ENHANCED ALGORITHMS FOR THREE-DIMENSIONAL OBJECT INTERPRETER

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for my late mother Hajjah Hambrah,
my mother-in-law Bonda Rokiah,
my father Hj Haron,
my wife Maria,

whose love and support
make life in this world
easier to manage

and

for my children
Amirul Akmal, Ahmad Firdaus, Mustaidah, Muhammad Syafiq, Mawaddah

thank you for the mess you created

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ABSTRACT

In designing an engineering product during the conceptual stage, freehand sketch plays an important role in conveying engineers' ideas. Solutions on the problems of representing, interpreting and reconstructing the sketch have been of research interest for several decades. The aim of this study is to propose enhanced algorithms to be used to interpret and reconstruct a sketch, and then to produce a three-dimensional model. The methodology used in this study is based on the framework of a sketch interpreter that contains three phases. In the first phase, two algorithms were proposed. The first is enhanced thinning algorithm that is used to thin the sketch while maintaining its topology and basic shape. The second is the modified Freeman chain code algorithm that is used to produce chain code series that represented a thinned binary image of the sketch. In the second phase, a new computational corner detection algorithm is proposed to analyse the chain code series to produce two-dimensional geometry entities of the sketch in which the irregular line drawing is transformed into regular line drawing. In the third phase, a new method to solve a linear system is proposed in which the regular line drawing is converted into three dimensional model by guessing the depth of each junction. The linear system consists of three image regularities, namely, spatial structure, gradient space, and skewed symmetry. The linear system is solved using bisection method of total least square approximation. Besides reducing the number of image regularities used and new method to solve the linear system, this study has proposed better solutions in terms of an enhanced thinning algorithm, a modified Freeman chain code algorithm as picture description language, and a new computational corner detection algorithm.

ABSTRAK

Semasa peringkat konsepsualisasi dalam merekabentuk satu produk kejuruteraan, lukisan lakaran tangan memainkan peranan penting dalam menzahirkan idea jurutera. Penyelesaian kepada masalah mewakil, menterjemah dan membina semula lakaran telah menjadi bidang penyelidikan sekian lama. Matlamat kajian ini ialah mencadangkan pembaikan terhadap algoritma-algoritma yang digunakan untuk menterjemah dan membina semula lakaran, dan seterusnya untuk menghasilkan model tiga dimensi. Metodologi yang digunakan dalam kajian ialah berdasarkan rangka kerja penterjemah lakaran yang melibatkan tiga fasa. Dalam fasa pertama, dua algoritma dicadangkan. Pertama ialah ialah pembaikan algoritma penipisan yang digunakan untuk menipiskan lakaran dengan mengekalkan falsafah memelihara topologi dan bentuk asasnya. Kedua ialah pengubahsuaian algoritma kod rantai Freeman yang digunakan untuk menghasilkan siri kod rantai bagi mewakili imej binari ternipis lakaran. Dalam fasa kedua, algoritma pengesanan selekoh pengiraan baru dicadangkan bagi menganalisa siri kod rantai untuk menghasilkan entiti geometri dua dimensi di mana lukisan garisan tak sekata ditukar kepada lukisan garisan sekata. Dalam fasa ketiga, kaedah baru untuk menyelesaikan satu sistem linear dicadangkan di mana lukisan garisan sekata ini ditukarkan kepada model tiga dimensi dengan meneka kedalaman setiap bucu. Sistem linear ini mengandungi tiga kenalaran imej iaitu struktur ruang, ruang gradien, dan simetri pencong. Sistem linear ini diselesaikan menggunakan kaedah pembahagian dua sama penghampiran jumlah kuasa dua terkecil. Di samping mengurangkan bilangan kenalaran imej yang digunakan dan kaedah baru untuk menyelesaikan sistem linear, kajian ini telah mencadangkan penyelesaian yang lebih baik dari segi pembaikan algoritma penipisan, pembaikan kod rantai Freeman sebagai bahasa penghuraian gambar, dan algoritma pengesanan selekoh pengiraan baru.

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LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
ADG	Angular Distribution Graph
APT	Automatically Programmed Tool
B-Rep	Boundary Representation
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CGT	Contour Generation Thinning
CSG	Constructive Solid Geometry
DCS	Design Capture System
DWG	AutoCAD Drawing File Format
DXF	Data Interchange Format
FCC	Freeman Chain Code
GVA	General View Assumption
LS	Linear System
LSA	Least Square Approximation
MGCC	Multi-Grid Chain Code
MSDA	Minimum Standard Deviation Angle
PCC	Primitive Chain Code
PDL	Picture Description Language
RAF	Right Angle Fit

TIFF	Tag Image File Format
TLS	Total Least Square
TOE	Table of Edge
TOF	Table of Face
TOV	Table of Vertex
VCC	Vertex Chain Code

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CHAPTER I

INTRODUCTION

1.1 Definition of Sketch Interpreter

Sketch interpreter is a system that allows engineers to design naturally using input devices and automatically interprets the sketch to a three-dimensional object. It consists of two parts namely the interface and the engine. In general, the interface must imitate a natural style of sketching by providing all attributes such as quick response and act as pencil and paper as used by engineers in sketching engineering product. The sketching concept used in Palm Desktop or commercial software such as PaintBrush or Adobe Photoshop software is an example of the interface. On the other hand, the engine of a sketch interpreter must be able to produce accurate two-dimensional regular line drawing or three-dimensional object by classifying type of drawing intended and validating the drawing.

1.2 Motivation

In engineering product life cycle, the cycle starts with conceptual design and ends with product marketing. Pencils and papers are common tools used to sketch by engineers. The rapid development of hardware and software enable these tools to be replaced by digitiser and light pen. The evolution of Computer Aided Design (CAD) initiated by Sutherland (1963) in 1960's had given tremendous effect on the development of Computer Aided Design software. Since then, developments of CAD softwares that cater needs in designing, updating, storing and visualising engineering drawing have rapidly improved. Unfortunately, the failure of conventional interface in CAD software that used mouse, pop-up menu, and icons at conceptualisation stage is a lack of the development of CAD software in manufacturing industries because engineers do not want to lose the naturalness of paper and pencil when conveying their ideas. This fact is supported by research done by a few number of researcher as explained in this section.

Foley (1976) examined man-machine communication from a language viewpoint. He claimed that the best interaction techniques are the most natural to the users. Therefore, better interaction tool is needed because the existing mechanism does not permit actions that are sufficiently natural.

Hwang and Ullman (1990) suggested that icons and menus are barriers between the designer and the design. They are the artificial devices added to enable the designer to instruct the interface of his attentions, rather than aiding the designer to visualise his design. He also pointed out that current interfaces are aimed at accurate graphical presentation, rather than rough sketches required when a designer is working quickly at a conceptual stage.

Goldschmidt (1992) examines architects at work during their design process, and concludes that sketch is not merely an output mechanism to record an idea, but actually a form of dialogue between the designer and the drawing, a form of external representation to aid the brain in visualising a design. He also stressed that the input method must be fast and natural to the user, to prevent the design dialogue from breaking.

Wang (1992) in his survey stated that there are two important research areas in the field of computer vision and artificial intelligence. They are the reconstruction of a three-dimensional object from its two-dimensional projections and its corresponding problem of 3D object recognition. He emphasised the importance of the degree of user interaction that is necessary for correct reconstruction and internal representation used in the reconstruction process.

Jenkins and Martin (1993) emphasised the importance of sketch in conceptual design. In a conceptual design process, a designer cannot tolerate losing ideas because of constraints created by devices such as mouse, icons, and menus. Therefore, pen and pencil are still preferred by designers.

Pham (1994) stated that CAD still falls short of designer's expectation; they still remain to be seen more as a drafting tool than a design tool. Designers cannot use or at best feel very uncomfortable to use these systems during the early stages of design.

Grimstead and Martin (1995) stated that CAD systems are biased towards computer rather than design; this introduces barriers between the designer and the modelling system. The use of natural pencil and paper style interface moves the CAD system near to the designer.

Matsuda et. al. (1997) emphasised the importance of the sketch in conceptual design. He introduced a new method to deal with sketches for inputting geometric model at a workstation using stylus pencil and a tablet.

Liu and Lee (2001) claimed to that current CAD tools cannot directly convert a line drawing into a 3D object, denying mean of input. Therefore, it is highly desirable to develop algorithms that can convert a design sketch into a 3D model.

Ullman (2002) stated that freehand sketches still constitute a fundamental tool for the engineer to express his or her creativity, because CAD systems are still not entirely suitable for conceptual design.

Therefore, the aim of this research is to propose methods that can be used in the development of sketch interpreter as commercial softwares, so that it can cater to the needs of natural style of sketch in conceptual stage that is important but yet still not available in market. To support the development, research on the techniques to develop a user-friendly sketch interpreter interface and more accurate and faster engine to reconstruct the drawing should be given attention. With the help of existing input tools, such as stylus pencil, tablet and digitiser, the objective to provide tools for engineers in sketching process is possible.

1.3 Objectives

There are three stages in the development of a sketch interpreter. The stages are pre-processing stage, two-dimensional feature extraction, and object reconstruction. The objectives of this research can be classified according to the stages involved. The three objectives are listed below:

i. To develop a new framework in representing, interpreting, and reconstructing a two-dimensional freehand engineering sketch of three-dimensional object that meets the general architecture of sketch interpreter.
ii. To maintain the continuity in representing, interpreting, and reconstructing sketches.
iii. To develop enhanced algorithms in sketch interpretation that consists of thinning algorithm in the pre-processing stage, chain code algorithm in representing the drawing, new corner detection method in 2D feature

extraction, and bisection method of total least square approximation in the object reconstruction.

1.4 Scope

There are many types of line drawing such as line drawing of impossible object, wireframe object, origami world, and engineering sketch. The research only accepts valid line drawing of engineering sketch that represents a three-dimensional object.

In the first stage, this research covers the improvement of existing thinning algorithm and proposes a closed loop chain code algorithm as a picture description language to represent the irregular line drawing. The development of interface for a sketch interpreter is beyond the scope of this research.

In the second stage, this research focuses on the use of chain code in feature extraction. The focused areas are on the corner and region detection of chain code representation besides the derivation of T-junction and lines. In this stage, a regular line drawing which is represented by boundary representation (B-Rep) scheme is produced.

In the third stage, this research investigates the mathematical model to recover hidden parts so that three-dimensional objects can be produced and visualised. Creating a linear system of three drawing image regularities namely spatial structure, gradient space, and skewed symmetry to produce the 3D object is the scope of the thesis. The linear system (LS) has been solved using bisection method of total least square (TLS) approximation. This research only recovers the hidden depth values of a visible junction. The recovery of invisible junction is beyond the scope of this research. This research produces and visualises a semi-completed 3D object.

1.5 Assumptions

This research has made a few assumptions to simplify the interpretation and reconstruction process. The line drawing of the system is assumed as a freehand sketch line drawing in the form of scanned image, drawn using any sketch software such as Adobe or any CAD software, and in format of Tag Image File Format (TIFF) graphic image.

In the sketch, when a scene is projected onto the view plane, only the edges are drawn and exactly two faces share every edge. For every face, one side of face is occupied with material and the other side is empty. Therefore, texture and scribbles on a surface are not drawn. The sketch is assumed to represent a valid three-dimensional object where all unwanted pixels have been removed and there is no unconnected pixel. The sketch is assumed as a sketch with all informative lines shown. The general viewpoint assumption (GVA) is applied in this research where the observer is not coplanar with any pair of non-collinear edges and the observer is not coplanar with any face. This eliminates degenerate case for example, a plane that is projected by a line.

These assumptions make the reconstruction more logical or otherwise line drawing of a cube projected on a view plane is seen as a square because the projection is parallel to three faces of the cube. In this case, it is impossible to interpret and reconstruct the line drawing as three-dimensional object.

1.6 Thesis Outline

The thesis is divided into six chapters. The first chapter gives an overview of the sketch interpreter, motivation, objective, scope of this research, assumptions made and thesis outline. This chapter ends with a brief explanation of contributions made in this research.

The second chapter discusses literature review on six areas namely the sources of line drawing, background of solid modelling, development of sketch interpreter, thinning algorithm, picture description language, and recovery of hidden parts. The inter-relationship between these areas and their importance in the research are explained in the summary of the chapter.

The third chapter explains the methodology used in this research. The discussion starts with the explanation on general framework of sketch interpreter development cycle and the proposed framework. This is followed by description of six steps involved in the methodology. The steps are problem identification and classification, nature of data, pre-processing, development of algorithms, model formulation, and testing and validation process. The six steps involved in the methodology are based on the general framework explained in the introduction of the chapter.

The fourth chapter explains contributions of the thesis that can be divided into five areas. First, this chapter gives details of the new framework for sketch interpreter development lifecycle in the form of the enhanced algorithms. Next, two pre-processing stages required by the new framework i.e. (the definition of data structure and the digitisation process) are discussed before the explanation of the other four contributions is preceded. The other four contributions discussed are the enhanced thinning algorithm, a closed loop chain code algorithm in deriving T-junction, corner and line, a closed loop chain code algorithm in deriving region, and model formulation in guessing depth values of visible vertices. Summary is given at the end of the chapter.

The fifth chapter discusses on the result of the enhanced algorithms. The discussion is divided based on steps involved in the interpretation and is supported by a sketch of a cube. Research contribution and discussion are given at the end of the chapter. Chapter 6 suggests future works of the research and gives conclusion of the whole thesis.

1.7 Contributions of the Research

There are five contributions of the research. The contributions are the enhanced thinning algorithm, closed loop chain code algorithm for T-junction, corner and line detection, closed loop chain code algorithm for region detection, mathematical model to guess depth values of vertices, and the new framework of sketch interpreter in the form of new algorithm for 3D object interpreter.

The proposed algorithm covers all stages in the development of a sketch interpreter. The enhanced thinning algorithm utilises image-processing concept in skeleton a sketch. The closed loop chain code algorithm acts as a language to represent the sketch. The closed loop chain code for corner and region detection algorithm detects the existing of corners and regions that are represented by the chain code series. The mathematical model guesses depth of each vertex of the sketch by utilising the number of image regularity and total least square approximation.

The algorithms and mathematical model presented and designed in this thesis can be used as independent tools in different areas have been designed to act as integrated tools in the proposed framework. The thinning algorithm that has been used as a tool in image processing is enhanced to produce thinned binary image. The thinned binary image then acts as an input of the chain code algorithm. Chain code representation that has been used as picture description language of line drawing is enhanced and applied in the corner detection algorithm, and T-junction, line and region detection. The image regularities that are used in constraining a line drawing are integrated into the linear system to form a mathematical model. The mathematical model is then solved using bisection method of total least square approximation. The integration of these tools produces a new framework of sketch interpreter.

The enhanced thinning algorithm has been used to remove unwanted pixel and to simplify the image so that the new image will suit the philosophy of chain code algorithm. The proposed thinning algorithm is an enhancement of the work by Pitas (1995).

The closed loop chain code algorithm is an improvement of work on Picture Description Language (PDL) by Freeman (1969) with specialization in representing a line drawing. A new scheme in traversing the pixel is proposed by introducing two parameters namely setting the first location of the code to be traversed, and the direction of the traversal.

The extraction of T-junction is based on the intersection of lines by utilising the series of chain code and their Cartesian coordinates. In the corner detection algorithm, computational method has been applied by introducing a new algorithm to detect corners between consecutive T-junctions. Region detection algorithm shows that the combination of Table of Vertex (TOV) and region chain code series can be used to produce the new algorithm.

In guessing the depth of junction, a mathematical model that use bisection method of total least square technique is applied by creating a linear system consisted of three image regularities namely spatial structure, gradient space and skewed symmetry. The selection of method to solve the linear system is an improvement of work by Grimstead (1997). In forming a linear system, the derivation of image regularity equations is based on work by Kanade (1981) and Friedberg (1986).

Applying these algorithms and models in the proposed algorithm produces an intermediate and final data structure to represent a solid model. The data structure is then saved as boundary representation that is now ready to be viewed using any CAD software. The solid model then can be saved as neutral CAD file format.

The proposed algorithm is able to produce a boundary representation of single planar, trihedral model drawn as single isometric, hidden-line removed sketch line drawing. The algorithm is an improvement on general framework of sketch interpreter proposed by Hwang and Ullman (1990). The objective of the algorithm is still similar namely to produce a valid 3D solid model.