk, 1999).

a) Select matching point in one image
b) Find conjugate point in other image
c) Compute 3D position of matched point in object space
d) Assess the quality of matched points

Three types of matching algorithms exist; area, feature and relational based. Out of these area and feature based are most widely used algorithms (Kasser and Egels, 2002). In area based matching a template compares the grey level value from one image with a value from another image based on a correlation coefficient, cross correlation and least square. The size of the template is important as it determines the area over which matching is performed. The matching is erroneous in urban areas where high level of occlusion, shadow and large homogenous areas exist and the contrast between objects is low. In feature based approach, matching entities are extracted features such as interest points, edges and regions from the images (Kasser and Egels, 2002). Correlation coefficient, cross correlation and least square matching are used to match features in images. This method can avoid poor contrast area however having a problem in urban areas where distinct features are difficult to find. Relational matching incorporates relation between entities and involving also consistent labelling relaxation and structural matching (Schenk, 1999). After the matching, interpolation is carried out to get a DSM. Interpolation can be performed using algorithms such as nearest neighbour, bilinear interpolation, cubic convolution, kriging and natural neighbour (Maune, 2007).

Various factors such as image projection, occlusion, shadow, homogenous and heterogeneous area and repetitive pattern etc affect the DSM generation procedure (Schenk, 1999). This causes problems in image matching procedure and introduces spurious pits and spikes during interpolation. Along with interpolation, source data errors, vertical and horizontal resolution also leads in formation of artefacts (Florinsky, 2002).These errors also propagate in the DTM if not identified and removed from DSM leading to erroneous prediction from HDM.

2.3. From DSM to DTM

This section deals with the conversion of photogrammetric DSM to DTM.

2.3.1. Filtering

Filtering is an operation which processes signal to manipulate information contained in the image. The manipulation of information results in extraction of desired information from the input image (Diniz, 2008). In order to estimate the DTM from DSM the most common method is the use of mathematical morphology filters. The idea is to analyse the shape of objects in an image by probing the image with a small geometric template called structuring element (SE) defined by its size and geometry (Kasser and Egels, 2002). The filtering consists of two main operation, erosion and dilation. In erosion, the boundary pixels are removed from the original image while in dilation the boundaries are enlarged. When erosion is followed by dilation it is termed as ‘opening’ while dilation followed by erosion is called ‘closing’. The series of erosion followed by dilation (opening) produces DTM with the desired result. The limitation is the choice of appropriate size of structuring element, if the size is small, an undesired area will be interpreted as terrain surface and if the size is large then the actual terrain forms such as peaks will cut off (Schiewe, 2003). The method does not preserve the curvature of land and as they are designed for specific features they fail to produce good result in heterogeneous and hilly areas (Kasser and Egels, 2002).

2.3.2. Selection of ground points in DSM

This approach consists of selecting a set of points from ground in DSM and interpolating these to obtain the DTM. The selection of point plays an important role and depends on the application of the DTM. The variation of the topography is difficult to maintain and it takes a lot of time in point selection. The selected points are then interpolated to make a continuous representation of the terrain. The accuracy however, is a function of point density and terrain characteristics (Kasser and Egels, 2002).

2.3.3. Classification

The main idea behind the classification approach is to identify and classify the features of interest that have to be removed from DSM using different object properties such as shape, size, pattern, tone, texture, shadow and context. The features can then be changed into binary values and removed from DSM using different raster operation available in remote sensing software (James et al., 2006).

Various approaches are available to classify the features, such as the crisp, fuzzy to knowledge based approaches. The crisp classification approaches classifies features based on some threshold values or classification algorithms while fuzzy classification uses the knowledge of fuzzy set to classify image into different classes (Lillesand et al., 2004). These approaches also use the segmentation approach discussed in the subsequent section 2.3.4. The segmentation of DSM is followed by assignment of different class based on certain criteria and then removal or interpolation of missing values.

2.3.4. Segmentation

The use of shape recognition techniques to circumscribe the extension of raised structures is another approach. The DTM is calculated by replacing the extension of detected structures and interpolating the gap values (Kasser and Egels, 2002). The slopes and curvature along with contour can be derived from DSM and used with condition such as closed contour and certain slope to make segments (Jamet, 2002). This is the simple approach and has many shortcomings. Baillard (1997) defined the raised structure on relation to the neighbouring regions by Markovian model while some other research focused on region growing approach (Jamet, 2002).The feature detection conducted alone results in problem in complex situation such as hilly landscape, forests and buildings in urban zone. As such, ortho-photographs of the same area are also used as supplementary information in segmentation (Jamet, 2002). Segmentation in OOA approach however is used to get initial object primitives for further analysis.

2.3.5. Interpolation

One of the most important steps in digital surface modelling is the interpolation technique that determines the unknown or missing height value of a point from the known heights of the neighbouring points. The interpolation technique is derived by two implicit assumptions a) the terrain surface is continuous and b) there is a high correlation between the neighbouring data points. The table 2.1 shows the classification of interpolation technique provided and summarised in (Zhilin Li et al., 2005).

Table 2.1: *A classification of interpolation technique*

Criteria	Interpolation Techniques
Size of area	Point based, area based (patch wise or global)
Exactness of the surface	Exact fitting, best fitting
Smoothness of the surface	Linear, nonlinear
Continuity of the surface	Step, continuous
Preciseness of the function	Precise, approximate
Certainty of the problem	Functional, Stochastic
Domain of interest	Spatial, spectral (frequency)
Complexity of the phenomena	Analytical, numerical iteration

Source:(Zhilin Li et al., 2005)

Many comparative studies have been carried out for determining the proper and appropriate interpolation algorithms. Studies showed Kriging (stochastic) yields better estimation of altitude than inverse distance weighting (IDW) regardless of the landform type and sampling pattern by (Erdogan, 2009; Zimmerman et al., 1999). Aguilar et al. (2005) highlighted multi-quadric radial basis function (RBF) as the best method for interpolation. However depending upon the terrain characteristics one or more algorithm has to be applied for proper interpolation of elevation information (Maune, 2007).

2.4. Errors and Effect on Flood modelling

The term error implies the deviation of a measurement from its true value, as such more accurate reference data has to be available for accuracy assessment (Fisher and Tate, 2006). The accuracy and precision of the source data together with quality of interpolation method determines the error in DTM (Heuvelink, 1998).

2.4.1. Error Source and Types

The errors from different sources and processing methods can be categorised into three groups namely; the gross, systematic and random errors. Gross errors are blunders that result from user error or equipment failure and are easily detected and removed (Fisher and Tate, 2006). Systematic errors are result of processing and recording procedure that shows some form of dependency or trend which as such can also be corrected. In photogrammetry these errors arise due to changes in film media, instrument errors, software precision (Fryer et al., 1994), and interpolation (Hu et al., 2009).Random errors accrue due to lack of precision from variety of operational tasks and are introduced by unknown reasons. They cannot be governed by certain standard rules thus being irremovable (Maune, 2007).

2.4.2. Effect on Flood Modelling

As stated in introduction, the effect of error on HDM can be divided into the one associated with production and the other with representation of topography. Neelz and Pender (2006) showed that the error significantly affects the flow dynamics and flow route, water level and velocity. They demonstrated that with increase in error of 0.05 and 0.10m (standard deviation) the peak discharge changed by 11% and 44 % while the maximum velocities were reduced around 9% and 39%.when adding the error in LIDAR DTM. Although the study was carried out using the LIDAR DTM, the effect of errors also has significance when photogrammetric DTM is used.

The error associated with production topographic representation is highly important in HDM and has been highlighted by many authors. Mark and Bates (2000) have highlighted importance of topographic representation in terms of simulation objective to derive bulk flow or local hydraulic characteristic. They have described that small change in topography has considerable effect on local hydraulic characteristics as seen by complex inundation pattern over an area with raised topography while the bulk parameters remain the same. The presence or absence of features such as buildings, embankments, groynes, and elevated roads act as obstacle to flow of water (Haider et al., 2003; Mark et al., 2004; Mignote et al., 2005), and the changes direction of flow (Maidment, 1993; Schmitt et al., 2004). This affects the spatial and temporal (travel time) distribution of flood water. In addition, either the use of DTM or DSM has considerable effect on flood prediction. A study by Sanders (2007) on Santa Clara river shows that flood height and travel time is 30 and 50% higher using unprocessed IFSAR that is considered as DSM than national elevation data (NED). They also showed that along a cross-section the IFSAR DSM acted as dam, thereby blocking the flow of water. These studies show that errors have significant effect on HDM and a correct elevation model is necessary for accurate analysis.

Horizontal resolution is another important factor as it determines the minimum size of the object present in DTM relevant for hydrodynamic modelling. Such features those that change the spatial and temporal pattern of water flow in modelling which can be houses, embankments, groynes, roads and dams.

2.5. Information Extraction

Various methods ranging from visual interpretation, semi-automatic to automatic techniques are available for information extraction from images. These techniques use the colour, shape, size, texture, pattern or context from images to derive appropriate information. Some automatic information extraction techniques are classification, linear feature extraction, mathematical morphology and statistical regression. The research focuses on object oriented analysis for information extraction. A detail on different information extraction techniques is provided by Baltsavias (2004).

2.5.1. Object Oriented Analysis

Object oriented analysis (OOA) is knowledge based approach that uses objects instead of pixels for extraction of features from images. These objects are created based on meaningful statistical, textural and contextual (shape and topology) information provided from different data source (Baatz and Schape, 2000). The initial step in creating objects is to divide image into intermediate objects called 'object primitives' by using a process called segmentation (Benz et al., 2004). The segments are then assigned attributes based on knowledge of objects and formulating rules. The rules incorporate object properties based on theory of fuzzy logic.

2.5.1.1. Image Segmentation

Segmentation is the process of information extraction from image by partitioning scene into non-overlapping regions (Schenk, 1999; Schiewe, 2002). It is the process by which an image is divided into spatially continuous, disjoint and homogenous parts (Baatz and Schape, 2000; Blaschke et al., 2008). The main strategy is to create objects based on properties such as spectral, textural and contextual that determines the homogeneity criteria. It relies on four mathematical principles (a) Union set of regions makes up the image, (b) Regions are not allowed to overlap, (c) Homogeneity criterion applies and (d) Homogeneity criteria of neighbouring regions differ.

2.5.1.1.1. Types of Segmentation

Based on different approach the algorithm used to create segments can be basically divided into three categories; a) Pixel based, b) Edge based and c) Region based (Blaschke et al., 2008).

Pixel based approaches perform segmentation within feature space and ignore the spatial dimension in real space. It is a form of unsupervised classification leading to classes but not to spatially contiguous regions (Blaschke et al., 2008). Edge based algorithms aim in finding the edges between regions described by their outlines generated through an edge detection and contour generating algorithm. Filtering and enhancement algorithms are applied before edge detection algorithms (Blaschke et al., 2008), to reduce the effect of noise that leads to over segmentation (Schenk, 1999). Region based methods assign pixels to certain regions by analyzing one or more properties that are characteristic for a region (Schenk, 1999). It uses the properties of neighbourhood to determine the heterogeneity of the pixel properties (Schiewe, 2002). This approach can be divided into region growing, merging and splitting techniques and their combinations. Region growing method uses the seed pixel as starting point and aggregates pixels from surrounding until a certain threshold is reached. Typically they are two staged as described by (Baatz and Schape, 2000), where first stage involves the extraction of characteristic features from input image while the later stage involves the grouping of the features extracted into homogenous segments. Region merging and splitting considers image as a discrete state and changes state when the boundary of the region is removed (merged) or introduced (splitting) (Schiewe, 2002). The discrete state is produced by the use of any segmentation algorithm (Blaschke et al., 2008).

2.5.1.1.2. Algorithms for Segmentation

Although the idea of segmentation was developed in the 1980s, the concept became common use recently. The algorithms are basically based on determining the homogeneity of the object based on geo-statistical analysis and similarity approach (Blaschke et al., 2008). Blaschke et al. (2008) have summarized different methods and approaches for image segmentation such as edge based method of Hoffman and Bohner (1999), combined colour and texture information by Dubuisson-Jolly and Gupta (2000), Gabor wavelet scale-space representation by Hofmann et al. (1998), and fractal net evolution approach by Baatz and Schape (2000).

The meaningful objects called as object primitives are created using the multi-resolution, quad-tree and chess-board segmentation algorithms. Multi-resolution segmentation is a region growing approach that starts with a pixel which is grown until criteria known as homogeneity is fulfilled. The homogeneity within object is determined by color and shape. The color determines the influence of spectral information in segmentation while shape determines the smoothness and compactness of object (Baatz and Schape, 2000). Quad tree algorithm makes square objects. The quad trees structure first builds square of maximum size followed by small squares of similar homogeneity defined by mode and scale parameter. Chessboard algorithm forms square grid and objects are cut along these grid lines (Baatz et al., 2007).

2.5.1.2. Feature Identification, Classification and Extraction

Feature identification and classification using the spectral, spatial as well as contextual information is the backbone of the object oriented approach. The generation of object primitives by segmentation lays foundation for further analysis of the image. The extraction of object or feature of interest involves the use of geometric and object properties such as spectral, functional and topological information that forms the knowledge. Knowledge can be referred as a) the target objects and their context within the scene, b) the input data to be used for object extraction, c) the processing method to be applied and d) the control mechanism (Baltsavias, 2004). This knowledge can be incorporated using various approaches as artificial neural networks, evidence theory and fuzzy logic.

Baatz et al., (2008) has described the spiral process for object identification, classification and extraction using OOA approach from image. The first step is towards the creation of object primitives using segmentation algorithms which is then used to perform evaluation and classification. The subsequent step is to refine the classified objects iteratively using the knowledge until desired object is achieved. The other approach of knowledge incorporation in object identification and classification is to describe the ontology of the objects to be detected. The ontology can be used to describe the knowledge about object of interest from a certain point of view using a defined language. These points of view give domains that represent image objects from real world as well as image domain itself. The real world domain describes objects from its observable properties that are typical or unique while image domain gives specific measureable properties of objects in image. (Hofmann et al., 2008) have used ontology to describe the settlement into informal and formal areas and used to extract the identified classes.

Baltsavias (2004) has summarized the papers using knowledge based approach for extraction of object such as buildings, roads and vehicles, aircrafts, crops, man-made structures, drainage channels, crops, agricultural fields and forests. Features such as houses (Kressler and Steinnocher, 2006), vegetation (van der Sande et al., 2003), and road networks (Hinz and Baumgartner, 2003), have been successfully extracted using OOA . These methods imply not only the use of photograph or DSM but combination of each other. The segmentation and classification of objects using height and its derivative such as slope, edges have been carried out by Schiewe (2003) to derive terrain model called as mDTM (m=masked). Shamaoma et al. (2006) used OOA to extract flood risk related base data.

2.6. Accuracy Assessment

Accuracy assessment has to be conducted in order to be sure that the edited DTM has acquired the specified accuracy. For this, reference values are required such that two different data can be compared and analysed using root mean square error (RMSE), mean error (ME), standard deviation (SD), geo-statistical variograms and Fourier-based analysis (Fisher and Tate, 2006). RMSE is the most common descriptor of error and based on the assumption that the errors are randomly distributed following the Gaussian distribution without outliers. RMSE has various draw backs as it only gives global summary for a data set failing to describe the spatial of error distribution. It only gives the assessment of how well a DTM corresponds to the calibration data. Due to this, researchers have proposed to use other statistical measures such as mean and standard deviation along with RMSE (Fisher and Tate, 2006; Höhle and Höhle, 2009). Surface derivatives are the other approach that describes the error rigorously (Wise, 1998). Wise (1998) used the surface derivative approach to assesses the error of DEMs generated from same input data using the range of interpolation methods. The author found that the RMSE of aspect to vary between 11^0–55^0 while RMSE of elevation was between 1.3 to 1.8m. This shows the sensitivity of the surface derivatives towards errors in DEMs. The accuracy of checkpoints should be at least three times more accurate than the DTM elevation being evaluated (Maune, 2007). The other criteria is the sample size, which has to be large enough to acquire reliable accuracy and be representative of whole DTM and randomly distributed (Höhle and Höhle, 2009).

2.7. Concluding Remark

This chapter provided the concept on hydrodynamic modelling, effect of error on modelling along with the DSM generation procedure. It summarized the process to get DTM from DSM and the accuracy assessment. It illustrated the idea about the application of OOA in information extraction from multiple images and DTM generation techniques from DSM.

3. Materials and Method

This chapter provides a detail description on the materials and method used to answer the research questions defined in section 1.4. The first section illustrates on study area, the data used and the description of the experimental setup. The latter section describes the method employed for feature identification and removal from DSM using orthophoto and DSM itself.

3.1. Study Area

The study area is situated in the Gelderland province, south-eastern part of Netherlands. The river Rhein originates in the Alps and flows through Switzerland, Germany and the Netherlands. In this region the river Rhein bifurcates into northern, the "Pannerdensch Kanaal" and the southern branch the river Waal. The study is focused on the one floodplain section (Figure 3.1) of the Waal River (Millinger Waard) which is one of the important distributaries of river Rhein.

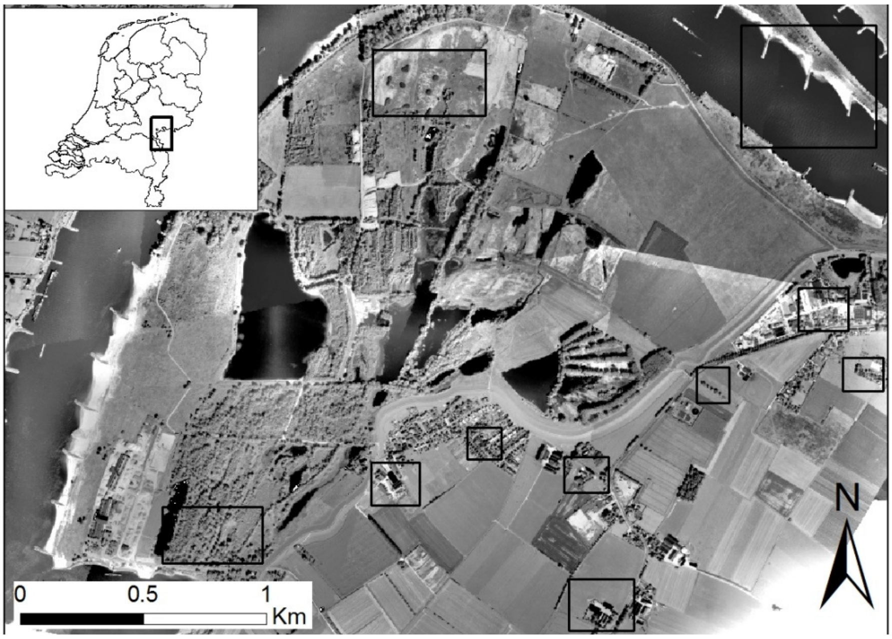


Figure 3.1: *Location of Study area and experimental cases*

The physiographic of the area shows relative flat terrain with average height of 11m above datum. The area is characterised by different land use types. The area contains human settlements, trees, agriculture land, grassland, river and lakes. The river Waal meanders in the area and is heavily trained to control the flood in the area. The area provides with the elements necessary for research.

3.2. Data

3.2.1. Orthophoto and DSM

The main source of data is ortho-rectified aerial photograph and digital surface model (DSM) of the study area. The photographs were captured using RMK TOP 30 film cameras during summer in year 2005 and ortho-rectified using Leica Photogrammetric Suite (LPS). The resolution of the orthophoto is 0.25 m. The photographs are colour infrared imagery (CIR) having spectral information in near infrared (NIR), red and green band.

The DSM has a resolution of 5 m and was generated using the photogrammetric technique described in chapter 2. It was generated by Sarkar (2009) using LPS. The accuracy of the DSM is 0.122m of RMSE. LIDAR DTM and DSM used for accuracy assessment also have 5 m resolution. It has been provided by the Geo-information and advisory service ICT prepared under the specification specified by Actueel Hoogtebestand Nederland (AHN) 2000 systems.

3.2.2. Field Observation

Field observation was carried out in order to find the areas that were confused during object identification and extraction process. The position of tree using global positioning system (GPS) and height using slope (clinometer) and distance were measure for 45 trees. The measurements were used in the accuracy assessment.

3.3. Proposed Method

In order to identify, delineate and remove the permeable features and artefacts the method was divided into two sections. First section used OOA for feature identification, delineation and extraction while latter section contained feature removal from DSM.

3.3.1. Experimental Setup

In order to find the feature in photograph, their subsequent representation in DSM and removal, an experimental setup need to be designed. The setup was designed to address the various complexities present in the study area that have implication in hydrodynamic models. This provided a framework for identifying object properties, rule set development and testing capability of the method in different settings. The Figure 3.2 shows the schematic diagram of different features that were concern of the research. The line diagrams represent the feature in DSM for the respective object in the photograph.

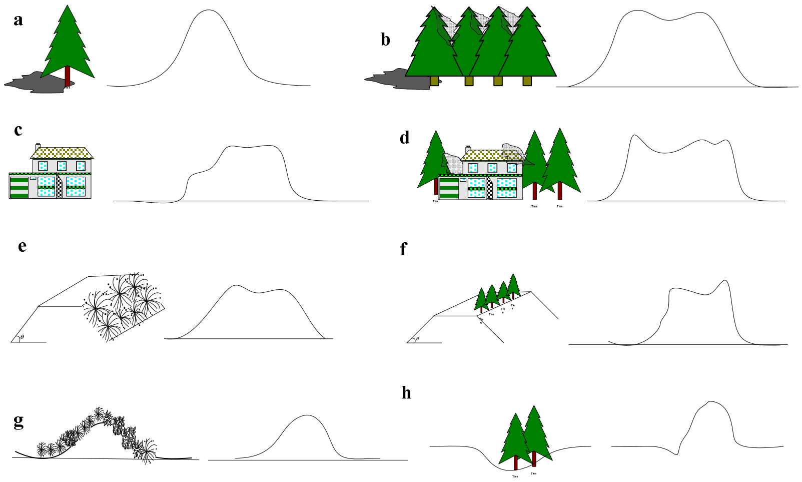


Figure 3.2*: The Schematic representation of features in photograph and profile in DSM (a) single tree (b) group of trees (c) single house (d) house surrounded with trees (e) embankment with grass (f) embankment with trees (g) hump covered with vegetation (h) depression with tree.*

3.3.2. Experimental Data

Based on the experimental setup, features were searched and subset from orthophoto and DSM (Figure 3.1). These data were grouped into simple and compound cases features based on their occurrence. The list of features along with the number considered in the study is shown in Table 3.1.

Simple Cases

Simple cases included features occurring in isolation where the boundary was easy to recognize in DSM. Individual houses, trees, embankment, groynes and group of trees fall under this category.

Compound cases

Compound cases features were more difficult to differentiate as the boundaries are not distinct and mixed with other nearby features in DSM. The compound cases were features such as houses occurring with trees and shadows, embankment with trees or depression covered with trees as presented in table 3.1. The pictures of the experimental data are presented in Figure 8.1-8.5 of Chapter 8.

The orthophoto of the study area was re-sampled to1m in order to facilitate the processing time during feature identification. The ancillary layers such as the edge and slope were derived from red band and DSM respectively using the algorithms embedded in Definiens Developer 7.

Table 3.1: *Experimental cases considered for the study*

Feature	Retain	Remove	No of cases	Remarks
Simple Cases				
Single House	Yes		2	Remove edge pixels
Embankment	Yes		1	
Groynes	Yes		1	
Single Tree		Yes	2	Remove all
Group of Tree		Yes	2	Remove all
Compound Cases				
House with trees	Yes	Yes	3	Trees has to be removed
Hump	Yes		1	
Shadow		Yes		Occurring with house and trees

3.3.3. Feature Identification

Features were identified by the use of object properties. The properties defined by spectral, spatial, contextual and textural characteristics can be unique as well as common to objects. These properties were derived from the orthophoto, DSM and ancillary layers.

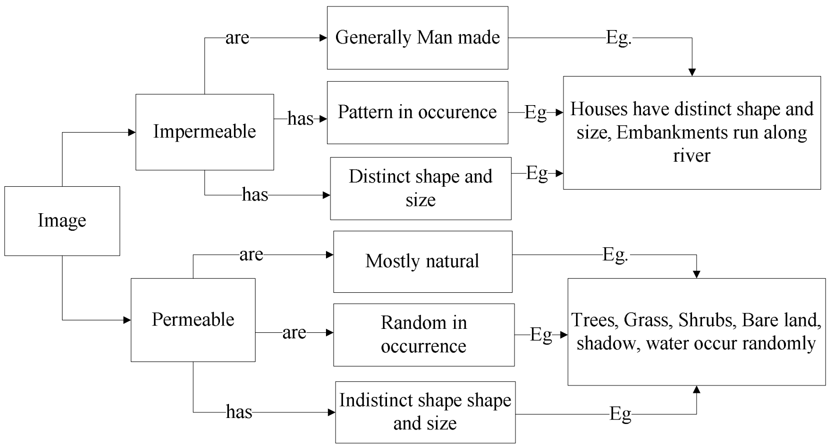


Figure 3.3: *General description of the impermeable and permeable features*

Figure 3.3 shows the general description used in the identification of the permeable and impermeable features for water flow. Single property was not enough to differentiate a feature, such that combinations of properties had to be used as seen in

Figure 3.3. Impermeable features generally are manmade and they have specific pattern in occurrence and are distinct in shape and size. For example, embankments and groynes occur proximity to river and have defined pattern. However, single houses do not have pattern in occurrence but have area, shape and size that differentiate from other features. The permeable features are natural and are random in occurrence without uniform pattern, shape or size (e.g. trees, shrubs, water bodies).

3.3.3.1. Segmentation

The meaningful objects called as object primitives were created using the multi-resolution, quad-tree and chess-board segmentation algorithms. These algorithms used spectral and height information as grey level values.

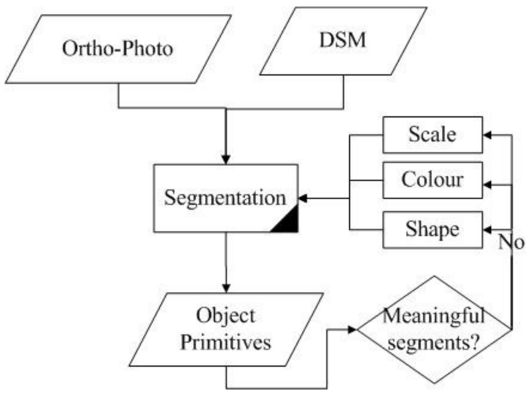


Figure 3.4: *Iterative process of segmentation using orthophoto and DSM*

Segmentation was a trial and error procedure as seen in Figure 3.4, where parameter such as scale, shape and colour were altered to get meaningful segments. Little bit of over segmentation was performed on the image instead of under segmentation, in order to apply the post segmentation procedure like merging, cutting or growing.

Table 3.2 shows the different parameter used for segmentation. The choice was dependent upon feature of interest. For example, embankment segments were performed using slope, edge and DSM as layer parameters at scale of 110 Table 3.2. The two algorithms shown in Table 3.2 indicated insufficiency of one scale to get proper segments for all the objects. Houses of different roof size and shape were identified and delineated by segmenting at two scales.

Table 3.2: *Parameters and object properties used for segmentation and feature identification.*

Feature	Segmentation Algorithm	Scale	Layer	Feature Properties
Simple Cases				
Houses	Multi-resolution, Quad-tree	45	DSM, Photo	Rectangular fit, length/width, height
Trees	Multi-resolution	35	Photo	NDVI, Std. deviation, height
Group of Trees	Multi-resolution	35	Photo	NDVI, Std. deviation, height
Groynes	Chessboard	25	DSM, photo	Existence of river, relative border to river, distance to ground
Embankments	Multi-resolution	110	Slope, Edge, DSM	Slope, Height
River	Multi-resolution	110	photo	NIR and Green
Compound Cases				
House with vegetation	Multi-resolution, chessboard	65,35	DSM, Photo	NDVI, rectangular fit, Asymmetry
Embankment with Trees	Quad-tree	35	Photo	NDVI
Humps	Multi-resolution	35	DSM, Photo	Relational-change in height with neighbouring objects within certain distance
Shadow of tree	Multi-resolution	25	Photo	existence to tree, std. deviation in NIR, relative border to tree
Shadow of House	Multi-resolution	25	Photo	existence to house, shape

3.3.4. Feature Delineation and Extraction

After the segmentation objects were delineated and extracted by the use of different object properties implemented through rule sets. The rules formed incorporated the spectral, spatial, contextual and relational attributes between objects and their neighbors using the fuzzy logic theory. A short description of the feature properties are provided in chapter 8 (Table 8.2).

Strategy of "elimination" was formulated, where features that were not used in further analysis were isolated. This reduced the computation time as well as complexity in differentiating between features during analysis. Features such as groynes, embankments, bare ground were identified and isolated at first few steps. The normalized difference vegetation index (NDVI) was used to identify vegetation from remaining objects. The vegetation was further analyzed to separate trees, shadow, crops and grasses. The remaining objects were analyzed for delineating houses and their shadow along with some remaining trees or vegetation. Object properties used for identification and delineation is shown in Table 3.2. An example on groynes separation is provided in Figure 8.6 of Chapter 8 (Appendix).

Trees and Houses

Houses were separated using the spectral and geometrical properties. The spectral properties varied with the construction material of the roof, while geometrical properties like height length, width and rectangular fit (Table 3.2) were used to delineate the houses from other features. The spatial property such as area was also used to differentiate houses.

A NDVI threshold of 0.1was used to separate vegetated and non-vegetated areas. Then standard deviation in the NIR band was used to segregate between different types of vegetation. Trees have higher standard deviation than grasslands. Height helped in segregation between mixed features. Agricultural crops and shrubs were identified using the spectral information from NIR band along with the height. The crops with height less than 20 cm when compared with bare agriculture area were not considered as crops as they exhibit similar properties to grassland. The shadow falling over tree from tree itself or house was retained as tree by use of contextual information such as relative border to and existence of, along with height.

Groynes and Embankments

Groynes are a protective structure of stone or concrete that extends from shore into the water to prevent erosion by diverting the flow of water from the banks. For separation of groynes contextual properties such as existence with river, relative border to river were used (Table 3.2, Figure 8.6).

Embankments are best defined by their geometry. The usual slope of the embankment lies between 8-15^0 while the length and width varies according to the landscape and purpose. Besides the geometry, embankment generally runs parallel to river and have road on it along with grasses and trees. The occurrence of grass and trees on embankments forced the use of slope and height for segmentation without spectral properties. Table 3.2 shows the properties used for delineation of embankments.

Shadows

Shadows were identified using the brightness values. The shapes of shadows depend upon the sunlight angle and feature that casts them. Shadows casted over the ground were differentiated using height information over the shadow casted upon elevated objects. The elevated shadows were again assigned the respective class such as tree or house using the context information like existence of and relative border to object. For this the shadows were re-segmented using the height and spectral information.

Hump

Humps are the surface features that protrude out in smooth plain. The humps were identified and extracted using relational feature algorithm that described the height difference with neighbouring objects within certain distance. The mean absolute difference with neighbor and shape index was used for delineation.

Depression with Trees

Depressions with tree will be identified as tree itself as it covers all the spectral properties the tree has. Removal of trees from depression is discussed in feature removal section.

The shape files of the features identified and delineated were exported from Definiens Developer 7. Two different files were exported. First file contained polygons with shape of permeable features, while second file contained point file with elevation as attribute values from ground and embankments.

3.3.5. Quality Assessment

The extracted feature quality were assessed by the use of method proposed by Zhan et al. (2005). The method used the correctness, completeness and overall quality to assess the quality of extracted objects. The concept differs from per pixel approach as it accounts objects instead of pixels. Three different measures were used for assessing the quality of the extracted features.

Overall quality gives the degree of similarity between the extracted features and the reference data. It refers to the percentage of the number of matched objects among the total number of objects in extracted result and reference data.

$$\text{Per}-\text{object overall quality} = \frac{N_0(C_K \cap R_K)}{N_0(C_K \cap R_K) + N_0(C_K - R_K) + N_0(R_K - C_K)}$$

Where, C is extracted (classified data) and R is reference data. The arguments $N_0(C_K \cap R_K)$ gives the number of features common to both C and R, $N_0(C_K - R_K)$ gives the number of feature that belong to C but not to R and $N_0(R_K - C_K)$ gives the number of features that belong to R but not to C.

Correctness gives the measure on how good the extracted results are when compared with the reference data. It is similar to user accuracy.

$$\text{Corectness} = \frac{N_0(C_K \cap R_K)}{N_0(C_K \cap R_K) + N_0(R_K - C_K)}$$

Completeness is similar to the producer accuracy and is calculated as

$$\text{Completness} = \frac{N_0(C_K \cap R_K)}{N_0(C_K \cap R_K) + N_0(C_K - R_K)}$$

In order to get the reference data, regular points were generated using Hawth's analysis tools in the orthophoto at every 20m. The points falling over houses and trees were used as reference point for digitization. Out of these, 81 houses, 40 individual and group of trees were digitized. All of the 38 groynes, 1 major embankment, 1 minor embankment and 7 humps of the study area were also digitized. The features were then extracted from the Definiens Developer 7 and analysis was carried out in ArcGIS based on the described quality measures. When the extracted feature overlapped for more than 50% of the reference data then it was counted as correctly identified otherwise was assigned as not detected.

3.3.6. Feature Removal from DSM

As the extracted vector map and DSM had same orientation, the features from vector maps were located in the DSM. The vector map coordinates at the nodes and vertices combined with the same (overlapping) grid coordinate of raster image. This provided with the location attribute. Once locations were determined, then the extent was defined by the boundary of objects from vector map. The overlapping boundaries with each are given attributes based on centre cell approach. In this approach the cells are given attributes of the corresponding objects given the location of centre cell value.

The information provided from the extracted vector map was used to identify and delineate the areas to be removed from DSM. The polygons were used to extract the DSM values. Extraction was carried out in ArcGIS. The extracted values were then used to define the area in DSM to be replaced by interpolated values. A condition was written in ERDAS model maker that replaced the DSM values with the interpolated ones. Interpolation was carried out using inverse distance weighting (IDW) method with the point map exported from Definiens Developer 7 which contained elevation as attribute values. The points were generated by making small segments of the objects identified as ground and embankments. The ground objects included grassland and bare land. A detailed workflow of the method is shown in Figure 3.8. The removal procedure was performed using two approaches.

3.3.6.1. Object Based Approach (OBA)

This approach used the shape of polygons of identified features. Figure 3.5 shows an example of OBA approach in feature removal. The identified tree is exported as polygon file (Figure 3.5 b), which is used to define the area to be removed from DSM as shown by demarcated line (Figure 3.5 c). This area is then removed and replaced with interpolated values as seen in Figure3.5 (d). The resultant Pseudo-DTM contains spikes of shadow and occlusion (Figure 3.5 d).

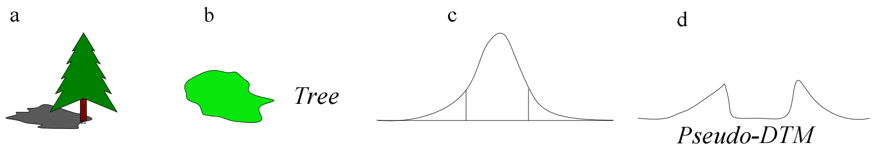


Figure 3.5: *Schematic representation of the feature removal by OBA approach; (a) tree along with shadow, (b) identified tree, (c) area in DSM defined by identified tree and (d) Pseudo-DTM.*

The spurious spikes formed by OBA approach had to be removed from DSM. An additional step was necessary that incorporated these artefacts. One approach was to form buffer around the features and remove them from DSM.

3.3.6.1.1. Object Based Buffer

The buffer can be created in two ways. First approach was to make a buffer of varying width along the polygon border containing shape of features. It was based on the notion that the artefacts will be covered by the width of buffer. The width was determined based on height, as height primarily determines amount of occlusion and shadow of feature. High variability in buffer width was expected due to high variability in feature size.

The second approach was to create buffer based on the information from the objects itself. It was based on the assumption that the artefacts have height greater than the surrounding objects (Figure 3.5 d) and are associated with elevated features. This contrast in height and relation with features can thus be used to create objects that are defined as object based buffer (OBB). OBB was not of fixed width or radius and varied according to the presence of additional height of the artefacts.

To test the applicability of the two approaches an experiment was performed on two datasets of the study area. The first set contained houses and trees near major embankment while the second set contained single house with trees. For the first approach buffer width of one half, one third and quarter the height of tallest house and tree were considered (Table3.3). For second approach segmentation was done to get the proper segments from the artefacts. A weight of 1 is given to DSM while 0.2 for the spectral information from one band of the image. The idea behind the small weight given to spectral information was to limit the size of objects within certain area. If only DSM was used then in some cases the segments were bigger than the actual spikes. A scale of 25 was chosen to incorporate the positional errors caused during ortho-rectification. After the formation of suitable objects contextual information in combination with height information was used to assign the objects as OBB.

Table 3.3: *Buffer width based on width of the features.*

	Features	Average Height (m) in DSM	Buffer width (m)		
			Half	One third	Quarter
Data set I	Houses	16	8	5.3	4
	Trees	12	6	4	3
Data set II	Houses	18	9	6	4.5
	Trees	16	8	5.3	4

3.3.6.2. Object Based Buffer Approach (OBBA)

In this approach the OBB method as described in the section 3.3.6.1.1 was incorporated in order to remove the artefacts. The polygon of permeable features along with OBB was exported for feature removal procedure. It differed from OBA approach only in consideration of the OBB.

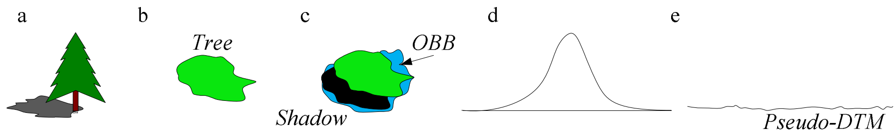


Figure 3.6: *Schematic representation of the feature removal by OBBA approach; (a) picture (b) identified tree and shadow (c)Identified tree with OBB (d)DSM representation of the tree (e)Pseudo-DTM after application of OBBA approach.*

The figure 3.6 shows schematics on the steps of OBBA approach. As a first step, tree along with shadow is identified (Figure 3.6 b) then OBB is formed (figure 3.6 c). The polygon of tree along with OBB is exported which is linked with DSM. This is then used to remove and replace as describe in section 3.3.6. The resultant Pseduo-DTM is without artefacts as shown in Figure3.6 (e).

The correction procedure should also work in compound cases feature not considered in the experimental data due to lack of such areas. Embankments which have trees can be identified as tree, the tree will be removed and replaced with the interpolated value from surrounding value of embankment itself and no sink will be formed. Depression with trees will be smoothened if trees cover all the area of depression. However, if the large part of depression is represented as low value in DSM then the removed tree will be replaced with the values associated with depression itself. So the preservation of depression depends on the area covered by trees of depression.

3.3.7. Accuracy Assessment

Due to uncertainties associated with feature identification and removal errors are introduced in the resulting DTM's. This will cause the derived product to deviate from the true value. The accuracy assessment is carried out to find this deviation of values from the reference elevation values. LIDAR DTM surface has vertical error of 17-19cm (Hodgson and Bresnahan, 2004), while DSM error varies up to 153 cm (Hodgson et al., 2003). LIDAR DSM contains all surface features while DTM contains elevation values representing bare earth.

The accuracy assessment was carried out in three different ways depending upon the features. First the accuracy was assessed only for single and group trees considered in the experimental setup using LIDAR DTM. The difference images were calculated by subtracting the Pseudo-DTM from LIDAR DTM. The difference images provided the spatial inference about the distribution of error for each and every pixel removed from DSM. Then the standard deviations with minimum and maximum values were calculated for the analysis. Hill shade analysis was also used to visualize and analyze the distribution of errors in Pseudo-DTM's using OBA and OBBA approach.

The second approach involved assessment for trees. The trees located in the field were used to extract the elevation values from photogrammetric DSM, and Pseudo-DTM's derived from OBA and OBBA approaches. The elevation values from corresponding elevation models were subtracted from field values. Trees heights from the field were converted to above datum by adding the LIDAR DTM height of the corresponding points. The analysis focused on finding if the trees located in field were identified and removed from DSM to create Pseudo-DTM. A high standard deviation in difference between field and Pseudo-DTM values shows that the trees have been remove in Pseudo-DTM's.

The third approach used LIDAR DSM in accuracy assessment. LIDAR DSM contains all the surface features while Pseudo-DTM only contains houses and embankments. A comparison between these two gives the extent of features removed as well as preserved. Comparison was made by comparing the height values and standard deviation along transects drawn over the images. This can be explained by use of schematic diagram in Figure 3.7. Figure 3.7 (a) shows the picture view (side view) of houses and trees occurring in isolated and grouped condition. When a profile is drawn in LIDAR DSM, then it looks as in Figure 3.7 (b), while the profile on Pseudo-DTM should look like in Figure 3.7 (c). The trees are missing in Pseudo-DTM as they are removed. So in order to find the deviation, the standard deviation of values along the transect was calculated and plotted as profile which should look like in Figure 3.7 (d), i.e. there should be high standard deviation in areas where trees are present and low deviation in area where houses are present in LIDAR DSM. This gives the comparative approach on finding the accuracy of corrected Pseudo-DTM with LIDAR DSM. In addition, deviation between the LIDAR DSM and Photogrammetric DSM was also calculated to see the association between the two different data acquisition system such that the deviation between the LIDAR surface and Pseudo-DTM's can be analyzed.

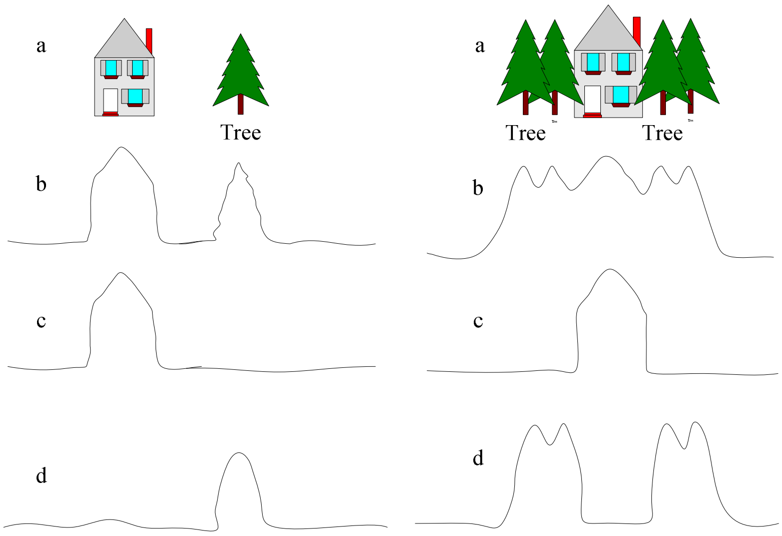


Figure 3.7: *Schematic representation of features and their profile in DSM (a) photograph b) LIDAR DSM c) Pseudo-DTM d) standard deviation between the LIDAR and Pseudo-DTM.*

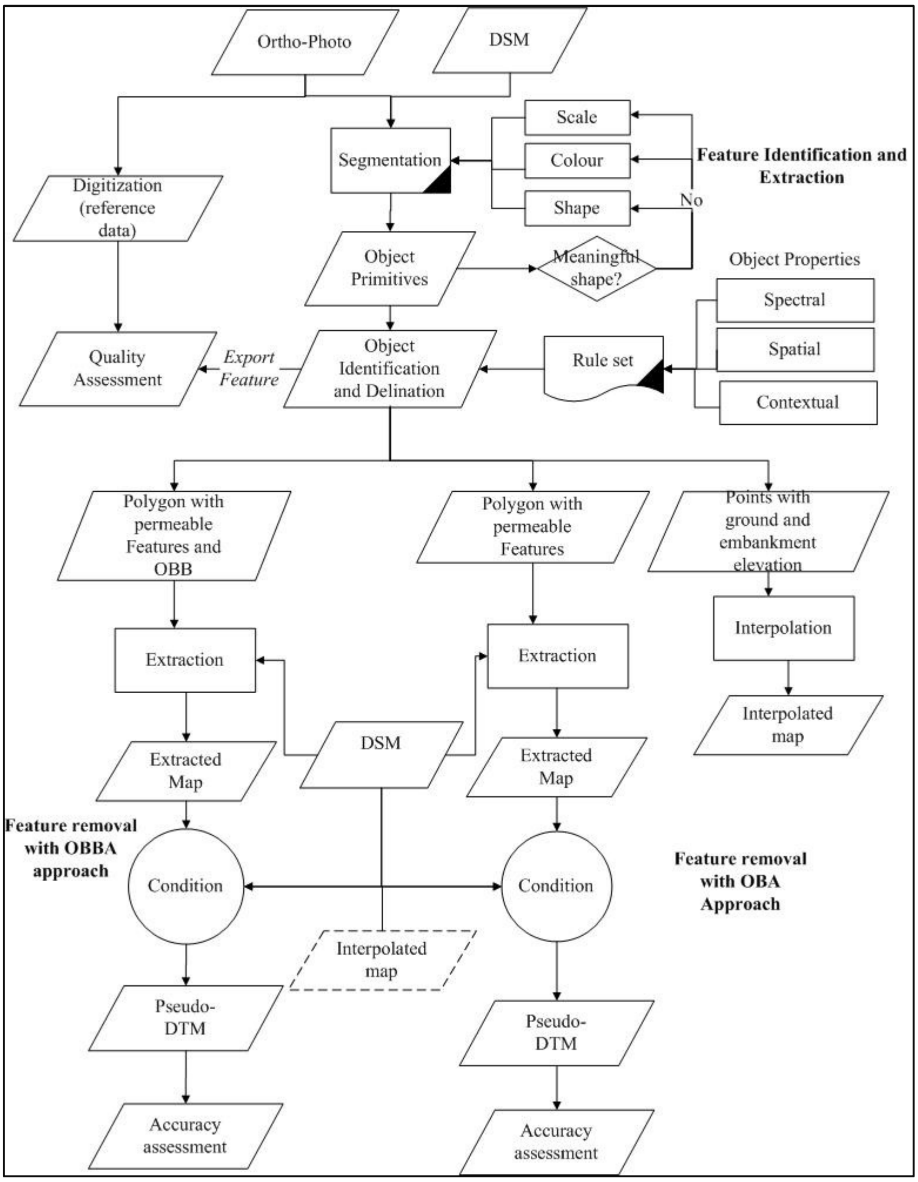


Figure 3.8*: Work flow of proposed method for identifying and removing features from DSM*

4. Implementation and Results

The results after implementation of the method presented in chapter 3 are depicted in this chapter. These are categorised based on the steps taken during the implementation. Features were identified, delineated and extracted using OOA while removed and replaced with interpolated values using a GIS procedure.

4.1. Feature Identification and Extraction

The features identified and extracted using the OOA approaches are presented according to the cases considered in the experimental setup. The results also include the buffer formed using OBB approach. The identified features were assessed visually due to lack of thematic object information.

Simple Cases

Visual interpretation of the Figure 4.1 shows that the simple cases houses are properly delineated from the surrounding objects. The shadows and trees are also delineated properly.

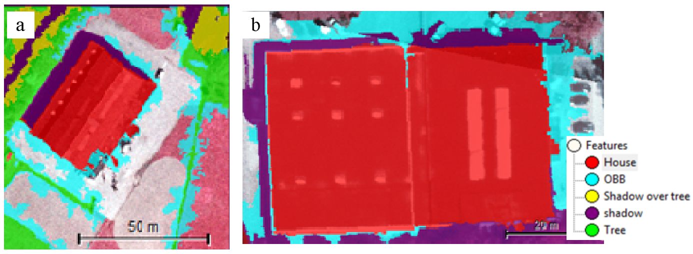


Figure 4.1: *Identification and delineation of individual houses (a) case I (b) case II.*

Trees occurred individually as well as in group. Most of the individual trees were not represented in the DSM due to the resolution as well as the matched point density during DSM generation. The individual and group trees are shown in Figure 4.2. They are well delineated from the grassland and bare land. The shadows were identified and delineated in these three cases. Shadows casted over the trees were delineated as shadow on trees. The OBB in Figure 4.2 (b) appears bigger because of larger segment formed to incorporate errors of ortho-rectification.

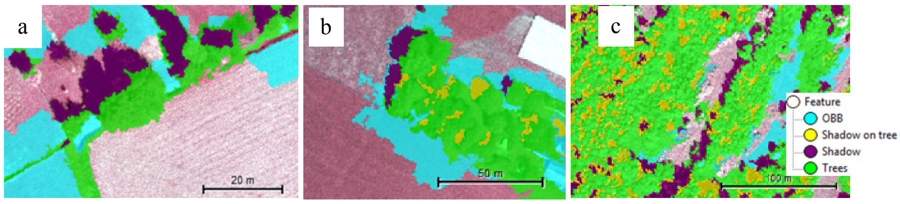


Figure 4.2: *Identification and delineation of trees in different context (a) single tree, group tree; (b) case I, (c)case II.*

Groynes are delineated accurately as can be seen from Figure 4.3 (a). The embankment with gentle slope was identified as minor embankment, while with steep slope as major embankment. The Figure 4.3(b and c) shows the identified and delineated embankments from other objects. It can be seen that major embankments are delineated satisfactorily while some parts of minor embankment with slope equal to the ground are missing.

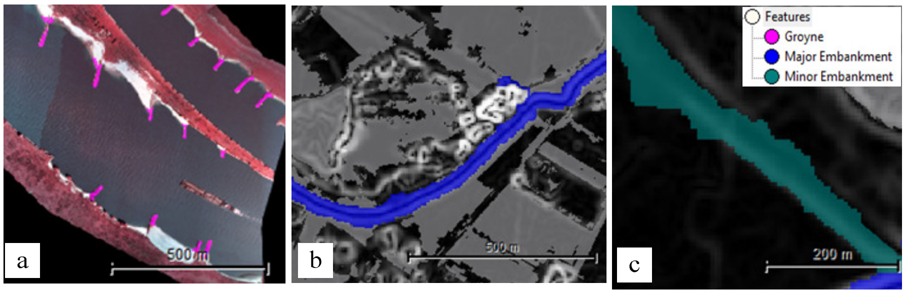


Figure 4.3: *Identification and delineation of (a) groynes (b) major embankment (c) minor embankment.*

Compound Cases

Compound cases houses were identified and delineated using the object properties and strategy explained in chapter 3.3.4. In cases where shadow was casted by trees over house, those shadows were assigned as house if it had height and high relative border to the house. The Figure 4.4 shows satisfactory delineation of houses, trees and shadows for the three different cases of houses. There is misidentification of ground as house indicated by circle in Figure 4.4 (c). However, none of the houses are misidentified as trees and none of trees as house, which is important in our study.

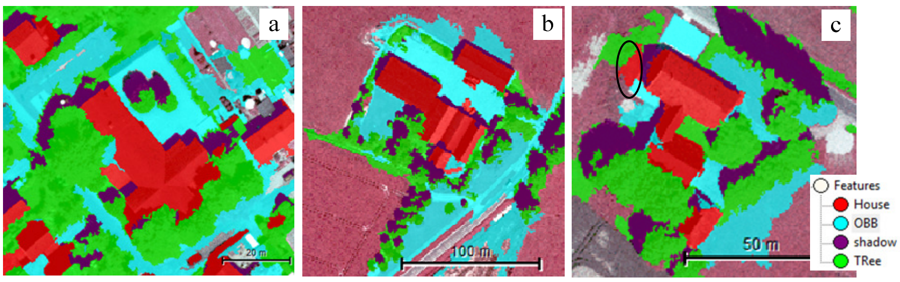


Figure 4.4: *Identification and delineation of compound case houses (a) case I (b) case II (c) case III.*

Humps present in the images were manmade. These have been identified using relational information as described in method section 3.3.4. The Figure 4.5 shows the humps delineated from the surrounding objects. A circle shows that one of it is missing. OBB was not formed due to absence of shadows.

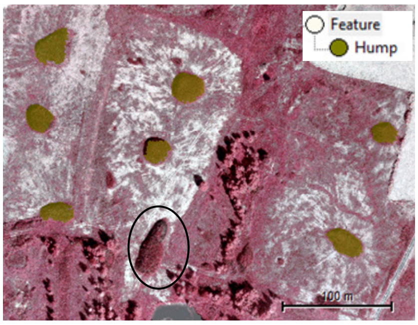


Figure 4.5: *Identified humps*

The result of feature extraction from whole image is shown in Figure 8.7 of chapter 8 (Appendix).

4.2. Quality Assessment

Quality of the extracted features was assessed for individual features. The extracted houses (Table 4.1) show that the overall quality (OQ) of 0.7283 while correctness and completeness of 0.9516 and 0.7564 respectively.

Table 4.1: *Error matrix for assessing the quality of Houses.*

		Reference Features			
		Houses	Others	Total	Correctness
Extracted Features	Houses	59	3	62	0.9516
	Not Detected	19			
	Total	78			
	Completeness = 0.7564		Overall Quality = 0.7283		

The OQ of the trees is 0.875 with correctness and completeness of 0.9459 and 0.8974. This shows that trees are more correctly identified than the houses.

Table 4.2: *Error matrix for assessing the quality of Trees.*

		Reference Features			
		Trees	Others	Total	Correctness
Extracted Features	Trees	35	2	37	0.9459
	Not Detected	3			
	Total	39			
	Completeness	0.8974	Overall Quality = 0.8750		

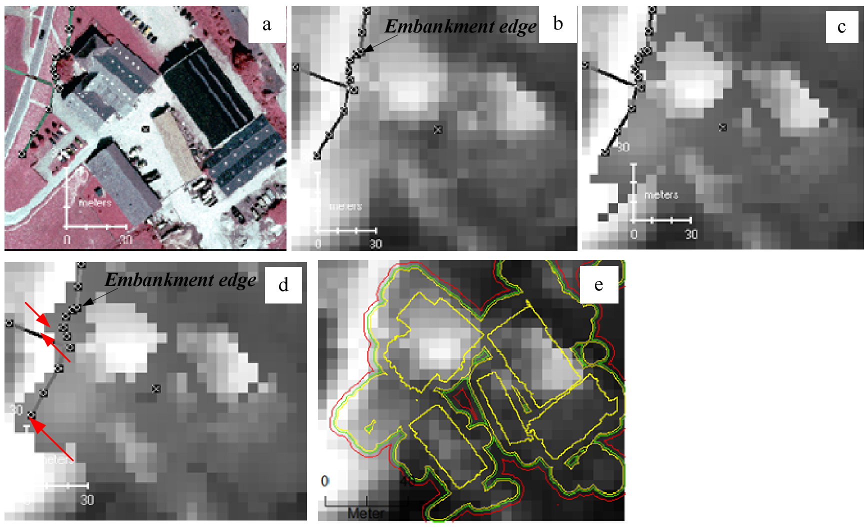
The Table 4.3 shows the quality measures for four other features. The statistics indicates good quality in extraction of features.

Table 4.3: *Per-Object statistics for Groynes, Embankments and Humps.*

Features	Per Object Statistics			
	Correctness	Completeness	Overall	Total Features
Humps	1	0.8571	0.8571	7
Major Embankment	1	1	1	1
Minor Embankment	1	1	1	1
Groynes	1	0.95	0.95	38

4.3. Object Based Buffer

Two approaches in addressing the edge pixels of features were tested with two different dataset derived from orthophoto and DSM. The result of first dataset is shown in figure 4.6. The OBB approach of buffer creation preserved the embankment (Figure 4.6 a), while normal method removed part of it (Figure 4.6 d). From Figure 4.6 (e) it can be seen that even the buffer width of one quarter the height of the building (yellow line) removes some part of embankment from DSM. Spatial profile (Figure 4.6 f) drawn along transects shows the extent of embankment is removed by normal buffer creation approach (Figure 4.6 f).



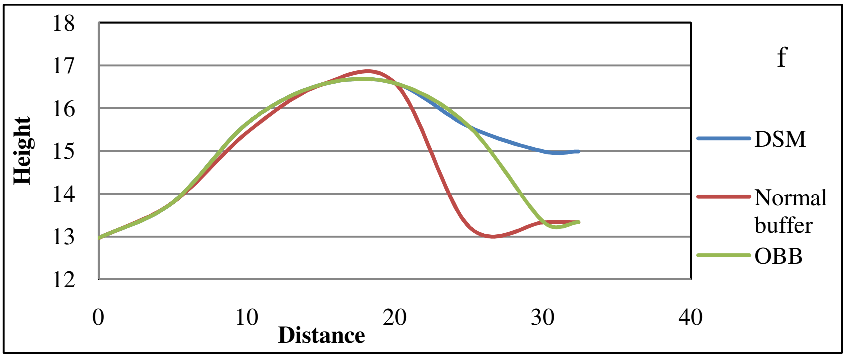


Figure 4.6 : *Application of normal buffer and OBB approach on data set I (a) orthophoto with embankment edge (b) DSM representation (c) result of OBB method (d) result of normal buffer method (e) expected area that would be removed with different buffer width (Table 3.3) from normal buffer method over laid on DSM (f) spatial profile along the transects seen in figures.*

Figure 4.7 (b) however shows that normal buffer method produces similar result as OBB method when isolated features are present. Figure 4.7 (c) shows that all the width of buffer; one half (red), one third (green) and one quarter (yellow) the height of house were able to remove the associated artefacts.

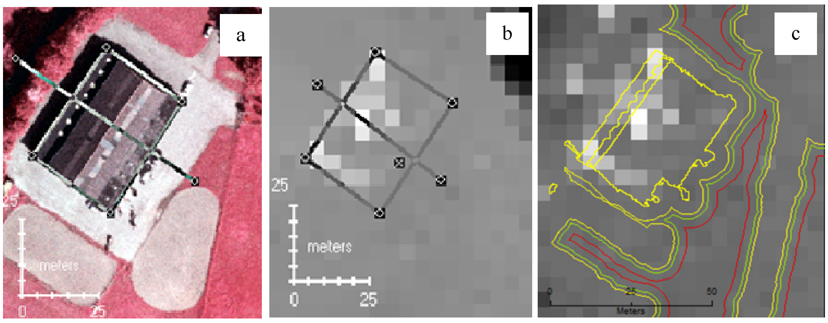


Figure 4.7: *Application of the normal buffer and the OBB approach on data set II (a) orthophoto representation (b) result from OBB and normal buffer method (same result) (c) Extent of DSM that would be removed by different width of buffer (Table 3.3).*

Although the normal buffer creation method is able to address simple cases feature, its insensitivity towards complex cases and difficulty in determining and implementing varying width conceives using OBB approach in buffer creation.

4.4. Feature Representation and Removal

Feature representations of the different cases are presented here to avoid the redundancy of the data. The OBA and OBBA approach were applied in the simple and compound cases features as well as for the whole image. The outputs are presented categorically with images and graph of spatial profile along transects drawn in images. A difference image between the DSM and Pseudo-DTM's was derived to get the spatial extent of removed features by the methods.

Simple Cases

Figure 4.8 (b) shows the DSM representation of single tree seen in orthophoto of Figure 4.8 (a). Transects drawn over the big tree in image shows that it is not well represented. The Figure 4.8 c shows that OBA method was unable to remove the pixels that lie outside the boundary of objects (shown by arrow) while OBBA was able to removed them Figure (4.8d).

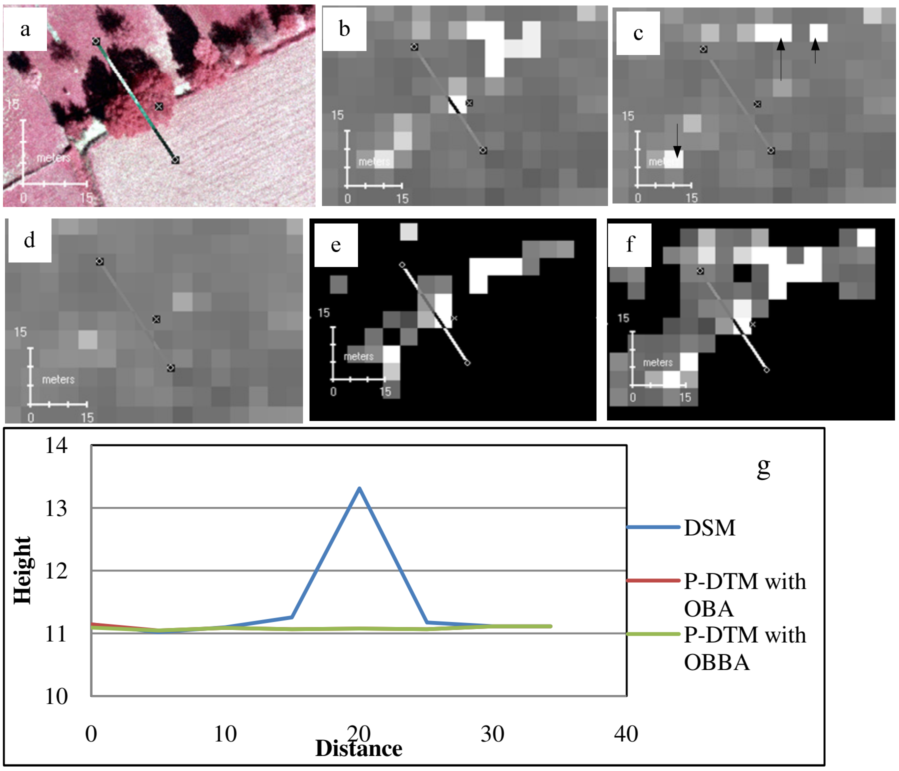


Figure 4.8: *Single tree representation (a) orthophoto (b) DSM (c) Pseudo-DTM with OBA (d) Pseudo-DTM with OBBA (e) difference of OBA (f) with OBBA (g) spatial profile along the transects seen in pictures.*

The difference image shows more pixels have been removed and replaced with interpolated values in the DSM by OBA (Figure 4.8 e) and with OBBA (Figure 4.8

f) method. Figure 4.8 (g) shows the profile in DSM and in Pseudo-DTM's created by the abovementioned two methods along transects seen in Figure 4.8.

The outline drawn in Figure 4.9 (a) shows the distinct house in orthophoto, but the representation in DSM is not well depicted (Figure 4.9 b). The Figure 4.9 (c) and (d) shows that the elevation falling outside of the outline has been removed and the extent of removal is shown in Figure 4.9(e) and (f). It can also be seen that the OBBA based method has removed the edge pixels of the corresponding features, while spike can be seen with OBA approach in spatial profile, Figure 4.9 (g).

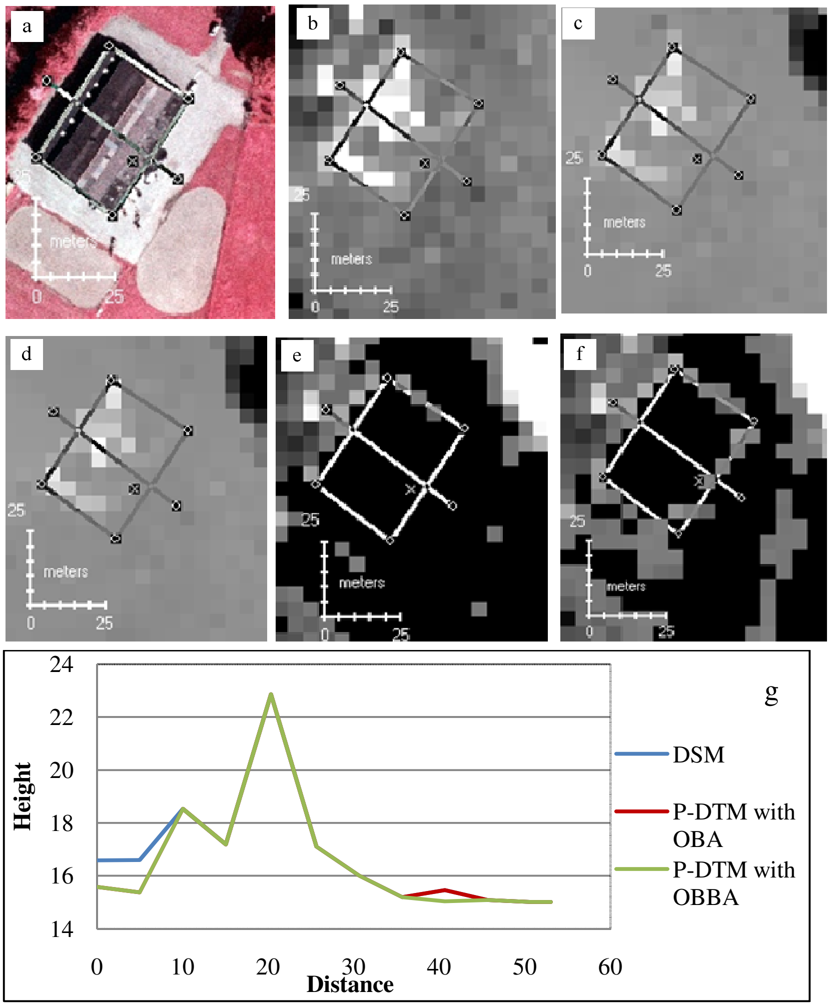


Figure 4.9: *Single house and its representation (case I) (a) outline in orthophoto (b) DSM (c) Pseudo-DTM with OBA (d) Pseudo-DTM with OBBA(e) difference from OBA (f) difference from OBBA(g) spatial profile along the transects seen in pictures.*

Figure 4.10 shows the second case of single house considered in the study. Here the house is well depicted than in first case. In Figure 4.9 gable type roof is present such that points were matched only for one part of roof while in Figure 4.10 flat roof is present and points are matched properly. Figure 4.10 (b) shows that DSM extent falls beyond the outline of the house which are artefacts for an HDM. The OBA approach was unable to remove those artefacts (shown by arrows) in Figure 4.10(c), while the OBBA approach was able to remove those pixels (Figure 4.10 d). The difference image (Figure 4.10 e, f) shows that more pixels have been removed by OBBA approach. This can also be seen in the spatial profile (Figure 4.10 g) where the extent of house is smaller in the OBBA approach than in the OBA and the DSM.

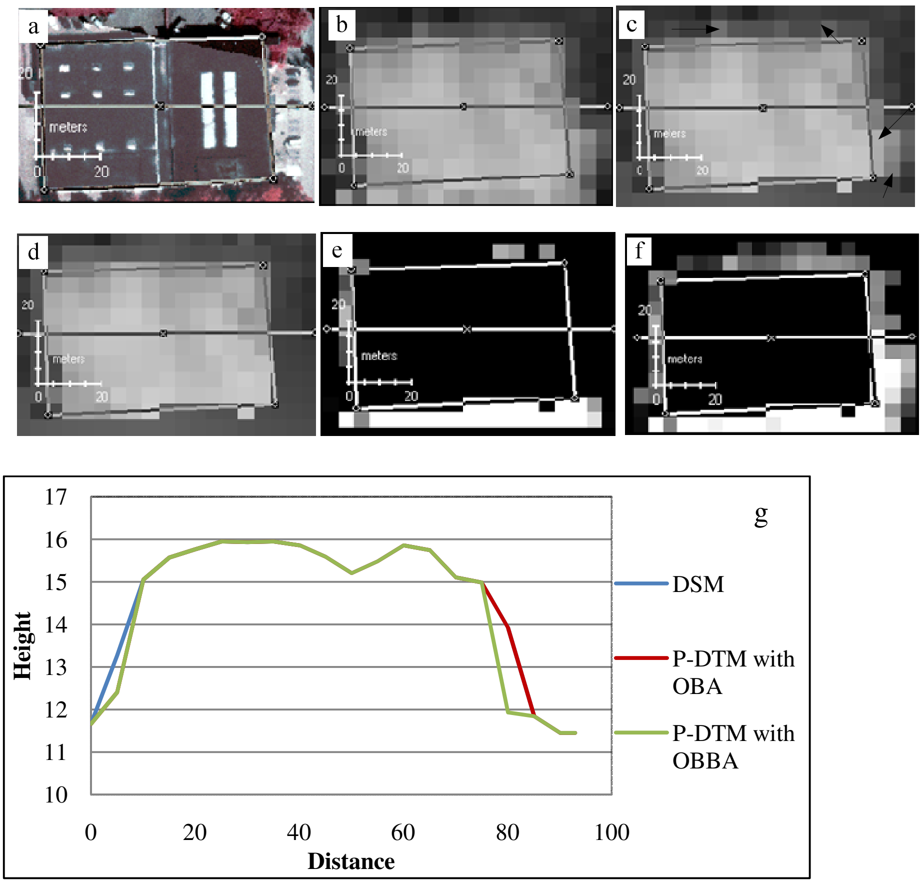


Figure 4.10: *Single house and its representation (case II) (a) outline in orthophoto (b) DSM c) Pseudo-DTM with OBA (d) Pseudo-DTM with OBBA(e) difference from OBA (f) difference from OBBA(g) spatial profile along the transects seen in images.*

The first case of group trees is shown in Figure 4.11. Individual trees can be seen within the clump (Figure 4.11 a) but their representation is single blob (Figure 4.11 b). It can be seen that the OBA method produces spikes as shown by arrows in Figure 4.11c and spatial profile (Figure 4.11 g) due to the artefacts. The OBBA has removed the edge pixels as shown in Figure 4.11 (d) and the spatial profile (Figure 4.11 g).

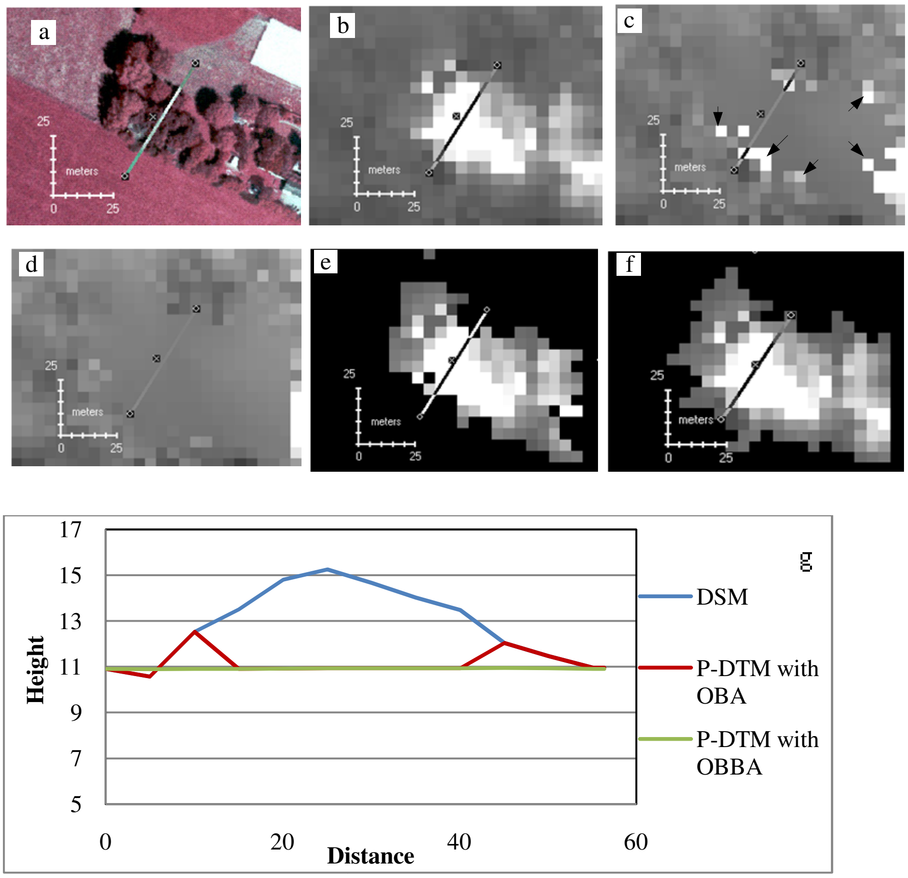


Figure 4.11: *Tree clump and its representation (Case I) (a) orthophoto (b) DSM (c) Pseudo-DTM with OBA (d)Pseudo-DTM with OBBA (e)difference from OBA (f) difference from OBBA (g) spatial profile along the transects seen on pictures.*

The second case of group trees considered is more heterogonous as seen in Figure 4.12 (a). The variation in trees height can be seen on profile drawn along the DSM. The OBA method was unable to remove artefacts associated with shadow or occlusion (Figure 4.12 c) as indicated by arrows. The OBBA approach in this case was also unable to remove few pixels (Figure 4.12d) from the DSM (shown in arrow) due to an identification error.

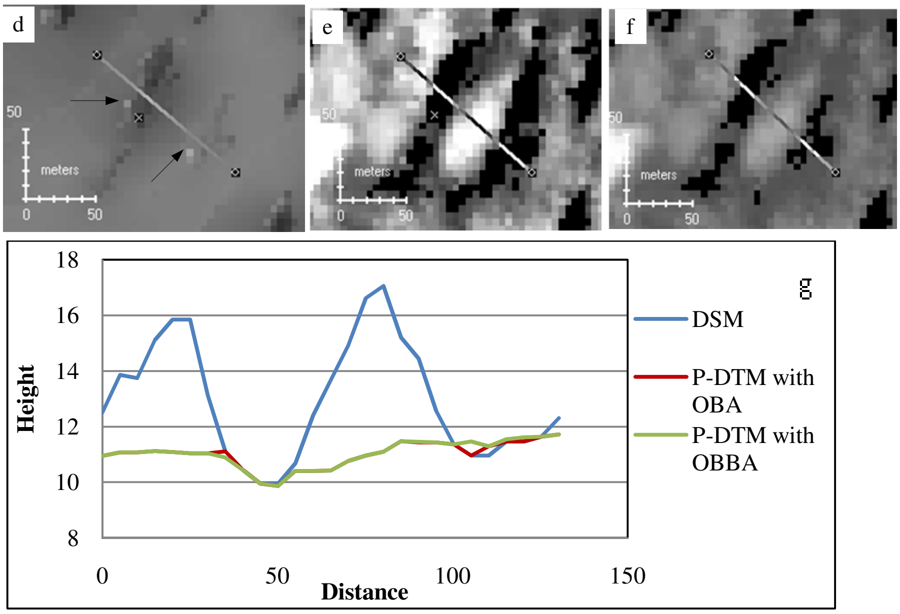


Figure 4.12: *Tree clump and its representation (a) orthophoto (b) DSM c) Pseudo-DTM with OBA (d) with OBBA (e) difference from OBA (f) difference from OBBA approach (g) spatial profile along the transects indicated in pictures.*

Compound cases

The compound cases as defined in experimental setup consist of individual features that occur in conjugation with each other. Three cases of houses present along with trees and shadows were considered in the experiment. The Figure 4.13 (b) shows that the DSM representation of house falling outside the boundary. The OBA approach was unable to remove the edge pixels indicated by arrows in Figure 4.13 (c). The OBBA approach however has preserved the house along the boundary and removed the artefacts. The spatial profile (Figure 4.13 g) also shows that the OBBA approach has removed more area belonging to artefacts than the OBA approach.

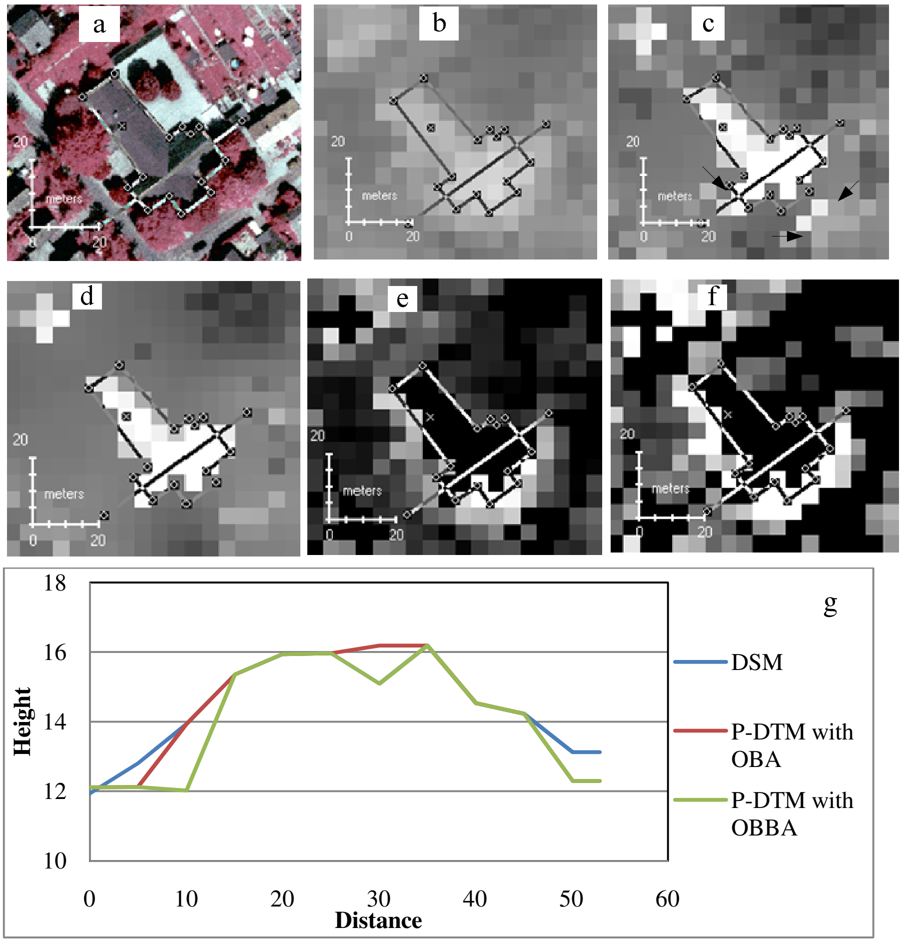


Figure 4.13: *Representation of house along with tree and shadow(a) outline of house in orthophoto (b) representation in DSM (c) Pseudo-DTM with OBA (d)Pseudo-DTM with OBBA (e)difference from OBA (f) difference from OBBA(g) spatial profile along the transects indicated in pictures.*

The result of second compound case is shown in Figure 4.14. The DSM shows that the house representation is not good on its own Figure 4.14(b). The arrows on Figure 4.14 (c) show the pixels not removed by the OBA method. While those pixels are removed in the OBBA method (Figure 4.14 d). The difference images (Figure 4.14 e and f) show the extent removed in both method. The spatial profile shows high variability in height as the transect passes through ground and houses (Figure 4.14 g).

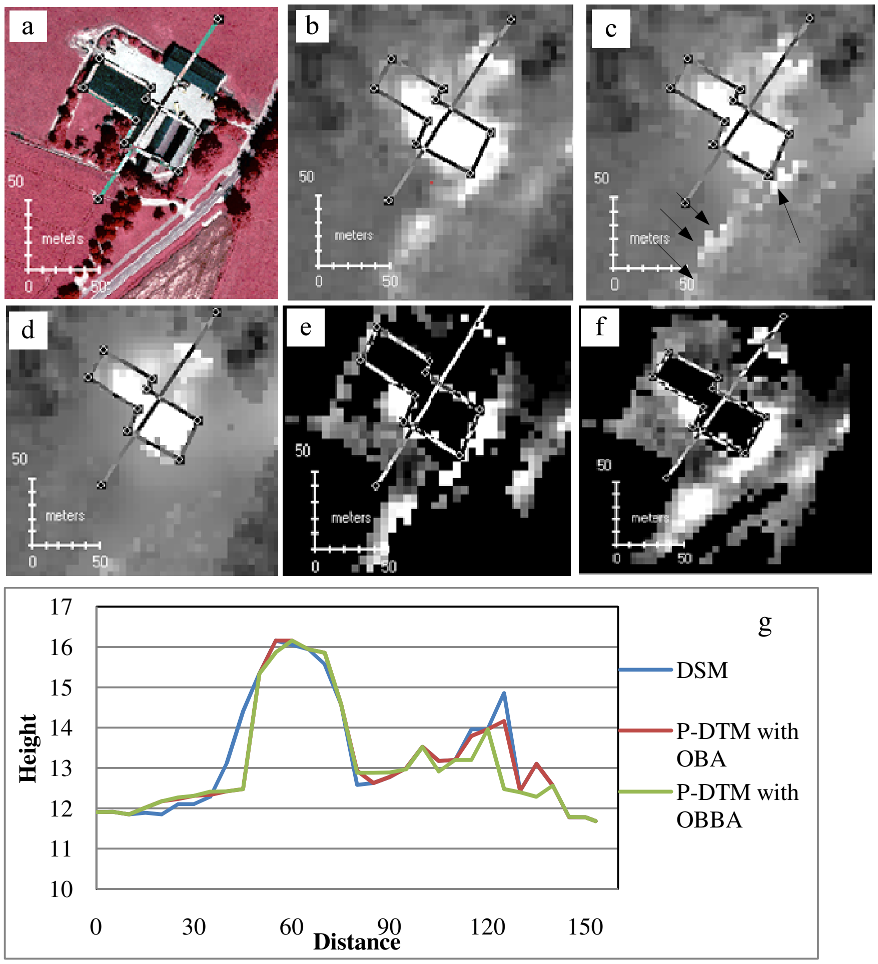


Figure 4.14: *Representation of house along with tree and shadow(a) outline of house in orthophoto (b) representation in DSM (c) Pseudo-DTM with OBA (d)Pseudo-DTM with OBBA (e)difference from OBA (f) difference from OBBA(g) spatial profile along the transects indicated in pictures.*

The third case of house and vegetation occurring in conjugation with each other is shown in Figure 4.15. In this figure it can be seen that trees are taller than house. The shadows of some trees occupy large part of road as outlined in the orthophoto (Figure 4.15 a). The shadow is seen as spike with positive value gradually decreasing as seen from the spatial profile drawn along the trees and shadows (Figure 4.15 g).

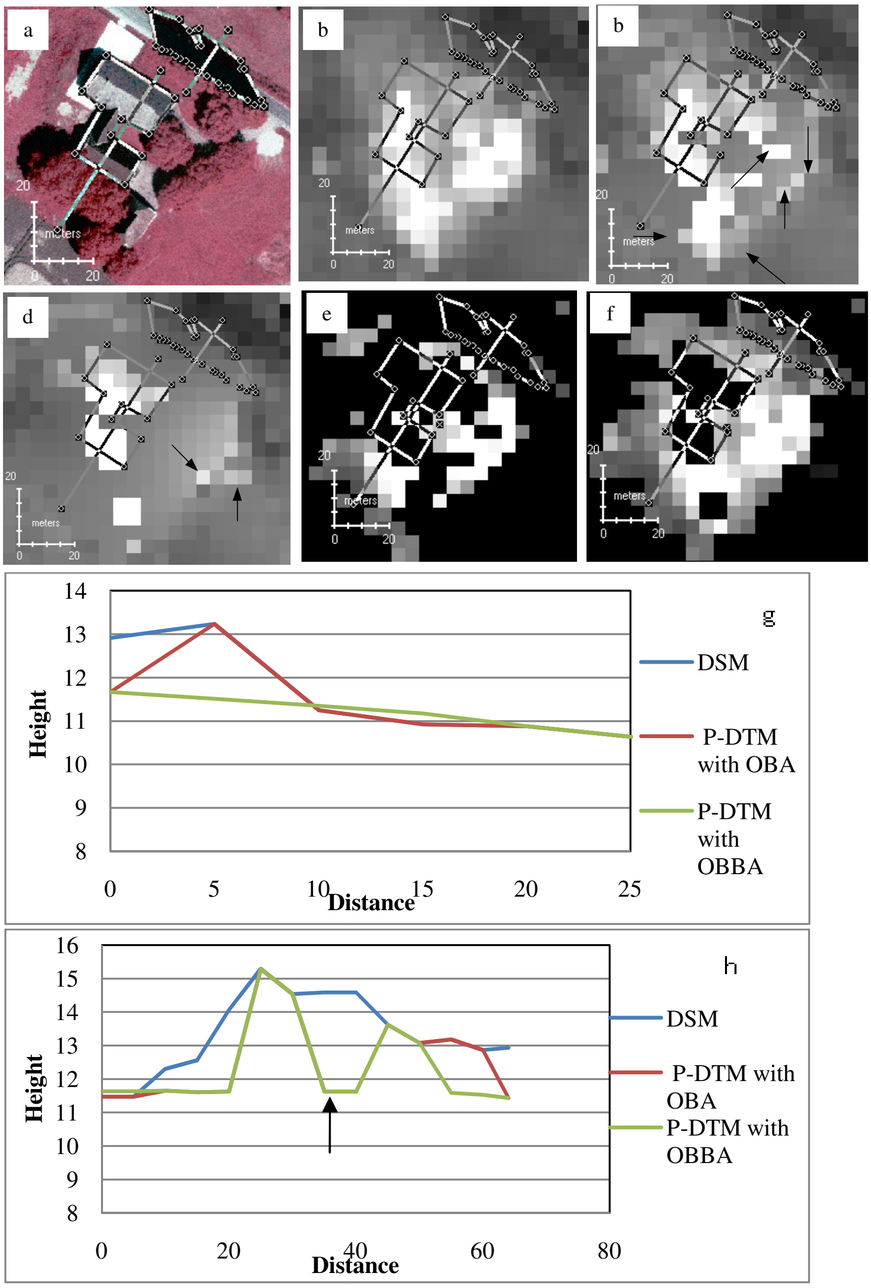


Figure 4.15: *Representation of house along with tree and shadow (a) outline of house in orthophoto (b) representation in DSM (c) Pseudo-DTM with OBA (d)Pseudo-DTM with OBBA (e)difference from OBA (f) difference from OBBA(g) spatial profile along the shadow as seen in a (h)Spatial profile along the transects seen in pictures.*

The OBA method leaves many artefacts as indicated by arrows in Figure 4.15 (c). In this case the OBBA was also unable to remove some pixels which can be either due to small size of OBB or error of ortho-rectification as the features are well delineated (Figure 4.15 c). The difference image shows the extent of house preserved in Pseudo-DTM's. Spatial profile in Figure 4.15 (h) shows that the artefacts have been removed by the OBBA method. The DSM shows continuous profile while Pseudo-DTM with the OBBA method shows the gap in between the house (shown by arrow) indicating the artefacts have been removed.

The compound cases such as embankment and depression with tree could not be identified as there were no such cases present in the study area. The results from the simple and compound cases show that the method with the OBBA approach was able to remove the features of various complexities along with the artefacts caused due to shadow and occlusion during DSM generation. The humps and embankments are not been presented as they were not removed during the removal process.

Both the approaches of feature removal were applied in the whole image. The results showed that the OBBA approach removed the artefacts while OBA approach was unable to remove the artefacts. The results are presented in Chapter 8 (Figure 8.8 and 8.9).

4.5. Accuracy Assessment

Three different approaches were applied to assess the quality of the Pseudo-DTM's derived from the DSM. The approaches were applied in different cases features considered in the experimental setup of 3.3.1. LIDAR DSM (bare earth and surface features) and DTM (bare earth) are used as reference surface.

According to the first approach described in the accuracy assessment of section 3.3.7, difference images were derived for individual and group trees. The difference images and their statistical analysis are presented in Table 4.4. The result shows that the OBBA has lower standard deviation than the OBA approach in all three cases. The minimum values are also lower meaning that the trees and artefacts have been removed by OBBA approach. The low standard deviation also indicates that the Pseudo-DTM from OBBA approach corresponds well with LIDAR DTM.

Table 4.4: *Statistics for the three cases in LIDAR DTM and Pseudo-DTM's. Unit are in meters*

			Group Tree			
	Singletree		Case I		Case II	
Parameters	OBA	OBBA	OBA	OBBA	OBA	OBBA
Minimum	-2.6650	-1.0892	-3.2147	0.2998	-11.9340	-3.1593
Maximum	0.1850	0.1805	1.0928	1.1476	1.0105	0.6771
Mean	-0.3310	-0.2440	0.4120	0.7710	-1.3300	-1.1090
Std. Deviation	0.4130	0.2270	0.5600	0.1470	1.1440	0.6350

The hill shade analysis also shows that the OBA approach has produced many artefacts indicated by arrows in Figure 4.16 (c). It can be seen that Pseudo-DTM obtained using OBBA (Figure 4.16 d) approach has smoothened the terrain when compared to the LIDAR DTM (Figure 4.16 a). While, comparison between the photogrammetric DSM and Pseudo-DTM from the OBBA approach shows that most of the trees and artefacts have been removed (Figure 4.16 b, d). Some trees are still because they were unidentified.

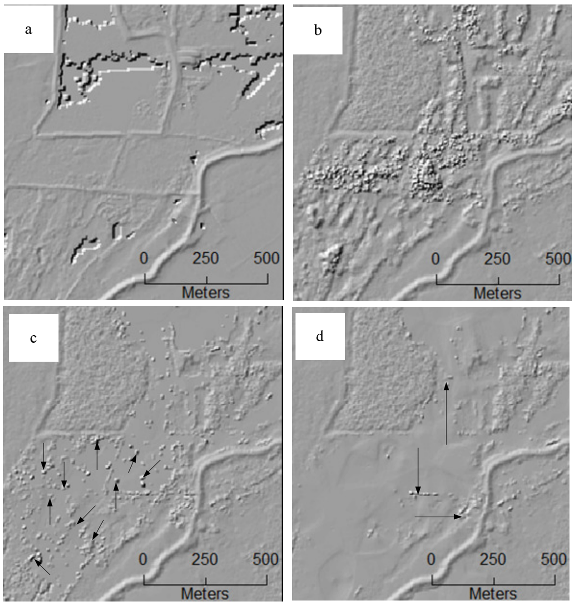


Figure 4.16: *Hill shade analysis (a) LIDAR DTM (b) photogrammetric DSM (c) Pseudo-DTM created with OBA (d) Pseudo-DTM with OBBA.*

The second approach involved the extraction of height values from, photogrammetric DSM (indicated as DSM in Table4.5) and Pseudo-DTM's with location attributes from the field data (Table 4.5). The differences were calculated between field values, DSM and pseudo-DTM with OBA and OBBA approach. The result shows that there are discrepancies in height values between photogrammetric DSM and filed data. The high standard deviation between field data and pseudo-DTM's as seen in columns (1-3) and (1-4) indicates that trees have been removed from Pseudo-DTM's. However, some errors are associated with positional accuracy of the field data.

Table 4.5: *Statistics for individual trees collected from field. Unit in meters*

Parameters	Field Height (1)	DSM(2)	OBA(3)	OBBA(4)	(1-2)	(1-3)	(1-4)
Minimum	14.34	10.48	9.11	9.11	0.61	3.67	3.67
Maximum	43.08	21.79	13.29	13.29	29.70	31.58	31.58
Mean	25.70	13.24	11.06	11.06	12.45	14.64	14.64
Standard Deviation	5.66	2.26	0.79	0.79	5.63	5.76	5.76

The third approach involved the comparison of the profiles between LIDAR DSM, Photogrammetric DSM, and Pseudo-DTM's along transects. This gave comparative feature representation in different data source and competence of the correction procedure either to remove or retain the features. The standard deviation calculation on the other hand gave the deviation of the elevation values of the respective surface models with reference to LIDAR DSM. A higher standard deviation of yellow line infers that the area has not been well represented in the photogrammetric DSM while lower standard deviation shows the correspondence with LIDAR DSM. A lower standard deviation in the Pseudo-DTM's shows that the features are either maintained or removed from DSM. The Table 4.6 shows the abbreviation used in spatial profile presented below. The Figures are presented only to show transects drawn over different DEM's.

Table 4.6: *Description of the abbreviation used in legend of profiles.*

Abbreviation	**Profile comparison**
L-DSM	Elevation values from LIDAR DSM
P-DSM	Elevation values from photogrammetric DSM
P-DTM OBA	Elevation values from Pseudo-DTM with OBA approach
P-DTM OBBA	Elevation values from Pseudo-DTM with OBBA approach
Standard deviation	
L with DSM	between Lidar DSM and photogrammetric DSM
L with P- OBBA	between Lidar DSM and Pseudo-DTM with OBBA approach
L with P-OBA	between Lidar DSM and Pseudo-DTM with OBA approach

House representation is distinct in L-DSM (Figure 4.17 b) while poorly depicted in P-DSM (Figure 4.17 c). The profile of standard deviation between L-DSM with P-DSM (Figure 4.17 f) also shows high standard deviation (area between red and black arrow) indicating half part of house is not represented in P-DSM. The house extent starts from green arrow and ends at black arrow in L-DSM, however the extent ends at red arrow in P-DSM. The OBA and OBBA approach have preserved the house represented in P-DSM as seen by low standard deviation (between green and red arrows) in Figure 4.17 (f).

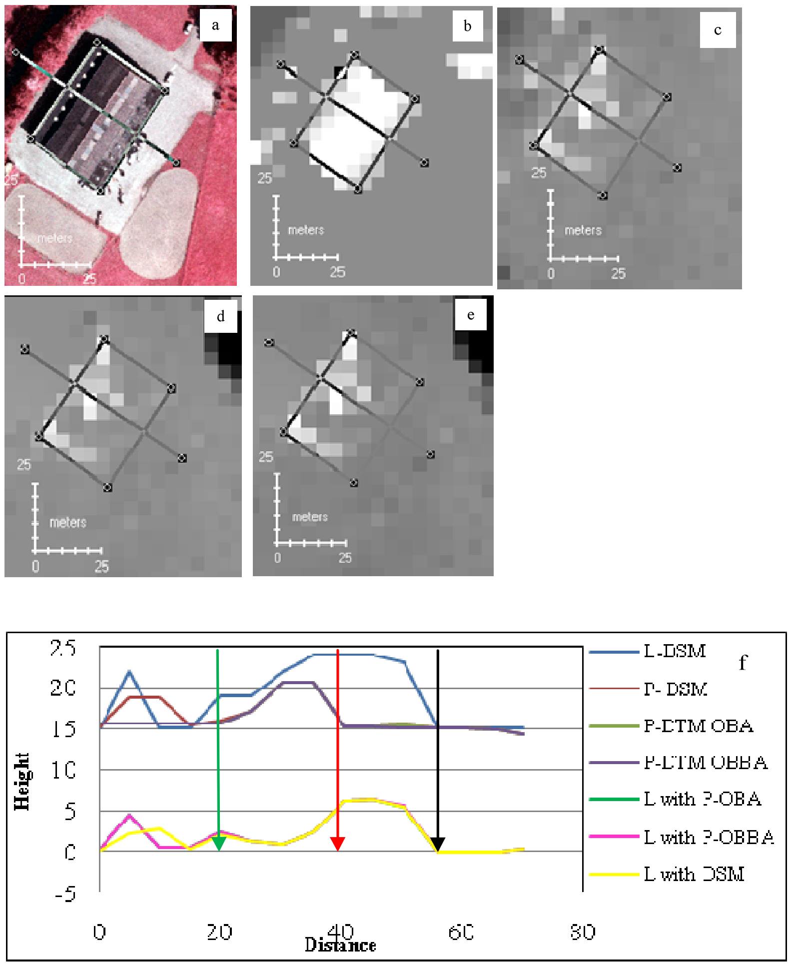


Figure 4.17: *Accuracy assessment of single house (a) orthophoto (b) LIDAR DSM (c) Photogrammetric DSM (d) Pseudo-DTM with OBA (e) Pseudo-DTM with OBBA (f)spatial profile of height and standard deviation(with respect to L-DSM) along the transects seen in pictures.*

Embankment profile comparison between the three different data shows that they are maintained in Pseudo-DTM's given the representation in the photographic DSM. The profiles of standard deviation presented in yellow, pink and green lying very close to zero shows that the minor embankments have been maintained in the Pseudo-DTM's (Figure 4.18). The height difference is around 1m while the curvature is similar in the L-DSM and P-DSM (Figure 4.18 e). Profile along the transect I (Figure 4.18 e) shows that minor embankment has been maintained by both approaches, while along the transect II (Figure 4.18 f) some part are missing in both approaches.

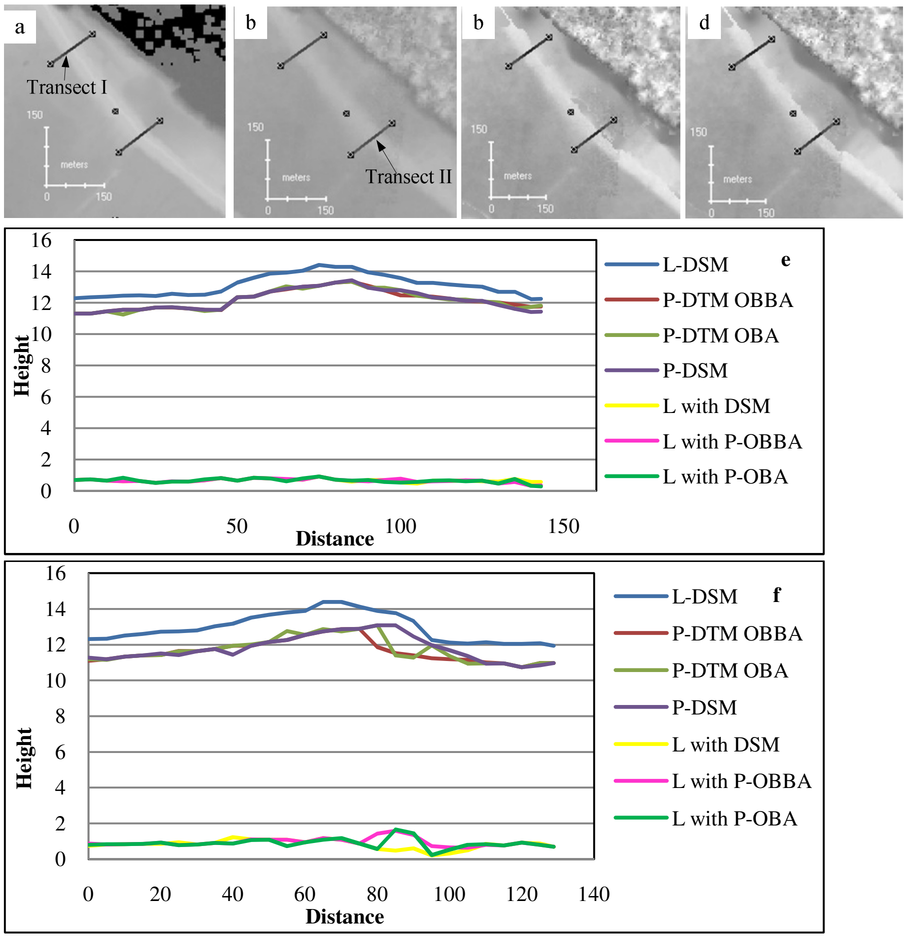


Figure 4.18: *Profiles along the transects I and II on a) LIDAR DTM, (b) Photogrammetric DSM, (c) Pseudo-DTM with OBA, (d) Pseudo-DTM with OBBA, (e) Profile along transect I and (f) profile along transect II as seen in pictures.*

Major embankment profiles along two transect show that they have been maintained by the correction procedure (Figure 4.19 e, f). The first transect profile of P-DSM corresponds with L-DSM although there are some difference in height. The standard deviation is close to zero. The OBA and OBBA approaches are also to maintain the major embankments (Figure 4.19 c, d). The second transect shows high deviation in values due to presence of trees in P-DSM in the area. Both the approaches have removed trees and maintained embankment (Figure 4.19 f).

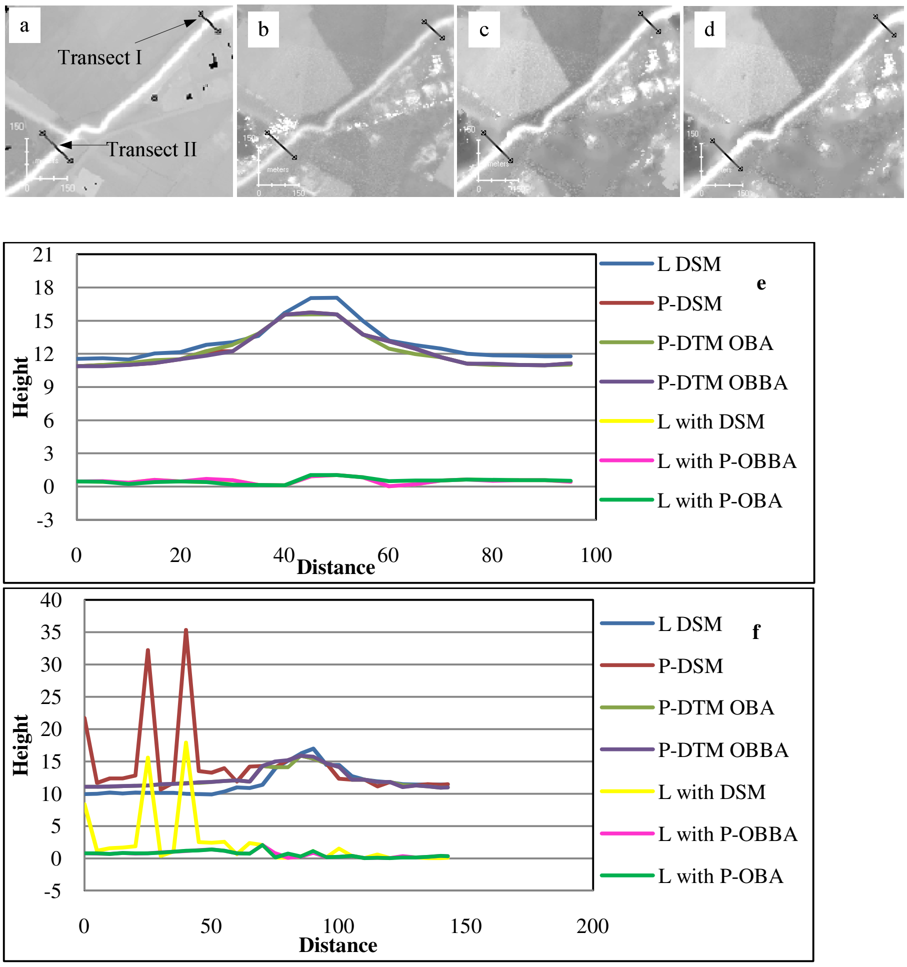


Figure 4.19: *Profiles along the transects I and II on (a) LIDAR DTM, (b) Photogrammetric DSM, (c) Pseudo-DTM with OBA, (d) Pseudo-DTM with OBBA (e) Profile along transect I and (f) profile along transect II as seen in pictures.*

First compound case profiles drawn along transect in figures show that there is large variation in height and extent representation between LIDAR and Photogrammetric

DSM. High standard deviation between the green and red arrows on Figure 4.20(f) shows that the tree is not represented, while low standard deviation between red and black arrow shows the area with tree, while the area between the red and black arrow has low standard deviation indicting the house along the transect. The low standard deviation in profile of OBA (green line) and OBBA (pink line) method shows they have maintained the house.

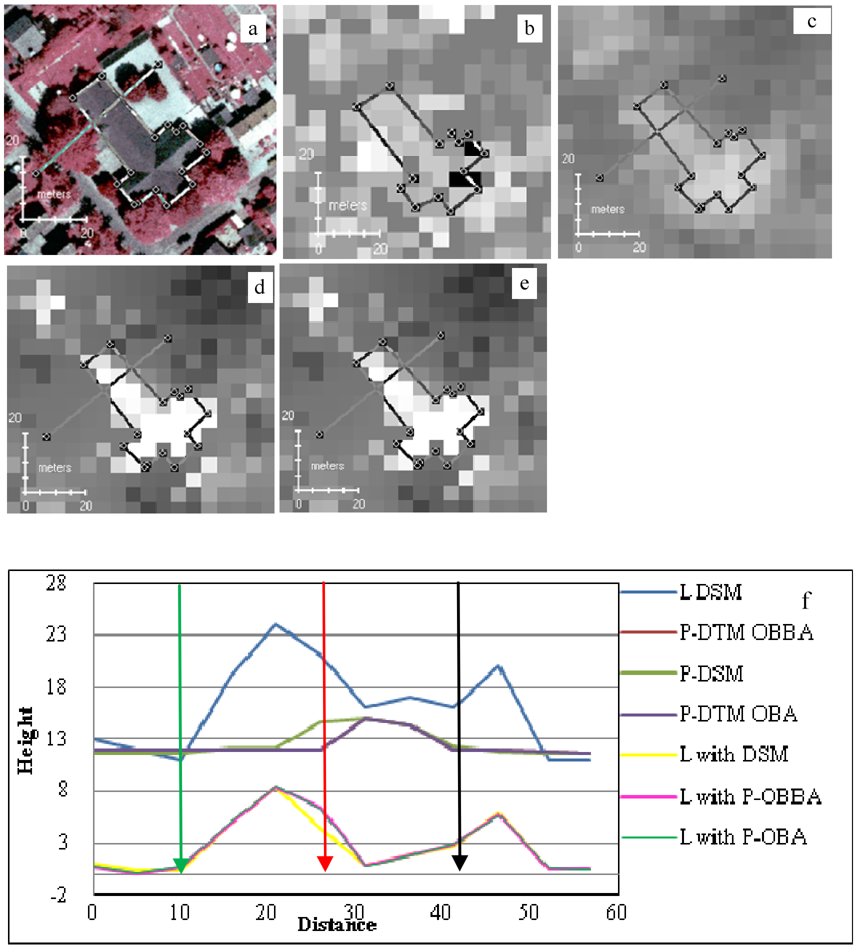


Figure 4.20: *Accuracy assessment of compound case I, representation on (a) orthophoto (b) L DSM (c) P-DSM (d) Pseudo-DTM with OBA (e) Pseudo-DTM with OBBA (f) spatial profile of height and standard deviation (with respect to L-DSM) along the transects seen in pictures.*

The profile of the second compound case of house is shown in Figure 4.21. The variation between the L-DSM and P-DSM is shown by yellow line in Figure 4.21 (f). Given this variation the OBA and OBBA approaches have maintained the house along transect as shown by low standard deviation (green and yellow colour lines).

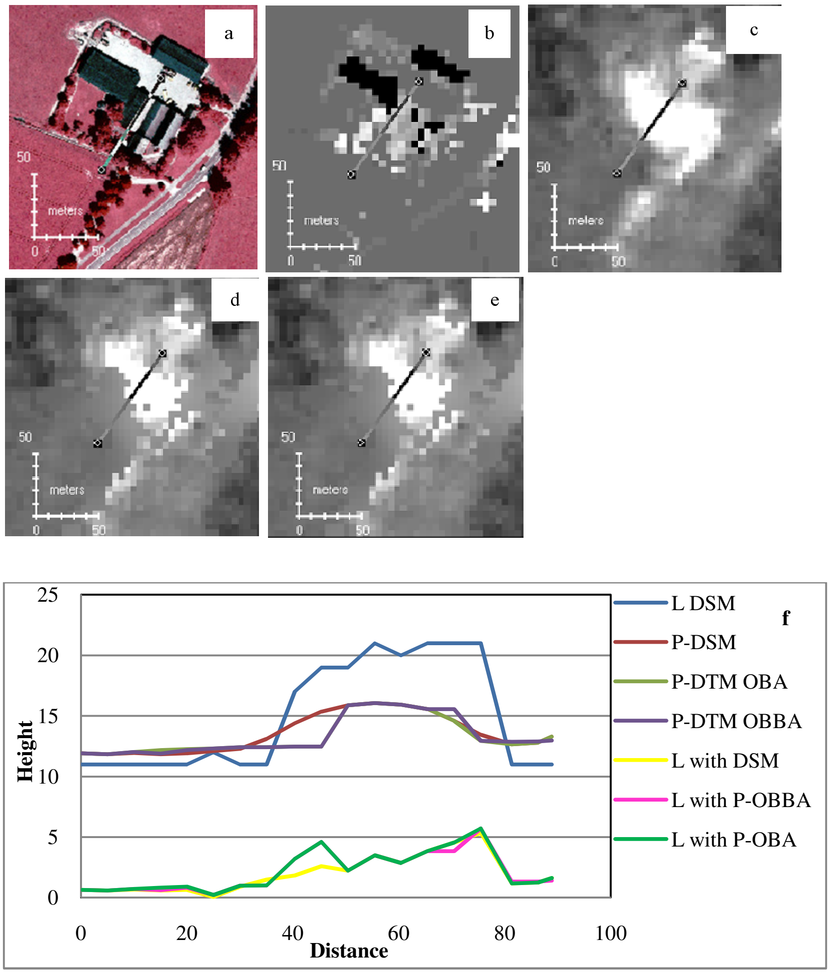


Figure 4.21: *Accuracy assessment of compound case II, representation on (a) orthophoto (b) L DSM (c) P-DSM (d) Pseudo-DTM with OBA (e) Pseudo-DTM with OBBA (f) spatial profile of height values along with standard deviation with respect to L DSM along the transects as seen in pictures.*

5. Discussion

The overall strategy of the research to get Pseudo-DTM was the use of OOA to extract the permeable features from orthophoto and DSM and then use the extracted vector file to remove and interpolate the height values in DSM. This chapter provides discussion on the method adopted in the research and the significance of corrected Pseudo-DTM on hydrodynamic modelling.

5.1. Methodological Approach

The method employed in the research was able to identify, delineate and remove the permeable features from DSM using OOA. The correction procedure operates only in the area defined by extracted polygon map of permeable features. As such, only the values defined in extracted maps are altered. For proper results, misidentification between the houses and trees should be avoided.

5.1.1. Feature Identification and Extraction

Features were identified and extracted using OOA. The integration of different type of information were possible as layers were treated as grey level values (brightness) in OOA (Baatz, 2004). The objects formed by group of pixels gave flexibility in deriving various object properties based on shape, colour and context (Blaschke, 2004). These properties integrated by use of fuzzy logic through rule sets helped in identifying the features and artefacts. Thus the integration helped in overcoming the limitations faced in object extraction by Sarker (2009) using pixel based analysis.

The simple and compound cases features of various complexities considered in the experimental setup provided the framework for formulation of strategy in identification and delineation of features. Strategy of elimination thus, applied to extract features of interest from the orthophoto and DSM proved to be useful as the identified features were not used in the further analysis which saved computation time as well as avoided conflict between different features. The experimental setup also provided framework for developing rule sets for application on the whole image. This helped in finding the representation of features from orthophoto in DSM via the geographic link. The outline of features drawn in photograph helped in visualisation of the extent of features along with the artefacts of shadow and occlusion in DSM.

Height from DSM as grey level value integrated with photograph from early stage of segmentation constrained the formation of segment between the elevated and ground objects of similar spectral properties. Authors such as Baltsavias et al. (1995), Haala and Bernner (1999) have considered the use of DSM to improve delineation of building and trees when spectrally similar features are present. However, the result depends on the quality of the feature represented in DSM. Nevertheless, some imperfections were present due to high spectral similarity of features and quality of DSM.

Houses identification and extraction were the difficult part in feature extraction process. The spectral similarity of houses with road, constructed objects and even with shadows caused misidentification of features (van der Sande et al., 2003). The misidentification of road or constructed feature as house does not have much implication in HDM as it will not be removed from DSM anyway. However, house should not be misidentified as tree as that would be removed from DSM. The tree also shouldn't be misidentified as house as that would retain it thus leading to erroneous prediction result from HDM. The use of NDVI avoided such misidentification. NDVI and standard deviation in NIR with height from DSM was able to differentiate between trees, shrubs and crops. The vegetation with height less than 20 cm was considered as grasslands they were spectrally similar and behave similarly as grass in HDM. The quality assessment result in section 4.2 shows that the overall qualities of the extracted features are satisfactory. The low overall accuracy in case of houses is due to missing houses, one of the reasons is houses being not well represented in the DSM. The overall accuracy of trees shows that most of the trees are removed from the DSM. The results are satisfactory; yet, there remains some difficulty in identification and delineation of features due to presence of spectrally similar objects, differing illumination of aerial photos and limited spectral and textural information.

5.1.2. Feature Representation and Removal

With same orientation of both the images and same geographic coordinates, the features from orthophoto were located in DSM along the overlapping coordinates. The representation of features and formation of artefacts in DSM largely depends on the input data quality, overlap of the images and density of correctly matched points (Lemaire, 2008). Because the images used had overlap configuration of 30/60% (side/forward) they had more effect of occlusion and shadow (Lemaire, 2008). As such, less points were correctly matched which resulted in incorrect representation of features. As a result, in some cases, distinct features in orthophoto was not well depicted in DSM (refer to section 4.3). The compound case features were represented as a single blob due to the resolution of DSM. The artefacts of shadow and occlusions were represented as spurious spikes as seen in example of third compound case in section 4.3.

Strategy of elimination in feature identification and delineation avoided formation of OBB in features such as hump or embankments that occur near to house or trees which otherwise were removed in normal buffer creation method. OBB was able to cover the artefacts in the DSM blobs. The OBB approach in some cases seems to be independent of height of object is due to use larger scale in segmentation to incorporate errors in orthorectified aerial photographs. A orthorectified image contains some positional errors (Baltsavias et al., 1995), and has to be removed. James et al. (2006) used morphological dilation to include errors of ortho-rectification during DTM generation by use of orthophoto and LIDAR DSM. The OBB however depends on appropriate choice of scale parameter during segmentation, a small scale might not consider all the variability while a large scale includes more than necessary. A little bit larger scale is preferred as it incorporates all the variability and avoids formation of spikes. The formation of OBB is limited to the features itself due to use of contextual information. The normal buffer creation method was discarded due to insensitivity towards nearby features (removal of embankments near house-section 4.3) and difficulty in implementing and determining of appropriate buffer width applicable for the whole image.

As a prerequisite for feature removal, correct identification of the features was necessary. The most important aspect is that houses shouldn't be misidentified as tree or vice versa as that would remove and retain the features in DSM. Theoretically, in cases where trees occur with embankment and trees on inclined areas should not produce spurious pits or spikes as the interpolated values are used to replace the removed values. This should as well preserve the curvature of ground. However, previous studies suggests that IDW produces errors in hilly areas (Erdogan, 2009; Longley et al., 2005), and use of interpolation causes smoothening of the surfaces (Zhilin Li et al., 2005). The fact that the study area was relatively flat and large number of elevation point generated allowed satisfactory results.

The two approaches considered during feature removal process differed in consideration of OBB. The OBA approach was unable to remove the artefacts of shadow and occlusion from DSM while the OBBA method removed the artefacts. The formation of OBB is important aspect of the method as it largely determines the quality of Pseudo-DTM. Although there is trade off of more area being removed than necessary, in HDM it is better to have smooth surface rather than surfaces with spikes. Accuracy assessment shows that the OBBA approach has reduced standard deviation than by OBA approach due to consideration of OBB. The assessment procedure from third approach however, does not provide completeness in assessment procedure as the representation of features differs in LIDAR and photogrammetric DSM. Although the OBBA approach has produced satisfactory results, it has not been tested in cases where trees occur on embankment or depression and hilly areas and should therefore be tested in further studies.

5.2. Significance in Hydrodynamic Models

The aim of the research was to develop a method for accurate surface representation needed for HDM. The surface representation in Pseudo-DTM thus should be able provide the velocity, water depth and travel time as in reality rather than lower or higher prediction by either use of DSM or DTM. The Pseudo-DTM from OBBA approach has more accurate representation of reality than the OBA approach as such the water velocity should be higher due to absence of artefacts. The significance of the correction or use of Pseudo-DTM however depends upon the frequency of the flood event to be modelled. Frequent floods with 2-10 years return period will have significant effect while flood with 100-500 years of return period has less significance (Sanders, 2007). Also significance depends on research interest on deriving bulk characteristics of flood or local hydraulics of flow parameters like, flow velocities, depth and pattern of inundation (Mark and Bates, 2000).

A Pseudo-DTM of higher resolution is preferred over lower resolution as features are well represented and topographic variation is well preserved. In flood modelling, aggregation of higher to low resolution gives better result as some features are preserved due to averaging rather than having no representation in lower resolution elevation models (Cook and Merwade, 2009; Kenward et al., 2000). The use of high resolution topographic representation and efficient simulation however has tradeoffs (French and Clifford, 2000), and proper choice largely depends on research interest.

5.3. Limitations

Some limitations of the method come with the limitation of photogrammetry to map surface such as water. In photogrammetry the water surface causes problems in matching process due to movement of water and also the refraction in air-water interface. This causes water surface to appear higher than the surrounding areas (Westaway et al., 2000). Direct use causes erroneous prediction by HDM’s. Also, in HDM elevation of the water bed is necessary instead of water surface. Since no information about the water bed is available, any correction procedure applied to correct water area will lead to erroneous results.

In case of depression with trees, depression if completely covered by trees cannot be maintained as depression itself, it will be generalised by the ground values as there is no information about the depth of depression. The method applicability in cases where trees occur on embankments or depression and features occurring in sloped areas have not been tested due to lack of such areas in study area. As such application in such area is suggested.

6. Conclusion and Recommendations

The aim of research was to develop a method to generate Pseudo-DTM using OOA and GIS tools from photogrammetric DSM. Four objectives were formulated to aid the generation procedure. The first objective was fulfilled as the permeable features along with artefacts were extracted using OOA. The rule sets integrated the height and spectra information as grey level values and used the spectral, contextual and relational information to identify and delineate the simple as well as compound features. The quality assessment of above 85 % for trees, humps, groynes, embankments and 70% (c.f. 4.2) for houses showed satisfactory result in identification of features. However, some misidentification and imperfection exist due to limited spectral and textural data and errors in aerial photos such as illumination.

The different cases considered in the experimental setup provided with the occurrence of features in various condition in photograph and their subsequent representation in DSM. The features with same overlapping geographical coordinates were linked to finding the corresponding feature in DSM. Feature removal from DSM was carried out using the two approaches. The OBA approach was able to remove the feature but not the associated artefacts. This necessitated in formation of object based buffer for addressing the artefacts. The OBBA approach incorporated OBB to remove the artefacts from DSM such that the standard deviation was lower than that of OBA as seen in results from first assessment procedure (c.f. Table 4.4). The accuracy assessment using LIDAR DSM was difficult as LIDAR DSM had all the surface features while Pseudo-DTM had only buildings. In addition the feature representation between the LIDAR DSM and Photogrammetric DSM were inconsistent (c.f. section 4.5).

The results from OBBA approach are satisfactory yet; the procedure has not been tested in condition where trees occur over embankments, depression and hilly areas. Nevertheless, the presence or absence of permeable features along with the artefacts has significant effect in simulation from HDM and use of Pseudo-DTM is highly recommended for flood modelling.

Recommendations

- Scanned aerial photographs lack enough spectral and textual information. The spectral signatures were limited and varied with change in illumination condition of different photographs. While, textural information was similar in all bands as they were scanned aerial photographs. This caused uncertainty in feature identification and delineation. Thus, use of digital aerial photograph is recommended over the analogue one.

- A DSM of higher resolution should be used during the correction procedure to reduce the effect of boundary pixels. A higher resolution DSM would result in continuous boundary of features instead of the serrated one and the feature representation along with artefacts are distinct for proper analysis.
- Correction of water surface can be carried out by incorporating external data of bathymetry. The bathymetric data can be derived from the sound navigation and ranging (sonar), LIDAR or altimetry satellites such as TOPEX, Jason and Envisat RA-2
- Significance should be tested by simulating flood on the derived Pseudo-DTM's, DSM and DTM. Flow velocity, travel time, peak flow discharge, extent of inundation should be considered in local as well as bulk flow characteristics while analysing the significance.

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8. Appendix

Experimental Data

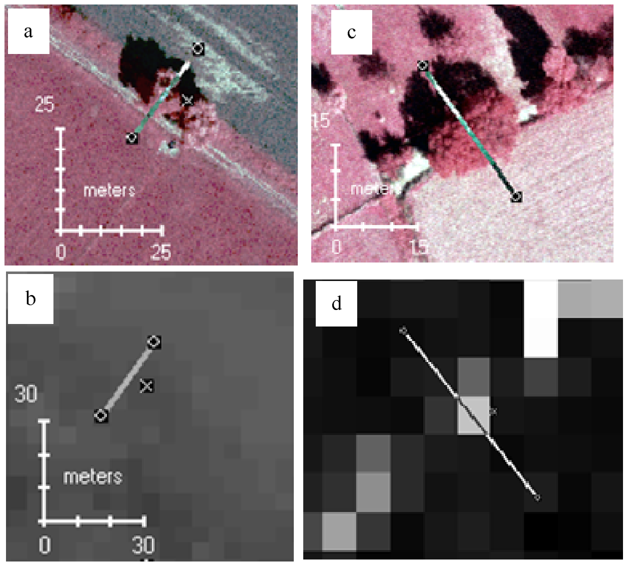

Figure 8.1: *Single trees and their respective representation: case I-(a, b), case II-(c, d)*

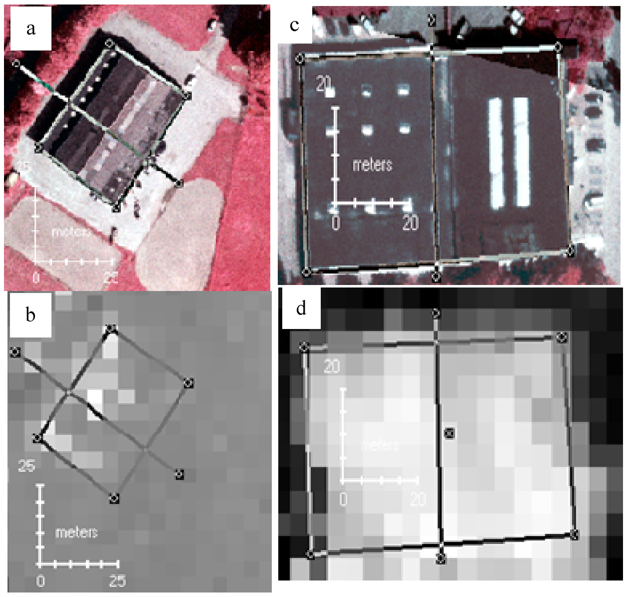

Figure 8.2: *Single houses and their representation case I-(a, b), case II-(c, d)*

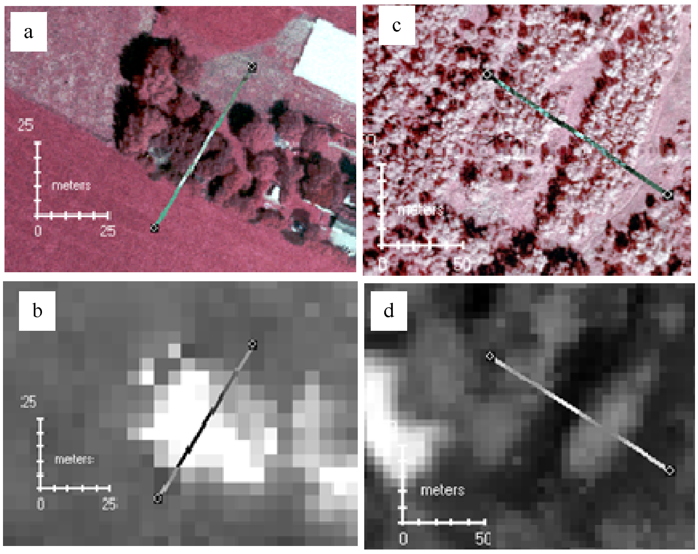

Figure 8.3: *Group tree representation; Case I-(a, b), Case II (b, c),*

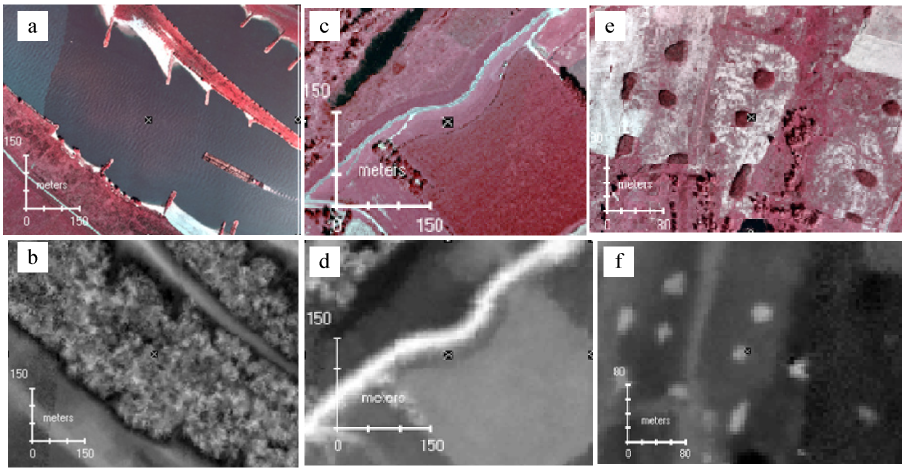

Figure 8.4: *Groynes representation-(a, b), Embankment representation-(c, d) Hump representation-(e, f)*

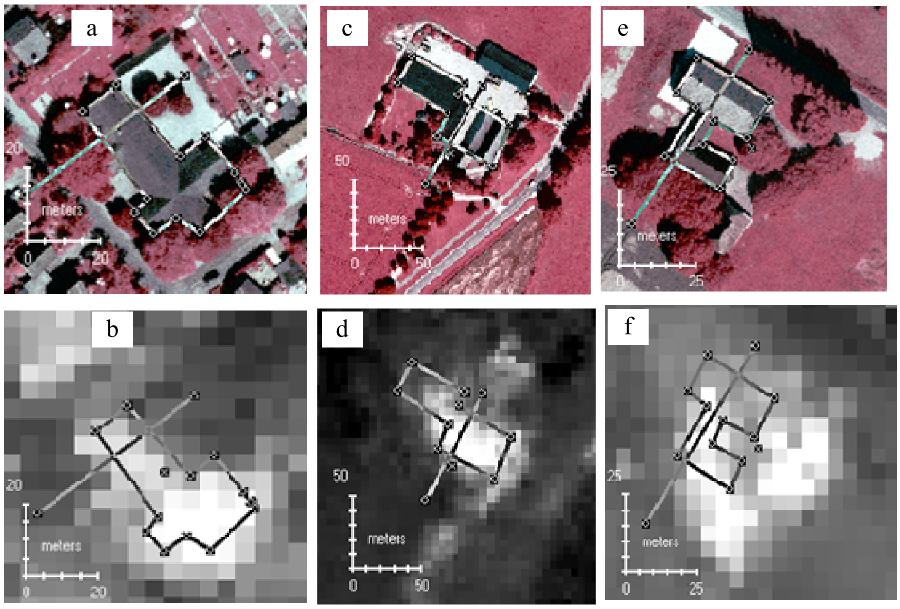

Figure 8.5: *House representation in orthophoto and DSM; Case I (a, b), Case II (c, d) Case III (e, f)*

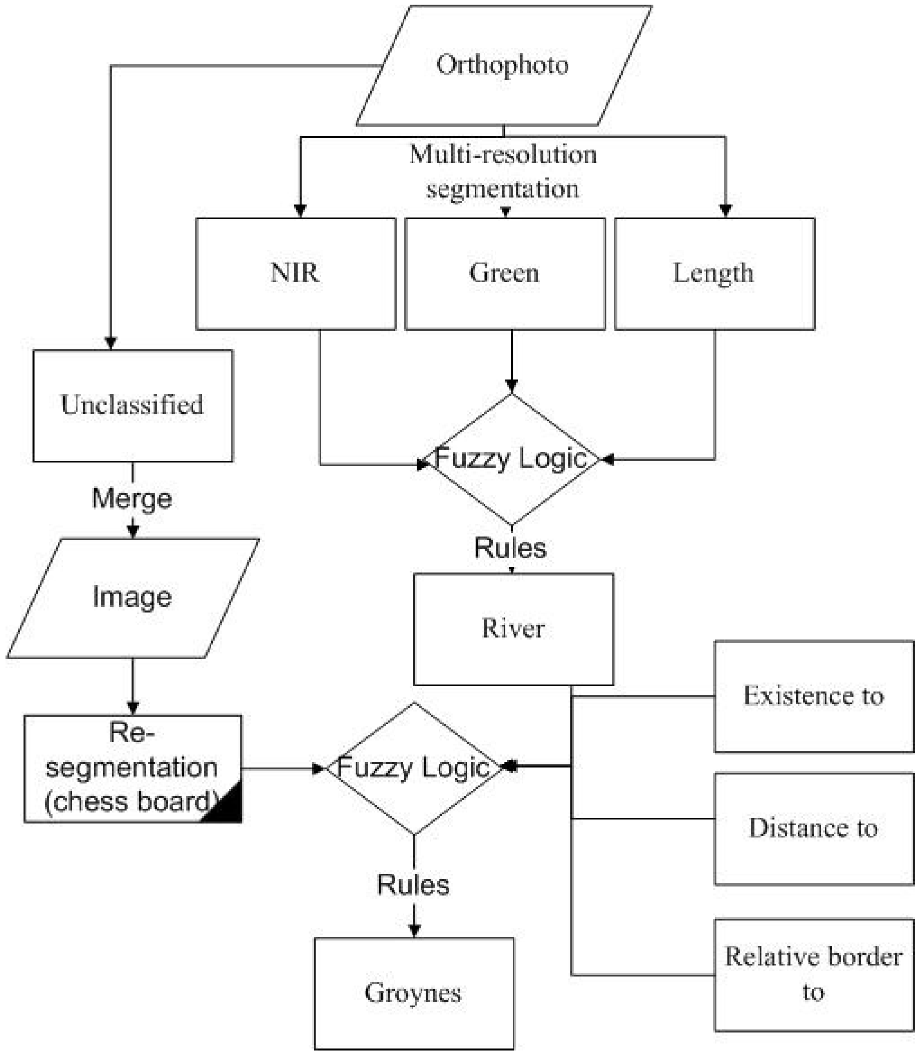

Figure 8.6: *An example on identification and delineation of features. Groynes are separated from the image using two different level of segmentation and rule set that combines various spectral and contextual properties of features.*

IMAGES

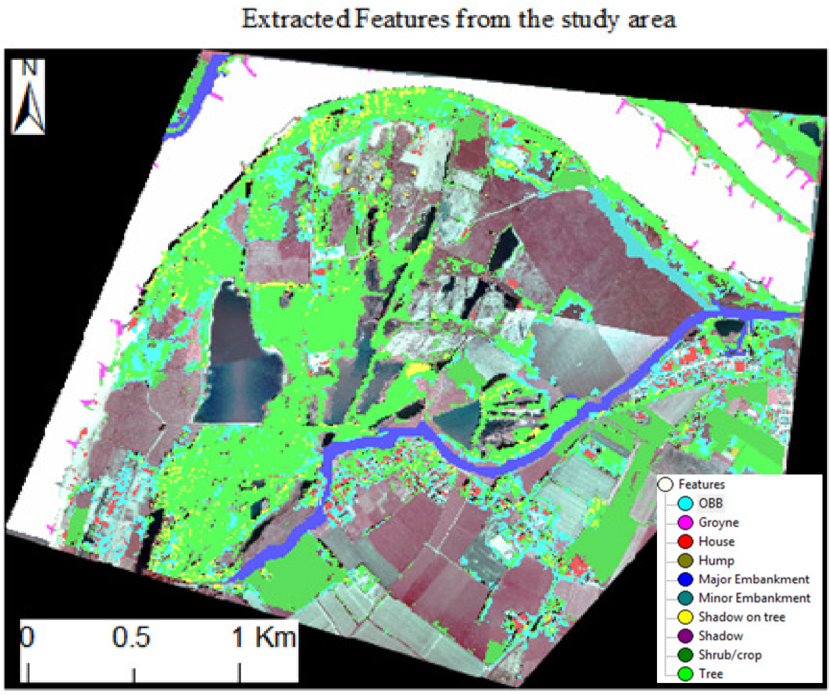

Figure 8.7: *Extracted image showing the objects that have been considerd under the study. Includes the features that are not removed from the DSM.*

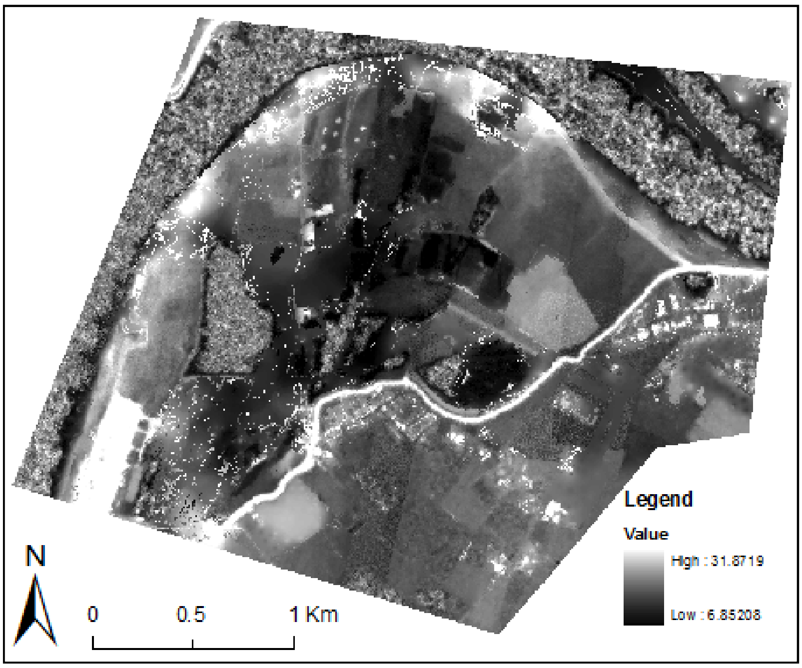

Figure 8.8: *Pseudo-DTM with OBA approach*

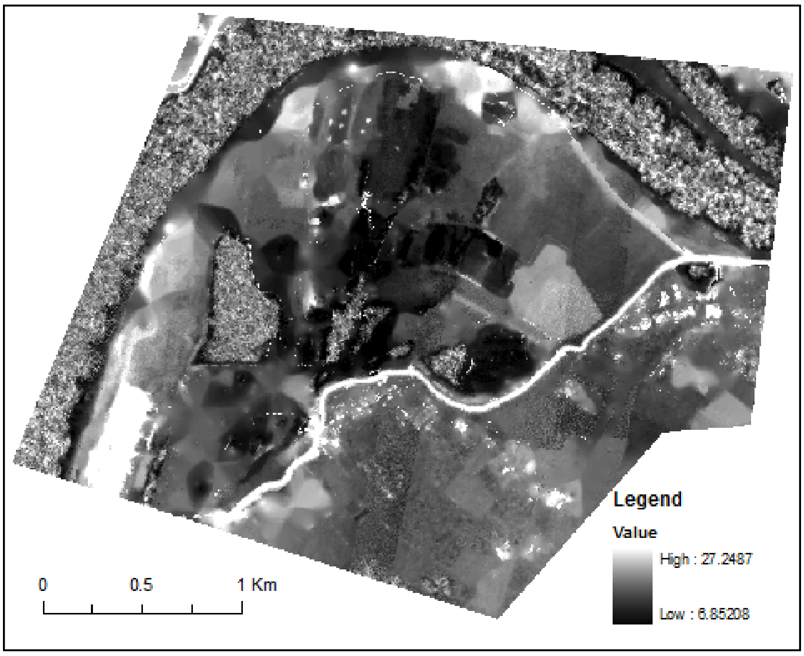

Figure 8.9: *Pseudo-DTM with OBBA approach*

Table 8.1: *Abbreviations*

AHN	Actueel Hoogtebestand Nederland
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
GIS	Geographical Information System
GPS	Global Positioning System
HDM	Hydrodynamic Models
IDW	Inverse Distance weighting
IFSAR	Interferometric Synthetic Aperture Rader
LIDAR	Light Detection and Ranging
LPS	Leica Photogrammetric Suite
NDVI	Normalised Difference Vegetation Index
NED	National Elevation Dataset
NIR	Near Infrared
OBA	Object Based Approach
OBB	Object Based Buffer
OBBA	Object Based Buffer Approach
OOA	Object Oriented Analysis
RBF	Radial Basis Function
RG	Regular Grid
RMSE	Root Mean Square Error
SRTM	Shuttle Radar Topography Mission
TIN	Triangulated Irregular Network

Table 8.2: *Description of the feature Properties used for identification and delineation of features*

Mean of layer-Layer mean value is calculated from the layer values of all pixels forming the image object

Brightness-Sum of the mean values of the layers containing spectral information divided by their quantity computed for an image object

Standard Deviation-Standard deviation calculated from the layer values of all n pixels forming an image object.

Existence of –It is assigned to a defined class in a certain perimeter (in pixels) around the image object concerned. If an image object of the defined classification is found within the perimeter, the feature value is 1 (= true), otherwise it would be 0 (= false).

Relative border to- It refers to the length of the shared border of neighbouring image objects. The feature describes the ratio of the shared border length of an image object with a neighbouring image object assigned to a defined class to the total border length. If the relative border of an image object to image objects of a certain class is 1, the image object is totally embedded in these image objects. If the relative border is 0.5 then the image object is surrounded by half of its border.

Distance to-The distance (in pixels) of the image object's centre concerned to the closest image object's centre assigned to a defined class. The image objects on the line between the image object's centres have to be of the defined class.

Asymmetry-The more longish an image object, the more asymmetric it is. For an image object, an ellipse is approximated which can be expressed by the ratio of the lengths of the minor and the major axis of this ellipse. The feature value increases with the asymmetry.

Rectangular Fit-A rectangle with the same area as that of considered object is calculated by the use of the proportion of the length to the width of the object. After this step the area of the object outside the rectangle is compared with the area inside the rectangle, which is not filled out with the object (Definiens, 2007).