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A NOVEL TECHNIQUE FOR CONTOUR RECONSTRUCTION TO DEM

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ABSTRACT

Contour lines recognition from raster topographic map is an interesting research in Geographic Information System. The majority of previous studies, either associates with manual digitizing, interactive or semi-automated process has several drawbacks. Generally, these approaches are time-consuming, inefficient and produced unreliable digitized data. Due to textured background and diverse information characterize on the map, extraction process has become complicated. This study concentrates on establishing an efficient approach for contour line recognition using local geometry and relationship derived from their neighbourhood pixels locality. The approach consists of three fundamental phrases: (1) pre-processing to obtain initial contour layer, (2) processing for enhancement and reconnection, and (3) post-processing to validate the extracted contour information. The entire methodology is decomposed into a number of tasks: (1) scan paper-based map into raster image, (2) colour quantization to reduce colour, (3) map layer separation and integration to acquire a comprehensive contour layer, (4) contour lines enhancement and thinning, (5) endpoints detection, (6) derivation of local geometries (distance, angle and directional information), (7) determination of best connection with identified endpoints, (8) reconnection of broken contour lines using cubic spline interpolation. In order to evaluate the applicability of this study, several experiments are conducted on topographic map in different scale and resolution. The results indicated that the usage of colour quantization is capable to extract contour layer from topographic map. Alternatively, the employment of cubic spline interpolation for contour lines reconnection has proven a favourable result. As a conclusion, this study has shown an acceptable result with low computation time and cost.

ABSTRAK

Pengecaman garisan kontur daripada peta topografi merupakan kajian yang menarik dalam Sistem Maklumat Geografi. Terdapat beberapa kelemahan dalam kaedah pengecaman garisan kontur yang telah dilaksanakan, sama ada cara manual, interaktif atau semi-automatik. Secara umumnya, kaedah tersebut memakan masa yang lama, kurang efisyen dan menghasilkan data digital yang kurang kepersisan. Dengan kehadiran latar belakang yang bertekstur dan beraneka kandungan data, proses pengekstrakan menjadi semakin rumit. Kajian ini bertujuan untuk membangunkan satu kaedah yang efektif untuk mengecam garisan kontur dengan menggunakan hubungan geometrik tempatan dan hubungan sesama diri antara piksel berdekatan. Terdapat tiga fasa utama dalam kaedah ini, iaitu: (1) pra-pemprosesan untuk memperolehi lapisan awal kontur, (2) pemprosesan untuk pembaikpulih dan penyambungan, dan (3) pasca pemprosesan untuk verifikasi garisan kontur. Methodologi ini dilaksanakan mengikut beberapa proses kerja berikut: (1) mengimbas peta topografi, (2) pengkuantuman warna untuk mengurangkan kandungan warna, (3) pembahagian dan pengabungan lapisan peta untuk memperolehi lapisan kontur yang lengkap, (4) pembaikpulih dan penghalusan garisan kontur, (5) pengesanan titik akhir, (6) perolehan maklumat geometrik tempatan (jarak, sudut dan arah), (7) penentuan cara penyambungan kontur yang terbaik berdasarkan titik-titik akhir yang ditentukan, (8) penyambungan garisan kontur yang terputus dengan interpolasi lengkungan kubik. Eksperimen dijalankan ke atas peta topografi yang mempunyai skala dan resolusi yang berlainan untuk menguji keberkesanan penggunaan kaedah ini. Hasil eksperimen menunjukkan penggunaan pengkuantuman warna adalah berkesan untuk mengekstrak garisan kontur. Selain itu, penggunaan interpolasi lengkungan kubik dapat menyambung garisan kontur dengan baik. Secara kesimpulannya, kaedah ini berjaya menghasilkan keputusan yang memuaskan dalam masa yang singkat dengan kos yang murah.

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LIST OF ABBREVIATIONS

RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SRG	Seeded Region Growing
OCR	Optical Character Recognition
DEM	Digital Elevation Model
TE	Terminal Element
HMT	Hit-and-Miss Transform
TSP	Traveling Salesman Problem
BMP	Bitmap
VICWIN	Victor Image Processing Library for Windows
JUPEM	Jabatan Ukur dan Pemetaan Malaysia
USGS	The United States Geological Survey
GIS	Geographic Information System
GRASS	Geographic Resources Analysis Support System
PDE	Partial Differential Equation

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CHAPTER 1

INTRODUCTION

Topographic maps are composite representation of landscape, geographic information, natural and manmade feature. Several features include contour lines indicating landforms and elevations, hydrographs (rivers, lakes, and marshes), transportation (roads, trails, railroads, and airports), vegetation, boundaries, urban areas, buildings, and others are portrayed. Therefore, they have been widely use in Geographic Information System (GIS), urban planning, military, earth science, industry, environment management, public works and etc.

The emerging of GIS has evolved digital maps production with sophisticated tools for analyzing and interpreting spatial information. Since data acquisition and retrieval have become the most expensive and time-consuming task in GIS, it is obvious that the reduction of expenses in data collection and maintenance is highly demand. Although satellite imagery is increasingly available for GIS, the development and deployment of satellites imagery are very expensive. Therefore, the wide range of information portrays in topographic maps has lead them to become a low-cost source data compare to other surveying technique, such as photogrammetry, remote sensing, satellite imaging, RADAR and etc. Consequently, a knowledge based features extraction process from topographic map is significant to be integrated into a full-featured GIS for ease of management, retrieval, updating and visualization.

Vector data is typically generated from paper maps or natural source images, such as aerial photos or satellite image. Traditionally, manual approach acquires vector data by digitizing tablet. There are several defects in this approach, including inaccuracy, time consuming and labour intensive. Hence, this has encouraged the development of an efficient features extraction and vectorization approach by performing image analysis and processing techniques. A number of commercial raster-to-vector conversion systems exist recently, including R2V (Able Software), WinTopo, Easy Trace, ESRI product (e.g. Arc View, Arc Map, Arc Info and etc), Draftsman2000 (Arbor Image) and so forth. These applications are capable to perform fully or semi-automated vectorization approach. However, they result in unreliability and inaccuracies due to unanticipated circumstances and limited intelligence. Consequently, human is indispensable for identifying and correct those errors, which are very time-consuming and ineffectual.

The efficiency of digitization comes in various points of view; consist of processing speed, precision of the results, and the functionality and effectiveness of raster and vector editor tools. Fully automatic acquisition of man made features from topographic map like roads, contour lines, buildings etc appear to be intricate and may even be impossible. The recognition and extraction process require a complete knowledge and interpretation of scanned raster imagery. Recently, computer has become an essential tool for extracting vector data from scanned images and getting rid of manual tracing process. Therefore, digitizing of large-scale map and GIS database management and storage can be accomplished in an effective manner, thus reducing time and human resources. However, recent computer algorithms and approaches are insufficient for this implementation. Limited success has been obtained in developing automatic cartographic feature extraction procedures.

1.1 Research Background

Many research efforts have been carried out on digitization of scanned topographic maps. There are texture analysis (Meas-Yedid, 1997), colours classification by using colour and neighborhood information to segment text and lines (Yan, 1993; Khotanzad and Zink, 1996), extraction and reconstruction of linear objects, symbols and characters obtained from map legend especially for contextual lines identification (Yamada et al., 1993; Kasturi and Alemany, 1998) and etc. However, most of the related works does not provide fully automated interpretation. Instead, they are only capable in semi-automatic or interactive approaches, where human interaction is required to initialize some line tracking processes and correcting errors (Suzuki and Yamada, 1990).

Early research associated with vectorization of line drawings generally introduced these essential procedures: (1) digitization of original paper document using a scanner; (2) filtering; (3) thresholding; (4) thinning and skeletonization; (5) raster to vector conversion (Xulio et al., 1998; Soille et al., 1999; Levachkine, 2003; Khotanzad and Zink, 2003; Salvatore and Guitton, 2004).

1.2 Motivation of Research

This research is intended to recognize and extract contour lines from scanned topographic map. Several factors are motivating this research: (1) inherit of raster image problem, (2) the image acquisition and analysis approach and (3) the need of digitize raster map into vector format in order to reduce human intervention. In consequence of not all vector data is available and accessible for usage and handling in GIS database, there is a demand of developing an efficient approach for map interpretation and vectorization.

Topographic map consists of different type of lines, text and symbols in colour, black or white. Since there are variety information depicted on the map, linear and area features always appear as closely spaced, intersecting or overlapping each another in certain circumstances. Besides, scanning and vectorization process invariably introduce errors and obliterate some information. Therefore, image acquisition and analysis have to carry out circumspectly to minimize errors generated by misalignment of scanner or human negligence. Various image processing techniques can be applied to improve the quality of scanned raster image, as well as verifying or correcting those erroneous data.

A number of general problems exist in contour lines recognition from scanned topographic maps: (1) inhomogeneity of scanner, (2) the presence of artifacts (dirt, folds etc), (3) existence of text, gridlines, river and etc, (4) the influence of resolution on colour appearance and so forth. For these reasons, several difficulties remain unresolved in state of arts in following fields: image acquisition, image processing, pattern recognition and artificial intelligence. It is hardly or may even impossible to obtain a fully automated map interpretation system that free of errors without human intervention.

Several standards sets of colour are defined in topographic maps. There are usually based upon the production and digitization technique that employ by map producer. Since majority of maps categorize brown colour for contour lines, a range of brown value need to be determined in order to distinguish contour lines from other features. However, typical colour space clustering techniques or thresholds are not able to address the problem in recognizing contour lines. In addition, broken contour lines reconnection remains as a challenging problem (Salvatore and Guitton, 2004). These gaps are typically identified by searching extension through discontinuity based on several rules. For instance, direction of endpoints and the maximum and minimum distance between neighboring segments. Then, it is reconstructed manually, or by using Delaunay edges (Salvatore and Guitton, 2004), curve approximation (Xulio et al., 1998) and so forth. However, all existing approaches have their advantages and disadvantages respectively in generating result.

1.3 Problem Statement

Current approaches in recognizing contour lines from topographic maps are still insufficient to produce vector data for integrating into GIS database. They are either time consuming and require heavy computations using powerful workstation, or involve much human effort in assisting or correcting recognition error. Hence, an algorithm with less computation time and cost should be developed to recognize contour lines, and eliminate undesired features, as well as preserve the topology of map. Finally, contour lines discontinuities due to deficiency of scanning or recognition process should be improved. Meanwhile all gaps should be reconnected in a least RMSE rate.

1.4 Goal

This research is intended to recognize and extract contour lines from scanned raster topographic map. The efficiency is evaluated by computation time and cost for the whole digitization process in achieving accurate result compare with other interactive, semi-automated or automated GIS application.

1.5 Objectives

(i) Recognize and extract contour lines from scanned topographic map.

(ii) Determine and identify contour lines, which intersect or overlap with other linear or area features on topographic map.

(iii) Remove other features, noise and texture background while preserving contour lines and its elevation.

(iv) Enhance and reconstruct the structure of contour lines; meanwhile thinning to result one-pixel width skeleton lines.

(v) Study on the local geometries rules (e.g., distance, angle and orientation) in order to reconnect disconnected contour lines (or generally known as gaps).

(vi) Convert raster contour map into vector format.

1.6 Scope of Research

(i) Raster colour topographic maps of different scale are scanned using desktop scanner in different resolution, which measured in dots per inch (dpi).

(ii) Colour quantization is applied for reducing the amount of colour information in alleviating the colour classification process.

(iii) Contour lines reconnection algorithm is based on observation of possible line continuities and may be subjected to several known constraints such as direction, distance, angle and etc.

(iv) The efficiency of algorithm is evaluated by computation time and cost in resultant vector data and visual inspection of raster data compare with several existing GIS application.

1.7 Research Contributions

As discussed in problem statement, this research is intended to discover an efficient approach for paper-based topographic map digitization, particularly for contour lines recognition and extraction. The extracted contour map is enhanced with corresponding image acquisition and processing procedures in order to produce accurate and reliable information in vector format. The work addressed in this study has contributed to the following aspects:

(i) Colour quantization can reduce colours contain in a topographic map with a small computation time, hence minimize the initial pre-processing phase for extracting contour lines.

(ii) Several criteria derived from local geometries (distance, angle and orientation) contribute significant information for seeking best connection path to reconnect broken contour lines.

(iii) By initializing control points based upon two endpoints detected and back tracing 10-pixel from these two endpoints, cubic spline interpolation is capable in reconstructing gaps exist in contour lines.

This study discloses a competent and less computation vectorization algorithm in handling topographic map, whilst result reliable data source for GIS.

This research can be considered as an applied research, which can benefit the following agencies:

(i) Geo-Information System œ A simple approach to digitize and recognize particular features from topographic map, which can be integrated in future GIS application.
(ii) Tourism Agencies -Virtual tourism and travel planning
(iii) Research bodies œ To help visualization process
(iv) Land Development œ Forestry and landscape architecture, Geological survey, urban planning

1.8 Organization of Report

This report consists of five chapters as following:

Chapter 1 briefly introduces map interpretation approach and some research background. Motivations of research and problem statement are also defined. Goal, objectives and scopes of research are stated clearly. Finally, research contributions are discussed.

Chapter 2 conducts a review to previous work, consist of the pre-processing and pre-acquisition approach to extract contour lines from topographic map, as well as discuss several existing process for contour lines reconnection.

Chapter 3 presents the methodology and theoretical framework of this study. It is consist of following procedures: colour quantization to reduce true colour, separate each feature into isolated layers, noise removal, contour lines enhancement, thinning, endpoints detection, broken lines reconstruction and finally export into vector format.

Chapter 4 reports on the implementation of the proposed approach. The methodology is designed to be implemented modularly by three phase, namely pre-processing phase, processing phase, and post-processing phase. This chapter illustrates how workflow and progress has been carried out in details for this study.

Chapter 5 presents and discusses the results of conducted experiments based on the proposed approach in this study. Several experiments are carried out on several portion of topographic map and comparisons are made between this study and several existing GIS application. The advantages, constraints and drawback are discussed in this section.

Chapter 6 summarizes and concludes the study and outlines topics for future work. The contributions obtained from this study toward current approach and improvement disclose from this research are clearly stated in this section.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

The rapid development of Earth Science visualization technologies has evolved raster data to become the main GIS data source. These technologies include remote sensing, SAR, airborne laser scan and photogrammetry. In these circumstances, GIS should capable to manage and process huge raster data sets. Meanwhile, current works for the production of GIS are almost directed towards particular problems. For instance, urban planning, emergency situation monitoring, agricultural development, military and other agencies that requiring maps. Therefore, it is encouraging if vectorization of traditional topographic maps can be conducted in a fully automated manner (Levachkine. and Polchkov, 2000).

Topographic maps are complex representation that contains enormous amounts of geographic information. Linear and area features are used to represent geographic and topographic information. In most cases, colours are assigned to differentiate these linear and area features. Meanwhile, contour lines and their elevation value are a significant characteristic to indicate three-dimensional terrain surface along with their height. Generally, contour lines are cluttered with non-contour data, including information on trails, streams, vertical coordinate, grid line and etc. Additionally, textured background and land use layer information that always overlaid on the contour lines with several descriptive texts has made the recognition process become more intricate.

United States Geological Survey (USGS) is one of the largest producer and supplier for topographic map. They use a range of manual techniques and procedures to perform map digitization. Operator is placed on the map using digitizing tablet and mouse is guided to trace each linear and area feature respectively (Khotanzad and Zink, 2003). Due to high cost associated with the extraction process, USGS are only capable to convert a small fraction of maps.

Many research efforts have been done in map interpretation. There are texture analysis (Heute et al., 1992; V.Meas-Yedid, 1997), colours classification (Yan, 1993; Khotanzad and Zink, 1996), linear features, symbols and characters extraction (Yamada et al., 1993; Deseilligny et al., 1995), road networks reconstruction (Chang et al., 1997; Bacher and Mayer, 2004) and so forth. Most of this works do not provide fully automated interpretation. Instead, they are only capable in interactive or semi-automated approaches, where human observer is required to initialize some lines tracking process (Suzuki and Yamada, 1990), or inspect reconstruction process (Ablameyko et al., 2002). In fact, digitization should manage to digitize all objects of a given class automatically. Consequently, no operator is involved to obtain vector layers. It sounds efficient and useful to GIS and digital mapping application, but it results high error in practice. Alternative methods must be sought in order to reduce high level of manual involvement and corrections.

Recent development on contour lines recognition from raster topographic map is still insufficient to provide a satisfying result in achieving accuracy while maintaining the topology of contour. Since topographic map is produced to be read by human and it includes objects with different font, orientation, size etc, it is impossible to recognize the whole map using an automated approach (Ablameyko et al., 2002). There are two main difficulties in this field: (i) how to perform contour lines extraction with less human intervention; and (ii) how to recognize contour lines accurately (least RMSE). Emphasis has placed on these two criteria to improve the research in this study. For contour line approximation or generalization, three requirements should be fulfilled (Li et al., 1999): (i) the contour lines should be simple, which mean the number of points are reduced, (ii) the contour should appear smooth, and (iii) the characteristic of contour lines should retain.

2.2 The Characteristics of Contour Lines in Topographic Maps

Topographic maps are complex representation of earth's surface that contains enormous amount of information. Various scales of topographic maps are produced by map producers with reference to their specification and standard respectively. The range of scale influences the accuracy of data representation. Conventionally, human visually inspect paper map, hence interpreting and deriving information from the map. However, information that obtained is usually limited by human mentally and physically constraints. Besides, paper map may cause storage and carriage problem. Therefore, it would be more efficient if the information from map can be interpreted, extracted, digitized and stored in GIS database.

Contour lines are the most traditional manner for characterize terrain surface. In addition to represent geometry of the earth's surface, contour lines implicitly preserve the topology. Elevation values are often presented as text descriptive on topographic map to indicate their height. Besides, there are also spot elevations, either perform as a dot or cross at a specific horizontal location. In this case, they are used to identify prominent natural features such as hilltops, knolls, isolated summits, mountain tops, mountain passes, saddles and other high points on a dominate area.

There are several topological characteristics appear on the contour lines. Foremost, contour lines are continuous, that means no broken on the circular shape of each contour line. Subsequently, they do not intersect each another. Meanwhile each contour line is either closed or started and ended within a domain boundary. However, the characteristics described above are not always preserved in map due to several reasons. Firstly, the lines are disconnected if the elevation value for a given contour line is placed on the map. Another reason is some sections of contour lines are not drawn and plotted fine in high-density regions. The following reason associated with deficiency of scanning device and process. Additionally, some unpredictable errors are arisen while map is plotted, cause contour lines to be merged or isolated in some particular region. Consequently, contour lines typically appear discontinuous with some gaps in a scanned raster map.

2.3 Digitization of Topographic Map

The demanding cartographic production in increasing the volume (more maps to represent more topographic areas in the world), quality (better maps), recently (up-to-date maps), accuracy (precise maps), cost (cheaper maps), variety (different maps) are necessitated in GIS. Since the use of GIS is increasing recently, retrievability of the information from raster topographic maps into vector data become an essential process to be integrated into GIS. Generally, extraction of features from raster map requires details interpretation of this imagery. The knowledge needs for recognizing and extracting relevant features is difficult to implement in computer algorithms. Therefore, only limited success has been achieved in developing automatic topographic feature extraction procedures. Human observers are still indispensable for reliable interpretation of raster images and they are talented in evaluating the quality of vector output (Vosselman, 1998; Ablameyko and Pridmore, 2000).

In order to digitize paper based topographic maps, diverse approaches have been developed during last two decades to acquire its information from raster into vector form (Levachkine and Polchkov, 2000). They can be categorized based upon different modes of operation: (i) manual digitizing, (ii) semi-automated, (iii) interactive and (iv) automated (Hori and Tanigawa, 1993; Eikvil et al., 1995). Most vectorizing systems require user to set an appropriate parameter for a particular map image. However, it seems difficult for a novice to adjust the parameters appropriately (Hori and Tanigawa, 1993; Boatta et al., 1992; Kasturi et al., 1990; Pavlidis, 1988; Suzuki, 1990). Since variety of colours is used to represent features in topographic map, majority of current vectorization systems separate these elements into different layers. Yet, fully automated system is still impractical and shown unreliable in recent times.

Features recognition in computer vision is largely based on matching of several descriptions shapes. Generally, Fourier descriptors, moment invariants, boundary chain coding and scalar descriptors are those methods that have been widely used to describe shape irrespective of position, orientation and scale (Laura and Adam, 2001). However, neither individual descriptor nor method is capable to produce consistent classification of contour lines until current study is carried out. Most of these available methods are relied heavily on image processing on pixel scale and pay little attention to spatial relationships, which inherent the characteristics of contour lines (Du and Zhang, 2004). Subsequently, a details survey on previous approaches associated with map digitization is conducted in this study.

2.3.1 Manual

Traditionally, manual approach is performed by tracing with digitizing tablet from paper map. Since most GIS packages support direct connection to digitizing tablet through computer I/O port, it has been widely used before development of semi-automated approach. The operator uses digitizing tablet to trace lines manually from the map; hence generate an identical digital map to be stored in computer. The lines are traced by a series of significant points, while rectilinear segments are used to approximate curvilinear contours. Although this approach is simple and straightforward, it requires an experienced operator. Meanwhile, the whole process is very time consuming and results unreliable data. This is because manual approach mainly relies on proficiency of an operator. In fact, human hand can only achieve around 40 dpi of spatial accuracy level.

2.3.2 Interactive

Interactive digitizing is similar to manual digitizing in the manner of the lines are traced by hand. It can automate individual lines tracing process by tracing one line in a time under guidance of an operator. This approach can work directly on computer screen by using the scanned raster image as backdrop. Although lines are still manually traced, the accuracy level is higher than manual digitizing. This is reason that raster images are scanned in high resolution, normally from 200 dpi to 1600 dpi. The operator can work with assist of display tools, such as zoom in and zoom out to achieve a higher accuracy level than manual digitizing. Therefore, it has proven significant improvement of the flexibility in tracing lines selectively with an operator control. This is apparently when fully automatic vectorization cannot be applied in low quality images and complicated layers. However, the accuracy is not satisfying and very time-consuming.

Interactive digitizers have been used for input units in conventional GIS due to several reasons: (i) high data compression rate, (ii) low hardware cost and (iii) operational simplicity. Since large number of manual operations involved in tracing, higher cost and much time are needed to digitize large geographical dataset. These manual operations can be reduced by scanner that is suitable for automatic map digitization (Kasturi et al., 1989; Suzuki and Yamada, 1990). Multi-Angled Parallelism (MAP) is an interactive method to recognize lines in binary images (Yamada et al., 1993). It is a unification of image representation by using directional planes and non-isotropic neighbourhood morphological operations. Binary image is transformed into directional planes; and directional operators of erosion-dilation are then applied iteratively. Subsequently, dissimilar types of lines (e.g. track, roads, stream, contour etc) are identified and extracted using a different set of operation.

Shimada et al. (1995) proposed an agent-based parallel recognition method to digitize contour lines. They introduced two categories of agents, a supervisor agent and vector trace agents (VTA), with a cooperative negotiable environment between agents to pass through irregular part of contour lines. Initially, contour images are displayed on a CRT. The contour lines are selected by an operator and started with a vectorized route search from trace base points in related direction. Then, feature points are extracted and their coordinates are memorized. If the vectorized route search has reached at an irregular point, but the next search direction is not determined, the VTA has to interact with the neighbouring VTAs. The trace direction is selected by a cooperative process between these VTAs. The vector trace agents, which arrive at the boundary points will return to the first trace point and start another route search in the opposite direction.

2.3.3 Semi-Automated

Semi-automatic is another approach towards automated raster to vector conversion. Operator is still needed to carry out the operation. It is an interactive process between operator and one or more computer algorithms. In order to initiate the process, the operator will interpret the image and decide those features that should be measured and algorithms to be applied according to particular feature. Sometime, operator may tune some of the algorithm's parameters and select an object model for particular feature. This approach is typically developed for measuring primitive features such as points, lines and regions, and for more complex or parameterized objects. Therefore, it combines the interpretation skills of an operator and computation time.

Helvaci and Bayram (2004) developed a semi-automated algorithm to accelerate the digitizing process. Initially, they rectify the map interactively using grid network. The operator indicates those elevation contour pixels as the training area, which they used as input data. Then, other elevation contour pixels are determined automatically from their centre points. The result of produced vectors may contain errors depend on the topographic condition of selected map area. Elevation contours with coordinates (x, y) are generated after manual editing. Meanwhile, Z values are given by the operator before the end of the entire process.

2.3.4 Automated

Automated approach traces lines from scanned image using image processing and pattern recognition techniques. The main purpose is to computerize the line tracing works instead of human intervention. Since it is very beneficial for GIS community, it has been a major research focus during past two decades. However, a number of difficulties are remained until current study is carried out. In recent years, several applications have become more practical and commercially available on personal computer. Indeed, increasing of complex methods and algorithms for machine recognition of cartographic objects cannot improve the results significantly

(Levachkine, 2002). Therefore, improvement is still necessitating in achieving better result. Furthermore, automatic processing of topographic map is not always the possible solution in converting analog map into structured digitized information. In some circumstances, interactive approach would be an alternative to this solution (Levachkine, 2003).

Frischknecht et al. (1998) implemented an automated approach to obtain multiple information and structure objects from raster topographic maps. Knowledge-based template matching is used to segment and isolate coherent areas of colour. All segmented areas are encoded uniquely; therefore, it allows each feature to be calculated in an isolated raster element. The colour image segmentation into dissimilar features is served as pre-selection in raster image to differentiate the interest region. Automatic vectorization is performed by adjusting the endpoints of line segments. Then, it is facilitated by robust estimation functions. In addition, Apaphant (2000) presented an automatic cartographic line tracking method, consists of line thinning and line following steps. After that, Lee et al. (2000) developed a knowledge-based system for automated vectorization of cartographic maps. Firstly, they thin an input image to produce a skeleton with definite unit width. The performance of representative thinning algorithms is systematically evaluated in various map images. Finally, appropriate rules for particular maps are devised. Each rule is characterized by the type of map, resolution, quality, line width, line slope etc.

Three main steps are involved in automated digitizing process for Levachkine's approach (2003): pre-processing, processing and post-processing. The pre-processing operation consists of preparing the cartographic materials for scanning; the scanning process and preparing for recognizing desire features. Whilst, the automated process is performed in the following scheme: (1) development of strategy for automatic digitization of raster maps; (2) definition structure of raster map (classification of recognized objects, definition of size, form and colour filling of semantic patterns, estimation of statistical weight of single element); (3) recognition of cartographic images; (4) recognition of attributive data of vectored objects (classification of attributive information carriers, location and identification of attributive information, errors correction of attributive data recognition); (5)

elimination of image covered by recognized objects. Finally, post-processing is carried out to correct vectorization errors by correcting the vector layers based on their internal topology, sources of evidence (textual, spatial distribution, geographic, symbol, linguistic and etc information), spatial and logical correlation with other vector objects; as well as final correction for the entire system.

The following Table 2.1 shows a comparison between four existing digitization approach with their briefly elaboration.

Table 2.1: A comparison on digitization techniques

	Manual	Interactive	Semi-Automated	Automated
Material	Digitizing tablet is used to trace the lines manually from the map; hence create an identical digital map and store in computer.	The lines are trace by hand, but it can automate individual line tracing process, detect corners, crossing junctions and gaps.	Vector editors can automatically digitize object of a given class, and operator is needed to correct errors	Traces lines automatically from scanned raster image using image processing and pattern recognition techniques
Advantanges	Simple and straight forward	Works directly on computer screen using scanned raster image as backdrop.	Lines tracing are automated based on given knowledge	Computerize line tracing work instead of human intervention
Operator	Need experienced operator	Need guidance of operator in line tracing process	Operator is needed to handle anomalous case and correct error	No operator needed
Computation time	Need a lot of time	Time consuming	Human effort is less with less computation time	Depend on image acquisition technique
Accuracy	Low	Medium	Medium	Sometime exist high error if the map semantic is anomalous and cannot be expected

2.4 Raster to Vector Conversion

Vectorization, usually known as raster to vector conversion, is a process to identify vectors (line segments) from raster images. It is widely applied in document analysis for high-level object recognition, such as Optical Character Recognition (OCR) and graphic object recognition. Vectors are a compact form that describes geometry of graphical object with a small number of attribute values. Almost all typical vectorization process consists of following basis scheme: medial axis points sampling, line tracking and line segment approximation or polygonalisation. In fact, they should be able to facilitate following circumstances: (i) conservation of information that is enclosed in an image; (ii) reduction of data storage; (iii) simplification and adaptability of the new representation space for further processing. Consequently, the most promising raster to vector conversion in GIS is the development of an advance technique, algorithm and system that are capable to focus on locating and identifying specific features that constitute the structure of map semantic (Levachkine, 2003).

Recent development on vectorizing maps, using either interactive, semi or automated approach is essentially performed by following the discrete points along the curve or line on the maps. Most of the present algorithms have to provide deterministic editing before, within or after the vectorization process. Then, existing defects are removed before storage (e.g. intelligent noise removal). Early vectorization of line drawings introduced following essential steps for automatic procedure: (1) digitization of paper-based document or image using a scanner; (2) filtering; (3) thresholding; (4) thinning and pruning binary image; and (5) raster to vector conversion. These sequential steps can be found in (Leberl and Olson, 1982) for automatic vectorization of clean contour, drainage or ridge sheets, in (Greenlee, 1987) for an early attempt to extract elevation contour lines on topographic maps, (Amin and Kasturi, 1987) for lines and symbols recognition, and (Musavi et al., 1988) for land record maps processing. Many criterions can be adopted for classifying various possible approaches for topographic map interpretation and vectorization. In general, the main and most common criterions are image-based approach and geometric based approach (Salvatore and Guitton, 2004).

2.4.1 Image based Approach

The algorithm of image analysis and processing are limited to handle symbols formed by regular or irregular geometrical shapes and different type of lines, either continuous or broken lines. These are often occurred in features analysis and topographic map interpretation process. In general, raster to vector conversion from line drawings and map image are based on perceptual principles, i.e. to make decision for closing or grouping two different segments or pixels. There are two main criteria: proximity and continuity that have been generally used in recent development (Salvatore and Guitton, 2004).

Kasturi and Alemany (1988) developed an integration of system, consists of pre-processor, query processor and image processor. The pre-processor is used to digitize and orient the map, separate text strings from graphics, and estimate the parameters required by image processor. After that, query processor is responsible to analyze the queries presented in a predefined syntax. A sequence of calls is generated to appropriate routines design for performing several operations like lines following, symbol recognition and so forth. However, they pay more attention on query processor for extracting information from paper-based maps and answering queries related to spatial features and geographic data. Later on, an improved system for interpreting paper-based line drawings images to locate and separate text strings and different type of lines is pursued by Kasturi et al (1990). The system used Hough transform to centre those connected components in the map image.

After several years, Lauterbach et al. (1992) incorporated adequate image analyzing methods for automatic data acquisition from topographic maps (PROMAP). The system is capable of generating symbolic description of map contents and it can be imported into other commercial GIS application (e.g. ARC/INFO). The main task of their raster data processing is composed of scanning, separation of colour layers, raster symbol and object recognition and vectorization. Subsequently, Yamada et al. (1993) presented a multi-angle parallelism (MAP) operation algorithm for extracting text and symbols from topographic maps. The

MAP performed parallel calculation on directional feature planes. Then, linear features are extracted using erosion-dilation operations on directional feature planes. Meanwhile, symbols are extracted using re-formalized and parallel version of generalized Hough transformation on the same directional planes. Their algorithm used symbols rather than contour lines to convey terrain elevation. Since they have focused on text and symbols extraction, it can only operate on binary images. Therefore, edge pixels that contain aliasing and false colours are assigned to 0 or 1. Aliasing is induced by scanner's point spread function (Wang and Pavlidis, 1993), while false colours are due to RGB misalignment (Khotanzad and Zink, 2003).

Previous research mainly focused on grey scale or binary map. After several years, colour information is commenced to be an essential element for recognizing particular features from maps. Soille et al. (1990) first used mean and variance of hue channel for discriminating soil types on a digitized soil map. Subsequently, Hedley and Yan (1992) developed a gradient thresholding scheme to overcome aliasing and false colour problems that always exist in colour map interpretation. They combine spatial and colour space information to remove those pixels containing colour aliasing and false colours, and left those pixels in a low-gradient set (i.e., those containing colours that perceived from the map). However, their algorithm is rendered ineffectively when apply into topographic map. This is due to most linear features belong to a high gradient set are removed by their algorithm.

For simple enhancement of elements, which are darker than foreground, image, morphological erosion can be applied to each RGB band separately. Although it is faster and yield better contrast in results, it perform unsatisfactorily result with presence of pepper noise. Therefore, Santos et al. (1993) presented Selective Attention Filter (SAF) to extract or enhance specific features of an image correspond to the conceptual layers in the map. The process is accomplished by extracting information from the results of clustering local regions on the map. Their technique reduces those interfering elements while preserving the edges of regions with different colours; as well as enhancing other features in an image. The clustering applied within SAF filter is simple K-Means with Euclidean metric. Consequently, this approach is competent to identify clusters that close to specific point in a parameter space and it can be used to enhance marks of a specific colour. Since clustering must be completed for all pixels (or even small regions) in an image, it is relatively slow in computation time.

Wu et al. (1994) performed multilayer neural network to extract characters and lines from colour maps. Although input data include features that comprehend colour intensity and gradients, they ignore the inherent of colour aliasing and false colours in a map. Therefore, it may not perform well on topographic maps that use very thin and closely spaced feature geometries. In the same year, Ebi et al. (1994) transformed the input RGB colour space into another colour space by considering chromaticity information. Classification or clustering techniques are then applied to the bivariate histograms that constructed from the resulting of two chromaticity channels. Then, Marcu and Abe (1995) detected RGB alignment and plotted this phenomenon in RGB space. They corrected the problem by realigning RGB channels using intense image processing computations.

Eikvil et al. (1995) presented an approach based on contour line tracing. They concentrated on data acquisition and vectorization of lines structures. The interactive vectorization consists of tracing lines, detecting corners and crossing junctions (straight crossing, left or right turning and reconstructing of contour); and crossing gaps. In their approach, it is assumed that there is only one possible continuation when gaps occur. The continuation can be found along current direction of the line. Gap is crossed by searching from endpoint of the line within a sector around current direction. However, existing closing algorithm based on perception criteria fails at discontinuity points (Salvatore and Guitton, 2004).

Alternatively, Chang et al. (1997) introduced an automatic road extraction technique from colour topographic maps. It is based on conditional dilation operation of mathematical morphology. Contour lines that have equal colour with roads have relatively high difference width compare with roads. Therefore, they are eliminated by morphological opening operation; whilst internal noise is deleted by morphological closing operation. However, distortions of road information cause by thinning operation occurred at the cross-points and these lead roads to be overlapped.

Matching is another basic approach for locating known objects in an image in order to search specific pattern. The best match relies upon objects properties and object relations. Frischknecht et al. (1997) applied hierarchical template matching procedure to extract text and symbol from topographic maps. This approach emphasizes on the critical areas for text or symbol to be matched, and de-emphasize non-critical areas such as edge pixels between symbol and its background. Although their algorithm has performed well for text and symbols, as well as avoiding aliasing and false colours inherent in edge pixels, it is not suitable in handling thin and closely space linear features like contour lines. They further their work in obtaining multiple information and structure objects from raster topographic maps by associating knowledge-based template (Frischknecht et al., 1998). Their approach results in a high recognition rates (about 95%). The entire rectangular matrix template is not necessary to be fully computed and compared within the expansion of map. Instead, template is weighted and built hierarchically as a multicolour template. This approach has been tested on several topographic maps and proven operationally and qualitatively suitable for automatic processing.

Dupont et al. (1999a) used external terrain elevation data to enhance contour lines extraction from scanned map. They use watershed divide algorithm in RGB space to assign pure map colour for every pixel. Then, local and geometrical rules, as well as orientation information that computed from external terrain elevation data are used to resolve ambiguities associate with broken and closely spaced contour lines. Their algorithm performs well for images scanned by high resolution and quality scanners, but poorly for image that contain aliasing and false colours. They extended their research by performing an automatic quotation of contour lines in order to create digital terrain models (Dupont et al., 1999). The skeleton of contour lines is computed using veinerization method (Deseilligny, 1998); whilst characters are extracted and recognized by rotation-invariant recognition approach (Deseilligny, 1995). Since veinerization method is based on computation of an extinct function, the result can be used to estimate the average thickness of a specified contour line. Every main contour line is separated from ordinary contour lines by applying Otsu thresholding method (Otsu, 1979). Finally, bicolouring method (Dupont, 1998a) is used to reconstruct the main contour lines.

Xulio et al. (1998) designed a vectorizer for colour topographic maps. Several procedures are carried out in their approach, including colour splitting, thinning and post-thinning and lines following. In colour splitting, they perform luminance threshold to remove background pixels. Generalized erosion is then applied to ensure the colours of line pixels reveal as darker and uniform. It is followed by applying clustering method from the palette until a stable position is achieved for colour distribution means. For line processing, they first filter the noise to remove all isolated pixels and small spots; and then thin those recognized lines by preserving one pixel width. A set of rules is defined in the beginning to remove all pixels that are not essential for connectivity. Subsequently, these pixels of lines are classified and lines following are performed based on the difference of slopes between outgoing lines and isolated lines. Generally, the number of pixels that involve in the intersection is more than one. Therefore, a set of data structure known as Macro Point is created. Those pixels that construct a Macro Point are treated as a single set. Then, the points of line segments are approximated by B-Spline curve, forming by a set of closely space points.

Yet, Arrighi and Soille (1999) used mathematical morphology in reconstructing contour lines. Initially, they extracted a mask for contour line by extracting all red hue image pixels. The resulting lines are disturbed by many noise pixels. Several morphological filters are applied to produce a clean mask for the contour lines: (i) removal of all isolated pixels using hit-or-miss transform, (ii) fill all one pixel thick gaps using non-homotopic hit -or-miss operations with a set of composite structuring elements, and (iii) removal of all holes within lines. Then, they extract extremities of lines before skeletonizing by generalizing hit-or-miss transform. Euclidean distances between extremities and differences between their directions are used to join disconnected lines. Once all possible distances are computed, extremities that produce lowest distance are connected.

On the other hand, Xi'an Zhao and Ping Xiao (2002) presented character recognition in digital mapping by utilizing wavelet transform. Several procedures are applied in their approach. First, median filter is used to retain the edge details and reduce noise in a grey scale image. Then, adaptive threshold is applied to transform the gray-level image into binary image. Mathematic morphology in 3x3-structure element is used to dilate character. Minowski operator is used to extract the edges of closed contour associated with character and the annotation for contour lines. Boundary is maintained as a single pixel point by morphology operator. This boundary of close contour is then traced clockwise starting from every closed-contour's northwest corner. During tracing process, the boundary chain code is recorded as one-dimensional (x-coordinate, y-coordinate, and tangential angle). At the same time, every close contour is numbered and total pixels are calculated.

Majority of map analysis techniques are performed on binary maps that have thicker features and spaced far apart from each another. Relatively, only few have focused on colour images and thin closely spaced linear features (Khotanzad and Zink, 2003). They developed a system by employing colour information for contour lines and other geographic features extraction from topographic maps. A colour key set is developed to overcome colour aliasing and false colours induced by scanning process. It is accomplished by eigenvector line-fitting technique in RGB space. The area features are extracted using RGB colour histogram analysis; while linear features are extracted using a valley seeking algorithm. Finally, A* search algorithm is used to form linear features and bridge gaps caused by intersecting features. The broken contour lines are then filled by means of the unique characteristics of contour lines. Their approach has several novel aspects. First are the development and use of colour key set to compensate aliased and false colour. Another is addressing the problem associated with thin, closely spaced and intersecting linear or area features.

2.4.2 Geometric Based Approach

There are two kinds of geometric features exist in topographic maps: (i) linear features, such as roads and railways that have an arbitrary length; and (ii) symbols that indicate a type of building or area of land usage or numerical information. The most difficult and important problem encounter in automated digitizing of topographic maps is the process of identification and separation of dissimilar features. In general, vectorization is performed at early stage to analyze a map. Then, sequential process is applied to separate and recognize features from the complicated background. However, many two-dimensional objects are mislaid; hence, calculation is increased severely by means of the rising of vector segments.

The raster to vector task can be carried out as a general problem of curve reconstruction by constructing graph. The first algorithm for curve reconstruction imposed a uniform sampling condition, as it is demanded on the distance between two adjacent samples (Edelsbrunner, 1983; Bernardini and Bajaj, 1997; Attali, 1997). Another approach is based on run graph to record the node areas, which are junctions. These approaches are capable in preserving both connectivity and line width information (Monagan and Roosli, 1993). They use nodes corresponding to endpoints of the vectors, along with a set of adjacent run graph to express digital segment between these two nodes. Since those intersection points cannot be located precisely, it is susceptible to noise and may cause distortions at junctions.

For contour lines recognition, Ablameyko et al. (1994) employed attribute grammars to classify line objects. The grammars are segment of line (S), gap (g), point (P); and closed contour (c). The terminal elements (TEs) are divided into two groups: constructive and connecting TEs. Constructive TEs are used to obtain geometrical coordinates; whilst connecting TEs are used to connect constructive TEs in a chain. Each TE has attributes like length, thickness, type etc. The description of lines is obtained by combining different TE. For instance, the description of an isoline formed by repetition of an open line segment, point and gap is given by following semantic rule, P: G -> sgpgG, where G represents non-terminal element and starting symbol. TEs consist of following attributes: (1) s = <thickness><type> <length>; (2) g = <length>; and (3) p = <diameter>. For recognizing an isoline, local search of neighboring segments whose belong to one line and comparison of extracted segment chains with reference chains of TEs are used in their approach.

Peter et al. (1994) presented an approach to compute vector representation of arbitrary line for bi-level raster image. Generally, lines are varying in width and have irregular borders. Their direction is diverse at line crossings and branches. For this reason, the method is designed for avoiding thinning and vectorization of chain codes. A contour follower associate with median line calculation is employed to obtain the line's information. As a result, this approach manage in extracting individual line efficiently due to these reason: (1) it can handle lines with irregular borders, skips short dead end branches and small holes; and (2) offers user in choosing the desire branches between several branches.

After several years, Amenta et al. (1998) introduced a concept for local feature (distance of a point to medial axis of the curve). By using this concept, they defined a non-uniform sampling condition that allows sampling of variable density. Subsequently, a correct reconstruction that satisfies this sampling condition (Delaunay Triangulation) is computed from a sample set of smooth close curves. Apart from that, Dupont et al. (1998) have quoted this portion of curves that present on the map based on external elevation information and a combination of local and global strategy. Their approach is initialized by pre-treatments on segmented quotation values. Then, contour lines are extracted using a combination of morphological and structural methods; whilst, curves are skeletonized by veinerization method and they are vectorized after polygonal approximation. A graph is resulted from this vectorization process. Subsequently, they detect and resolve non-ambiguous cases based on local and geometrical rules. An analysis is conducted based on contour lines' skeleton and Voronoi's skeleton. After that, an iterative algorithm based on constraint propagation method is used to quote the curve. Finally, the coherent verification and correction procedure are accomplished to detect any possible errors, due to bad colouring or high imprecision of the database. Since the information for unquoted curves is lost, major progress is concerned on the interpolation step. They integrated a constraint of tangency to elastic grid or used some methods in (Muraki et al., 1990) to remedy the problem.

A survey of algorithms based on Delaunay filtering can be found on Edelsbrunner (1998). A number of variations that handle smooth close curves is presented (Dey and Kumar, 1999; Gold, 1999). Later, Dey et al. (1999a) extended this work to handle a collection of open and close smooth curves. After that, Giesen (1999) used a different sampling condition for corner areas. He discovered that

Travelling Salesman Problem (TSP) is the correct reconstruction for a single close curve (possibly with corners). Then, Althaus and Mehlhorn (2000) extended their work by showing that TSP can be computed in polynomial time. However, TSP can only handle single and close curves.

Alternatively, Dey and Wenger (2000) proposed an algorithm that capable to handle corners and endpoints excellently. However, their algorithm cannot guarantee good results. Recently, Salvatore and Guitton (2004) presented an algorithm based on Delaunay filtering. Unlike previous algorithms, they used local geometries rules and global topology of a generic topographic map to recognize contour lines. Initially, they segment the map by colour classification process using HSV colour space. Almost 80% of pixels are black or white, while the remaining pixels are fallen in the chromatic region of HSV cone for a scanned topographic map. Therefore, hue histogram is generated of these remaining pixels and the resulting peak that near to brown value ($10<hue<30$) is referred as contour lines. The resulting binary image is thinned and vectorized using Delaunay triangulation. Reliably edges are detected using Amenta's properties. Finally, these broken line segments are connected using a combination of distance and direction establish from the endpoints of resulting smooth chains.

2.5 Image Segmentation

The main purpose of colour image segmentation is to identify regions of interest and objects in a scene. It is very beneficial to computer vision, image analysis and acquisition application. However, the use of colour increases the amount of information needed for processing; and this complicates the problem definition. Therefore, automatic evaluation of low-level segmentation that does not require user to set any parameter or threshold values is still an increasing demand in image analysis. In general, these methods can be categorized into histogram thresholding; colour space clustering; edge detection and region extraction; Marcov Random Filed (MRF) and Gibbs random field (GRF); neural network; and various combinations of above techniques.

Initially, image segmentation performs several procedures to partition an image into disjoint regions that having strong correlation with objects or distinguish objects of interest. It is often describes by analogy to visual processes as foreground or background separation, implying that the selection procedure concentrates on particular feature and discards the rest. This task can be performed directly if the objects in an image have very distinct colours and well separated. On the other hand, if the scene is composed of composite objects with less distinct colours, the process would become more intricate. In addition, objects that contain gradual variations of colours should be taken into consideration when performing segmentation.

Many algorithms for colour image segmentation that combines several approaches have proved promising result. The quality of an image segmentation or edge detection algorithm depends on several factors, including the type of images being processed, the requirement of application, computation time and cost and visual inspection. Since correct segmentation could not be achieved without specific domain knowledge, low-level segmentation is often applied as an initial step for image analysis (Pavlidis and Liow, 1990).

Thresholding is the simplest, conventional and computationally inexpensive technique among these segmentation methods. There are several approaches in thresholding, consist of basic thresholding, iterative (optimal) thresholding, recursive multi-spectral thresholding and hierarchical thresholding. Most of these practical segmentation processes requires information than more than one spectral band. Colour image is coded in three spectral bands, for example, red, green and blue; whilst multi-spectral remote sensing images or meteorological satellite image may contain several spectral bands. The automated pixel-based segmentation process needs to select a colour ranges associated with each object in an image. In general, the largest local maxima are selected from the colour histogram that has distinct peak. Unfortunately, the direct approach of scanning the highest peaks does not always work. This is due to the colour of interest is not always the major colour in an image. Consequently, position and shape of the peaks are needed to be considered for accomplishing this task.

Region-based segmentation approach relies on the hypothesis that those adjacent pixels in the same region have similar visual features such as grey level, colour value, or texture. A well-known technique from this approach is known: split and merges (Haralick and Shapiro, 1985; Chang and Li, 1994; Hojjatoleslami and Kilter, 1998). Seeded region growing (SRG) technique is applied for tuning the homogeneity parameters (Adams and Bischof, 1994). SRG is capable to find an accurate segmentation of an image with the property that each connected component of a region meets exactly one of the seeds. Additionally, the selection of seeds can exploit high-level knowledge of image components. However, automated selection of initial seeds is a critical issue to outcome an accurate image segmentation result. Another approach combines region growing and edge detection for image segmentation (Pavlidis and Liow, 1990). The image is segmented by split-and-merge based on quad tree decomposition, while region boundaries are eliminated or modified based on following criteria: (i) contrast with boundary smoothness, (ii) the variation of image gradient along boundary smoothness, and (iii) a criterion to detect and remove artifacts generated by the quad tree segmentation.

Gao et al. (1993) employed a feed forward neural network for separating colours in topographic map. The three-layered network is composed of three input nodes that correspond to red, green and blue intensity of each pixel. Several errors are occurred in the result of neural classifier due to incompleteness of the training samples and several other reasons. These reasons include insufficient of time, variance of paper, rubbing of paper, inhomogeneous of painting and optical distortion of scanning. These errors are adjusted based on the distribution of classified result of a pixel's neighbourhood.

For GIS research and development, Khontanzad and Zink (1996) presented an automatic colour segmentation algorithm using eigenvector line-fitting technique for USGS topographic map. Their approach overcomes false colours problem introduced by scanning process due to RGB misalignment. Since all USGS maps are printed on white paper as background, their algorithm is started by segmenting the white background from the map. Then, red, green and blue intensity of each pixel is examined and classified. The eigenvector line-fitting technique uses the colour information of pixels in a 7x7 window to classify the colour transitional pixels. In this case, the direction of eigenvector corresponding to the largest eigen value is parallel to the line. This minimizes the perpendicular distance between 49 pixels and become the best-fit line in RGB space. Therefore, the high eigen value that occurs in the region of high colour change and aliasing. The direction of eigenvector represents the colour perceived for these pixels. This approach has been experimentally verified to be robust and accurate for USGS topographic map. However, it remains problem for those regions contain overlapping lines.

Comaniciu and Meer (1997) presented several procedures for colour image segmentation by initializing the segmentation parameters. User indicates the desired class of segmentation, where the class definition is translated into three parameters: (i) the radius of search window, (ii) the smallest number of elements required for a significant colour and; (iii) the smallest number of contiguous pixels required for a significant image region. The size of search window determines the resolution of segmentation, where smaller value corresponding to higher resolution. The second step is definition of search window, where initial location is chosen randomly. In order to ensure that the search can be started close to the highest density region, several candidates in different location are examined. Mean shift algorithm is applied to selected search window to locate the closest mode and those detected features are removed. In addition, eight-connected neighbours in the image domain are removed without concerning of their feature vector value. These steps are repeated until the numbers of feature vectors in selected search window no longer exceed the smallest number of elements required for a significant colour. Throughout these sequences, initial and final feature palette can be determined.

Yining et al. (1999) introduced a new approach for fully automatic colour image segmentation (JSEG). Initially, colours in an image are quantized into several representing classes to differentiate the regions. Then, image pixel colours are replaced by their corresponding colour class labels, hence form a class-map for the image. A region growing method is used to segment the image based on multi-scale images. They has resulted good segmentation on a variety of images. After several years, JianPing et al. (2001) proposed another automatic image segmentation technique based on seed region growing (SRG). Initially, the colour edges are obtained automatically by combining an improved isotropic edge detector and a fast entropic thresholding technique. Then, the centroids between these adjacent edge regions are taken as initial seeds for SRG. These seeds are replaced by the centroids of generated homogeneous image regions by incorporating the required additional pixels. Finally, the results of colour-edge extraction and SRG are integrated to provide homogeneous image regions with accurate and closed boundaries.

Mathematical morphology is a geometric approach applied in numerous image processing and analysis applications, such as noise suppression, image segmentation, feature extraction and image compression. However, it is not suitable for filtering content-dependent quantization noise, which may destroy fine image structures that carrying crucial information. On the other hand, fuzziness is an intrinsic property of images and the natural outcome of many image processing techniques. Fuzzy set theory has established a promising field in the domain of image processing and analysis application. The respective brightness and colour values of two neighbouring pixels in an edge are significantly different in a colour image. Both characteristics should be investigated for developing an efficient colour-edge extraction. Louverdis and Andreadis (2003) introduced a framework for soft morphological colour image processing using a fuzzy model in the HSV colour space. They extended the standard colour morphological operators in the same way that soft greyscale morphology extends the standard greyscale morphology theory. The proposed operators are less sensitive to image distortion and small variations in the object's shape. As a result, they performed significantly improvement for impulse noise removal compared to the standard morphological operators.

Another novel approach is proposed by Xu Jie and Shi (2003) for natural colour image segmentation. It is accomplished by integrating edge, edge's position, local colour difference and overall colour distribution information in an image. Edges are detected in term of high pass congruency in grey-level image. They categorized long edge lines using K-means clustering based on global colour information to estimate the distribution of objects in the image generally; and merge short edges based on their positions and local colour differences to eliminate the negative affection caused by texture or other trivial features in an image. Then, region growing and merging technique is used to form close regions by assuming the allocated edge pixels as initial seeds. The method has shown stable results accordant with HSV colour space for different types of natural images.

2.6 Edge Linking

Boundaries or outlines of an object are usually used to differentiate an object or to detect abnormalities. For this reason, a great number of edge detection methods have been developed to locate the boundaries of objects in image based on local pixel properties. Several edge detectors used in these techniques, including Sobel, Roberts, Canny, Prewitt operators etc. In general, the result of these approaches can only provide candidates for region boundaries because the obtained edges are normally discontinuous or over-detected. Edge linking is a process to complete the boundary, and delete spuriously detected edge elements from the edge map. A common factor for edge linking is the assumption that configurations of edge elements must possess the properties of thinness and continuation. Gaps are filled in order to find configurations that comply with these properties.

Lines and edges arise as low-level features to be extracted from map images. For example, roads, railroads, rivers and contour lines are important lines extracted from topographic map for integrating into GIS database. Several methods are developed to extract lines directly from raster images using local operators (filters), Hough transform etc. Since their great directionality prevents them from extracting lines with several directions along their path, they are unable to identify specific features. Therefore, other processes like edge tracking, gaps filling, smoothing and thinning should be attached to assemble edge pixels into contours correspond to the meaningful boundaries in an image. Although several properties such as alignment and symmetry allow a human to reconnect the missing edge point, indeed, human perception is the best-known method for edge linking.

Classical techniques first skeleton the lines and search for relevant extremities of the skeleton for recovering the missing parts of the lines (Eikvil et al., 1995; Oivind et al., 1995; Xulio et al., 1998; Dupont et al., 1999). There are some problems with this approach because skeletonization is very sensitive to noise and regularly creates small branches at the extremities of the lines. These can remove by pruning easily, but it result shorter lines. Therefore, some relevant information is lost. Line following identifies a series of coordinates in each individual thinned line. In general, the object-based method first detects the endpoints of lines, and then individual objects are followed from the beginning node of the objects through the ending node of the objects (Greenlee, 1987; Moore, 1992). Several problems occur in line tracing which leads erroneous in vector lines extraction. These includes (i) a number of spurious branches may be introduced (ii) a number of genuine lines may be loss from the image pre-processing step, like image colour segmentation, thinning and etc. (iii) large errors in lines orientation and position maybe introduced.

Xulio et al. (1998) first filter the noise in order to remove all isolated pixels and small spots. Then, a thinning algorithm is applied to obtain one-pixel width skeleton line. Since some pixel configurations may represent potential problems for line following process, post thinning is performed. After that, they classified the points in the image into the following classes: points with only one neighbour (endpoints), two neighbours (line points) and more than two neighbours (intersection points). In line following, they follow the different lines based on the difference of slopes between all outgoing lines. A data structure known “Macro Point” is created (Figure 2.1) for the number of pixels involved in the intersection points. Figure 2.1 shows the solution in their approach for bridging the gaps occur in the lines.

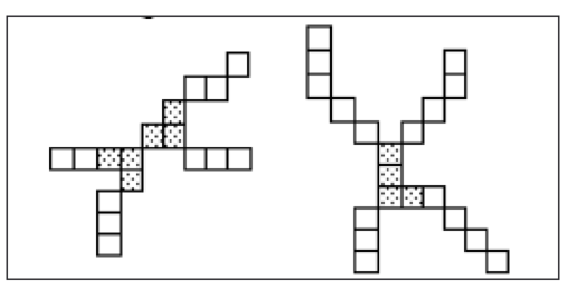

Figure 2.1 Examples of macro-points (the shaded pixels set up the macro-points)

Bacher and Mayer (2004) proposed an approach for road extraction. The best path for the connection to close gaps is obtained by optimizing a zip lock snake between two adjacent endpoints of the linear features. For verifying these road sections, paths of the snakes are evaluated using line strength and the gradient image.

2.6.1 Morphological Operations

If the fragmentation of boundary is not too severe, morphological operation like dilation, erosion, opening, closing and hit-or-miss transform are appropriate to fill small gaps and eliminate spurious edges and spurs. Leymarie and Levine (1989) presented a scheme to obtain the discrete curvature function of planar contours based on chain-code representation of a boundary. The important features such as peaks and segments are extracted from curvature function using mathematical morphological operations. The MAP operation (Yamada et al., 1993) unifies both representations by directional feature planes and non-isotropic neighbour operations. It is an expansion of conventional erosion-dilation operation (Haralick et al., 1987).

Barrett et al. (1994) developed an image space contour interpolation algorithm, which exploits local and global contour morphology. The algorithm is particularly appropriate for DEM generation. Then, Du and Zhang (2004) employed mathematical morphology to acquire spatial relationships of contour lines. Each line segment is dyed with a unique colour. They made use of adjacent and directional information, as well as distance information for matching and connecting broken contour lines. However, their approach can perform well if the contour lines are not too fragmentary and sufficient spatial information.

2.6.2 Graph Searching (Chain Code)

Graph searching is a comprehensive approach to find a minimum cost path between nodes in a graph. The algorithm starts from a single boundary pixel, and attempts to join neighbouring pixels based on their edge strength and direction. At the end of the process, boundaries contours are thinned by removing pixels until one-width pixel is remained. This strategy indicates that two adjacent pixels can be joined by calculating the edge magnitude and direction. For this approach, graph is used to represent edge points, where edge points correspond to graph nodes. The nodes are connected to each other if local edge linking rules are satisfied.

Gao et al. (1993) converted thinned image into chain code by a scan-line line following algorithm. It is vectorized based upon a set of geometric measurement. For the connection phrase, a neighbouring graph of vectors is created by sorting and scanning. By inferring on the neighbouring graph, broken lines are connected. There are several representations of contour paths, for instance, freeman chain code or an ordered of coordinates. Figure 2.2 shows how to determine the boundary list of a region from a starting point using 8-connectivity (Ferdinand, 1994).

Input: region, starting point $P_{init} = (n_0, m_0)$

1. Create an empty boundary list and put P_{init} on top of it, set $P = P_{init}$
2. From the 8 neighbors of P_{init}, choose a point, *q,* that is not part of the region, that is, $q \in N_8(P_{init})$ and $q \in N_8(P_{init})$.
3. Set $q_{init} = q$
4. Determine the 8-neighbors r_i (where $i = 0, ..., 7$) of p such that;
   (a) $r_i \in N_8(P_{init})$
   (b) $r_0 = q$
   (c) $r_0, r_1, \ldots, r_7$ is a counter clockwise oriented closed contour
5. Select j such that:
   (a) $r_0, \ldots, r_{j-1} \notin region$
   (b) $r_j \notin region$
6. Set $p = r_j$ and $q = r_{j-1}$
7. Append p to boundary list.
8. If $(p = p_{init})$ and $(q_{init} \in \{r_0, \ldots, r_{j-1}\})$ exit.

9. Go to Step 5.
Output: An ordered of boundary list.

Figure 2.2 Contour tracing

Lee et al. (2000) developed an automated vectorization process that consists of four steps: (1) thinning, (2) transformation of the skeletal image into graph in order to produce vector data effectively (Suzuki, 1988), (3) optimization of the graph, where extra edges unnecessary for preserving the topology of the map are deleted and (4) extraction of feature points and line approximation. The line approximation is performed by least-squares method to the resulting set of arcs. Figure 2.3 shows the result in their approach of transforming a skeletal image into a graph, where (a) is a skeletal image, (b) is the graph representation of (a), and (c) is the data structure of representing the graph respectively.

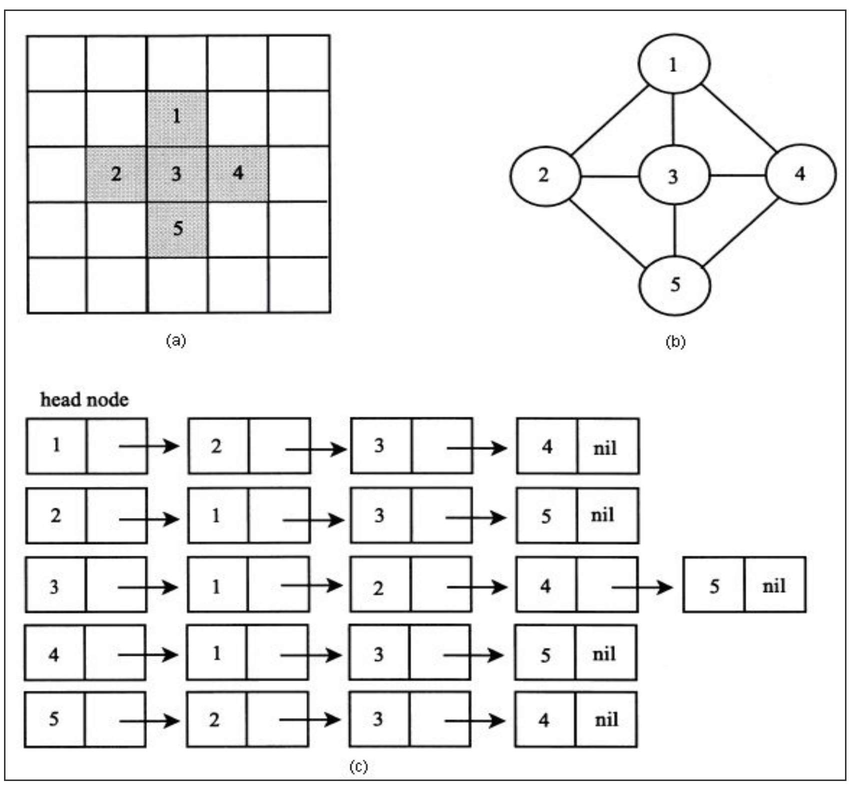

Figure 2.3 Transformation of skeleton into graph (a) skeletal image, (b) graph, (c) data structure

Lourens et al. (2001) carried out an approach to symbolic contour extraction that consists of three stages: enhancement, detection, and extraction of edges and corners. A greedy edge contour following algorithm is used to avoid manual threshold. They first detect corners and local edge maxima by thresholding. Then contours are extracted starting at local maxima and corners. This is followed by connecting corners with edge contours and each other. Finally, contours and corners are activated and linked to with their neighbours along an edge contour.

2.6.3 Curve Fitting and Correlation Techniques

Curve fitting and related techniques assume a boundary is consists of a number of boundary segments. Each segment is described by a curve of a given functional form and the parameters of the curves define the boundary. Curve fitting is the estimation of the parameters of a curve given a set of detected edge elements. Correlation involves the determination of a measure of match between detected edge elements and hypothesized curve. However, the more complicated curve interpolation methods are counterintuitive in more subtle ways. In fact, a completely reasonable interpolation method does not exist since the concept can be shown to be self-contradictory (Franklin, 2000).

Wood and Fisher (1993) reviewed four different interpolation routines in their study (three of which are available in GRASS). There are consist of (i) Inverse Distance weighting find the *n* nearest neighbours and calculate the weighted average according to the inverse squares distance away from the cell; (ii) contour flood filling search around each cell to find the surrounding contour lines, and then apply linear interpolation down to the steepest path between adjacent contours; (iii) simultaneous over-relaxation is an iterative technique that solves the PDE to produce a continuous surface; (iv) one-dimensional spline fitting is a method of producing a raster map layer that contains the RMSE for every interpolated cell. For instance, cubic spline fitting interpolate along each profile and impose an additional contour constraint on interpolation to prevent the cubic function from ranging beyond one contour interval.

Internal representation of lines is usually performed using polylines, circular arcs or using B-Spline (each line represented by a set of control points). Each type of curve allows different precision with a dissimilar graphic speed. B-Splines are the most precise but slowest; while polylines are the less precise and fastest. Xulio et al. (1998) used cubic B-Spline curves based on Least Mean Square approach that allows computation of the optima B-Spline parameters. Their approach determined an equation for an exact spline and finds the minimum error solution (RMSE) (Saint-Marc et al., 1993).

Gaps with a width of a few pixels can be bridged by extrapolation of edge segments. The parameter of the tangent of a non-close segment from one of its end point is estimated. Edge linking is performed by continuing the segment along the tangent until an element from another edge segment has been found. In order to decrease the sensitivity for errors estimation of the parameters of the tangent, it is advantageous to search in a sector surrounding the tangent instead of restricting the search to the tangent solely. Zhou et al. (1989) have implemented edge linking based on extrapolation of linear edge segments.

2.7 Comparison on Several Vectorization Approaches

The last few sections discussed several approaches in map vectorization. The following Table 2.2 shows the comparison are made between those approaches.

Table 2.2: Comparison on several vectorization approaches

Researcher/ Year	Single colour extraction	Thinning	Contour lines reconnection	Type of digitization	Recognized feature
Eivil et al. (1995)	None (Initial from contour map)	Representative point is computed based on midpoint of contour point	Line tracing based on direction	Interactive	contour lines

Chang et al. (1997)	Interactive clustering algorithm	Parallel thinning algorithm	Conditional dilation operation of mathematical morphology and polygonal approximation algorithm	Automated	roads
Xulio et al. (1998)	LBG algorithm apply to RGB colour space	Jennings et al.'s sub pixel thinning method (1993)	Line following is based on the difference of slopes between lines. B-Spline curve is used to form a set of contour points that are closely approximated	Interactive/ Semi-automated	contour lines
Arrighi and Soille (1999)	First extract all image pixels which have red hue. Several morphological filters are used to produce a clean mask for contour.	Hit-or-miss transform is generalized to extract the extremities of one-pixel thick lines.	Euclidean distances and differences between their direction are weighted and combined to compute a new distance.	Interactive	contour lines
Apaphant (2000)	None (Initial from contour map)	Based on peeling approach and divide the	Node marking algorithm determines all	Automated	contour lines

		border point into four types: north, south, west and east	types of nodes (isolated, junction and terminated node) in the thinned image.		
Ablameyko et. al. (2000; 2002)	Colour space clustering	Thinning is performed in one scan and storing 3 lines in the stripe. In the stripe medial line, black pixels are analyzed using a crossing number.	The algorithm is based on a dashed line etalons, which includes several parameters.	Automated/ Interactive	contour lines
Khontanzad and Zink (2003)	A colour key set is developed to overcome colour aliasing and false colours. Eigenvector line-fitting technique is applied in RGB space.	Area features are extracted using RGB colour histogram analysis. Linear features are extracted using a valley seeking algorithm.	A* search algorithm is used to link valleys to form linear features and close the gaps caused by intersecting features.	Interactive/ Automated	contour lines and other geographic features
Salvatore and Guitton (2004)	HSV colour space is used and contour lines are extracted based on	4-connected pixels use to thin lines.	Voronoi diagram is used, where Delaunay edges are filtered using	Automated	contour lines

	0<hue<30		local rules (length and direction) and global rules.		
Helvaci and Bayram (2004)	Training samples are collected and colour threshold is determined by calculating the training set.	All pixels are scanned with their 8-neigborhood.The centre of gravity is calculated using the coordinates of pixels that have one grey value.	The operator chooses an appropriate threshold value distance for broken contour lines reconnection.	Semi-automated	contour lines

2.7.1 Comparison on Several Approaches in Colour Extraction

A more details comparison is made between several existing approaches for single colour extraction. The following Table 2.3 shows the comparison between those approaches. In order to simplify contour lines extraction process, Jeff Prosise's approach (1997) that capable in computing static colour palettes for bitmap images is adopted. Hence, it creates a composite static palette which is suitable to define a specific colour for contour lines in a standard topographic map.

Table 2.3: Comparison on several single colour extraction approaches

Year	Researcher	Approach	Advantages/ Disadvantages
1982	Heckbert	Colour quantization reduces the number of colours in an image by replacing them with the closest representative colour.	There are two main problems in colour quantization: the selection of an optimal colours palette and the optimal mapping of

			each pixel from an image to a selected colour from the palette.
1997	Jeff Prosise	A colour quantization approach is introduced to compute static colour palettes for the bitmaps image. A composite of palettes are created for displaying two or more images.	Designed a palette-generating utility that takes as input one or more BMP files and outputs a text file containing a table of RGB colour values.
1998	Xulio et al.	Linde-Buzo-Gray (LBG) algorithm is applied into RGB colour space to reduce the number of colours. Luminance threshold is used to remove background, whilst generalized erosion is performed to make the line pixels uniform and darker. Clustering is applied to the colours in the palette of map.	Their approach can solve these problems: (i) lines that are comprised of a number of spurious colours, (ii) separate contour lines from background and (iii) darker contour lines. However, colour clustering need human supervision and more computation time.
1999	Dupont et al.	Watershed divide algorithm is used in RGB space to assign a pure map colour to each pixel.	It performs well for high resolution and quality images, but may not for image that contains aliased and false colours.
2002	Ablameyko et. al.	Statistic data in RGB space are calculated. Colour extraction is based on colour space clustering.	Map colour layers are extracted automatically based on human desire.

2003	Khontanzad and Zink	A colour key set is developed based on eigenvector line-fitting to overcome the affects of aliased and false colours. Colour histogram analysis algorithm is used to extract features.	The development and use of a colour key set to compensate for aliased & false colour is a new technique.
2004	Salvatore and Guitton	Colour quantization is applied into HSV colour space. The colours are classified as following: value< 0.25 as black; saturation<0.20 and value> 0.60 as white; and 10< hue< 30 as brown are referred to contour lines.	By pre-classify the pixels into black and white, it reduce computation time for contour lines extraction It can perform well for USGS topographic maps or a map that is comprised of a standard set of colours.
2004	Helvaci and Bayram	Firstly, a set of training sample contours is collected and grouped. Different threshold values are calculated for each group. For calculation process, minimum and maximum RGB values are found for each group.	The collected samples have to distribute normally to have accurate measurement. None statistical adaptation tests are needed to control the distribution of pixels.

2.7.2 Comparison on Several Approaches in Contour Lines Thinning

After that, a comparison is made between several existing thinning approaches to generate one-pixel width contour lines. The following Table 2.4 shows the comparison between those approaches. Zhang and Suen (1984) thinning method is adopted in this study. However, some enhancement facilities like diagonal fill or pruning are needed to generate fine thinned contour lines. The details depiction would be discuss in the following Chapter 3.

Table 2.4: Comparison between several thinning approaches

Year	Researcher	Approach	Advantages/ Disadvantages
1981	Arcelli and Baja	This is a sequential algorithm that uses a crossing number (Rutovitz, 1966) to determine whether the pixel is to be deleted.	Preserves significant contour protrusions and prominences in thinning process.
1984	Zhang and Suen	Repeatedly deletes contour points respecting a number of conditions until a 1-pixel wide 8-connected skeleton is obtained. The algorithm alternates between two passes, each selecting points for deletion based on different criteria.	It performs well for extracting straight lines from a raster and has immunity to boundary noise. However, it seriously eroded two-pixel wide diagonal lines and completely deletes 2 x 2 squares.
1985	Cohan and Landy	All 256 possible surrounding conditions for the pixel of interest were employed for decision-making of line thinning.	Produce poor results for some specific cases.
1987	Holt et al.	A parallel thinning algorithm that considers information from a 4 x 4 window in order to determine pixel deletion.	It considers the edge information on neighbouring pixels in order to use only one sub iteration per cycle.
1988	Chen and Hsu	A parallel algorithm with two sub-cycles.	It avoids serious erosion.

2.7.3 Comparison on Several Approaches in Contour Lines Reconnection

Another comparison is established between several existing approaches for contour lines reconnection (Table 2.5). Among these approaches, local and geometrical rules, as well as neighbourhood relationships are recognized as considerable elements to bridge broken contour lines. Due to natural characteristic derive from contour lines; spline or correlation curve fitting approaches seem talented in solving this problem.

Table 2.5: Comparison between several contour lines reconnection approaches

Year	Researcher	Approach	Advantages/ Disadvantages
1995	Shimada et al.	An agent-based parallel recognition approach is used to pass through irregular part of contour lines.	It can significantly reduce the cost of inputting contour drawings.
1998	Xulio et al.	They used difference of slopes between line segments to trace lines. A data structure called "Macro point" is created to deal with intersection points. Least Mean Square (LMS) approach that allows computation of the optima B-Spline parameters is used to represent the contour lines.	B-Splines can only valid for very smooth curves. If a line has some corners, it must be split into different smooth curves.
1999	Dupont et al.	An expert system is used to resolve ambiguities associated with broken and closely spaced contour lines, using some local and geometrical rules as well as orientation information as computed from the external terrain elevation data.	This algorithm performs well for images scanned by high resolution and quality scanners.

1999	Gamba and Mecocci,	An A*-based search algorithm is used to detect and track discontinuous chains of symbols. It operates directly on a grey-scale version of the map and performs well for extracting symbols and dashed lines on topographic map.	The algorithm is not optimized for non-dashed lines such as contour lines, and it may be difficult to apply the algorithm to colour images.
2002	Ablameyko et. al.	The developed algorithm is based on dashed line etalons. The etalon for each dashed line includes these parameters: (i) min and max width and length of segments, (ii) min and max distance for gaps and (iii) minimal available quantity of segments in a dashed line.	It is an effective interactive object digitizing techniques, which allow digitizing large-size maps in a restricted computer memory.
2003	Khontanzad and Zink	A valley seeking algorithm is developed to locate valleys, corresponding to the linear features. Graph theoretic techniques are used to link valleys to form contour lines. Broken lines are repaired using an A* search algorithm.	The approach is tested successfully on several challenging samples of USGS maps, but it may be insufficient for non-USGS map.
2004	Salvatore and Guitton	The map is vectorized using Delaunay Triangulation, where Delaunay edges are filtered using local and global rules. Local geometric properties are used to construct reliable chains of edges. Using global information, the matrix of weights is used to fill remaining gaps by grouping different segments.	Although the algorithm is capable to seek all the contours in a well-conditioned map, there are some problems remain in general map.

2.8 Summary

Digitizing map remain as an important resource data for GIS application. Several problems are needed to be overcome with real maps: (i) poor conditions of map representation, (ii) error induced by scanner and (iii) topological error. Thick contour lines are a problem occurs in this research, where it causes difficulty in recovering the proper topology indicated by the map. In addition, the same colour that used to represent contour lines and elevation numbers also make it complicated in the automated approach. As a result, it has become apparent that fully automatic recognition of entire features from topographic map is yet unrealistic. None of these approaches is capable to digitize map without assistance of human. From previous researches that have been discussed in this chapter, the most effective organization of map digitizing process is suggested as following sequence. It can be obtained by integrating three main processes: (i) manual digitizing or labelling is performed for objects, which are known that they cannot be recognized automatically, (ii) automatic vectorization and interpretation of map layers and; (iii) interactive correction of recognition errors and input of unrecognized object.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

Computerize representation of maps and line drawings enable efficient updating and facilitate computer-aided design for land development, architecture, and similar disciplines. Raster and vector are two basic data structures for storing and manipulating map images. In general, map digitization can be categorized into four intersecting groups: manual, interactive, semi-automated and automatic (Levachkine and Polchkov, 2000). Fundamentally, digitization process should be able to facilitate the following circumstance: (1) the conservation of information contained in an image; (2) the reduction of data storage; (3) the simplification and adaptability of a new representation space for further processing (Levachkine, 2003).

Majority of digitization approaches use vector editors to digitize object; and leave operator to correct errors in the resulting vector layers. They usually generate huge amount of errors and involve a lots of human intervention. Previous researches disclosed that the increasingly complex techniques and algorithms for feature extraction from topographic map are not substantially in improving the results (Levachkine et al. 2000; 2002). In fact, the ability to construct a representation from individual pixel of an image, exploiting the relationships such as local proximity and highlights the structures of underlying components, are important for features extraction during interpretation and recognition process (Doermann et al. 2002).

Large scale map digitizing and GIS database management and storage should be accomplished in an effective approach, which reduce computation time and human involvement. In general, the whole raster map is not always needed to be vectorized. In some circumstances, only particular features from maps (e.g. rivers, contour lines, road or etc) are vectorized depending on the user requirement. This research is carried out to recognize and extract contour lines from raster topographic map. Due to global constraint on their unique topology and limited computer algorithm in image analysis, it is difficult to extract contour lines successfully without human intervention. In fact, as current GIS application is attempted to provide effort in automating the recognition process, it should be followed by a significant amount of interactive post-processing to correct errors.

A further barrier to widespread industrial acceptance is that most fully automated systems rely upon powerful workstations or specialized hardware (Ablameyko and Pridmore, 2000). These facilities are only available for larger companies. For this reason, the technology can only achieve its potential if the developed method is capable to produce high-level representations at reasonable speeds on PC-based systems. Consequently, the effectiveness of automated process comes into different view. This includes the speed of automated procedures, the precision of results, and the functionality and effectiveness of raster and vector editor tools. In an attempt to provide a generally applicable framework for map interpretation, Ablameyko and Pridmore (2000) have suggested several principles. These involve: (1) combined automatic and interactive interpretation, (2) sequential processing of map layers, (3) explicit multi-level recognition, (4) the use of auxiliary information, (5) proceed from simple to complex entities, (6) exploit all available knowledge, for instance, knowledge of map conventions, cartographic objects, scenes and etc, (7) separate the knowledge for particular features and its recognition algorithms and; (8) emphasis should be placed on the structure of line drawings.

Figure 3.1 shows the methodology developed in this study using a combination of interactive and semi-automated approach for contour lines recognition. The methodology is divided into following phases: pre-processing, processing and post processing.

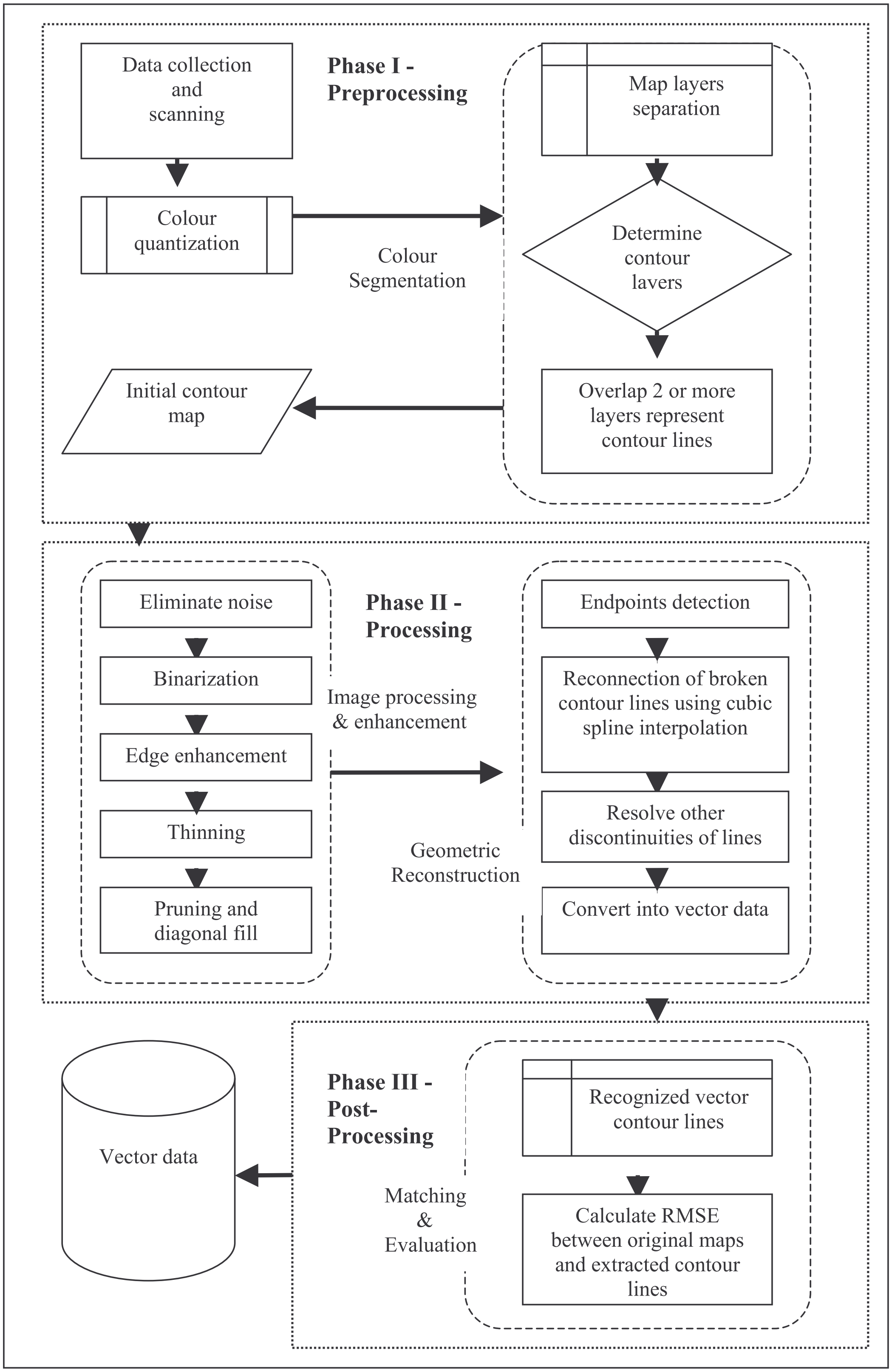

Figure 3.1 Design of methodology for contour lines recognition and extraction

3.2 Phase I - Preprocessing

A typical topographic map consists of different types of lines, texts and symbols in various colours. The pre-processing phase is intended to extract and clean extraneous information overlaid on map for resultant a preliminary contour map for sake of further processing.

3.2.1 Data Collection, Analysis and Scanning

Data sources for a comprehensive GIS are probably more numerous and of greater variety than other information system. Although most of the problems associate with data collection for GIS has been identified by the mid-1970s, it remains the most expensive and time-consuming aspect for setting up a major GIS facility (Ablameyko and Pridmore, 2000; Bernhardsen, 1999; Du and Zang, 2004). In this research, paper based topographic map for different district, scale and scanning resolution are collected for testing purpose.

Since the evolution of scanning technology, many colour scanners are capable of producing high resolution image with compatible cost. However, several shortcomings, such as colour aliasing and false colour remain induced by scanner. Higher resolution does not necessarily produce better quality result and increase the accuracy of vectorization significantly, but it does increase data volume, memory and storage. On the other hand, lower resolution can lose fine line work and result in gaps or discontinuities. Consequently, a compatible resolution should be chosen for the scanning process to preserve both quality and accuracy in an acceptable storage.

Before scanning process, a paper based map should contain following criteria: It must be high cartographic quality, with clearly defined lines, text and symbols. Then, it must be cleaned without extraneous stains for avoiding undesired noise. It is preferred to have lines of width 0.1 mm or greater to ease digitization process in order to extract information from map more accurately (Bernhardsen, 1999). Nevertheless, it is advised to ensure the quality of map in the preparation phase. This is important for reducing additional work in editing task, which is much more difficult and time-consuming.

3.2.2 Colour Quantization

Maps are constructed in a number of layers, where each layer is printed in a distinct colour to represent a subset of map information. For this reason, colour is a significant attribute to distinguish various features on map. Contour lines always exist in brown colour and it can be extracted by preserving brown pixels while eliminating the others. However, this is not always the good means to derive an initial comprehensive contour map. Several deficiencies exist when using colour to segment contour lines. Firstly, not all contour lines appear in brown value. It is usually rely on specific map standard agreed by map producer. Second, several other features are presented in brown colour, like road, bridge, elevation value etc. Thirdly, since the map is scanned in 24-bit RGB colour, the pixels appear in brown value can be a vast of range, varying in each R, G, B channel.

For colour image segmentation, all features can be distinguished by assigning an arbitrary or average pixel value to a particular regions separated by a chosen threshold value. In general, segmentation of pixels, lines and features from digital map are accomplished by considering spectral, spatial and context information on the maps (Santos et al., 1998). Spectral information is colour or grey level pixel on a digitize map; while spatial information is associated with features continuity and homogeneity, especially for roads detection, contour lines and other linear features recognition. On the other hand, context information is the most complex feature, consists of high-level description and relations between different features or information obtained from index table and legend from a map.

Colour quantization is a process to reduce the number of colours in an image by replacing them with the closest representative colour. In general, the processes are classified into four phases: (1) sampling the original image for colour statistics; (2) choosing a colour map based on the statistics; (3) mapping the colours to their representative in colour map; and (4) quantizing and generating new image (Heckbert, 1982). Besides that, there are two main problems in colour quantization: the selection of an optimal colours palette and the optimal mapping of each pixel from an image to a selected colour from the palette (Michael and Charles, 1991).

In this work, colour quantization is employed for reducing the colours exist in topographic map. Many current approaches make use of several advanced colour classification methods in contour lines recognition process. For instance, neural network (Gao et al., 1993), fuzzy set theory (Louverdis and Andreadis, 2003), K-means clustering (Xu Jie and Shi, 2003), eigen vector line-fitting technique (Khontanzad and Zink, 1996; 2003) etc. However, these methods involve some complicated algorithm with heavy computation cost and time to obtain an excellent result. Since the entire features on map is typically represented by a small number of colours (usually not more than 8), colour quantization approach can be established to reduce the amount of true colours in the map. For the sake of intricate extraction process, contour lines are recognized after colour quantization process.

3.2.3 Map Layers Separation

An important task for determining intersection or overlapping features on the map is first separates each feature (e.g., annotations, contour lines, physical boundaries, land use area shadings etc) based on their representative colour. However, they are not easily separable due to complex interactions among various colours employed during printing and digitization process. This becomes evident when some colour pixels borders appeared next to another colour area. For instance, the black features cross or border with green-forested areas, or pink urban areas etc. Therefore, linear and area features should be isolated into different layers to separate the contour layer. Experience has suggested that the most effective interpretation sequence is by firstly process the layer containing area objects, followed by contour lines and hydrograph layers and finally end with black layers (Ablameyko et al., 2001). In this work, the maximum amounts of colour layers that are extracted should not exceed sixteen. Then, one or more possible layers are chosen from these layers to be attached together for the purpose of characterize an initial contour layer.

3.3 Phase II – Processing

A suitable approach for map processing should carefully distinguish between topological aspects, concerning the map structure and mutual relations of its entities, metric, as well as its local shapes (Dettori and Puppo, 1996). Several image processing approaches should be applied to improve the image quality for assisting subsequent map interpretation procedures. Initially, the pixels are traced to obtain their underlying position. The most difficult task in this phase is to develop an efficient algorithm to identify broken line segments, and then reconnect them accordingly. These disconnected line segments are typically resulted of several reasons: (i) intentional gaps; (ii) intersect or overlap with other information layers and; (iii) deteriorated by image acquisition technique. In general, once the pixels on the edge for the contour lines are identified, these pixels are linked together to form close objects boundaries. Nevertheless, determination of particular pixels to be connected is complicated due to difficulty in employing edge tracking algorithm for all enumeration of possible edge configurations. Edge tracking based neighbourhood pixels is succeed if the edge points on object boundary are fully connected. Conversely, if there are gaps along the edge, then tracking algorithm have to modify to leave out those gaps or terminate with a partial object boundary.

3.3.1 Image Processing and Enhancement

3.3.1.1 Eliminate Noise

Noise is originated from paper-based map or as a result of poor-sampling process after colour quantization. Since these isolated small noise spread over desire features, it causes ambiguity in contour lines classification. Therefore, the main purpose for noise removal is to reduce undesired noise before further recognition and vectorization process. Median filter is applied for this study to eliminate majority of the noise. Then, connected component labelling algorithm is used to remove those remaining speckles, spots and blemishes from the map. A speckle is removed in case both width and height are smaller than a preset threshold; while a hole is filled in the same manner (Lee et al., 2000).

3.3.1.2 Binarization

Binarization reduces map resolution into two intensities value (0 or 1). Thresholding is a conventional method of segmenting scanned map into two classes: (1) contain those pixels with intensity above a given value (e.g. background); (2) contain those pixels below a given threshold value (linear features, e.g. contour lines).

$$g(x,y) = \begin{cases} 1 & if \ f(x,y) > T \\ 0 & otherwise \end{cases} \tag{3.1}$$

3.3.1.3 Edge Enhancement

Edge detection is based upon discovery of local discontinuities that mainly correspond to the boundaries of objects in a map image. Several operators and filtering approaches like Sobel, Gaussian, homogeneity, low pass, high pass and so forth are performed to result an improved and more comprehensive contour map. Another important image enhancement technique that typically applied is mathematical morphology (Yamada, Yamamoto and Hosokawa, 1993). These include dilation, erosion, opening, closing and hit and miss transform. The appropriate operator and structuring element are applied in order to improve edge continuity for alleviating further tedious process.

3.3.1.4 Thinning

The main purpose of thinning is to reduce and simplify the data needed for subsequent process. On the other hand, the major drawbacks are loss of line width information, shape distortion at junctions, computation inefficiency and less suitable for interactive approach (Eikvil et al., 1996). In view of the fact that topographic map represent spatial data, the skeleton produced must preserve both topology and its geometry for accurate vectorization (Lee et al., 2000). Due to boundary noise inherent from original map, noisy branches may exist and result of additional vectors. For this reason, thinning algorithm (Zhang and Suen, 1984) is applied. Isolated pixel is then removed by examining all 8-connected neighbours for every pixel in the thinned image. If the entire 8-connected pixels are shown white, then the examine pixel is deleted (Figure 3.2).

i-1, j-1	i, j-1	i+1, j-1
i-1, j	i, j	i+1, j
i-1, j+1	i, j+1	i+1, j+1

Figure 3.2 Examine 8-neighbors by 3x3 mask to delete single isolated pixel

3.3.1.5 Pruning and Diagonal Fill

After thinning process, many tiny spurs are discovered from the skeleton lines. These spurs are probably treated as unnecessary artefacts caused by small irregularities in contour lines originated from topographic map. Pruning is another thinning operation that removes spurs by eliminating endpoints of a skeleton. Hit-and-miss operation with structural elements given in Figure 3.3 can be used to detect all (8-connected) endpoints. Consequently, the sequence of thinning process, $A \otimes B$ (Equation 3.2) by these elements, $B_1 - B_8$ can be used to prune spurs. A denote the original set image.

$$A^{i+1} = \left[\left\{ \left(A^i \otimes B_1 \right) \otimes B_2 \right\} \otimes \ldots \otimes B_8 \right] \tag{3.2}$$

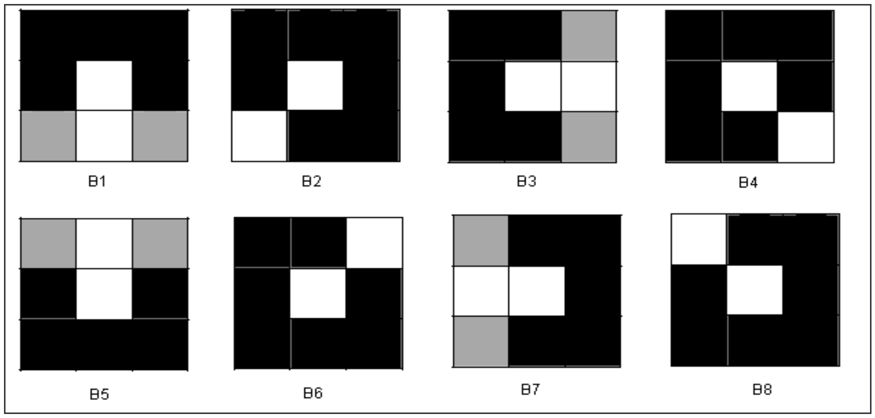

Figure 3.3 Structural elements for pruning operation

On the other hand, structuring elements of diagonal fill as shown in Figure 3.4 is used to detect all 8-connected structures that are not 4-connected after hit-and-miss transform (HMT). Although the union $\cup$ of original set with these structuring elements assures 4-connectivity, it tends to insert additional points. For this purpose, a thickening operation ¤ (Equation 3.3), which comprise of a sequence of HMT and unions is implemented to prevent this deficiency. The diagonal fill operation is defined in Equation 3.4.

$$A \text{¤} \mathrm{B} = \mathrm{A} \cup \mathrm{HMT}(\mathrm{A}, \quad \mathrm{B}) \tag{3.3}$$

$$(((A \text{¤} \mathrm{B}_1) \text{¤} \mathrm{B}_2) \text{¤} \mathrm{B}_3) \text{¤} \mathrm{B}_4 \tag{3.4}$$

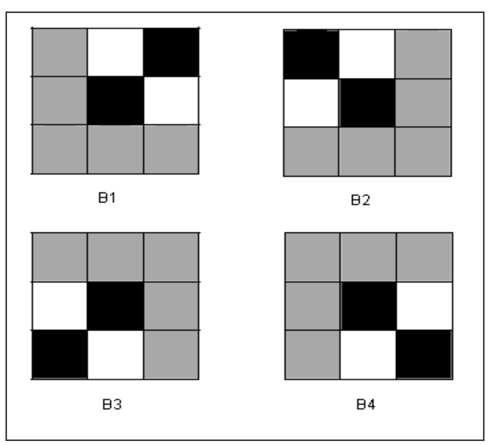

Figure 3.4 Structural elements for diagonal fill

3.3.2 Geometric Reconstruction

3.3.2.1 Endpoints Detection

From skeleton lines that presented in one-pixel width, an edge line has three basic properties: type, position and direction. The type can either be end points or continuous lines. The ending pixel is defined to have exactly one neighbour pixel that belongs to one of the particular mask as shown in Figure 3.5. In contrast, a continuous lines is defined to have exactly three or above neighbouring pixels.

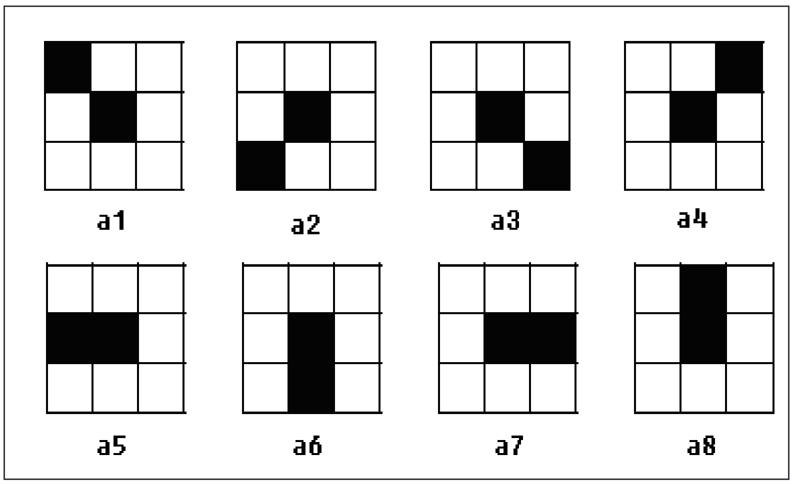

Figure 3.5 3 x 3 masks to detect endpoints

3.3.2.2 Contour Lines Reconnection

Inevitably, detected contour lines may appear non-continuous, or generally known as gaps due to several reasons: (i) intentional gaps exist in topographic map to locate elevation index, (ii) some section of contours cannot be detected in the dark areas of map, (iii) some contour lines appeared as dash lines to illustrate uncertainty or they are left incomplete by map producer, (iv) linear or area features that always overlap or intersect each another in the map, hence cause misclassification and reveal as gaps and; (v) inefficient in digitizing or scanning devices.

Generally, contour line extraction algorithms utilize their unique properties to split closely space features and resolve broken contour lines. Since they never intersect each another and form close loops, each broken end of the line is either matched by another broken end line or routed to the physical edge of a map. From previous experience, the classical techniques are first to skeleton the lines, and then seek for relevant extremities of skeleton to recover the missing parts of the lines. However, problem occurs because thinning process is very sensitive to noise and it creates small branches at the edge of the lines. Therefore, every contour line should be inspected to discover and correct blunder such as breaks in the lines, intersections of lines, insufficient colour segments, noise etc.

Human perception of curve shape includes not only topological aspects, such as the identification of connected components and the differentiation between open and closed segments. It also includes geometrical aspects, like qualitative measures of curvature and winding. If the sample is large enough and well distributed, it is an easy task for human being to perceive the shape of the curves. In contrast, a computer has no such natural perception. In general case of curve reconstruction, the sample does not have a priori structure that can be exploited to provide a computational description of the curve. For the machine, the sample is merely a set of coordinates. A fundamental problem, which is expected to solve using such computational descriptions, is exactly how to sort the points in an order compatible with the natural trace of contour line, as perceived by a human. This order can be used to structure the sample into a polygonal approximation of the curve, thus reconstructing the curve from the sample.

Initially, bridging gaps between five pixels width can be accomplished in the following steps. Firstly, several masks 5x5 in different direction are formed as Figure 3.6. The search is established from every detected endpoint; and seeks to connect another detected endpoint in various directions based on defined mask. If one of the directions from these defined masks is acquired, the gaps between can be filled. If no edge pixel is found through all the directional matrices, then major gaps might exist. For this reason, it is insufficient to bridge gaps whose comprise of more than five pixels.

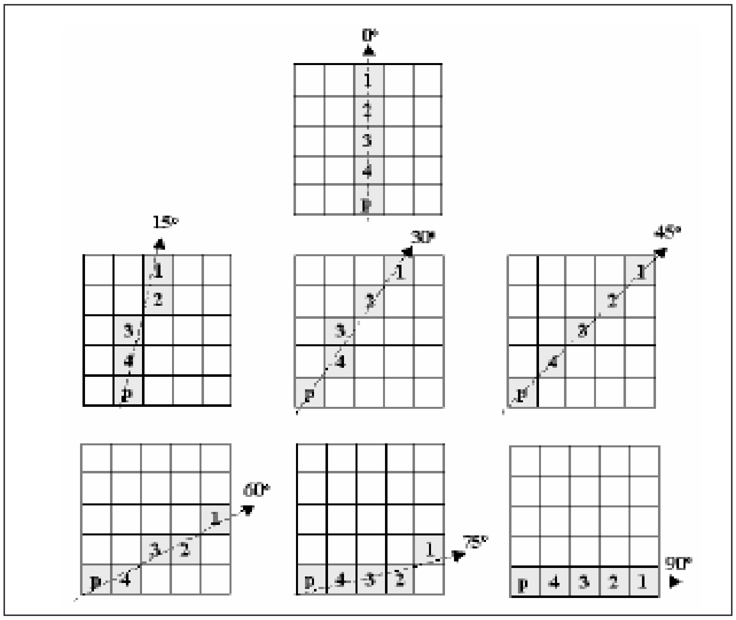

Figure 3.6 Several search directional of contour tracing

Although direct searching is insufficient in reconnecting elongated broken lines, it does reconnect most of the small gaps exist in skeleton map. For this reason, two methods are used for reconnecting broken contour lines. Both methods are avail of distance, angle and directional information to connect broken lines. For Method I, two broken line segments are connected using cubic spline interpolation, with consideration of criteria described above. Distance between two endpoints are calculated in Equation 3.5; while angle is calculated by back tracing ten pixels from every detected endpoint to form a triangle as shown in Figure 3.7 and Equation 3.6.

$$Euclidean \quad dis\tan ce = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \quad (3.5)$$

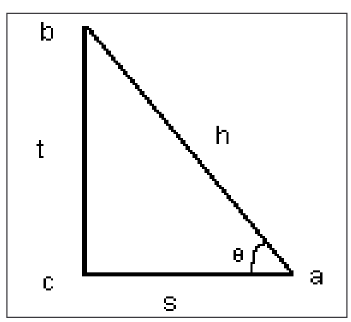

Figure 3.7 Angle calculated using triangle property

$$\angle \theta_a = \sin^{-1}\left(\frac{t}{h}\right) \tag{3.6}$$

By considering two line segments *ab* and *cd,* where *b* and *c* are endpoints of these line segments correspondingly (Figure 3.8). Method I would connect point *b* and *c* if following criteria are met. Initially, emphasis is placed on adjacent endpoint detected within 2*hx2h* search window beginning at each endpoint. The size of the search window is determined by human observer. Then, appropriate angle and orientation are chosen based on empirical results.

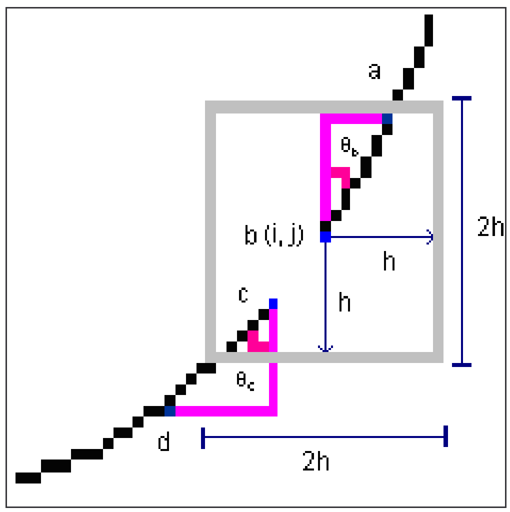

Figure 3.8 Distance, angle and orientation for broken line segment

h : Euclidean distance estimate from endpoint
a (x1, y1): Pixel back trace from endpoint b (x2, y2)
b (x2, y2): Endpoint
c (x3, y3): Nearest endpoint detected in search window *(2h* x *2h*)
d (x4, y4): Pixel back trace from endpoint c(x3, y3)

- Distance $_{bc}$ <= Distance within other endpoint in *2h x 2h* search window
- $\left|\angle \theta_b - \angle \theta_c\right| \prec Angle$, where θ_b is the angle between directional line segment *ab*; Y-axis and θ_c is the angle between directional line segment *cd* and Y-axis. Angle should not more than 90 degrees.

- Orientation for each line segment is based on 8-directional chain code (0 - 7).

Orientation for every single line segment begin from each endpoint (i, j) is determined using chain code. The direction of line segment can be divided into four zones, where these zones establish direction for relevant line segments. Then, the chain code can be categorized into 8-direction, from 0 to 7 (Figure 3.9). Each broken line segment is supposed to connect another line segment, which position at its opposite direction. For instance, if line segment *ab* is observed as direction-5 using chain code, then line segment *cd* should be observed in direction-1 as it's oppose line segment detected within the search window (Figure 3.8).

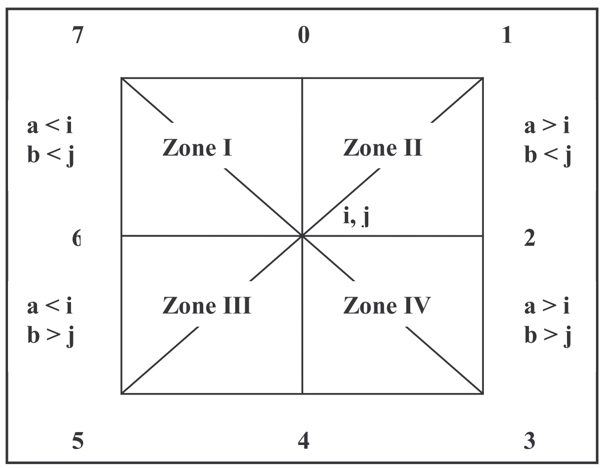

Figure 3.9 Eight-directional chain-codes

After those criteria as mentioned above are examined comprehensively, these broken line segments are prepared for reconnection phase. Initially, the nearest endpoint is chosen from the defined search window. Then, the line segment that comprises of least angle and opposite orientation is considered for reconnection. After two line segments are verified for reconnection, cubic spline interpolation (McKinley and Levine, 1998) is used to reconstruct the approximating curve lines. Four control points are taken instantly from two endpoints and another two points are picked by back tracing from the 10-th pixel commence from corresponding endpoint (Figure 3.8). By means of these control points, cubic spline interpolation would be able to reconnect greater part of the broken lines within the search window.

However, broken line segments that cause by depiction of elevation value or character are generally comprised of a large amount of pixels (50 or above). For this reason, vectorized contour lines may not appear as continuous contour even though there are no visible breaks. Since these gaps width are too wide, they are not always success in connecting using cubic spline interpolation. In fact, a larger search window is established for searching the adjacent endpoint. Then, Method II, which adopts Newton interpolation polynomial, is applied for this particular case. It is initiated by interpolating a function *f* at *n+1* distinct values of *x* using the Newton Interpolation Polynomial. The coefficients of this polynomial are calculated using the divided differences of *f*. The following Equation 3.7, 3.8 and 3.9 show how Newton Interpolation Polynomial works.

$$P_n(x) = c_0 + c_1(x - x_0) + c_2(x - x_0)(x - x_1) + \ldots + c_n(x - x_0)(x - x_1)\cdots(x - x_{n-1}) \tag{3.7}$$

The divided differences are defined as follows:-`

$$\begin{gathered} f[x_0] = c_0 = f(x_0) \\ f[x_0, x_1] = c_1 = \frac{f(x_1) - f(x_0)}{x_1 - x_0} \\ f[x_0, x_1, x_2, \ldots, x_n] = c_n \end{gathered} \tag{3.8}$$

$$\begin{aligned} p_n(x) = {} & f[x_0] + f[x_0, x_1](x - x_0) + f[x_0, x_1, x_2](x - x_0)(x - x_1) + \ldots + \\ & f[x_0, x_1, \ldots, x_n](x - x_0)(x - x_1)\cdots(x - x_{n-1}) \end{aligned} \tag{3.9}$$

3.3.2.3 Vectorization

After a sequence of procedures has been accomplished for extracting contour lines, manual correction is needed for resolving anomalies case. Finally, this data should be well organized before storing into vector format. In order to improve the performance of data retrieval and manipulation, an efficient vector data is essential for GIS use. The data can be recorded with several fields of identification number, number of pixels, the status of close contour, elevation value, adjacent region's id and chained pixels. In this study, raster contour image is converted into 2D-vector format (x, y) , which can be used in all GIS application.

3.4 Phase III - Post-Processing

Post-processing is the final stage of the recognition process in this work. It is mainly based on evaluation of the accuracy of extracted contour data. Since this work is intended to develop a combination of interactive and semi-automated approach for contour lines recognition, the result of data can be evaluated and inspected by human observers. Several criteria should be studied to evaluate the precision and robustness of this approach. The following perspectives are chosen to be compared with existing GIS applications.

3.4.1 Accurateness

The definition of the accurateness of contour lines recognition is more complicated than usual character or symbol recognition (Shimada et al., 1995). The accuracy can be evaluated by standard deviation, or more generally expressed as Root Mean Square Error (RMSE). Several comparisons between this study and existing GIS applications are performed to evaluate the percentage of RMSE.

3.4.2 Digitizing Cost and Computation Time

The efficiency of digitization is mainly relying on the computation time and cost for the entire recognition process compare with other existing GIS application. In this study, two aspects of computation time are compared: (1) the processing time for colour extraction in extracting contour lines and (2) the reconnection time for broken contour lines.

3.4.3 Labour Intensive Cost

Since this research emphasizes on an interactive and nearly automated approach, human interaction is reduced compare to other conventional approach, either manual digitization, semi-automated or interactive approach. However, due to the occurrence of some anomalies case and errors, human observer is indispensable to supervise the operation as well.

CHAPTER 4

IMPLEMENTATION

4.1 Introduction

A system is developed based on the design methodology in previous chapter for contour lines extraction from scanned topographic map,. The implementation is comprised of three essential phases, pre-processing, processing and post-processing. Each phase contributes to the final result.

4.2 Phase I – Preprocessing

4.2.1 Victor Image Descriptor

In order to alleviate the effort in implementation of some fundamental process for image processing, the Victor Image Processing Library for Windows and its device support modules in Dynamic Link Libraries (DLLs) is adopted. The information necessary for a Victor function to operate on an image area is contained in the image descriptor data structure that describes that image. The image descriptor is a required argument for most Victor functions and it is defined as type *imgdes*.

```
typedef struct
{
        unsigned char huge *ibuff;          // Image buffer address
        unsigned stx, sty, endx, endy;      // Image area of interest
        unsigned buffwidth;                 // Image buffer width in bytes
        RGBQUAD far *palette;               // Palette address
        int colours;                        // Number of palette colours
        int imgtype;                        //Grayscale image type: bit 0 = 1
        BITMAPINFOHEADER far *bmh;          // BITMAPINFOHEADER address
        HBITMAP hBitmap;                    // Device Independent Bitmap handle
} imgdes;
```

Figure 4.1 Victor image descriptor define as type *imgdes*

4.2.2 Colour Quantization Class

The scanned topographic map is in raster form, which is represented by 24-bit colour RGB model. The format and scan resolution that is chosen should be suitable to the scanned map and easy to be manipulated and implemented using C++. In this work, Bitmap format is chosen. Colour quantization is applied in order to reduce the number of colours in a map by replacing them with the closest representative colour. This ensures fast image manipulation, coding and processing tasks that operating on a reduced colour palette.

The principle of the octree algorithm is to sequentially read in the image. Every colour is then stored in an octree of depth 8 (every leaf at depth 8 represents a distinct colour). A limit of K (in this case K = 256) leaves is placed on the tree. Insertion of a colour in the tree can result in two outcomes. If there are less than K leaves, then the colour is filtered down the tree until either it reaches some leaf node that has an associated representative colour or it reaches the leaf node representing its unique colour. On the other hand, if there are greater than K leaves in the tree, some set of leaves in the tree must be merged (their average of representative colours) together and a new representative colour stored in their parent. Figure 4.2 shows the CQuantizer class that has been implemented in this work. After colour quantization, the map is separated into maximum sixteen layers representing different quantized colour.

```
class CQuantizer
{
        typedef struct _NODE
        {
        BOOL bIsLeaf;                  // TRUE if node has no children
        UINT nPixelCount;              // Number of pixels represented by this leaf
        UINT nRedSum;                  // Sum of red components
        UINT nGreenSum;                // Sum of green components
        UINT nBlueSum;                 // Sum of blue components
        UINT nAlphaSum;                // Sum of alpha components
        struct _NODE* pChild[8];       // Pointers to child nodes
        struct _NODE* pNext;           // Pointer to next reducible node
        } NODE;

protected:
        NODE* m_pTree;
        UINT m_nLeafCount;
        NODE* m_pReducibleNodes[9];
        UINT m_nMaxColours;
        UINT m_nOutputMaxColours;
        UINT m_nColourBits;

public:
        CQuantizer (UINT nMaxColours, UINT nColourBits);
        virtual ~CQuantizer ();
        BOOL ProcessImage (HANDLE hImage);
        UINT GetColourCount ();
        void SetColourTable (RGBQUAD* prgb);

protected:
        void AddColour (NODE** ppNode, BYTE r, BYTE g, BYTE b, BYTE a,
UINT
        nColourBits,
        UINT nLevel, UINT* pLeafCount, NODE** pReducibleNodes);
        void* CreateNode (UINT nLevel, UINT nColourBits, UINT* pLeafCount,
        NODE** pReducibleNodes);
        void ReduceTree (UINT nColourBits, UINT* pLeafCount, NODE**
        pReducibleNodes);
        void DeleteTree (NODE** ppNode);
        void GetPaletteColours (NODE* pTree, RGBQUAD* prgb, UINT* pIndex,
        UINT* pSum);
        BYTE GetPixelIndex(long x,long y, int nbit, long effwdt, BYTE *pimage);
};
```

Figure 4.2 Class of colour quantization

4.2.3 Map Layers Separation and Merging Modules

For map layers separation module, the map is isolated into maximum sixteen layers representing different quantized colour. Each layer of colour represents different colour based on statistics generated from the process map. The colours data are represented in RGB format, and the map is separated into dissimilar layers.

Red	Green	Blue
162	161	138
144	149	117
85	137	31
115	144	83
56	132	1
45	101	135
0	0	0
45	134	90
146	63	23
73	71	9
103	144	139
151	134	48
193	137	45

Figure 4.3 Storage of RGB colour data for each isolated layer of map

Subsequently, the layers merging module is accomplished by *andimage* function (Equation 4.1) from VICWIN. It combines the value of each pixel in the source image area with the value of the corresponding pixel in the operator image area and place the result in the result image area. It can be one or more than two source image to produce a combined image to represent an initial contour map.

$$\text{Result} = \text{Source} \ \& \ \text{Operator} \qquad (4.1)$$

4.3 Phase II – Processing

The processing part is comprised of work to improve the result of extracted contour map from previous phase. Several procedures are included in this phase.

There are noise removal by median filter, binarization, edge enhancement, thinning, pruning and diagonal fill, contour line tracing, broken line reconnection and etc.

4.3.1 Eliminate Noise

An approach is required to remove those uninterested features and eliminate noise exists in the map. The fundamental idea behind many noise removal algorithms is to replace anomalous pixels with the value derived from nearby pixels. The *removenoise* function (Equation 4.2) from VICWIN is used to remove random noise from the map image area by replacing each pixel value with the median value of the 9-pixel local region. Intensity values are sorted in ascending or descending order, and the median values is chosen as the new intensity value of the pixel in the local neighborhood. In case one pixel in the neighborhood is dramatically different from others, it is defined as noise and the median filter would remove it completely.

$$\text{Result} = \text{median of } 3 \times 3 \text{ local region} \tag{4.2}$$

4.3.2 Binarization

Binarization module converts all pixels in any colour except white colour into black colour as stated in Figure 4.4.

```
if pixel colour is not white
set pixel colour into black
```

Figure 4.4 Binarization Module

4.3.3 Edge Enhancement

Several operations of edge enhancement are equipped in this work to improve the result of extracted contour lines. This process includes morphological operation like dilation, hit-and-miss transform; high pass or low pass filtering, homogeneity, variance, Gaussian, Sobel and etc. Although not all the process mention above are required for better result, it provide an improve contour map for further processing. Fundamentally, it operates by raster scanning the pixel from left to right and top to bottom by different type of mask along with its 8-connected neighbors. Table4.1 shows several operations with its description for contour lines enhancement that implemented in this work.

Table 4.1: Several function for edge enhancement

Operation	Function
3 x3 Mask (for morphological operation)	0 1 0 0 1 0 0 1 0 0 0 0 1 1 1 0 0 0 0 1 0 1 1 1 0 1 0 1 1 1 1 1 1 1 1 1
Dilation	Performs the basic dilation operation. If a 0 pixel has more than threshold number of value neighbors, dilate it by setting it to value.
Mask_dilation	Perform the dilation operation using the erosion-dilation 3x3 masks. It works on 0-value images.
Dilate_not_join	Use a variation of the grass fire wave front approach. Single complete pass is started with raster scan an image left to right and examines and dilates the left edge pixels (a value to 0 transitions). Process them normally and "save" the result. Next,

<table>
<tr><td></td><td>raster scan the image right to left and save. Raster scan top to bottom and save. Raster scan bottom to top and save.</td></tr>
<tr><td>Hit-and-Miss</td><td>Operate using the following defined 3 x 3 structural mask:
<table><tr><td>-1</td><td>1</td><td>-1</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td><td>-1</td></tr></table>
<table><tr><td>-1</td><td>1</td><td>-1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr><tr><td>-1</td><td>0</td><td>0</td></tr></table>
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</td></tr>
<tr><td>High_pass</td><td>Replaces the pixel at the center of a 3x3, 5x5, etc. area with the maximum value for that area</td></tr>
<tr><td>Low_pass</td><td>Replaces the pixel at the center of a 3x3, 5x5, etc. area with the minimum value for that area</td></tr>
<tr><td>Range</td><td>Performs the range operation by replacing the pixel at the center of a 3x3, 5x5, etc. area with the max – min for that area.</td></tr>
<tr><td>Homogeneity</td><td>Performs edge detection by searching for the absence of an edge. The center of a 3x3 area is replaced by the absolute value of the maximum difference between the center point and its 8 neighbors</td></tr>
<tr><td>Filtering</td><td>Filters an image by using a single 3x3 mask.
<table><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>2</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr></table>
</td></tr>
<tr><td>Component Labeling</td><td>Labels every line segment as different components and extracts connected component form the contour lines</td></tr>
</table>

<table>
<tr>
<td>Gaussian_edge</td>
<td>Use 7 x 7 mask or 9 x 9 mask to enhance the edge lines.
<table>
<tr><td>0</td><td>0</td><td>-1</td><td>-1</td><td>-1</td><td>0</td><td>0</td></tr>
<tr><td>0</td><td>-2</td><td>-3</td><td>-3</td><td>-3</td><td>-2</td><td>0</td></tr>
<tr><td>-1</td><td>-3</td><td>5</td><td>5</td><td>5</td><td>-3</td><td>-1</td></tr>
<tr><td>-1</td><td>-3</td><td>5</td><td>16</td><td>5</td><td>-3</td><td>-1</td></tr>
<tr><td>-1</td><td>-3</td><td>5</td><td>5</td><td>5</td><td>-3</td><td>-1</td></tr>
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<tr><td>-1</td><td>-3</td><td>-1</td><td>9</td><td>9</td><td>9</td><td>-1</td><td>-3</td><td>-1</td></tr>
<tr><td>-1</td><td>-3</td><td>-1</td><td>9</td><td>19</td><td>9</td><td>-1</td><td>-3</td><td>-1</td></tr>
<tr><td>-1</td><td>-3</td><td>-1</td><td>9</td><td>9</td><td>9</td><td>-1</td><td>-3</td><td>-1</td></tr>
<tr><td>0</td><td>-3</td><td>-2</td><td>-1</td><td>-1</td><td>-1</td><td>-2</td><td>-3</td><td>0</td></tr>
<tr><td>0</td><td>-2</td><td>-3</td><td>-3</td><td>-3</td><td>-3</td><td>-3</td><td>-2</td><td>0</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>-1</td><td>-1</td><td>-1</td><td>0</td><td>0</td><td>0</td></tr>
</table>
</td>
</tr>
</table>

4.3.4 Thinning

A thinning algorithm (Zhang and Suen, 1984) that requires two successive iterative passes is performed (Figure 4.5). In first and second iterative, a logical rule P1 and P2 is applied locally in a 3 x 3 neighborhood respectively to flag border pixels for deletion. Pixels are arranged in following format (Figure 4.6), where p1 is the pixel under consideration and p2 - p9 are its corresponding neighbors. The flagged pixels areas are deleted and the procedures are applied iteratively until no thinning process can be performed.

1. **Input:** Pixel data is stored in 2D array (column and row number)
2. Define number of pixels deleted -> 0
3. **Iteration 1 (P1):**
   (a) Start from top corner of the image.
   (b) If pixel value is 1, and if all of the following conditions are satisfied.
      (i) 2 <= p1.N <= 6 (checks if the pixel is one of the ends of the image. If so its left unchanged)
      (ii) p1.S = 1 (checks if the image is 1 pixel width at that point)
      (iii) (p2.Data) * (p4.Data) * (p6.Data) = 0
      (iv) (p2.Data) * (p6.Data) * (p8.Data) = 0
   (c) Then the pixel is marked for deletion. ie. set p1. Mark = 'D' and increment number of pixels deleted by 1.
4. Iteration 1 is repeated for all pixels in the image and deletes pixels marked.
5. **Iteration 2 (P2):**
   (a) Start from top corner of the image.
   (b) If pixel value is 1, and all the following conditions are satisfied.
      (i) 2 <= p1.N <= 6 (This step checks if the pixel is one of the ends of the image. If so its left unchanged)
      (ii) p1.S = 1 (checks if the image is 1 pixel width at that point (p2.Data) * (p4.Data) * (p8.Data) = 0
      (iii) (p2.Data) * (p6.Data) * (p8.Data) = 0
   (c) Then the pixel is marked for deletion. ie. set p1. Mark = 'D' and increment number of pixels deleted by 1.
6. Iteration 2 is repeated for all pixels in the image and deletes pixels marked.
7. Delete all the pixels marked for deletion at the end of the iteration.
8. If number of pixels deleted is not equal to zero, then go to step 4.
9. **Output:** Skeleton with one pixel-width.

Figure 4.5 Algorithm for thinning

p9	p2	p3
p8	p1	p4
p7	p6	p5

Figure 4.6 Pixels arrangement for thinning

4.3.5 Endpoints Detection and Broken Contour Lines Reconnection

Every pixel is examined to authenticate whether it is an endpoint using defined mask (a1 to a8) as described in previous chapter (Figure 3.5). Figure 4.7 shows the algorithm for detecting and verifying pixel which are classified as endpoint.

```
1.    For each column in image area (Image width)
2.    For each row in image area (Image height)
      n1 -> (i-1, j-1)
      n2 -> (i, j-1)
      n3 -> (i+1, j-1)
      n4 -> (i-1, j)
      n5 -> (i, j)
      n6 -> (i+1, j)
      n7 -> (i-1, j+1)
      n8 -> (i, j+1)
      n9 -> (i+1, j+1)
3.    If one of the mask (a1 to a8 from Figure 3.5) is detected
4.    Set one of the following pixel (n1 to n9) as endpoint
```

Figure 4.7 Algorithm for endpoint detection

For broken contour lines reconnection, it is comprised of several modules as following: (i) nearest endpoint detected within search window; (ii) least angle computed; and (iii) opposite direction estimated. Figure 4.8 show these sequential algorithms work in separate modules.

Module 1: Nearest endpoint detection within square window (h x h)

1. If detect endpoint, *e1*
2. Search within square window by using endpoint as center pixel

2.1 If detect other endpoint (*e2, e3* and etc) within square window 2.2 Calculate distance for all detected endpoint with *e1* 3. Result the most adjacent endpoint
Module 2: Direction estimated by chain code for two chosen endpoint, *(e1, e2)*
1. If two chosen endpoint are detected, *(e1* and *e2)* 2. Construct 8-directional chain code 3. Estimate the direction of two chosen endpoint (*e1* and *e2)* 4. Match endpoint with its pair (endpoint in opposite direction) 4.1 0-directional to 4-directional 4.2 1-directional to 5-directional 4.3 2-directional to 6-directional 4.4 3-directional to 7-directional 5. Result an appropriate endpoint
Module 3: Least angle computed for two chosen endpoint, *(e1, e2)*
1. If two chosen endpoint are detected, *(e1* and *e2)* 2. Back-trace 10 pixel from *e1* and *e2* respectively 3. Mark the 10-th pixel for *e1* as *a* and; the 10-th pixel for *e2* as *c* 4. Setup triangle correspondingly 4.1 Triangle I is comprised of *a (x1, y1), e1 (x2, y2), b (x2, y1)* 4.2 Triangle II is comprised of *e2 (x3, y3), c (x4, y4), d (x4, y3)* 5. Calculate the angle from triangle form using trigonometry 6 Result the least angle between directional line segment (*a* and *e1*) or (*e2* and *c*) with Y-axis. 7. Validate the most appropriate endpoint to be connected

Figure 4.8 Algorithm for choosing two most appropriate end points to be linked

Another essential module for accomplishing contour lines reconnection module is conducted by Method I and Method II. Cubic spline interpolation is carried out in Method I while Newton polynomial is applied in Method II. These two methods are elaborated in Figure 4.9.

Method I: Cubic Spline Interpolation

1. If two chosen endpoint are detected, (let said *b* and *c*)
2. Back-trace 10 pixel from *b* and *c* respectively
3. Mark the 10-th pixel for *b* as *a;* and the 10-th pixel for *c* as *d*
4. Setup control point:
   - 4.1 *a* – first control point
   - 4.2 *b* – second control point
   - 4.3 *c* – third control point
   - 4.4 *d* – fourth control point
5. Perform cubic spline interpolation by means of these control point.
6. Result a representation of smooth spline to reconnect broken contour lines.

Method II: Newton Polynomial Interpolation

1. If two chosen endpoint are detected, (let said *b* and *c)*
2. Back-trace 10 pixel from *b* and *c* respectively
3. Mark the 10-th pixel for *b* as *a;* and the 10-th pixel for *c* as *d*
4. Setup control point:
   - 4.1 $a - (x_0, f[x_0])$
   - 4.2 $b - (x_1, f[x_1])$
   - 4.3 $c - (x_2, f[x_2])$
   - 4.4 $d - (x_3, f[x_3])$
5. Compute coefficients of this polynomial from these chosen points:
   - 5.1 1st coefficients -> $f[x_0] = c_0 = f(x_0)$
   - 5.2 2nd coefficients -> $f[x_0, x_1] = c_1 = \dfrac{f(x_1) - f(x_0)}{x_1 - x_0}$

5.3 *nth*-coefficients -> $f[x_0, x_1, x_2, \ldots, x_n] = c_n$

6. Perform Newton interpolation polynomial

$$P_n(x) = c_0 + c_1(x - x_0) + c_2(x - x_0)(x - x_1) + \ldots +$$
$$c_n(x - x_0)(x - x_1)\cdots(x - x_{n-1})$$

7. Result contour lines as a set of lines representation of polynomial

Figure 4.9 Algorithm for contour lines reconnection using Method I & Method II

4.3.6 Raster to Vector

In this stage, raster contour image is converted into vector format that can be applicable in all GIS application. Several vector format are familiar in GIS, for instance AutoCAD DXF (*.dxf), ArcView Shape (*.shp), MapInfo Interchage (*.mif), WinTopo Data File (*wtx, *txt, *.dat), R2V ARC File (*.arc), ASCII x, y, z format (*.asc), Windows MetaFile (*.wmf), Enhanced Window Metafile (*.emf) and etc. Vectorization software like WinTopo, R2V, Easy Trace 7.9, ESRI and others is used to complete this task.

4.4 Phase III – Post-Processing

Finally, human observer is indispensable to verify the accuracy of vectorized contour lines. The extracted contour lines from this work is compared with the digitize data establish using other GIS application.

4.5 Engine Specifications

Table 4.2 shows the specifications of this system. Basic image processing enhancement and editing tools are included into this system to assist human operator for the entire process. There are some additional features included into this system such as a friendly graphical user interface (GUI) and display of raster image format after and before every process. The result in vector format is portable to be used for integration into majority of existing GIS and CAD application.

Table 4.2: Engine specifications

Software	Specification
Supported Operating System	Win98/ Win2000/ WinXP
Developments Tool	Visual Studio 6 (MFC)
Programming Language	C++
Graphic Library	Victor Image Processing Library
Other Features	Object oriented design Graphical User Interface (GUI)
Algorithm	Pattern Recognition, basic image processing tools
External Features	Result in vector format can be integrated into GIS/ CAD application

4.6 Hardware and Software Requirements

The implementation is accomplished by following hardware and software requirement as shown in Appendix B1 and Appendix B2. However higher performance hardware and software is recommended to produce faster processing runtime. The system is implemented for a PC using Windows platform. The input binary images are obtained from maps of size A4A1, usually scanned at 180-600 dots per inch (dpi) resolution. The raster data for processing are represented as Bitmap (*.bmp) formats, whilst the output data are represented in raster and vector formats.

CHAPTER 5

RESULTS AND ANALYSIS

5.1 Introduction

The map interpretation technique that proposed in this study is applied to recognize and extract contour lines from raster topographic map. Previous work has shown that it is impossible to recognize a whole map automatically because it is produced by human interpretation, and includes objects with different fonts, orientations, sizes and etc (Ablameyko et al., 2001). In addition, automated approach is usually followed by a significant amount of interactive post-processing to correct recognition errors. By identifying these constraints, a combined technology of colour map digitization is developed by means of automatic and interactive contour lines recognition and extraction controlled by a human observer. This chapter discusses about the combined technology that is carried out along with experimental results. Such a combination minimizes digitization errors, decreases the timescale for the entire digitization process, and the complication task conducted by an operator. It allows one to reach an acceptable compromise between the ratio of quality, time (speed of processing time) and level of automation in the digitization process, and avoids the need and time spent for errors correction.

The main distinctions of this approach from those existences are:-

1. The combination of different technological processes to digitize maps, which allows a high level of automation, at an acceptable timescales.

2. A simple, fast and efficient colour separation algorithm using colour quantization approach to reduce a large amount of colours in topographic map.
3. A specialized discontinuities (broken contour lines) reconnection scheme, by consideration of following criteria: nearest distance between endpoints, least angle between directional line segments and vertical line (Y-axis); and directional information among chosen endpoints.
4. Newly established a combination of interactive and semi-automated approach, particularly for contour lines recognition and extraction techniques rely upon the unique characteristic of contour lines.

4.1 Image Data

Topographic map is scanned either in monochrome, grey scale or 24-bit colour depends on the map quality and the capability of a scanner with different resolution. Experiments are carried out on different scanned portions of topographic maps. Each map image may vary in producer, scanning resolution, scale and size. The raster data format is scanned in Bitmap format (BMP). Most of the image data is comprised of topographic map from several areas in Malaysia. Whilst, the data for the third experiment is a standard USGS topographic map downloaded from United States Geological Surveys (USGS) database. A brief descriptions of the data used for testing purpose in this work are summarized in Table 5.1.

Table 5.1: The image data used for the experiments

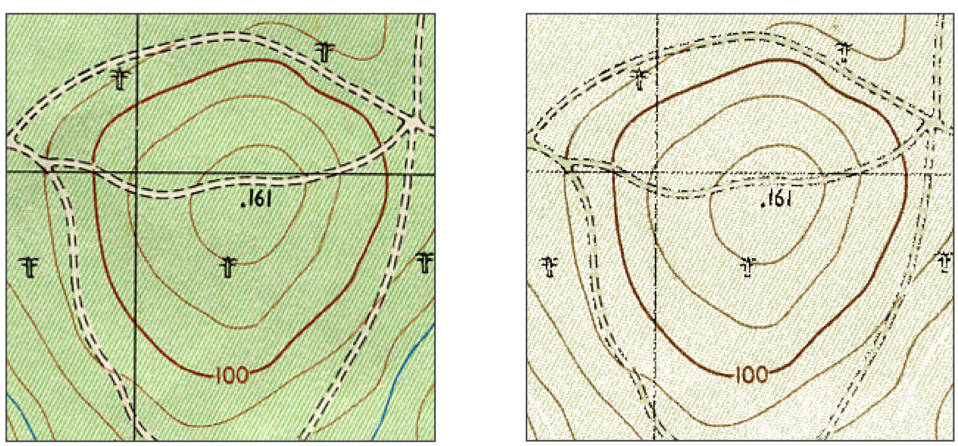
Experiment	Size (Pixel)	Resolution/ Scale	Descriptions	Source
1	290 x 290	200/ 1:10,000	North of Klang area in Malaysia	JUPEM
2	512 x 512	360/ 1:25,000	Pahang, Peninsular Malaysia	JUPEM
3	435 x 435	96/ 1:50,000	Kotabunan, Indonesia	USGS

4	1031 x938 399 x 361	72/1:25,000	A place in France	Department of Geography of University of Erlangen-Nurnberg

4.2 Experiments and Results

4.2.1 Experiment 1: Topographic Map scale 1:10,000 (200 dpi)

The work is carried out for 24-bit RGB colour map image in this experiment. Although RGB colour space is perceptually non-linear, it is the set of all colours produced on a computer graphics monitor. Since the colour for contour lines is distorted in contrast to its background, the background of topographic map always influences the extraction process. If the background is presented in single neutral colour, the procedure become easier compare to multiple background colours. HSV colour space is an initial step to apply, where hue value is set in range 0-30 to separate desirable features (contour lines) from undesirable features (other information portray on maps, like stream, character, texture background etc).



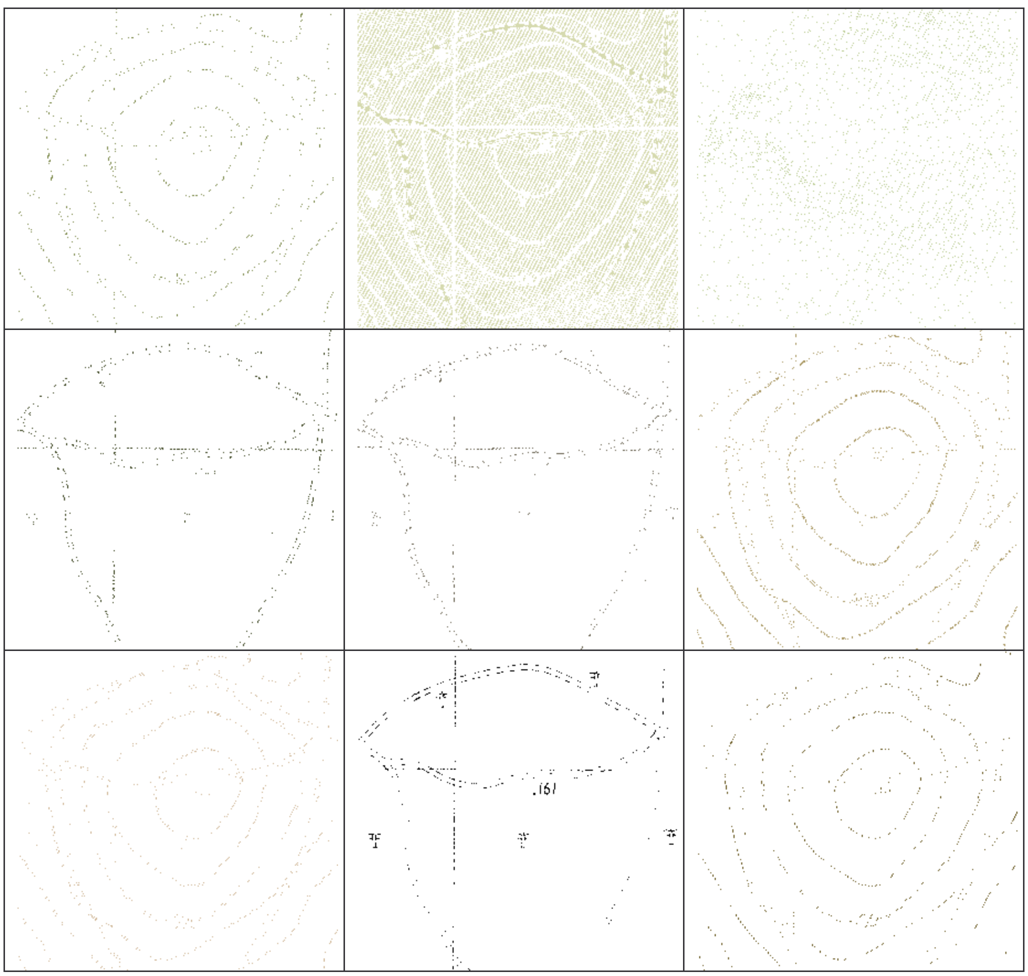
(a) The scanned topographic map (b) Apply HSV with hue in range 0-80

Figure 5.1 Topographic map scanned in 200 dpi with scale 1:10,000

An analysis is carried out for a portion of scanned topographic map (Figure 5.1(a)). To our naked eye, this map is consists of five distinct colours: brown, blue, black, green and white. However, it reveals 29,693 of distinct colours in reality. These additional colours are known as false colours that induced by scanning process due to RGB misalignment. Since HSV colour space is applied to segment particular brown value, these additional colours can be ignored. As a result shown in Figure 5.1(b), the portion of map is comprised of 14 distinct colours at this phase.

5.3.1.1 Map Layers Separation using Colour Quantization

Each distinct colour is separated and represented in different layers. The result is shown in Figure 5.2.



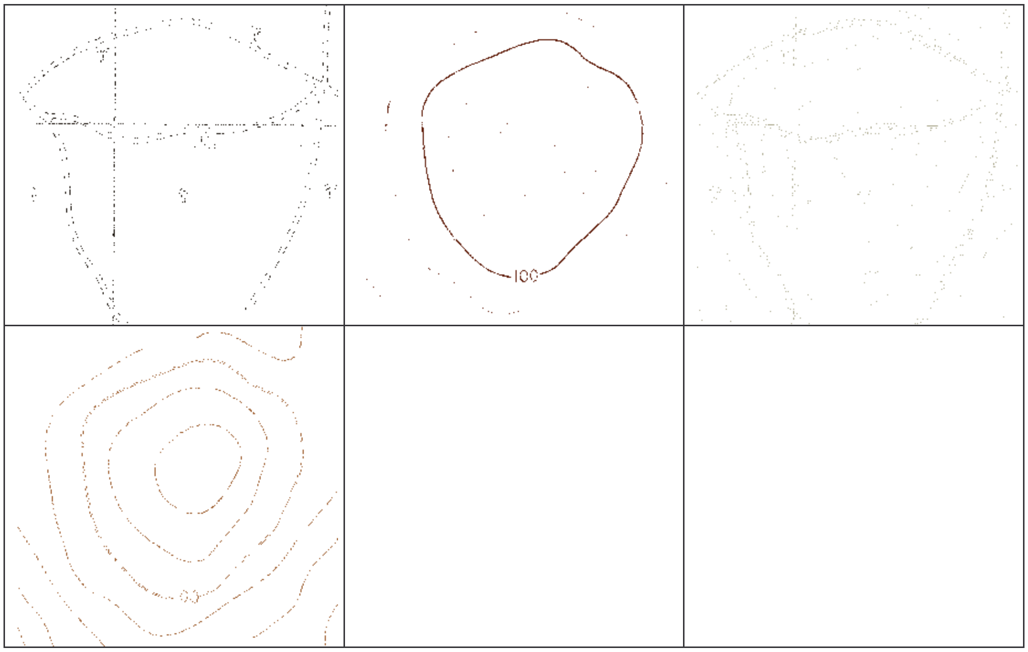
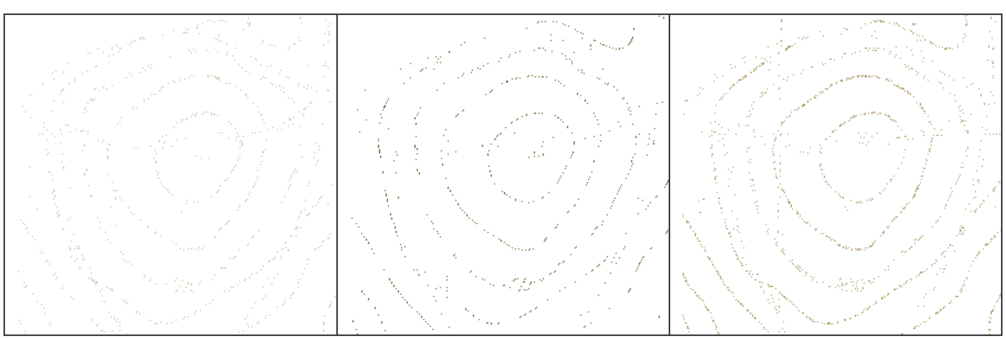


Figure 5.2 Colour quantization and map layers separation

5.3.1.2 Map Layers Combination

Due to intersecting and overlapping of several features on the map, a fine contour map is still cannot be employed from either one of the layers. In general, several layers are likely combined to represent a comprehensive contour map (Figure 5.3). This work is supervised by human observer to authenticate the appropriate combination of colour layers. However, noise always exists in the resultant image and further process is required to clean this extraneous information while retains contour lines.



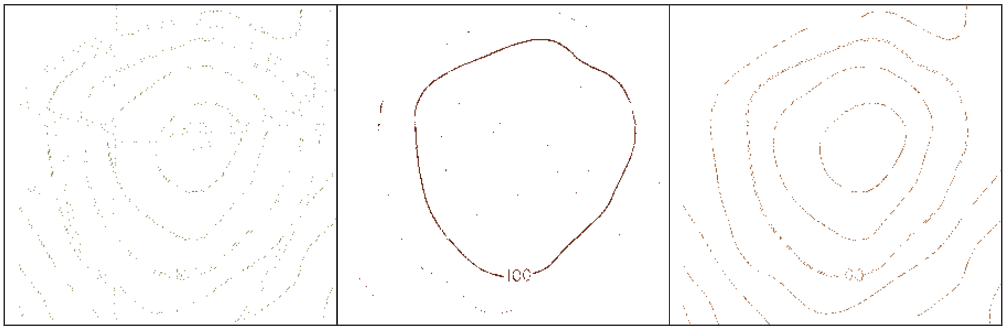
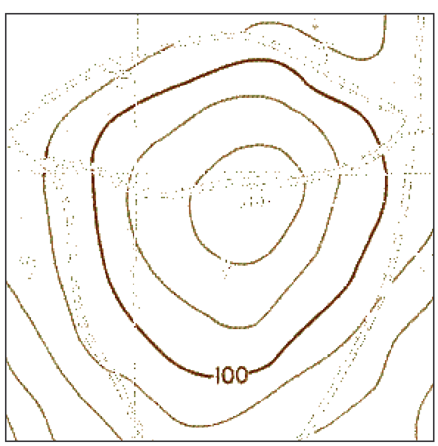


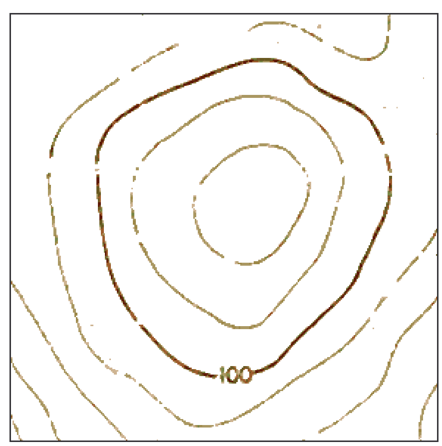
Figure 5.3 Combination of several layers representing contour lines

5.3.1.3 Contour Lines Enhancement

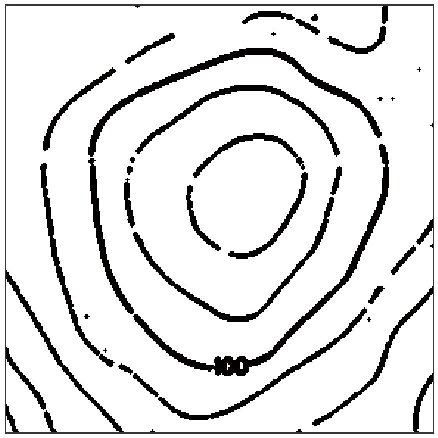
Several image enhancement processes discussed in previous chapter are applied to improve the result until a skeleton contour image is obtained (Figure 5.4(a)-(f)). This enhancement process may be differed but mostly similar for different map. For this experiment, noise is eliminated by applying median filter in local neighbourhoods for the contour map. Intensity values are sorted in ascending or descending order, and the median value is chosen as the new intensity value of the pixel for the local neighbourhood. In case of one pixel in the neighbourhood is dramatically diverse from the others, it is defined as noise and median filter can remove it completely. The result is shown in Figure 5.4(b).



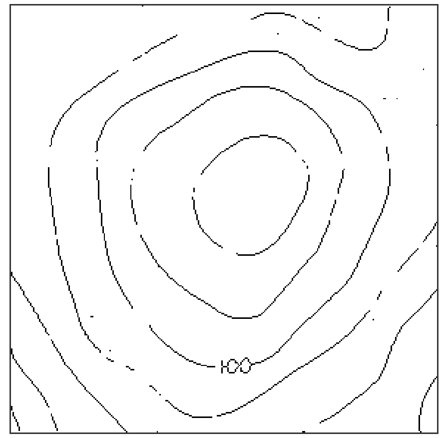
(a) Result of initial contour layer



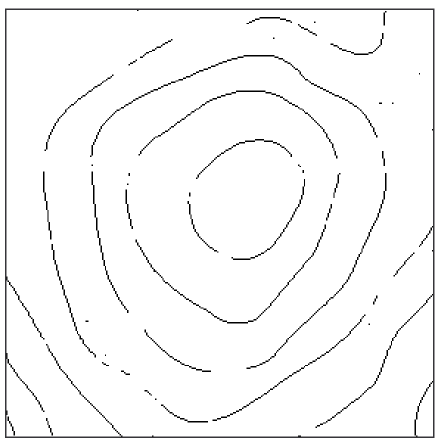
(b) Remove noise (Median filter)



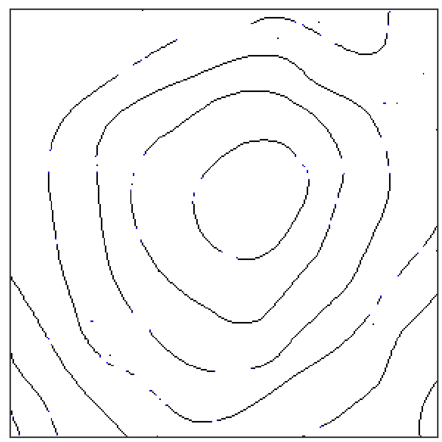
(c) Image filtering



(d) Thinning



(e) Remove elevation value



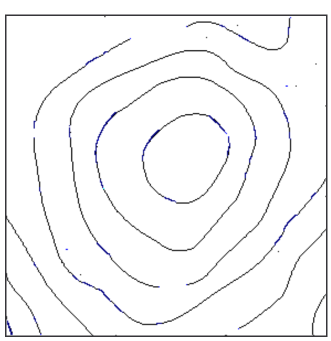
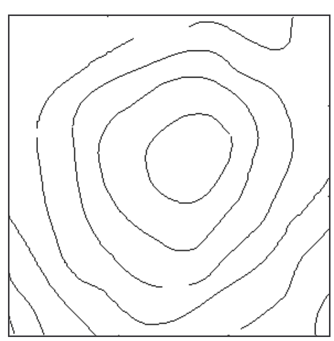
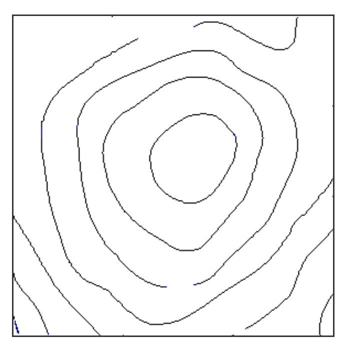
(f) Endpoint detection

Figure 5.4 Remove noise and edge enhancement

For increasing pixel representation of the contour lines, 3 x 3 mask using the following data structures [(0, 1, 0), (1, 2, 1), (0, 1, 0)] are applied to filter the image (Figure 5.4(c)). Thinning is the final course of procedure after image enhancement has improved the quality of image (Figure 5.4(d)). Subsequently, elevation value and other characters exist in the map are removed before contour lines tracing process can be established (Figure 5.4(e)). Endpoint for every line segment is detected using endpoint detection mask as discussed in previous chapter. The blue pixels indicate the detected endpoint (Figure 5.4(f)). In this circumstance, these broken line segments are equipped throughout the reconnection phrase.

5.3.1.4 Reconnection Phrase

As described in previous chapter, two methods are used to reconnect the broken part of contour lines. The size of search window is another essential aspect in this phrase. It can be varied for different scale and scan resolution of topographic map. If the gaps exist is small, the size of search window is correspondingly small. On the other hand, if the gaps exist is large (e.g. intentional gaps allocate for elevation value), the size of search window is ideally to be large. Since the scale for this experiment is 1:10,000, contour lines are visibly wide among each another. Therefore, parameter of search window is set to 15 x 15 from every detected endpoint. Several iterations of Method I (cubic spline) are applied to reconnect the broken part of line segments. Then, the size of search window is enlarged to 70 x 70 for reconnecting larger gaps. Hereby, Method II (Newton interpolation polynomial) is used to reconnect gaps consequence of elevation index. In general, cubic spline interpolation is appropriate for arc segment; whilst Newton interpolation polynomial is more suitable for wider gaps that appear with a slightly slope. Figure 5.5 (a)-(f) shows the entire sequences in obtaining the result for contour lines reconnection.

Search window (15 x 15)		
		
(a) Method I (Cubic spline – 1^{st} iteration)	(b) Remove isolated pixel	(c) Method I (Cubic spline – 2^{nd} iteration)

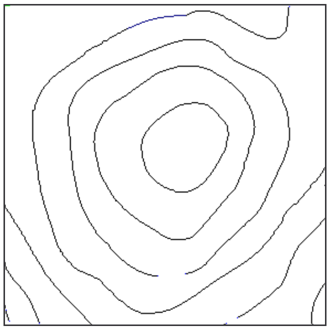
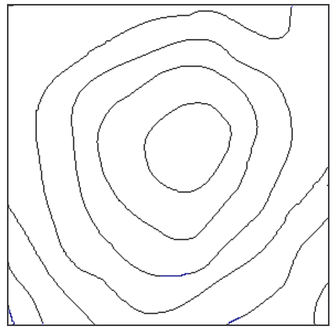
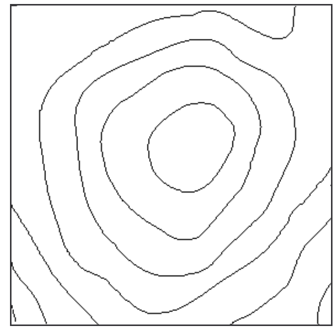
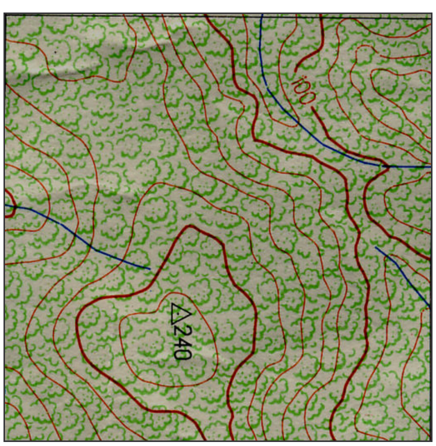
Search window (70 x 70)		
		
(d) Method II (Newton Polynomial)	(e) Method I (cubic spline – 3rd iteration)	(f) Final result of extracted contour lines

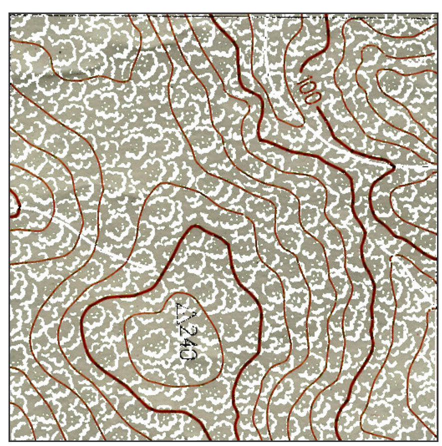
Figure 5.5 Contour lines reconnection using Method I and II for Experiment 1

4.2.2 Experiment 2: Topographic Map scale 1:25,000 (360 dpi)

The second experiment is carried out on a map (Figure 5.6(a)), which has dissimilarity in scale representation and resolution in contrast with the former one.



(a) The scanned topographic map



(b) Apply HSV with hue in range 0-80

Figure 5.6 Topographic map scanned in 360 dpi with scale 1:25,000

For this portion of topographic map, it consists of 92,379 distinct colours. The RGB colour space is converted into HSV colour space, while hue value is set in range of 0-80 to reduce the colour exist on the map. The result remains 42,848 colours and it is shown in Figure 5.6 (b). The conversion into HSV colour space is not an essential procedure for every experiment. It acts upon an alternative manner to distinguish brown value pixels from the other colours exist in the map.

5.3.2.1 Map Layers Separation using Colour Quantization

Colour quantization is applied to reduce the amount of colours present in a topographic map into an optimize level. The amount of colours to be quantized is constrained to less than 16 colours. Figure 5.7 shows the result of colour quantization and relevant layers of map correspondingly.

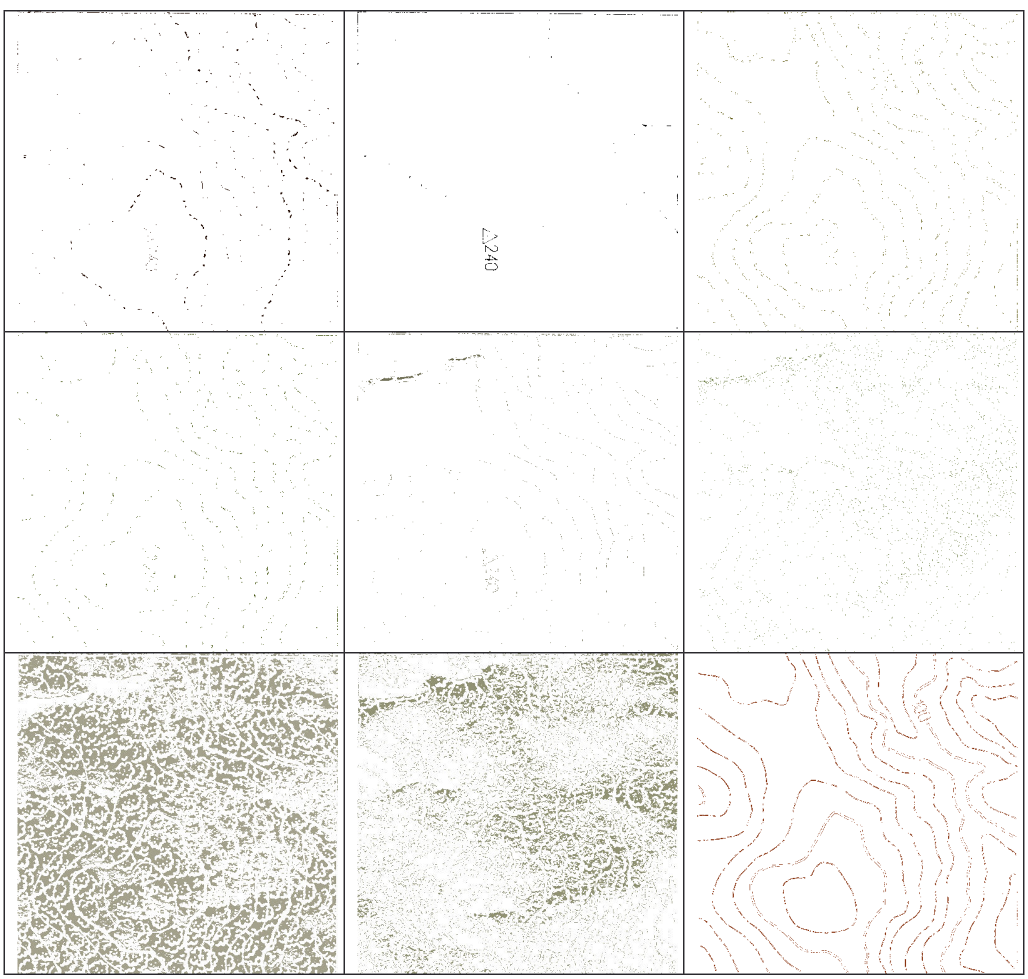


Figure 5.7 Colour quantization and map layers separation

5.3.2.2 Map Layers Combination

Generally, a number of layers as shown in Figure 5.8 are attached to represent a comprehensive contour map. The interactive procedure performed in the study relies upon human observer to justify those appropriate layers for attachment. Therefore, the number of layers to be attached varies for each experiment.

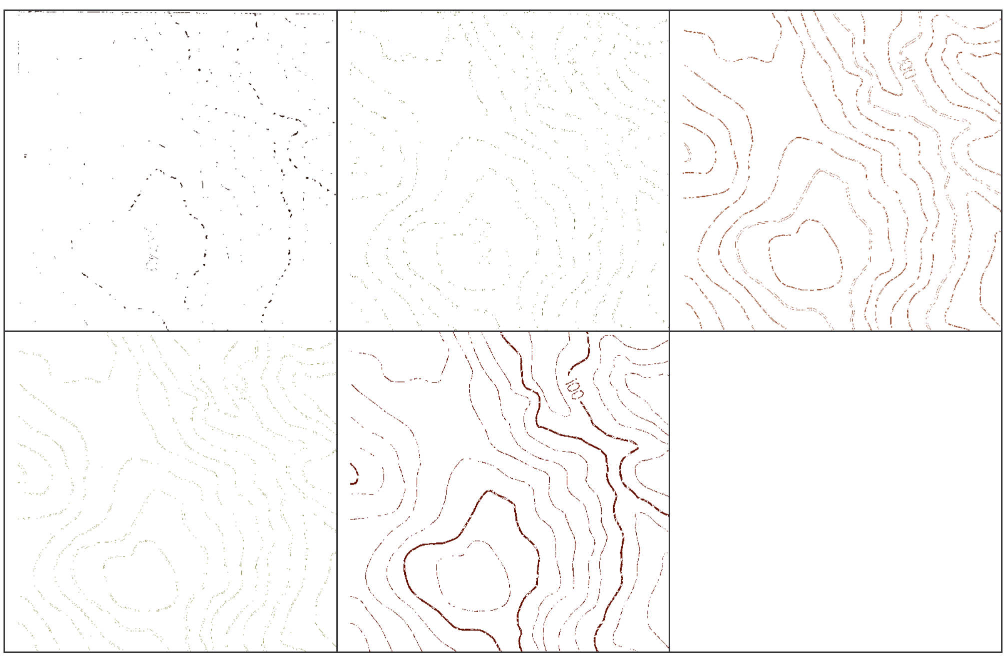
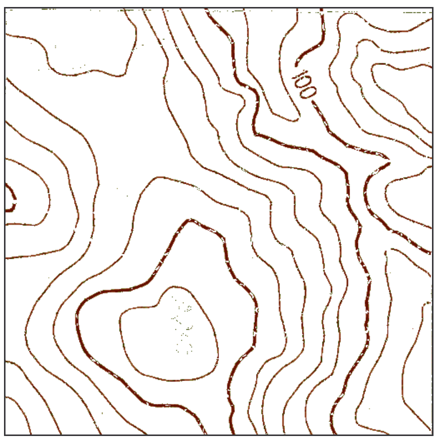


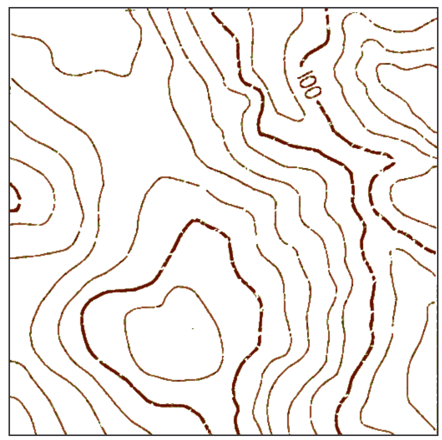
Figure 5.8 Combination of several layers to represent contour lines

5.3.2.3 Contour Lines Enhancement

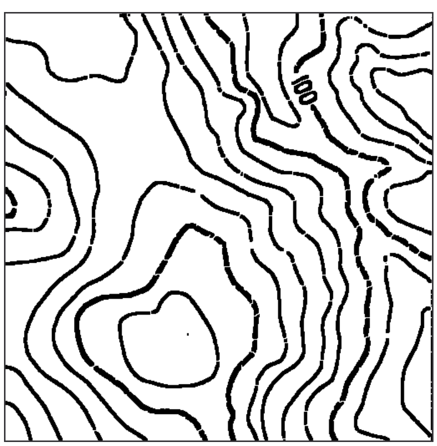
Different operation is performed in this section to obtain a finer result. In this experiment, dilation that is not joined each other line segment is adopted to improve the lines structure. Figure 5.9 (a)-(f) shows the results of contour lines enhancement until attain a skeleton image with detected endpoints for every single line segment. For ease the process, all contour annotations exist in raster image are removed before reconstruction algorithm is performed in subsequent step.



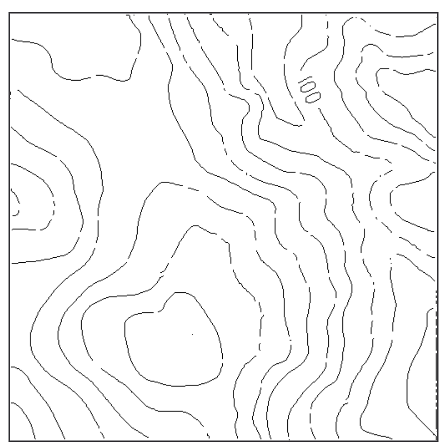
(a) Result of initial contour layer



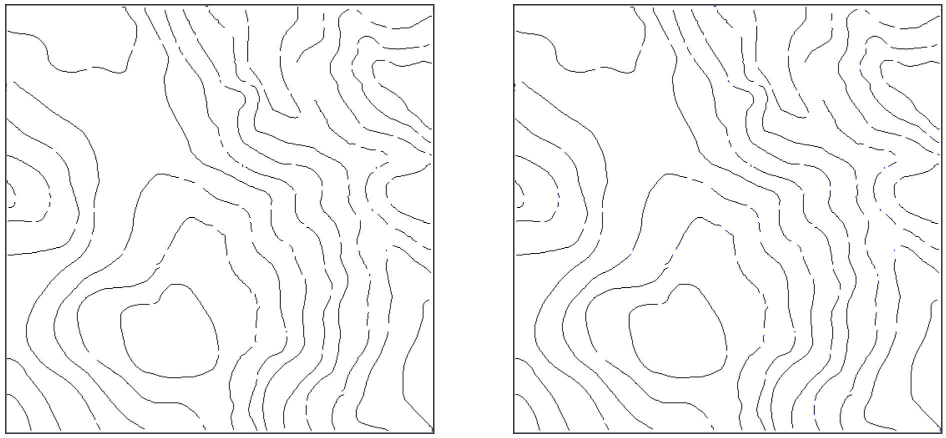
(b) Remove noise (Median filter)



(c) Dilate Not Join



(d) Thinning

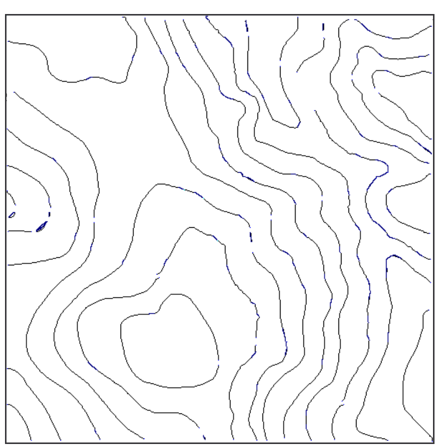
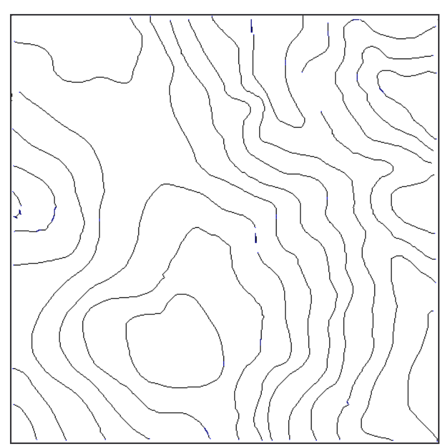


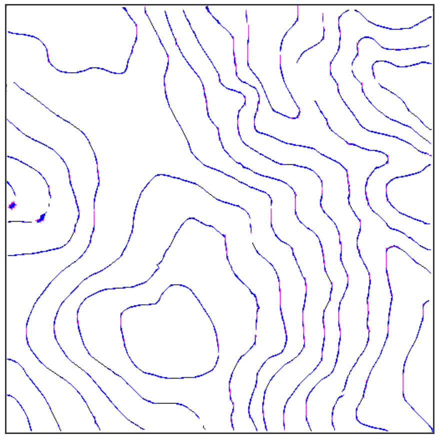
(e) Remove elevation value (f) Endpoint detection

Figure 5.9 Remove noise and edge enhancement

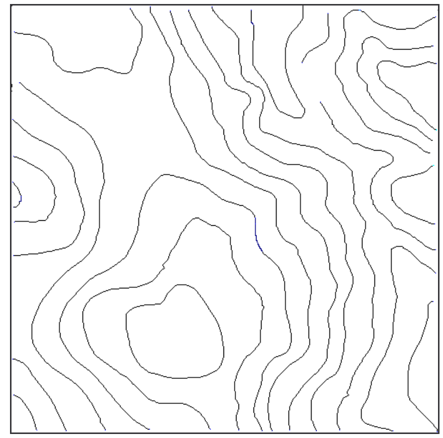
5.3.2.4 Reconnection Phrase

In this phrase, two search windows, which are comprised of (15 x 15) and (70 x 70) respectively, are set to contour lines reconnection. Iterative cubic spline interpolations are sufficient for reconnecting the broken part of line segments in this condition. The results are shown in Figure 5.10 (a)-(f).

<table>
<tr><th colspan="2">Search window (15 x 15)</th></tr>
<tr><td>
(a) Method I (cubic spline – 1st iteration)</td><td>
(b) Method I (cubic spline – 2nd iteration)</td></tr>
</table>

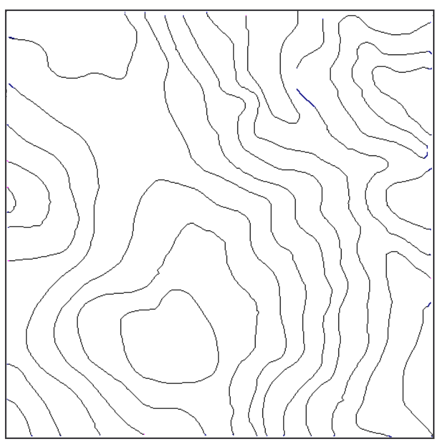


(c) Directional 5 x 5 mask

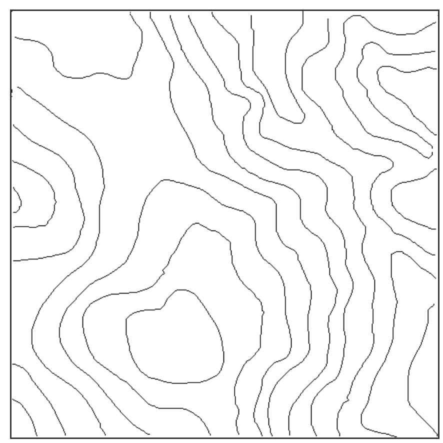


(d) Method I (cubic spline – 3rd iteration)

Search window (70 x 70)



(e) Method I
(cubic spline – 4th iteration)



(f) Final result of extracted contour lines

Figure 5.10 Contour lines reconnection by different size of search window

5.3.3 Experiment 3: Topographic Map scale 1:25,000 (96 dpi)

The following experiment is tested on a portion of USGS topographic map (Figure 5.11). USGS is well-known as one of the largest suppliers of topographic map. USGS maps are produced by scanning published paper maps on high resolution scanners and they are only consists of seven distinct colours.

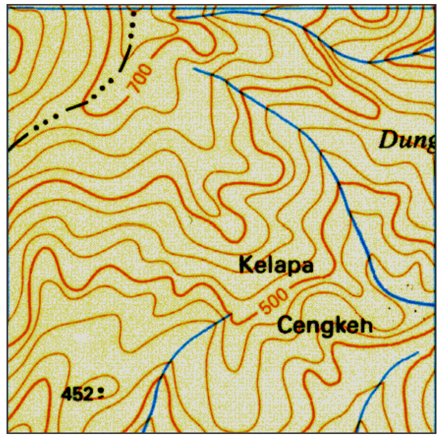


Figure 5.11 Topographic map scanned in 96 dpi with scale 1:25000

5.3.3.1 Map Layers Separation using Colour Quantization

Since USGS topographic maps have their unique characteristic, where the map is generally represented in 8-bit RGB colour, HSV colour space is unproductive for reducing the colours. For this reason, colour quantization is adequate for reducing colours in a raster map. There are represented in different layers as shown in Figure 5.12. Each layer consists of a single representative colour which is the outcome from colour quantization process.

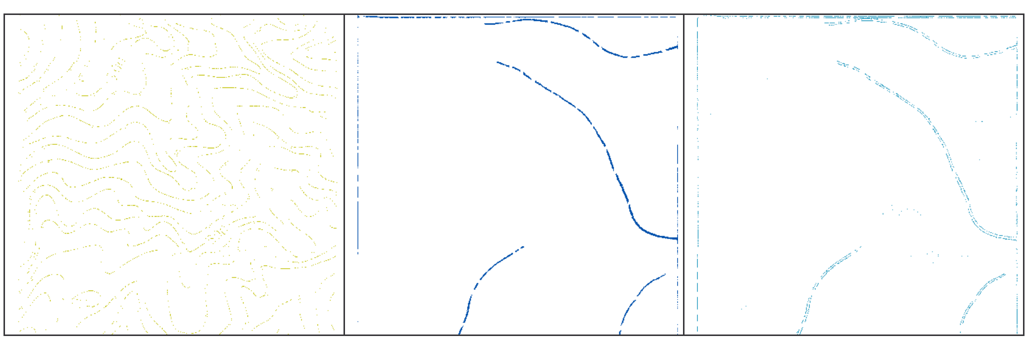
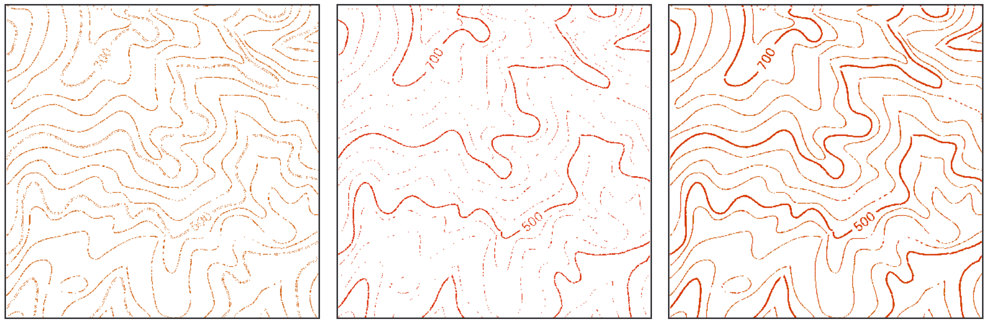


Figure 5.12 Colour quantization and map layers separation

5.3.3.2 Map Layers Combination

Although many layers are perceived to characterize contour lines, only two layers are chosen in this experiment. Incorrectness in determining map layers may result of generating noise in an image. Figure 5.13(a)-(b) illustrate two map layers are involved in generating a comprehensive contour map (Figure 5.13(c)).

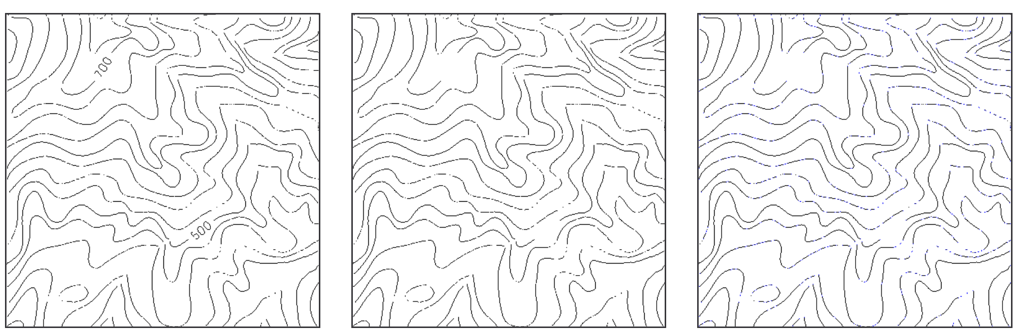


(a) (b) (c)

Figure 5.13 (a) and (b) Combination of several layers representing contour lines, (c) Result of an initial contour map layer

5.3.3.3 Contour Lines Enhancement

Since USGS topographic maps are deserved for their high quality, enhancement phrase can be performed in a much simpler manner in achieving a skeleton map image. This section is accomplished by thinning, removal of elevation value and detection of end points for each line segment. These procedures can provide visible individual line segments for further recognition and vectorization process. If contour lines cannot be well identified after this process, then recognition process might end up unsuccessful. In view of this reason, almost all topographic maps cannot be recognized automatically without human intervention. Figure 5.14 (a)-(c) shows the procedures involve in this enhancement phase.



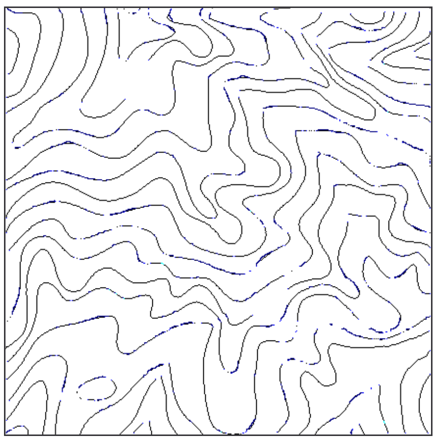
(a) Thinning (b) Remove elevation value (c) Endpoint detection

Figure 5.14 Contour lines enhancement

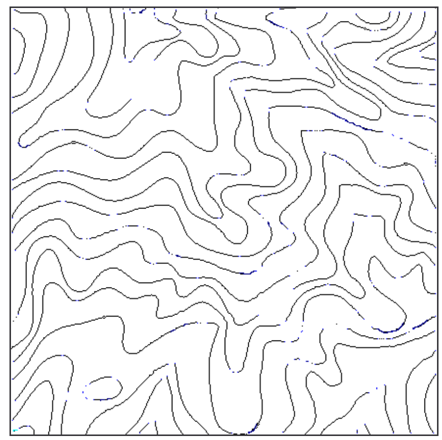
5.3.3.4 Reconnection Phrase

Several iterations with different sizes of search window are used to reconnect the broken part of line segments (Figure 5.15 (a)-(g)). There is another approach to make use of connected component labelling algorithm to identify and detect holes exist in map image. It is then thinned to remove the holes remain in the map.

Search window (5 x 5)

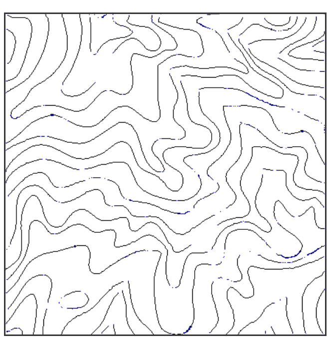


(a) Method I (Cubic spline – 1st iteration)

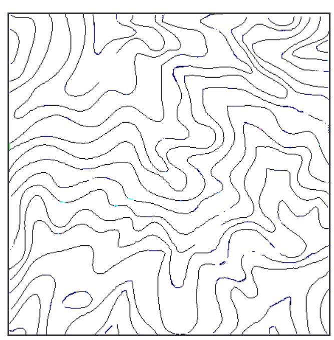


(b) Method I (Cubic spline – 2nd iteration)

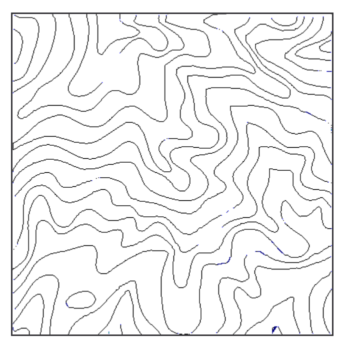
Search window (10 x 10)



(c) Hole Detection



(d) Method I (Cubic spline – 3rd iteration)



(e) Method I (Cubic spline – 4th iteration)

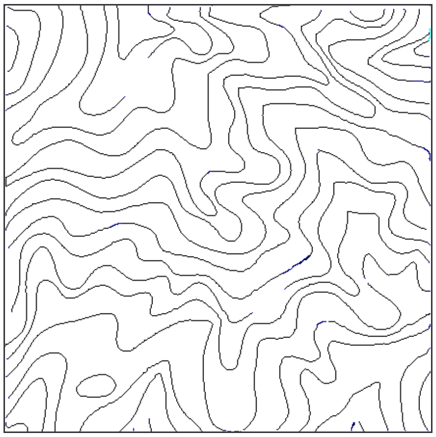
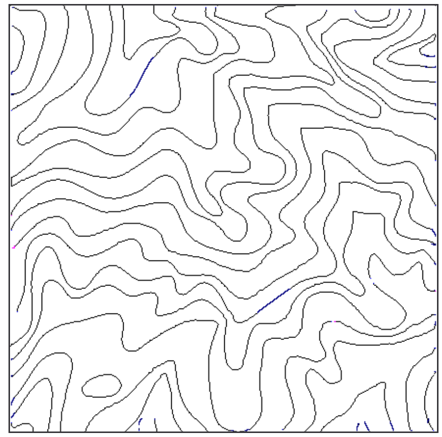
Larger Search window (15 x 15) & (70 x 70)	
	
(f) Method I (Cubic spline – 5^{th} iteration)	(g) Method I (Cubic spline – 5^{th} iteration)

Figure 5.15 Contour lines reconnection

5.3.4 Experiment 4: Topographic Map scale 1:25,000 (72 dpi)

The final experiment is applied to a portion of topographic map (1031 x 938 pixels) as in Figure 5.16 that implemented in Salvatore and Guitton's (2004) work.

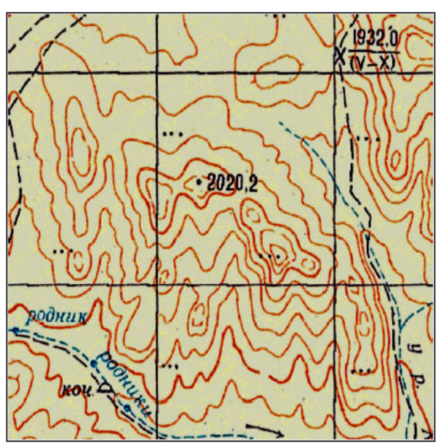
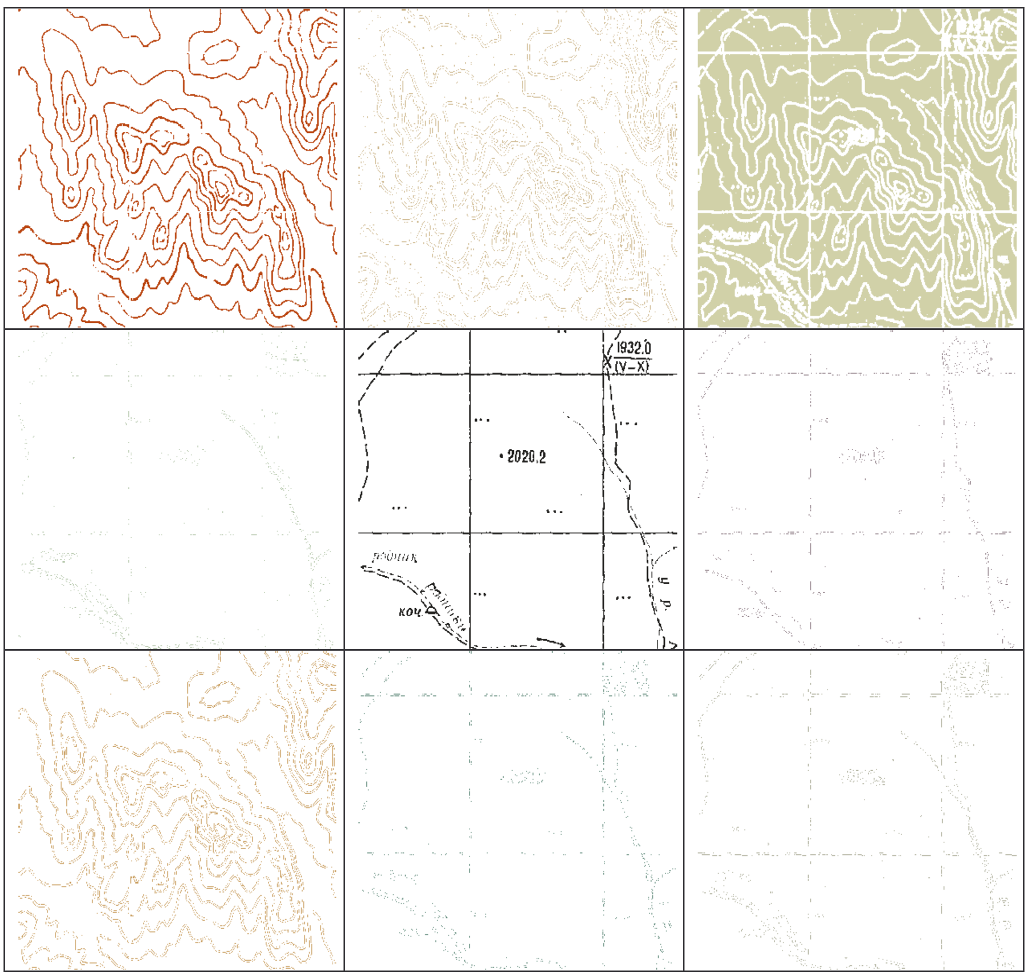


Figure 5.16 Topographic map in Salvatore and Guitton's work

In their approach, local geometries properties are used to recognize contour lines. The skeleton lines are vectorized using Delaunay Triangulation. Delaunay edges are filtered using local and global rules. Subsequently, a complete construct reliable chain of edges and the matrix of weight are used to fill in the remaining gaps grouping different segments.

5.3.4.1 Map Layers Separation using Colour Quantization

In this colour classification section, colour quantization is applied to separate the map into several layers. The result is shown in Figure 5.17.



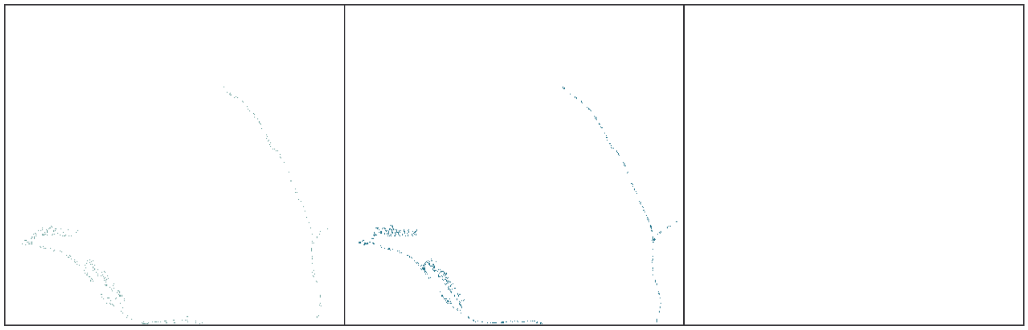
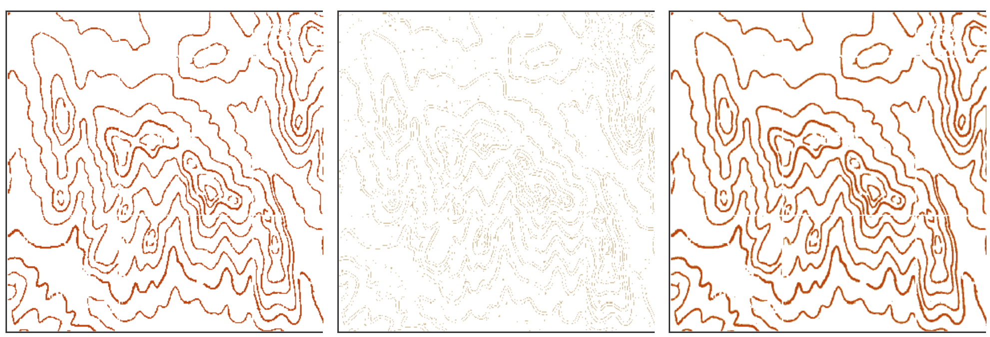


Figure 5.17 Colour quantization and map layers separation

5.3.4.2 Map Layers Combination

Several layers of map as shown in Figure 5.18(a)-(b) are used to attach together to generate a more comprehensive contour map (Figure 5.18(c)).

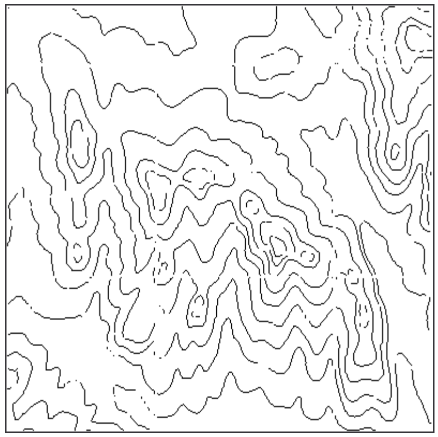


(a) (b) (c)

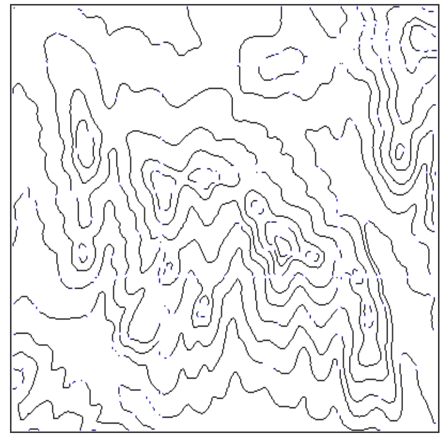
Figure 5.18 (a-b) Combination of several layers representing contour lines, (c) Result of initial contour map layer

5.3.4.3 Contour Lines Enhancement

Since the initial contour map is obtained in good quality and sufficient in representing contour information, enhancement phrase can be accomplished without difficulty. Thinning algorithm is applied to skeleton the contour maps and endpoint is detected using particular 3 x 3 masks (Figure 5.19(a)-(b)).



(a) Thinning



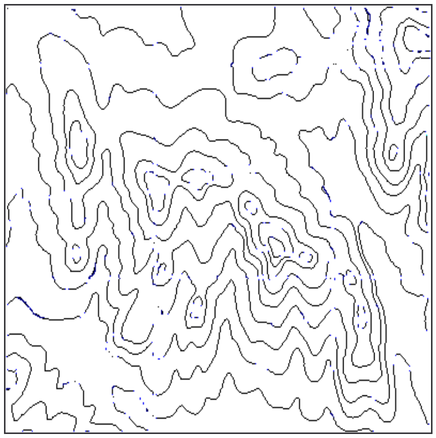
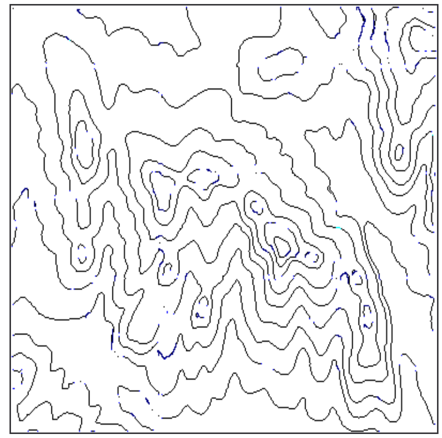
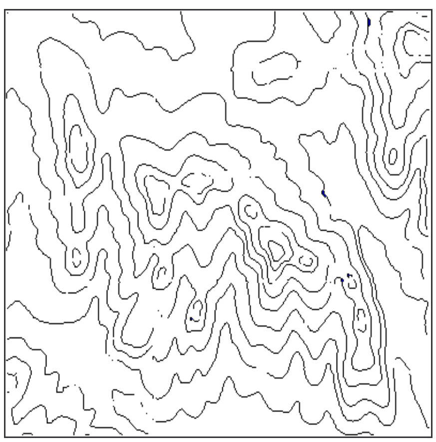
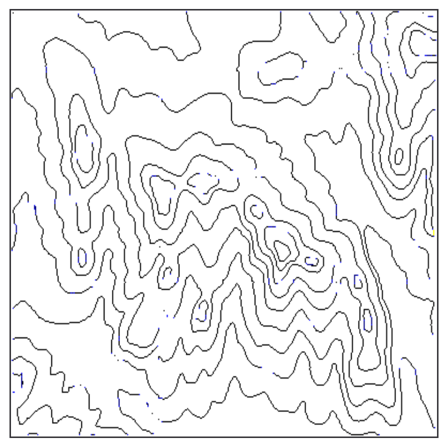
(b) Endpoint detection

Figure 5.19 (a) Thinning and (b) Endpoint detection for every line segments

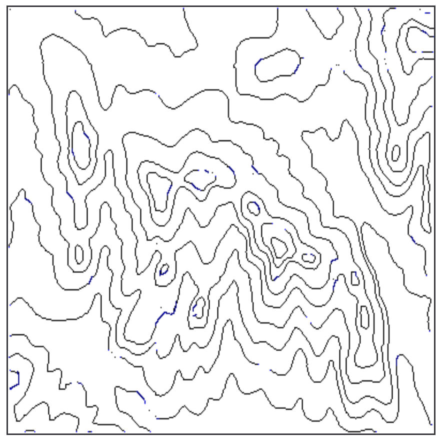
5.3.4.4 Reconnection Phrase

The reconnection phrase is performed using different sizes of search window. Each size of search window is significant to reconnect dissimilar gaps that exist in a map (Figure 5.20 (a)-(h)). Following the idea described in previous chapter, any possible connection path between two endpoints is computed. These prove that cubic spline interpolation with specific criteria (angle, distance and directional information) is capable to generate an acceptable result for contour lines reconstruction. Without these criteria, the reconnection process may not proceed successfully.

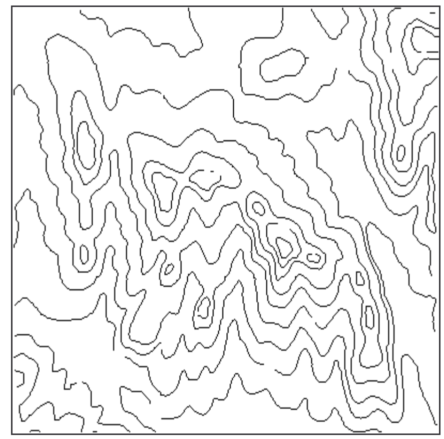
Although there are still drawbacks arisen from this approach, it reduces human involvement in verifying each broken line segments circumspectly. In this approach, human observer is required to set the size of search window for reconnecting the broken line segments. Then, other tasks are left for the hybrid approach, which combine of interactive and semi-automated manner that was implemented in this study. In any case, human is still indispensable in the final stage concerning verification and error correction.

Search window (3 x 3)	**Search window (5 x 5)**
 (a) Method I (Cubic spline – 1^{st} iteration)	 (b) Method I (Cubic spline – 2^{nd} iteration)
Search window (5 x 5)	**Search window (5 x 10)**
 (c) Hole Detection	 (d) Vertical and Horizontal connection

Search window (10 x 10)

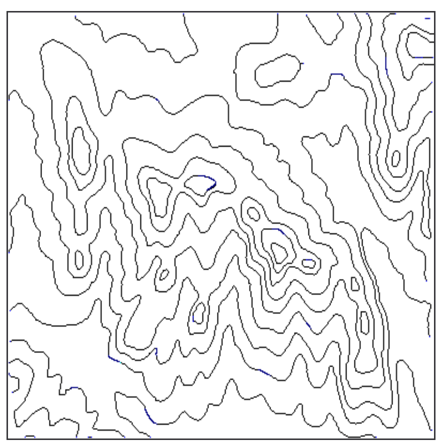


(e) Method I (Cubic spline –3rd iteration)

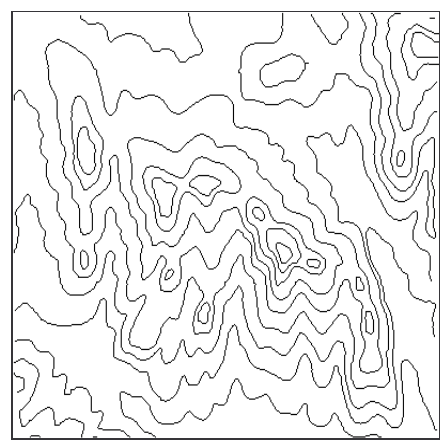


(f) Method I (Cubic spline –3rd iteration)

Search window (15 x 15)



(g) Method I (Cubic spline –4th iteration)



(h) Final result of recognized contour lines

Figure 5.20 Reconnection using different size of search window

5.4 Discussion

For decades, geodesists and topographers have concerned about the lack of a good approach for analysis of accuracies, or more generally, for examination of the quality of digitize contour data. Since there are various applications and technological advances enhance the quality of digital data, they are expected to have higher quality than conventional topographic map data. However, digital data systems are not inherently more accurate than the analog systems they supplant. In general, digital systems are capable of processing data precisely than analog systems, but their overall accuracy still depends on the accuracy of their source data, which in most cases remain analog. The final accuracy of data depends on the quality of original input data, as well as relies strongly on the precision with which input data is processed. Higher accuracy entails higher initial data quality and more precise processing, and both of them increase system costs. Therefore, GIS data quality is a compromise between the need of accuracy and costs.

In this study, the most important issue is the error between the raw data (the paper based topographic map) and the digital data (the result after vectorization). When raster file is scanned from map sheet, the accuracy should be examined in followings two aspects: (i) The accuracy between papers based map and the raster file; (ii) The accuracy between the raster file and the resultant of vector file based on the raster file. Among these, the former is related to the accuracy of a scanner used for digitizing a paper based topographic map into a raster file map. Secondary, the accuracy of resultant vector file process from the raster image is determined by the efficiency of vectorization process and the characteristic of an operator or computer intelligent algorithm in correcting and editing error. However, comparison with fully automatic vectorizing method could not be performed because the number of vectors and the accuracy for automated vectorizing methods are variable. Therefore, a details comparison is carried out between several vectorizing systems to indicate the similarities and dissimilarities, as well as their advantages and disadvantages. In addition, visual interpretation approach is significant in evaluating the quality of result. For this reason, human supervision tends to be a straightforward and evidence manner to verify the robustness of the approach in this study.

5.4.1 Computational Measurement between Existing Application

The efficiency of proposed algorithm is based on a combination of local and global criteria. A significant structural relationship is identified, while perceptual organization is started with the edge (line segment). Local geometric properties like distance, angle; directional or orientation information are used to construct reliable chains of edges. Using global information, topology of contour lines is preserved while texture or complicated background is removed from the input raster data. These steps have simplified the problem and make possible for the recognition of further comprehensive contour lines. The accuracy and efficiency of the developed procedures and vectorization approach in this study are examined and compared with the screen digitizing method using several popular GIS and vectorization application. These systems include WinTopo, Vextractor, AutoMNT, and Easy Trace. The engine specification, software and hardware used are specified in previous chapter (Table 4.2), Appendix B1, and B2.

Evaluation is conducted in different categories and circumstances. Firstly is the computational approach among existing raster-to-vector software and this study. These include the computation time for colour segmentation in order to extract contour lines; and the computation time for identifying and reconnecting broken contour line segments. Another measurement of accuracy between raster file and the resultant of vectorize data is based upon Root Mean Square Error (RMSE), which can be interpreted as the standard deviation of error distribution. Each circumstance is tested independently on four portion of topographic map as illustrated in Table 5.1. The results are shown and discussed in the following section.

5.4.1.1 Computation Time for Colour Segmentation

The efficiency of colour separation technique for extracting brown value contour lines is conducted on several experiments based on four set of data. WinTopo and Vextractor system employed conventional thresholding approach to separate desired colour layer from complicated map image. Therefore, human participation is needed for inspecting, hence setting a range of value to threshold particular features. It is generally difficult to be examined; hence no experiment is conducted for the purpose of comparisons in this study.

Easy Trace enables vectorizing and separating of particular features from colour map (e.g. rivers, contour lines etc.). The system in an interactive approach, where user can make decision on constructing colour masks to trace particular features. This is because linear features are usually represented in different lengths, and their pixels are composed of different tints. In addition, distortions at scanning and printing cause the colour of single-type objects differ greatly. Adaptive expanding mode is intended to utilize the specified pixel with its neighbouring pixels in order to accelerate the entire process. Alternatively, merge masks are applied for shortening the colour masks list by joining of similar masks.

Experiments are carried out correspondingly between Easy Trace, AutoMNT system and the proposed colour quantization approach in this study. Since the dataset is comprised of a large range, the result is tabulated discretely in Table 5.2.

Table 5.2: Computation time for colour extraction between this study and other existing systems

System/ Test Sample	Computation time for colour extraction (In Second)		
	This study	AutoMNT	EasyTrace
1	0.37	0.058	51.005
2	0.672	0.027	35.08
3	0.558	0.056	28.558
4	0.352	0.143	43.007

5.4.1.2 Computation Time for Contour Lines Reconnection

This section shows the experimental results using cubic spline interpolation that proposed in this study to reconnect broken contour line. In fact, it is comprised of a set of geometrical rules and procedures by taking into consideration of angle, position, orientation and distance of each recognized endpoints. In order to evaluate the efficiency of proposed algorithm in this study, the overall processes for identifying these broken line segments and reconnection phrase are computed and tabulated. The computation time is then compared with other GIS and vectorization system and is summarized in Table 5.3. The results have revealed and demonstrated several basic concepts and issues for map interpretation and digitization. However, comparison with fully automatic vectorizing approach cannot be performed because the number of vectors and the accuracy of automated vectorizing method are varied.

Table 5.3: Computation time for contour lines reconnection between this study and other existing systems

System/ Test Sample	Computation time for contour lines reconnection (In second)				
	This study	AutoMNT	EasyTrace	WinTopo	Vextractor
1	0.432	0.290	11.050	11.035	12.410
2	5.426	0.720	13.008	13.028	21.088
3	8.773	0.456	14.040	12.011	16.541
4	9.005	0.134	17.033	15.046	23.680

AutoMNT is the most recent vectorization system among these applications designed for scientific research. Since it is still an undergoing research, it has known inaccuracies and not designed to be used in mission-critical GIS applications. However, it is capable to reconnect major part of broken contour lines by constructing Voronoi diagram and Constrained Delaunay Triangulation (Salvatore and Guitton, 2004). Several criteria including maximum distance, distance power and angle power, as well as lines or bi-cubic representation of lines are taken into consideration. From the result obtained, it shows its capability in reconnecting contour lines in a short computation time after particular criteria are acquired and input from user. Nevertheless, each broken line segments should be identified and indexed in a former stage. Relatively long computation time is needed for indexing before reconnection process can be established.

Easy Trace, Vextractor and WinTopo are software packages on Windows for semi-automatic and interactive vectorization of binary and colour raster files. For successful object recognition, it is necessary to specify prevalent object type, either linear or polygonal. Several parameters are specified for Easy Trace before tracing and gap removal process. For instance, the maximum and average width of lines to be traced and the parameter of ignore bridges, pins, and strokes. These parameters are measured in pixels of the raster map image. Subsequently, contour lines are traced based on parameter set and the guidance of user. The significant dissimilarity between Easy Trace, Vextractor and WinTopo is the two following systems need supervision of a user to determine node from two discontinuity lines to be joined.

The result from Table 5.3 is then illustrated in Figure 5.21. This corroborate that cubic spline interpolation is competent to reconnect major part of the broken contour lines in a satisfying computation time. The parameter of search window is defined by user and some iteration is needed for accomplishing this task.

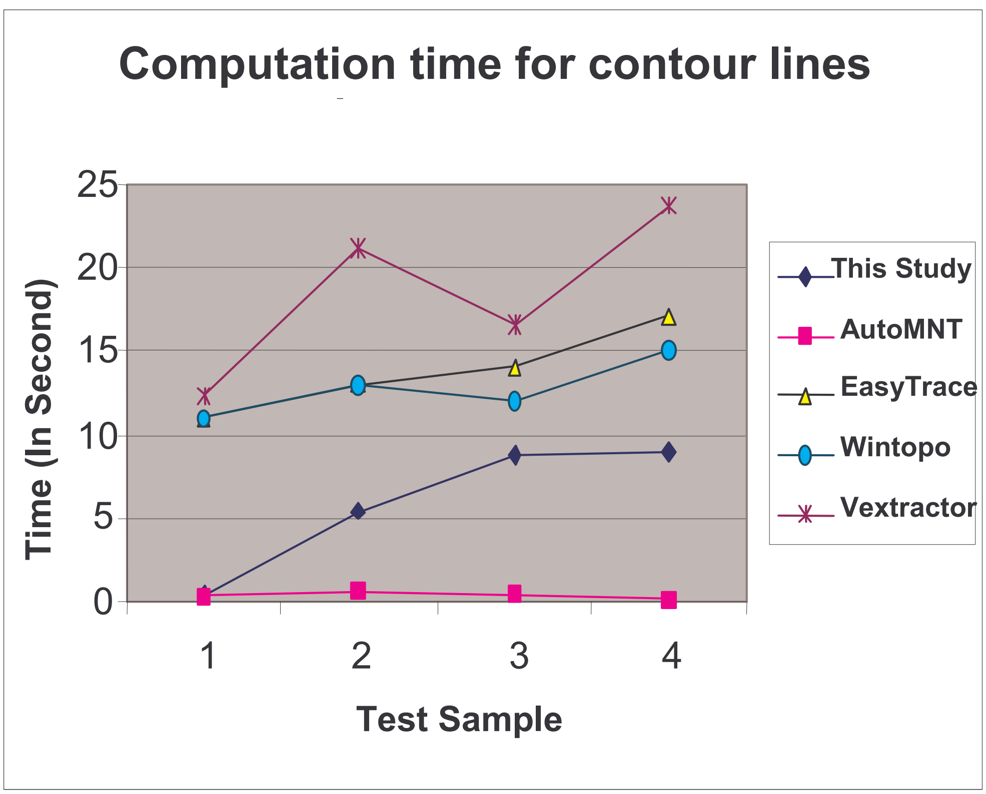


Figure 5.21 Comparison on computation time for contour lines reconnection

The accuracy of extracted contour lines is evaluated using standard deviation, or more generally expressed as Root Mean Square error (RMSE). RMSE values for each test sample that apply in several applications are tabulated in Table 5.4. The results for measurement the accuracy between extracted contour lines data and raster file data are illustrated in Figure 5.22. The least value of RMSE signifies the more accurate of digitized data.

Table 5.4: Comparison on accurateness in RMSE for digitize contour lines between this study and other existing systems

System/ Test Sample	Accurateness in Root Mean Square Error (RMSE)				
	This study	**AutoMNT**	**EasyTrace**	**WinTopo**	**Vextractor**
1	0.0151	0.0025	0.0029	0.0021	0.0028
2	0.0011	0.0030	0.0637	0.0024	0.0161
3	0.0020	0.0023	0.0027	0.0036	0.0022
4	0.0018	0.0029	0.0029	0.0260	0.0021

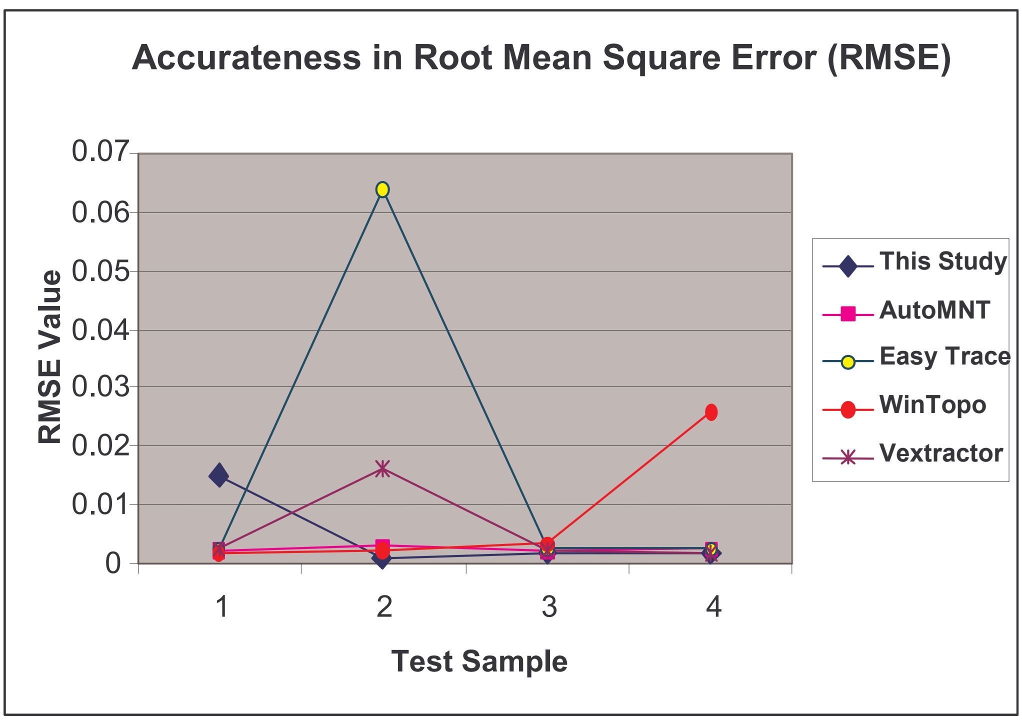


Figure 5.22 Comparison on accurateness in RMSE for digitize contour lines

As indicated in Figure 5.22, the approach applied in this study shows a favourable result. Since the results are capable to attain small RMSE value, this study is successful in preserving the topology of contour lines. Thus, it can generate reliable digital data source for GIS efficiently through a practical approach.

5.4.2 Non-Computational Comparison Between Existing Approach

Besides computational approach described in above section, several aspects are delivered for evaluation purpose in this study. These include: (i) reliably in extracting contour lines in this study, (ii) the influence of diverse criteria in seeking best connection path, (iii) comparison on several existing vectorization approach, where each of them are comprised of dissimilar procedure and (iv) visual inspection by human observer for the quality assessment.

5.4.2.1 Contour Lines Extraction

The size and colour of sample data reflects directly the result of quantized image and the accurateness of extracted contour lines derived from topographic map image. In this respect, experiment is carried out to evaluate the accurateness of contour lines extracted based on colour quantization in this study using different sizes of sample data. These samples of dataset are derived from two types of topographic maps: (1) USGS topographic map and (2) non-USGS topographic map. Different size and portion of map are used and the results are illustrated in Table 5.5. The table shows that USGS topographic map can work well under colour quantization approach in this study. On the other hand, non-USGS topographic map that usually represents in 24-bit RGB true colours have variety of colour distributions. Due to this reason, contour lines comprise of a range of brown value and become complicated to classify using conventional threshold approach. The results seem satisfying, where colour quantization is capable of reducing the colours on a map with a small measure of computation time. Yet, map separation process needs human supervision to verify those equivalent contour layers.

Table 5.5: Colour quantization result using different type and size of topographic map

Type / Size of map image		Colour Quantization				
		Processing time (In second	**Total of layers extracted**	**Number of match contour lines layers**	**Number of false match colour layers**	**Total colours in map before colour quantization**
1	475 x 413	1.059	8	1	1	8
	3269 x 2759	27.998	8	1	1	8
2	567 x 574	0.346	12	2	1	102,184
	1735 x 1744	3.014	16	2	1	327,059

5.4.2.2 The Impact of Different Criteria for Seeking Best Connection Path

Several criteria are established in this study for seeking the best connection path in order to reconstruct broken contour line segments. These criteria are tested respectively to authenticate their impact towards reconnection phase. Corresponding criteria involve in this study are distance (within a user defined search window), angle and orientation. Table 5.6 illustrates the results of experiment conducted on four portion of topographic map (refer Table 5.1 and their consequence results after thinning). From the results, it indicates how these different criteria have taken place in seeking the best connection path for constructing gaps. Among these criteria, distance for corresponding line segments is identified as the most significant aspect. It is then followed by angle and orientation. These two criteria are competent to assist in achieving the appropriate connection path, but it seems difficult to verify which is more important. Therefore, these three criteria are defined in this study for sustaining each another to determine the best connection path. Additionally, the sizes of search window that define in the system have a significant effect on seeking the best path connection. An appropriate parameter is set to limit the searching process, hence reduce the search space and considerably improve the result. Consequently, the seeking process to identify the best connection path can only be accomplished within the search window on their neighbouring endpoints.

Table 5.6: Best connection for broken contour lines using different criteria

Test data	Number of test	Criteria			
		Distance	Angle	Orientation	Percentage of best connection (%)
1	1	√			55.00
	2	√	√		60.00
	3	√		√	87.50
	4	√	√	√	95.50
2	1	√			60.64
	2	√	√		87.23
	3	√		√	85.11
	4	√	√	√	96.81
3	1	√			56.88
	2	√	√		69.97
	3	√		√	77.85
	4	√	√	√	94.53
4	1	√			63.84
	2	√	√		76.58
	3	√		√	82.23
	4	√	√	√	93.36

5.4.2.3 Comparison on the Entire Vectorizing System

For verifying robustness of the developed vectorizing system in this study (Contour Recognition System), AutoMNT systems are studied. A detail comparison is carried out regarding the approach applied in these systems. The advantages and disadvantages of these systems are mentioned in following Table 5.7. However, some of the experiments cannot not be performed due to the numbers of vector are variable for different approaches. Moreover, the thinned contour lines of the various methods differ considerably, and each method has a significant impact on the quality of the final vectorization. The results of comparisons can be observed in several computational approaches in Section 5.4.1 and the visual inspection in following Section 5.4.2.4.

Table 5.7: Comparison on several vectorizing systems

Process and Result	**AutoMNT system (Salvatore and Guitton, 2004)**	**Contour Recognition System**
Single colour extraction	Colour quantization is applied into HSV colour space. The colours are classified as following: (value< 0.25 as black; saturation<0.20 and value> 0.60 as white; the remaining pixels fall in the chromatic region of HSV cone, then the value of 10< hue< 30 as brown, which referred to contour lines.	Colour quantization is applied into RGB colour space to reduce colours present in the map. The maximum of quantized colours cannot exceed 16. Each quantized colour represents an isolated layer of the map. One or more layer that represents contour lines are attached to resultant a comprehensive contour layers. Several image enhancement approaches are used to eliminate noise and improve the topology of contour (as described in Chapter 3 and 5).

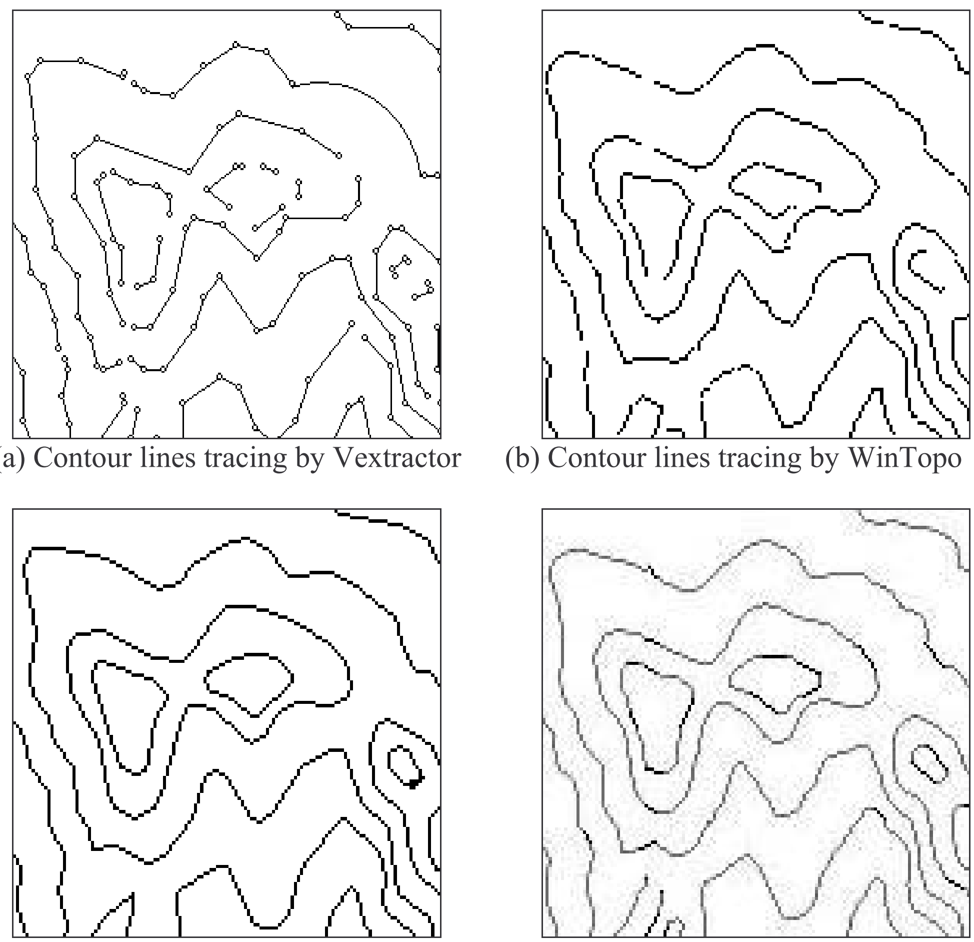
Result of single colour extraction	**Advantages:** • By pre-classify the colour or pixels in the map into black and white, it reduce computation time for brown pixels extraction that representing contour lines. **Disadvantages:** • Contour lines can only be extracted well for topographic maps that are produced by USGS or a map that is comprised of a standard set of colours. • It needs a lot of human supervision for the non-standard map, consequent of large computation time in the colour classification process.	**Advantages:** • Colour quantization reduces the computation time for contour lines extraction. • The map is isolated into different layers to ease the process in determining an initial contour layer. **Disadvantages:** • Since RGB colour space is not perceptually uniform, the accuracy of resultant contour lines may be affected. • The map separation process needs human supervision to identify those appropriate contour layers.
Thinning	They determine 4-connected pixels in generating the resultant thinned lines. Therefore, it is straightforward to extract a set of non-intersecting segments. These segments are smooth using a Laplacian Operator.	Thinning algorithm (Zhang and Suen, 1984) is used in this study (as described in Figure 4.5). This is because it is more commonly used than any other method in raster-to-vector conversion systems, and its strengths and weaknesses tend to characterize most thinning algorithms.

Result of thinning	**Advantages:** • Reduce the thickness of contour lines into one-pixel width. **Disadvantages:** • Need smoothing to avoid excessive branching in the further process.	**Advantages:** • Reduce the thickness of contour lines into one-pixel width. **Disadvantages:** • It does not always result unitary skeleton. A non-unitary skeleton is one in which some points that are not intersections have more than three neighbour pixels. This confuses further endpoint detection process.
Line tracing **Result of line tracing**	They used vertices of the Voronoi diagram to approximate the medial axis of a set of sample points from smooth contour lines. It is vectorized using Delaunay Triangulation, where Delaunay edges are filtered using local and global rules (i.e. complete contours and weight matrix). **Advantages:** • The crust of the contour lines can be extracted if the original curve is sufficiently well sampled. Therefore, it can work well if the	An algorithm (refer Figure 4.7) is used to determine endpoints. Several 5 x 5 mask formed by different directions are used to trace and bridge short gaps (refer Figure 3.6). Then, several criteria (distance, angle and orientation) are used to determine two most appropriate endpoints to be connected (refer Figure 4.8). **Advantages:** • Endpoints are detected easily. Those criteria for seeking best connection are useful for line vectorization.

	distribution of contour lines in the map is sparse. **Disadvantages:** • It is an intricate and complicated process to represent contour lines in Voronoi Diagram.	**Disadvantages:** • Not all endpoints are satisfied with the best connection defined using criteria mentioned above.
Lines vectorization	The line structure is changed from Delaunay Triangulation into an indirect graph. For each edge, a weight is associated depending on its length and direction related to the existing chain. The weight of possible connection-path between two endpoints is computed and they are connected with minimal weight.	User needs to define the size of search window in seeking the possible connection-path. Two methods: (i) cubic spline interpolation and (ii) Newton polynomial are used to bridge or reconnect broken contour lines (refer Figure 4.9). Four control points for cubic spline interpolation are chosen (refer Figure 4.9).
Result of lines vectorization	**Advantages:** • It is capable to reconstruct contour lines of the map if the contour lines are sparse and well plotted. **Disadvantages:** • It is insufficient to reconstruct the whole set of contour lines for a complex map.	**Advantages:** • The algorithm is capable to reconnect majority of the broken line segments and shows good results. **Disadvantages:** • There are some disconnected line segments due to several reasons (refer Section 5.5).

5.4.2.4 Visual Evaluation of Quality

Besides measuring extracted contour lines based upon computational approach as discussed in previous section, visual judgment also contribute in verifying the effectiveness of the developed approach in this study. This is due to human is still essential for evaluating the quality of contour lines data. Majority of existing systems use arc segment for reconnecting broken line segments with the guidance of an operator. It can perform well in certain circumstance, but it does result unsmooth contour lines. In view of this problem, this study has established an approach to remedy this problem by means of cubic spline interpolation with particular rules and conditions. Figure 5.23 shows the result of experiments conducted for a set of test sample between this study and other existing systems. The other results are illustrated in Appendix A from Figure A1 - A4.

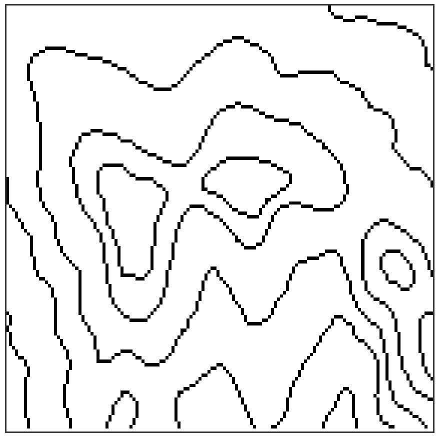


(a) Contour lines tracing by Vextractor

(b) Contour lines tracing by WinTopo

(c) Contour lines tracing by EasyTrace

(d) Contour lines tracing by AutoMNT



(e) Contour lines tracing in this study

Figure 5.23 Comparison on quality between this study and several systems

In term of visual measurement, several criteria are under human supervision. It is clearly that human observer has a great impact on the quality evaluation of digitize contour lines. Therefore, this again substantiates that map interpretation approach rely strongly on the reliable judgment of human observer, regardless how robustness the developed approach is. The results indicate the difference quality regarding this study and other systems. Among these systems, AutoMNT is identified as the best reconstruction of contour lines (Figure 5.23 (d)). It is followed by Easy Trace, WinTopo and Vextractor. Easy Trace can work well if the map is equipped in good condition (Figure 5.23 (c)). However, it generates sharp edges and tends to misinterpret the structure topology of contour lines. WinTopo seems to create unsmooth results, and this is probably cause by different thinning or line tracing approach during the vectorization process (Figure 5.23 (b)). On the other hand, Vextractor is capable in reconstructing all the broken contour lines, but it tends to create unnatural effects (Figure 5.23 (a)). This is due to arc segments and straight lines are used to reconnect the broken line segments manually.

Figure 5.23 (e) illustrates that the approach in this study can work well to preserve the original line segments in the map. Although there are several circumstances that cause gaps in contour lines, the correlation between geometric approach and image enhancement are very useful to increase the overall feasibility of contour lines recognition algorithm. Without the derivation of local geometric information, the reconnection of broken contour lines might not be successful. In contrast, if none of edge enhancement approach is being applied, the geometric information cannot be derived specifically. Experiments have revealed that the approach in this study is adequate to result in an acceptable quality in view of visual aspect.

5.5 Constraints and Drawbacks

Although contour lines recognition and extraction algorithm that applied in this study has performed well for several test samples of topographic map, it retains several constraints and drawbacks. Fully automated recognition process cannot be a promising solution for interpretation and analysis of topographic map. There are several problems that must be considered in real cartographic maps. Poor conditions and topological errors are the two great obstacles for raster to vector conversion process. A semi-automated or interactive approach by a human expertise could be an alternative and produces good result. If the input image is poor, it is difficult or impossible to find a proper classification method that can recognize particular feature successfully without guidance of human.

Several problems are identified in this study. Thick lines are the first problem discussed in this section. While thick lines exist in a raster map, they cause complexity in recovering the right topology. Therefore, many gaps are preferred to thick lines. Although thinning algorithm is applied to produce skeleton lines, the closely spaced features reason from thick contour lines is inclined towards misinterpretation, hence it results in incorrect topology or misleading of digitize data. Even though thinning algorithm is able to produce representation that is both closely related to the required output format and well suited to approximation and/ or structural/ syntactical line recognition (Ablameyko and Pridmore, 2000), it results in several deficiencies. For instance, it is very sensitive to small irregularities in contour lines and produces small branches. Besides, junctions that are not represented properly tend to generate extraneous noise. These noisy line segments cause of misleading relation. Then, the misleading relation contributes significant errors to the subsequent detection of endpoint from neighbourhood line segments.

Consequently, the error-prone endpoints lead to false connection pairs of line segments. This will be elaborated comprehensively in the third problem.

The second problem is associated with topological problem. It is an intricate process to recognize contour lines from a complicated texture map. The reason is not only contour lines are depicted in brown value in a map. There are several symbols or features represented in brown value in a topographic map, such as imagine relief lines, annotation and etc. Since constraint is placed, the problem might be disregarded in this study. Colour quantization is used to reduce colour comprise in a complicated map. All features are then separated into different layers. Subsequently, preliminary contour map is produced by composing one or more layers. Although this approach involves human interactive guidance, it is capable of establishing a satisfying result for further vectorization procedure. In addition, this approach is simple and uncomplicated compared to other advanced technologies, like neural network colour training set, colour clustering etc. These advanced approaches are usually computationally intensive and require some expensive hardware.

The third problem relevant to this study is reconstruction of broken contour lines; or generally expressed as bridging gaps exist in skeleton lines. Almost all recently developed techniques are insufficient to construct a fully automated contour lines extraction process. Yet, a combination of interactive and semi-automatic system is able to minimize errors, reduce the time required for map digitization and diminish an operator's task (Ablameyko and Pridmore, 2000). In this study, several criteria are taken into consideration to acquire spatial information and local topology from neighbourhood pixels. There are comprised of examining the nearest endpoints using different size of search window, the angle form by each detected endpoint and its vertical axis; and directional information originates from each endpoint.

The last problem is regarding the elevation indexes that typically exist on the contour lines to indicate height. Since fonts presented in topographic map may vary in different type, size and orientation, it is difficult to recognize these fonts. Adding an optical character recognition (OCR) pre-processing might probably solve this problem. However, character recognition is beyond the scope of research in this study.

Experiments which carried out on several map with different resolution, quality and acquisition conditions (refer Table 5.1) have revealed that local criteria are inadequate to identify significant structural relationships between line segments. The perceptual organization starts from basic primitives: edge or each single line segment; and then local geometric properties are used to construct reliable chains of edges to form close contours or connect broken line segments. However, the angle and orientation considered in this study are confined only to well-distributed line segment with none-intersection or overlap between features. The broken line segments cannot be fully reconnected due to several circumstances:

1) The relation exists between detected endpoints from two line segments are in fact out of the range of search window defined by user.

2) The local geometry information cannot be obtained if the length of line segment established from each identified endpoint is less than 10 pixels. Neither angle nor orientation information is derived from this case. If this occurs, control points that are required for constructing cubic spline interpolation cannot be established. In addition, if control points detected are less than three, then cubic spline cannot be applied to reconnect broken line. Consequently, Newton polynomial or vertical and horizontal search is adopted to accomplish the reconnection phrase.

3) The local relation derivation algorithm used in this study (angle and orientation) is based on two neighbouring lines, which is prepared for the reconstruction phase. However, the angle and orientation information is not always sufficient to produce the suitable results for all cases. The reconstruction algorithm cannot be applied if only one endpoint is detected, hence no associated endpoint or line segment to be considered for broken line reconnection;

4) Thinning algorithm does not preserve one-pixel width in some particular condition (junction, branch etc), hence line tracing algorithm cannot be employed successfully in this case. Since thinning algorithm is adopted for resulting skeleton lines, emphasis is not placed on advance thinning algorithm in this study;

5) The existence of noise (even though single isolated pixel) may influence the detection process for the nearest endpoint. Hence, it may cause misinterpretation in reconnecting broken line segments.

Apart of several constraints and drawbacks mentioned above, the algorithm applied in this study is capable in generating an acceptable result with low computation cost and time.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Summary

The demand of developing an efficient data acquisition and map interpretation approach is significant for GIS application and database. Automatic recognition of features and characters from scanned map to derive useful information is still an immature research area. Several problems need to be considered in a paper-based topographic map, especially the poor conditions of map representation, topological error and the error induced by scanner. Although many feature extraction approach (e.g. broken-line extraction algorithms) and frameworks have been developed in recent years, recognition of contour lines from scanned topographic maps still remain as one of the classic problems in line drawing interpretation. Many current approaches, either interactive or semi-automated perform deterministic editing before vectorization process. Therefore, human observer is indispensable to perform editing task for the map image manually, either before, within or after the image preprocessing techniques.

This study presents a combination of interactive and semi-automated approach in order to recognize contour lines from raster topographic maps. It is decomposed into a number of tasks and the flow of tasks is presented as following. It is initialized from the pre-processing steps of colour quantization for extracting contour layer, down to employment of local and global information from neighbourhood pixel using several criteria (distance, angle and directional information); and finally how to seek the best connection between these derive information within an user define search window. For the nearest endpoint detected, the least angle formed aligns Y-axis and the opposite direction estimated between two corresponding endpoints is defined as the possible connection. Control points are then assigned for these end points, as well as the 10-pixels, which back trace from each identified end point. Subsequently, cubic spline interpolation is applied to reconnect these control points, hence form a representative of arc segment to accomplish reconnection phrase.

As a conclusion, maps can be scanned and vectorized automatically, but object recognition and map interpretation should be carried out by a hybrid approach, which combines semi-automated and interactive techniques. This is due to the large number of errors after automatic recognition, leading to considerable error correction effort, and possibly compromising the benefits of automation. As a result, it is impossible to reach 100% automatic recognition. However, the system overcomes these problems by reducing human factor and computation time for data acquisition, as well as improving the operation efficiency. Since this study is designed for scientific research, it has known inaccuracies and deficiency as discussed in previous chapter. However, the major merits of this proposed algorithm rely upon its efficiency and simplicity. The defects are identified and are attempted to be solved in future work. Finally, this research is intended to develop an efficient and precise map interpretation approach to recognize contour lines from raster topographic map.

6.2 Future Work

Several issues concerning derivation of contour lines information from a raster topographic map image and the broken lines reconnection strategy proposed in this study deserve further investigations, developments and experiments. In this section, several important directions for further research are being explored to incorporate more knowledge into map interpretation.

(1) The first one is to employ the knowledge based human operator. By using the computer's speed for low level image processing and recognition of simple patterns, thus leaving the complicated interpretation tasks to the operator, interactive algorithms are very attractive means to accelerate the mapping process. One possibility that can be extended would be a more interactive system that allowed the user to facilitate the vectorizer and provided extra knowledge where required. In fact, user could interactively correct the first mistake. Then, the system could be prevented from making several subsequent mistakes.

(2) The local properties and relationships derive from neighbourhood pixels, for instance distance, angle and directional information which considered in the study is only confined to well-conditioned map. The next challenge regards to the extended incorporation of other possible interrelationships between broken line segment features like disjoint, contains, intersects, overlap etc. To improve the robustness of the method described in this study, more varieties of relationship are needed to describe the contour lines information of a map image. More definitions of different relations types that are possible to occur need to be covered up in future study. It should be able to deal with more variety of topographic maps, which compose of different size, scale, and resolution.

(3) In this study, the employment of cubic spline interpolation is introduced to reconnect the broken line segments. Several criteria as discussed above are used to determine the best correlation for bridging gaps. Two endpoints, as well as another two pixels are identified as control points for reconnection phase. In this view, control points are determined by back tracing each identified endpoint, which lack of any spatial information. Further extension to incorporate other line segments properties are needed to increase the robustness of reconnection. These include connected component labelling, direction changing of each connected pixels, the examination of other curve fitting approach and etc.

(4) Further investigations are needed on the removal of other extraneous features, like road, trails, and etc. This is because these undesired features are always presented in the same colour value as contour lines. It is an unavoidable circumstance which occurs in a complicated topographic map. Therefore, a knowledge-based system with artificial intelligence is looking forward to being incorporated for determining the desired linear features accurately and minimizing errors in recognition. On the other hand, the method in this study is worthwhile to expand for recognizing other variety of linear features in topographic map (besides contour lines). It could be roads, relief lines, rivers and etc.

(5) Geo-reference capabilities can be integrated into future framework in order to save out contour points in a latitude/longitude coordinate system (or UTM coordinate system) rather than in a pixel coordinate system.

(6) Another possible area that should be incorporated into vectorizer is Optical Character Recognition (OCR). It is an advantageous if OCR facilities could be incorporated in recognizing different types of fonts and texts on a topographic map.

(7) A last important area of further research consists of pre-processing and enhancement phase. It is better if more contour lines information can be extracted and preserved at the initial phase to avoid misinterpretation of data.

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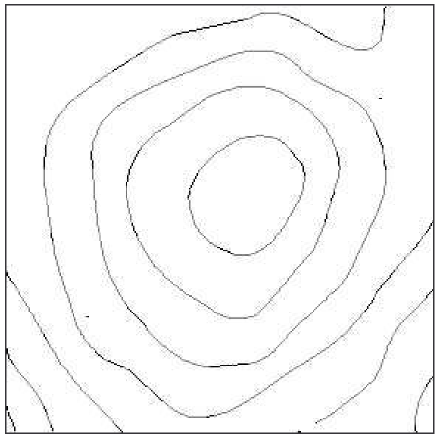
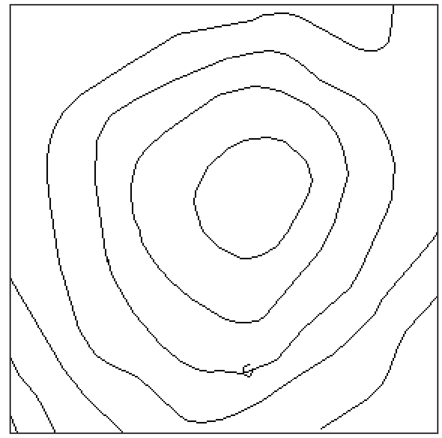
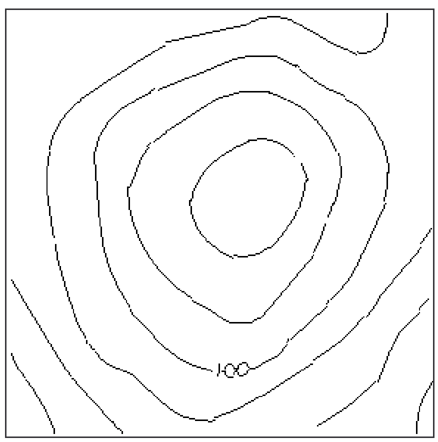
APPENDIX A



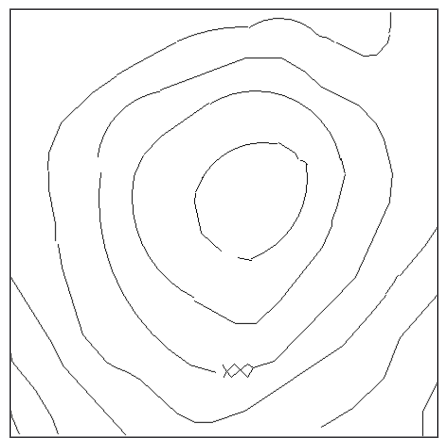
(a) AutoMNT



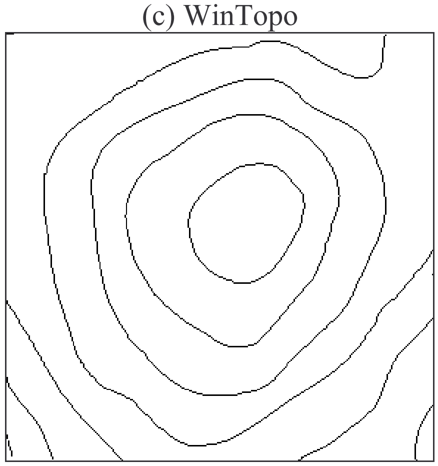
(b) Easy Trace



(c) WinTopo

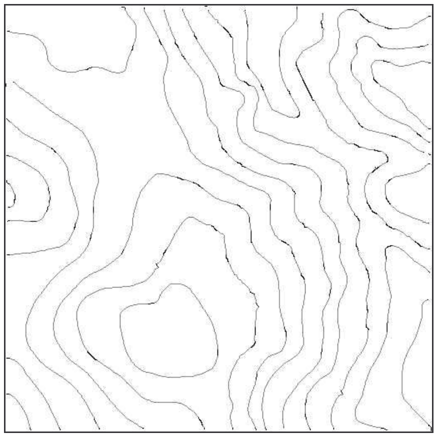


(d) Vextractor

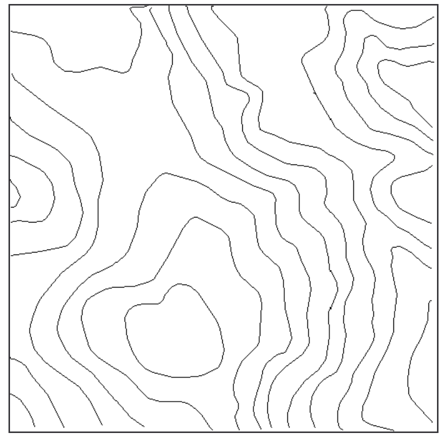


(e) Mine result

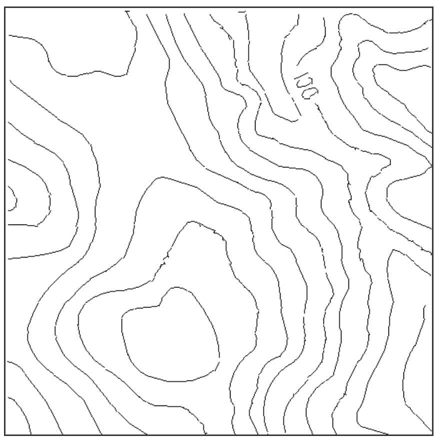
Appendix A1 Comparison on visual evaluation for test sample 1



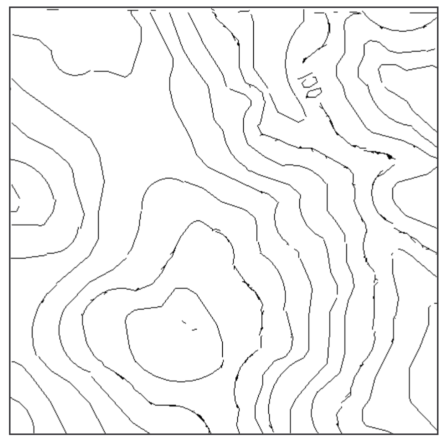
(a) AutoMNT



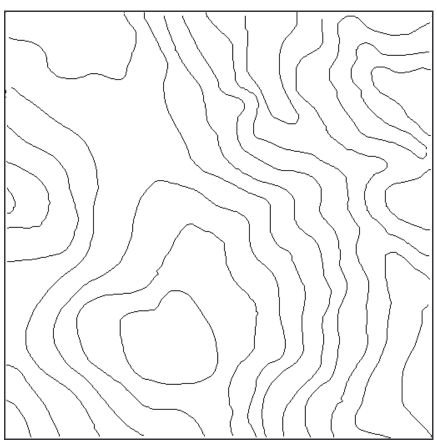
(b) Easy Trace



(c) WinTopo

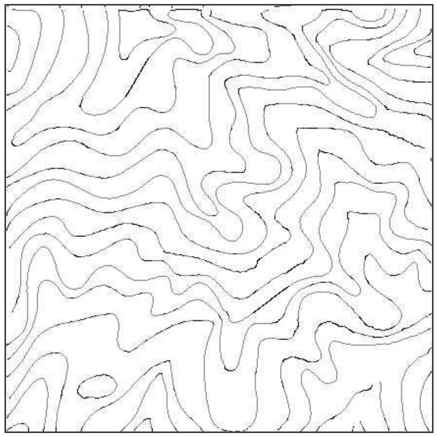


(d) Vextractor

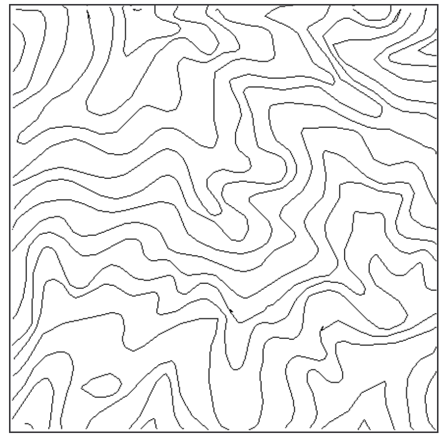


(e) Mine result

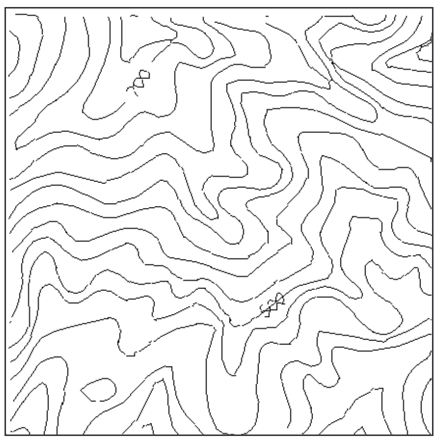
Appendix A2 Comparison on visual evaluation for test sample 2



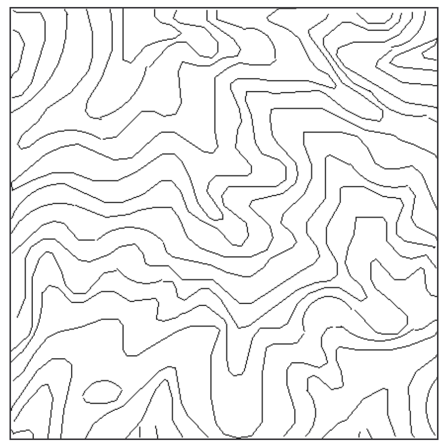
(a) AutoMNT



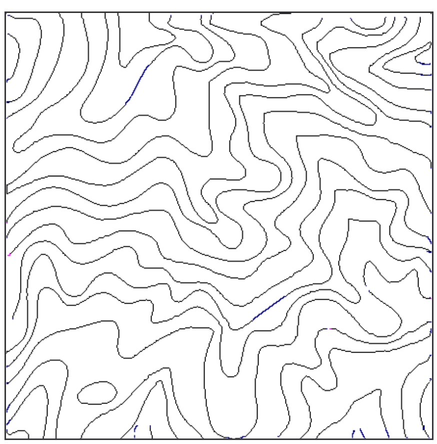
(b) Easy Trace



(c) WinTopo

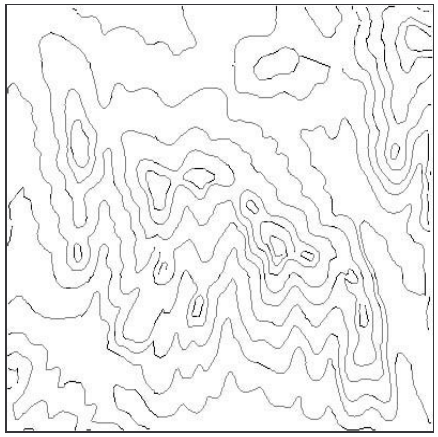


(d) Vextractor

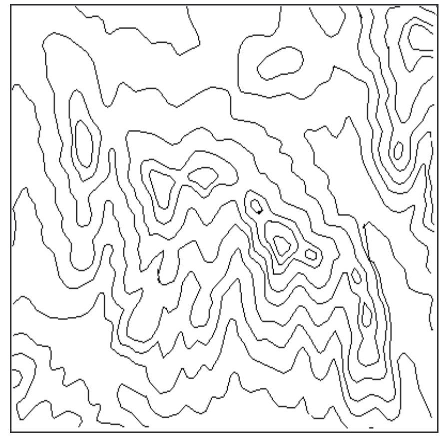


(e) Mine result

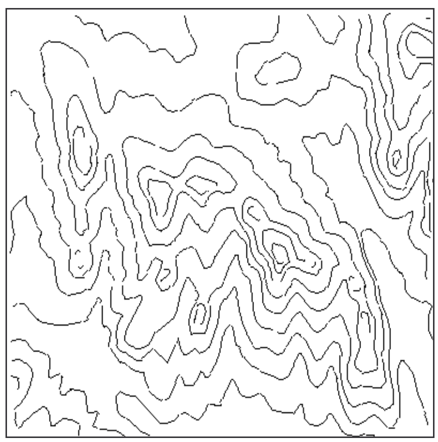
Appendix A3 Comparison on visual evaluation for test sample 3



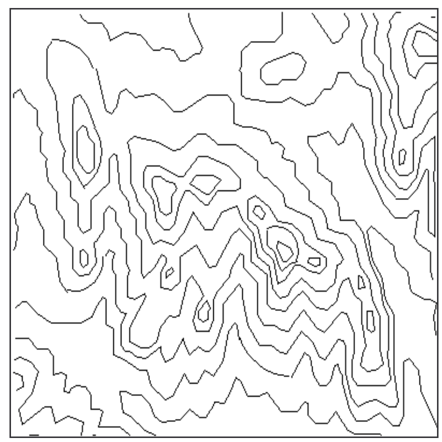
(a) AutoMNT



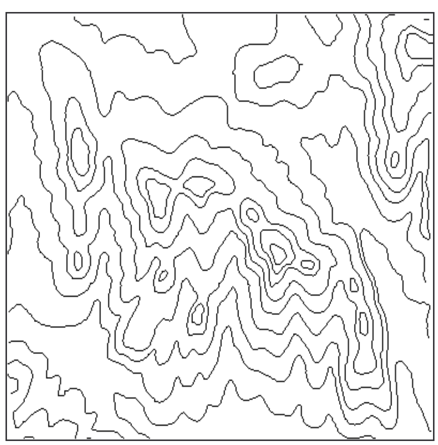
(b) Easy Trace



(c) WinTopo



(d) Vextractor



(e) Mine result

Appendix A4 Comparison on visual evaluation for test sample 4

APPENDIX B

Appendix B1: Hardware requirements

Hardware	Specification
Processor	Intel Pentium 4 CPU2.4 GHz
Memory	2 x 512 MB DDR Ram 400Mhz
Graphic Card	NVIDIA GeForce FX 5700
Storage	120 Gb

Appendix B2: Software requirements

Software	Specification
Operating System	Win98/ Win2000/ WinXp
Developments Tool	Visual Studio 6
Programming Language	C++
Graphic Library	Victor Image Processing Library
External GIS for vectorization	WinTopo, R2V, Easy Trace 8.0, Vextractor, AutoMNT and ESRI

Lampiran 20
UTM/RMC/F/0024 (1998)

UNIVERSITI TEKNOLOGI MALAYSIA

BORANG PENGESAHAN
LAPORAN AKHIR PENYELIDIKAN

TAJUK PROJEK : A NOVEL TECHNIQUE FOR CONTOUR RECONSTRUCTION TO DEM

Saya NIK ISROZAIDI NIK ISMAIL
(HURUF BESAR)

Mengaku membenarkan Laporan Akhir Penyelidikan ini disimpan di Perpustakaan Universiti Teknologi Malaysia dengan syarat-syarat kegunaan seperti berikut :

1. Laporan Akhir Penyelidikan ini adalah hakmilik Universiti Teknologi Malaysia
2. Perpustakaan Universiti Teknologi Malaysia dibenarkan membuat salinan untuk tujuan rujukan sahaja.
3. Perpustakaan dibenarkan membuat penjualan salinan Laporan Akhir Penyelidikan ini bagi kategori TIDAK TERHAD
4. * Sila tandakan (/)

☐	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau Kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
☐	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh Organisasi/badan di mana penyelidikan dijalankan)
✓	TIDAK TERHAD	

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TANDATANGAN KETUA PENYELIDIK

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Nama & Cop Ketua Penyelidik

Tarikh : 25 DISEMBER 2006

UNIVERSITI TEKNOLOGI MALAYSIA
Research Management Centre

PRELIMINARY IP SCREENING & TECHNOLOGY ASSESSMENT FORM
(To be completed by Project Leader submission of Final Report to RMC or whenever IP protection arrangement is required)

1. **PROJECT TITLE IDENTIFICATION** :

A Novel Technique for Contour Reconstruction to DEM Vot No: 75163

2. **PROJECT LEADER** :

Name : Nik Isrozaidi Nik Ismail

Address: Faculty of Computer Science and Information System

Universiti Teknologi Malaysia, 81310 Skudai, JOHOR

Tel : 07 – 5532328 **Fax :** 07 – 5565044 **e-mail :** isrozaidi@ utm.my

3. **DIRECT OUTPUT OF PROJECT** *(Please tick where applicable)*

Secientific Research	Applied Research	Product/Process Development
[`] Algorithm	[`] Method/Technique	[ ] Product / Component
[ ] Structure	[ ] Demonstration / Prototype	[ ] Process
[ ] Data		[ ] Software
[ ] Other, please specify	[ ] Other, please specify	[ ] Other, please specify
______________	______________	______________
______________	______________	______________
______________	______________	______________

4. **INTELLECTUAL PROPERTY** *(Please tick where applicable)*

- [`] Not patentable
- [ ] Patent search required
- [ ] Patent search completed and clean
- [ ] Invention remains confidential
- [ ] No publications pending
- [ ] No prior claims to the technology
- [ ] Technology protected by patents
- [ ] Patent pending
- [ ] Monograph available
- [ ] Inventor technology champion
- [ ] Inventor team player
- [ ] Industrial partner identified

5. LIST OF EQUIPMENT BOUGHT USING THIS VOT

1. Computers
2. Printer
3. Digital data capture

6. STATEMENT OF ACCOUNT

a)	APPROVED FUNDING	RM : 31,000.00
b)	TOTAL SPENDING	RM :
c)	BALANCE	RM :

7. TECHNICAL DESCRIPTION AND PERSPECTIVE

Please tick an executive summary of the new technology product, process, etc., describing how it works. Include brief analysis that compares it with competitive technology and signals the one that it may replace. Identify potential technology user group and the strategic means for exploitation.

a) Technology Description

The development of computers and related technologies has accelerated the demand for mapping information to be stored, manipulated, accessed and retrieved in computer-compatible form. The accuracy of digitized data from topographic maps is remains an indispensable tool for government, science, industry, military, urban planning and etc. Yet, map digitization emerges as a process to ensure all features on topographic map being well separated, located, classified, and traced, consequently stored in vector format. Majority of recent digitization approach, either associates with human interaction or semi-automated process are insufficient in various aspects. There are usually time-consuming, inefficient, and shown inaccuracies in digitized data. This research is intended to find a better solution in performing a fully automated extraction of contour lines from topographic map. Several vectorization and image acquisition techniques are performed at early stage to analyze the map. The overlaid information and texture background are segmented by sequential coordinated steps. Then, color is the main characteristic to distinguish the dissimilarity features in the map. It is followed by several post-processing procedures to authenticate the digitized data. Finally, the precision of underlying data extracted from the map and computation time should be preserved.

b) Market Potential

This research can be considered as an applied research, which can benefit the following agencies

- Geo-Information System - A simple approach to digitize and recognize particular features from topographic map, which can be integrated in future GIS application.
- Tourism Agencies -Virtual tourism and travel planning
- Research bodies - To help visualization process

c) Commercialisation Strategies

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8. RESEARCH PERFORMANCE EVALUATION

a) FACULTY RESEARCH COORDINATOR

Research Status	( )	( )	( )	( )	( )	( )
Spending	( )	( )	( )	( )	( )	( )
Overall Status	( )	( )	( )	( )	( )	( )
	Excellent	Very Good	Good	Satisfactory	Fair	Weak

Comment/Recommendations :

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b) RMC EVALUATION

Research Status	( )	( )	( )	( )	( )	( )
Spending	( )	( )	( )	( )	( )	( )
Overall Status	( )	( )	( )	( )	( )	( )
	Excellent	Very Good	Good	Satisfactory	Fair	Weak

Comments :-

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Recommendations :

☐ Needs further research

☐ Patent application recommended

☐ Market without patent

☐ No tangible product. Report to be filed as reference

……………………………………………….. Name : …………………………………………

Signature and Stamp of Dean / Deputy Dean Date : ………………………………………….
Research Management Centre