Chapter 1

Introduction

1.1 An overview on the Zagros forests

Iran is located in one of the world's driest region. With about 12 million hectare of forests (i.e. 7.3 percent of total area of the country), it is considered to be amongst the low forest cover countries (FAO, 2002). The forests of Iran can be classified into five zones: Caspian, Zagrosian, Arasbaran, Irano-Touranian, Khalijoomanian, which include varied forest types and are rich in terms of the biological diversity. The Zagros forest zone is the second most important forest region that includes more than 180 tree and shrub species, predominantly of the oak genus (Quercus spp). Western oak forests cover an area about 5.5 million hectares (about 3.3% of Iran's territory) of a topographically complex and extensive system of mountains, extending from North-west to the South-east of the country. Regarding water balance, the role of Zagros forests is indispensable, while the region collects around 30% of the annual precipitation and includes some of the most important rivers of the country. Beyond ecological functions, these forests play an important role in safeguarding the livelihood system for around 30% of the country's population and their livestock (more than 50 % of the livestock population of Iran). In fact, the western oak forests have multiple socio-economic and ecological functions that are important at the global, national and local scales. They also play vital roles in improving landscape aesthetics, water supply, reducing runoff, and preventing soil erosion. According to such a high ecological and socio-economic values of the Zagros forests, forest managers have to balance conservation, economy and other aspects of these forests. So far, the conversion of forested lands to agriculture, illegal logging, fuel wood collection and charcoal production have been considered as the most important reasons of forest degradation in this region. During past decades, Zagros forests have been under drastic anthropogenic pressures, which threatened their future existence and

Government activities failed to halt forest degradation. Since 1961, most of the forest management plans have never been implemented or could not achieve their goals, because of the lack of detail information as well as weak stakeholders participation between the relevant sectors (Fattahi, 2003). Therefore, investigation on the present status and changes of Zagros forests is essential to find more reliable and sustainable solutions for the both forest managers and decision makers.

In 1996, Iran joined to the United Nations Convention on Biological Diversity and protection of the Zagros Biodiversity received a high priority in the Biodiversity's National Action Plan. Since 2000 a new long-term program for conservation of the Zagros forests has been developed by the Forest Rangeland and Watershed Management Organization (FRWO).

1.2 General motivation

With growing concerns about sustainability in forest management practices, the request for accurate and reliable information on forest attributes on both tree and stand levels such as crown area, tree height, volume and percent cover are becoming more and more demanding. The traditional labor intensive and field based forest inventory is normally expensive and time-consuming. The high expenses are due to the large amount of human labor used in data acquisition and processing (Hyyppä *et al*., 2005). Remote sensing as an alternative approach offers the potential for more efficient assessment of various forest attributes especially for situations where site access is limited. For many years traditional medium spatial resolution remote sensing imagery has been used to describe and predicting forest parameters using classification and regression methods (De Wulf *et al.,* 1990; Trotter *et al.,* 1997; Franklin & Turner, 1992; Franklin & McDermid, 1993). In Iran, many efforts have been done to generate forest density maps in Zagros area using low to medium resolution satellite imagery (Saroe, 1996; Riyahi, 2001; Darvishsefat & Saroe, 2003; Ahmadi Sani *et al*. 2006). The results of these approaches often are too inaccurate to be used in any modeling or management scenarios. These studies revealed that the special structure of the Zagros forests, i.e. low crown cover and effects of background reflectance restricted the application of low resolution satellite imagery for estimation of the forest parameters accurately. On the other hand, rapid decline of the Zagros forests necessitates the development of more accurate and sustainable management regimes. In recent years the availability of high resolution airborne (i.e. CASI, MEIS-II) and space borne (i.e. IKONOS, QuickBird) imagery, present an opportunity to shift from extracting average values of stands toward the single tree scale (Gougeon 1995a, Gougeon *et al.*, 2003). Potential improvement of the utility of remote sensing may be achieved through the application of very high resolution imagery that allows improving the estimation of stand density, volume, basal area, and canopy closure compared to the lower resolution data. In fact, automatic individual tree crown delineation can provide detail and reliable information to improve forest planning and decision making for forest conservation in the Zagros area. Therefore, a shift in image analysis paradigm is also needed in order to automatically extract tree based attributes. Simple pixel based classifiers can hardly be used to delineate individual objects in high resolution imagery and consequently it is essential to develop new image segmentation techniques and examine them under different forest type and acquisition conditions. The interaction between forest canopy and incident sunlight can result in a variety of spectral and spatial characteristics which are highly dependent on sun, sensor and target configuration (Lamar *et al.*, 2005). Coniferous trees have rather distinct tree crowns especially species which have conical crown shapes which cause bordering shadows that are particularly useful in delineation process. Moreover, in coniferous stands, the tops of the trees are typically the brightest pixels in high spatial resolution images (Gougeon, 1997) which make it feasible to find the tree location and the crown projection line. In contrast, deciduous trees typically have broad elliptical spreading crowns with specific self-shadowing foliage and multi crown crests. Also in natural forest stands deciduous trees tend to interwine and form mixed groups. These particular spatial arrangements of trees as well as inherent crown surface heterogeneity make individual tree crown delineation a highly demanding challenge in deciduous forests. Most of the current automated tree crown delineation algorithms have been applied in high density planted conifer forests and developed for symmetrical and circular crowns which have one bright point at the center Table (1.1).

Table 1.1 A selection of important references for individual tree crown delineation.

Reference study	Data type	Resolution (m)	Forest type	Location
Wang *et al.* (2004)	CASI	0.6	conifer	Canada
Dralle &Rudemo (1997)	Aerial photo	0.15	conifer	Denmark
Maltamo *et al.* (2003)	Digital video	1	conifer	Finland
Wulder *et al.* (2000)	MEIS II	1	conifer	Canada
Zagalikis *et al.* (2005)	Aerial photo	0.32	conifer	Scotland
Brandtberg (1999a)	Aerial photo	0.1	conifer	Sweden
Erikson (2004)	Aerial photo	0.03	conifer	Sweden
Pouliot *et al.* (2002)	Aerial photo	0.05-0.15	conifer	Canada
Leckie *et al.* (1999)	CASI	0.7	conifer	Canada
Bai *et al.* (2005)	Aerial photo	0.5	conifer	Canada
Haara & Haarala (2002)	Aerial photo	0.25	mixed	Finland
Korpela *et al.* (2006)	Aerial photo	0.1	conifer	Finland
Uuttera *et al.* (1998)	Aerial photo	0.25	conifer	Finland
Erikson (2003)	Aerial photo	0.1	conifer	Sweden
Pitkänen (2001)	Aerial photo	0.5	conifer	Finland
Fuchs (2003)	Aerial photo	0.25	Con./ Dec.	Germany
Bunting & Lucas (2006)	CASI	1	Mixed	Australia
Warner *et al.* (1998)	Aerial photo	0.06	Deciduous	USA
Pollock (1998)	CASI & MEIS II	0.6,0.36	conifer	Canada
Wulder *et al.* (2004)	IKONOS& MEIS II	1	conifer	Canada

While developments of algorithms for conifer forests attract significant attention, relatively fewer efforts have been spent on the natural deciduous forests which accommodate trees with variable crown size and shape. Moreover, comparative studies among the existing methods are rare so far. In order to make multitude methods more operational, it would be desirable to characterize them according to their strength and weakness for example methods that can better handle sparse deciduous forests and which that can better handle dense conifer forests.

In spite of disadvantages of aerial photos and airborne imagery, these data were the main sources for the bulk of earlier investigations (Table 1.1). Some disadvantages of these data include inherent geometric artifacts that are a function of the camera or sensor optics and the relatively small area of the ground they typically cover (Wulder *et al.*, 2004). With the advent of new very high resolution satellite imagery, another chapter was opened in the individual crown detection era. Very high-resolution satellite imagery (<1m) with multi-spectral high-revisit frequency and large area coverage has the potential to overcome some of the common problems of airborne data. The commercially available high resolution satellite imagery with competitive cost relative to existing aerial photos can deliver unprecedented high quality georeferenced data with spatial resolution suitable for individual tree crown detection. The rapid increase in the number of high resolution satellite imagery that will be available in the near future motivates further studies about their application, advantages and limitations. The primary objective of this study is to apply image fusion techniques available in commercial image processing softwares on QuickBird data and evaluate the objective and subjective quality of synthesized images. The results and outcomes help understanding advantages and disadvantages of such fusion methods for QuickBird imagery. Fundamental studies are needed to clarify how much a crown delineation method is reliable with respect to the different forest conditions and satellite imagery. The main objective of this study is to apply relevant crown delineation methods on QuickBird imagery and assess the accuracy of the results qualitatively and quantitavely. This knowledge is supposed to provide an opportunity to find a suitable combination of image processing and image segmentation methods to be used in open forests of Iran and elsewhere.

Individual tree delineation appears to be a reasonable starting point for additional efforts to estimate tree sizes and volume. The delineation approaches developed in this study provide tree positions and the immediate neighborhood constellation for each tree that were laborious and hardly available before. Such datasets are sufficiently accurate for evaluating spatial patterns of tree populations and examining the degree of aggregation in the distribution of tree species. This information is a basis for distance-dependent individual tree growth models (Gadow & Hui, 1999). Tree delineation has the potential to model tree structural variables such as tree height and stem diameter (Pouliot *et al*., 2002). Variables such as DBH, tree height and crown length were the best to estimate biomass of all above- and belowground compartments (Xiao & Ceulemans, 2004). Forest structural features (e.g., snags, stem density, species composition) have been proposed as indicators in sustainable forestry programs.

1.3 Potential applications of the very high resolution imagery in precision forestry

Precision forestry deals with the possibilities of obtaining relevant information for forest management and forest planning precisely and linking this information to the locations (coordinates) using advanced methods of information technology to improve operations and processes (Becker, 2001). Precision forestry employs high technology sensing and analytical tools to support site-specific, economic, environmental, and sustainable decision-making for the forest sector (Bill Dyck, 2003). Very high resolution imagery in conjunction with the global positioning system (GPS), and geographic information systems (GIS), play a key role in precision forestry approaches. Very high resolution remote sensing can deliver data at a scale which individual tree crowns can be detected, and capability of up scaling to stand and forest level. Gougeon & Leckie (2001) contend that high resolution imagery encourage and facilitate precision forestry. Many argue that high resolution imagery would allow capturing a range of multi-resource management information such as stem density, crown closure, snag locations, forest gap size and distribution, more rapidly, objectively and cost effectively than current ground based survey or manual interpretation of aerial photographs (Gougeon *et al.*, 2003, Zagalikis *et al.*, 2005, Maltamo *et al.*, 2003).

As could be expected, high spatial resolution imagery has a wide spectrum of applications ranging from individual stem counting to more advanced biomass estimation (Table 1.2). Successful delineation of individual crowns using automated processes, provide an opportunity to generate a range of spectral and spatial information of each crown. This information can be combined with field-measured values and environmental datasets for modeling and mapping tree attributes across the whole landscape. The number of stems is one of the first attributes of interest which may be used in modeling tree interactions e.g. growth modeling (Pitkänen, 2001). Detail information concerning the natural variation in the spatial distribution of trees between and within the stands could improve the management planning in terms of robust growth prediction (Pukkala, 1990). Moreover, tree species composition, size distribution and spatial distribution of trees affect processes, such as regeneration, growth, competition and mortality of trees (Uuttera *et al.*, 1998).

Table 1.2 Examples of applications of high resolution data in precision forestry applications for a wide range of attributes.

Topic	Related studies
Tree species classification	Brandtberg, 1999a ; Erikson, 2004; Pollock, 1998; Gougeon, 1995a; Gougeon *et al.*, 1999; Bunting & Lucas, 2006; Larsen, 2007; Olofsson *et al.*, 2006; Brandtberg, 2002; Leckie *et al.*, 1999b; Pinz, 1999; Leckie & Gougeon, 1999
Damage assessment	Leckie *et al.*, 1992 ; Murtha & Fournier, 1992 ; Haara & Nevalainen, 2002
Crown closure and forest gap	Leckie *et al.*, 1999b
Growth and change detection	Bai *et al.*, 2005
Stem diameter and basal area estimation	Wulder *et al.*, 2000; Zagalikis *et al.*, 2005
Spatial pattern analysis and tree position	Dralle, 1997; Uuttera *et al.*, 1998; Korpela *et al.*, 2006
Crown area and diameter distribution	Maltamo *et al.,* 2003 ; Pouliot *et al.*, 2002 ; Gougeon, 1995a
Tree volume	Zagalikis *et al.*, 2005
Stem counting	Gougeon, 1995b; Dralle & Rudemo, 1996; Leckie & Gougeon, 1999
Canopy height	Zagalikis *et al.*, 2005
Biomass estimation	Zagalikis *et al.,* 2005

Multitemporal very high resolution data provide the capability for monitoring and assessing the mortality of individual trees over time. A great change in the reflectance of tree crowns subject to stress and pest infestation can be detected using high resolution imagery, especially in the near infrared spectral range. It is feasible to identify the stressed and damaged individual crowns as well as resistance individuals which survived after disease or insect/pest outbreak. Very high resolution data has a valuable role to play in forest health monitoring programs. This data offers an alternative for estimating the location and extent of pest attacks (Coops *et al.*, 2006), for example, Leckie *et al.* (1992) outlined the capabilities of high resolution imagery for operational use in damage assessment and found a close relationship between spectral features extracted from MEIS imagery and tree defoliation caused by the spruce budworm. Haara and Nevalainen (2002) argued that segmentation of very high spatial resolution imagery can provide satisfactory results with adequate accuracy for detecting dead or heavily defoliated trees.

Tree species identification is crucial in many forest studies, forest inventories, forest management and other applications. Extracting spectral properties of delineated tree crowns provides an opportunity to identify individual trees species. Numerous studies have demonstrated the suitability of very high resolution imagery for individual tree based species identification including Erikson (2004), Pollock (1998), Gougeon (1995a), Gougeon *et al.* (1999), Bunting & Lucas (2006), Larsen (2007), Olofsson *et al.* (2006), Brandtberg (2002), Leckie *et al.* (1999a).

Maltamo *et al.,* 2003 suggested that not only possible to separate tree species most precisely by stable geometric characteristics of digital images, but also it is doable to construct diameter distribution and tree models for each species.

The correlation between crown characteristics and tree diameter has been found to vary and to be dependent on the tree species (Maltamo *et al.*, 2003). After the tree crown size has been detected and measured, it is possible to utilize the correlation between crown and diameter at breast height to estimate tree and stand-wise forest characteristics (Zagalikis *et al.,* 2005). But that relation is frequently weak.

1.4 Goals and Objectives

The overall objective of this thesis research was to improve forest planning and decision making for conservation by providing detailed and reliable information. The specific objective was to evaluate the potential of QuickBird data to automatically delineate individual tree crowns in deciduous forests. To achieve the overall objective, the following technical objectives have been formulated:

- To increase the spatial resolution of multispectral data using different image fusion techniques.
- To evaluate the visual and statistical quality of different fused images acquired from QuickBird Panchromatic and multispectral images.
- To analyses the relationship between crown area and tree height.
- To adapt an appropriate individual tree crown delineation algorithm for Zagros forests.
- To evaluate the accuracy of the delineation results.

1.5 Outline of the study

This thesis analyses and evaluates the potential of QuickBird data to delineate individual tree crowns in deciduous sparse forests.

Chapter 1 provides a general introduction to the thesis and it emphasizes the importance of the Zagros forests and motivates the necessity of reliable and accurate individual tree based information for planning and managing this region. Forestry potential of high resolution technology as well as QuickBird imagery is described. Also the research objectives are listed.

Chapter 2 explores the challenges and possibilities of high resolution data for automated individual tree crown delineation approach through literature review. The existing methods for individual tree crown delineation are categorized. Practical applications of individual tree delineation in the forestry domain are described.

Chapter 3 describes the location of the study forest site as well as the field measurement protocol. The general approach of this research is introduced. Individual tree crown delineation is consisting of three main parts: pre-processing, image fusion and image segmentation.