CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

In the past few years, there has been increasing research into automatic feature extraction due to the great demand for large scale digital maps from a variety of users. Digital large scale maps are important for developing Geographical Information Systems (GISs), which are essential database for both planning and fieldwork operation. Buildings and roads are the most important components of such maps. Accurate maps of buildings and roads can provide critical information to planners for improving quality in urban areas as well as for homeland security. Digital road maps can be used in many applications such as finding the shortest route between two given locations, providing an estimation of the time required to travel from one location to another and estimating the direction of the traffic and the speed limit. On the other hand, the extracted building are useful for many applications such as urban planning and management, 3D city models, disaster management, telecommunication antenna localization, utility services and many more.

In most cases, building and road maps are derived from existing maps through digitization. The accuracy of the data derived through digitization is relatively low and it is often out of date. This conventional approach for large scale mapping, on the one hand, is a costly task that requires extensive and time-consuming field revision. This creates so many problems for engineers, planners and other professionals who need to develop their work based on reliable current data. On the other hand, this represents a great challenge especially for a developing country such as Egypt which has agro-based economies and is yet to be fully mapped even at the basic scale of 1:50,000. Thus, it becomes crucial to develop unconventional strategies for mapping at large scales. This objective can be achieved by automating the mapping process using high-resolution aerial imagery and/or airborne laser scanner (ALS or lidar) data (Champion, 2007).

Photogrammetry is the primary approach for cartographic and GIS production at present. At the same time, new sensors have been developed that bring new technologies into the photogrammetry community, such as lidar (Light Detection and Ranging). Unlike photogrammetric sensors, lidar systems measure 3D coordinates of ground points. As a result, digital surface model (DSM) can be derived automatically, and hence building candidates can be extracted more accurately. The availability of both images and lidar has led to the topic of this research on information extraction by the fusion of aerial images and lidar data so that the strengths of each data type can compensate for the weaknesses of the other, thus improving the quality of extract features. However, despite the current accomplishments by researchers in the field of mapping by aerial images and lidar data fusion, there are still many unsolved problems. The most important problem is to find an appropriate approach for the fusion of the two types of data for the extraction of buildings and roads. Therefore, this is the objective of this research. Achievement of this task will assist to develop expertise in the use of lidar in Egypt, and hence researchers will be able to apply their image processing and machine learning algorithms for information extraction from image and lidar data.

1.2 Fundamental Concepts

Multispectral aerial imagery and lidar data provide different, but complementary information for any feature extraction algorithm. Although lidar data has high vertical accuracy (15-20cm), its horizontal accuracy is limited to about the half meter level. Also, lidar data has poor structure or texture information, thus it is difficult to extract edges of objects accurately solely from lidar data (Ma, 2004). On the other hand, aerial photographs generally provide higher horizontal accuracy than lidar data (Ackermann, 1999), as well as plenty of texture and structure information. But low contrast, occlusions and shadow effects in the images edges usually result in lower classification accuracy when aerial images are applied as a single data source.

It has been shown in several studies that the combination of aerial images and lidar data significantly improves the performance of land cover classifications, since the strengths of each data type can compensate for the weaknesses of the other. On the other hand such diverse data sets result in the demand for an adequate classifier, which enables handling the differences in spectral and spatial resolution. The development of such algorithms is perhaps the most challenging research topic in the field of remote sensing (Richards, 2005). The conventional parametric statistical classifiers, such as maximum likelihood, which have been applied successfully in remote sensing, are not appropriate for this purpose, since a convenient multivariate statistical model does not exist for such diverse data (Benediktsson et al., 2007).

Applying Machine Learning techniques to solve image analysis problems has been increased over the last decade. Compared with other methods, machine learning algorithms are a relatively straight-forward alternative approach for image analysis and land cover mapping from multidimensional data, because they are nonparametric and do not require any assumptions about the distribution of the input data. Furthermore, they have the advantage of being independent of whether the variables are a mixture of categorical and continuous. Finally, they are relatively simple and require significantly less work on tuning parameters. Recently researchers have shown that neural network classifiers, statistical classifiers, and support vector-based classifiers have proven to be the most effective Machine Learning classifiers for information extraction from aerial images and lidar data. Given a set of attributes for a certain feature in the data, it has been shown that the algorithm could learn how to distinguish this feature from other features.

Neural and statistical algorithms may represent a valuable alternative for handling such highly dimensional imagery. Kanellopoulos et al. (1997) have demonstrated the complementary characteristics of neural and statistical algorithms in terms of classification errors. Therefore these classifiers result in uncorrelated classification errors and hence the performance can then be improved by combining them. Integrating neural and statistical classifiers into a unified framework will take advantage of the complementary information about image data provided by these classifiers. Building on these facts, the three classifiers that have been selected to be incorporated in the proposed system are: 1) Self-Organizing Map (SOM) as a neural network classifier; 2) classification trees (CTs) as a statistical classifier, and 3) support vector machines (SVMs).

The research presented here will describe and analyze for the first time in remote sensing field, a new method to integrate neural and statistical classifiers based on Dempster-

Shafer theory (D-S) of evidence, which provides tools for dealing with uncertain and incomplete knowledge about the statistical properties of the data.

1.3 OBJECTIVES

The main objective of this study is extraction of buildings and roads by the fusion of aerial images and lidar data in different urban environments. More specifically, this objective will be achieved through:

- Providing guidelines for tuning the SOM parameters for feature extraction.
- Assessing the impact of changing the CT model (Entropy, Gain Ratio and Gini), as well as the SVM kernel (Gaussian Radius Basis Function; Linear; Polynomial; and Sigmoid) on the overall classification accuracy.
- Developing a simple technique that can effectively filter lidar data by removing non-ground points. A minimum number of tuning parameters is the main target.
- Developing a new powerful Multiple Classifier System (MCS), based on the D-S theory of evidence, to combine the outputs from statistical and neural classifiers in order to improve the quality of the classification results. This requires investigating an appropriate method to transform the a posteriori probabilities derived from each classifier into probability masses.
- Evaluating the complementarities of the three classifiers to investigate the impact on the classification performance of adding more classifiers.
- Introducing an accurate approach of vectorizing and simplifying the shapes of buildings derived from the classified data by removing unnecessary or unwanted details, while maintaining their essential shape and size; the aim is also to develop an accurate method of extracting road centrelines from the classified data.

1.4 OUTLINE OF THE THESIS

The remainder of the thesis is organized as follows:

Chapter two addresses background information related to the research. First, the chapter gives an overview of airborne lidar, followed by a comparison of photogrammetric imaging systems and lidar. Consequently, chapter two presents a review of the available approaches for combining classifiers. Furthermore, this chapter summarizes the previous approaches taken for automatic buildings and roads extraction based on lidar data as a single data source, as well as based on aerial image and lidar data fusion.

Chapter three provides theoretical background and concepts for the selected methods for image classification, including: SOM; CTs; and SVMs. On the other hand, elements of accuracy assessment are briefly outlined.

Chapter four describes an innovative framework for the classification of land covers by the fusion of multiple classifiers based on Dempster-Shafer theory of evidence. This allows for the combination of the evidences derived from the three classifiers described in chapter three, SOM, CTs and SVMs. The chapter is closed with a brief overview to the combination techniques applied for comparison.

Chapter five is concerned with the process of data preparation. First, the chapter describes the study areas and data sources, and then a novel technique for filtering of lidar point clouds is presented. After that, the process of image to lidar geographic registration is explained. Finally, the generation of attributes from both image and lidar data are discussed in full detail.

Chapter six assesses the performance of the three classifiers introduced in chapter three (SOM, CTs and SVMs), based on the four study areas described in chapter five. Beside the SOM classifier, four SVMs kernels were tested and compared to each other in order to select the kernel with the best performance as a representative of SVMs in the hybrid system. Also, three CT splitting algorithm were tested and compared to each other for the same purpose.

Chapter seven evaluates two components. First, the performance of the developed Multiple Classifier System (MCS) to combine the results obtained for the three classifiers (SOM, CT, and SVM), based on the D-S theory of evidence was evaluated, incorporating three methods for the prior probabilities (leading to methods referred to as *DS-1*, *DS-2* and *DS-3*). Secondly, the results from the combination process were converted from raster to vector and simplified for the extraction of buildings and roads. By comparing the results with reference data, this chapter will be able to provide confidence in the performance of the proposed system.

Chapter eight concludes the dissertation research by summarizing the achievements in extracting the features in the classifications and vectorizing the final outputs. The chapter highlights the major contributions of this research and analyzes its shortcomings. Recommendations for further future studies are provided.

For clarity, Figure 1.1 demonstrates that three studies that were undertaken in this research. These studies are focusing on: (1) optimization and validation of the applied classifiers; optimization and validation of the proposed system for combining classifiers with its three alternatives; and (3) linear feature extraction and graphic representation.

All the methods proposed in this research and other researchers' methods which are utilized for comparison were implemented through programs generated by the author in Matlab environment.