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3D Reconstruction From Paper-Based Sketches Using An Optimization Based Method

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Abstract—this research aims to reconstruct a 3D model from conceptual sketches. The motivation behind this research is because the paper sketches still remain relevant to designer despite the abundance of sketch digital tools application. Secondly, the tedious task to convert this sketch into 3D model that created manually leads to inefficiency to the whole design process. Developing an algorithm of 3D reconstruction from paper sketches input is very difficult. This is due to the personal ways of drawing as different designer may produce different sketches. Even though, the available digital sketching tools is claimed to make the reconstruction process easy and fast, somehow these tools are still far from natural real drawing and require designer to design in details to make it function therefore reduce the immersion and ease of use. To achieve this, the system will accept a raw sketch which needs to be tidied up due to the imperfection of line or strokes. This will result a uniform line drawing and consequently need to be interpreted accordingly to extract two-dimensional geometrical entities and continue with deriving the depth value of each corner. The solutions will be a visualization of 3D model complete with face and size of object. This automatic reconstruction is foreseen can shorten the current practices and better support the conceptual design phase. For this paper, some preliminary experiments using image processing techniques are included. The output and information obtained will be later used for the next stage.

Index Terms—paper-based sketches, conceptual design, 2D line drawing, image regularities, 3D reconstruction

1 INTRODUCTION

Sketches are important activity in developing new ideas at conceptual design phase. The human ability to infer 2D drawing by abstraction of 3D model can be transmitted easily with only a few strokes. The expression of idea can be conveyed using pencil and paper or digital tools; also it is referred as offline sketch and online sketch respectively [1]. Generally, paper sketch seems more efficient and practical because it allows rapid presentation of idea, with only a few strokes, any design can be evoked. The nature of designer's practice which illustrates conceptual sketches are usually and necessarily ambiguous and the content mostly consists of uncertainty lines of strokes such as unparalleled, short, long and discontinue as shown in Fig. 1. With these strokes, they are drawn randomly, using intersection and even overlapped. Definitely this deficiency requires beautification technique in order to design uniform lines in sketch. The tidy lines can ease the interpretation of drawing before proceed to 3D reconstruction stage.

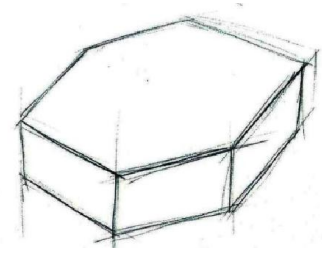

Fig. 1: Paper sketches with uncertainty and overlapped strokes

Consequently, this sketch needs to be transformed into a 3D model as it is an important element in design process. Commonly, CAD systems are used for this purpose but the concern is the 3D model is created separately from the sketch. This individual task cannot be separated from the whole process because the efficiency may be interrupted. Due to the mentioned reason, Sketch-based Modeling tool (SBM) is designed to support the sketching activity and provided with more intuitive interface and real for user. However, still it is faintly to develop an interface that able to imitate to the natural hand drawing [2].

Despite the existence of these digital tools, designer tends to use pencil and paper to rapidly express and record their ideas [3]. Besides, several research

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recommends the paper sketches as effective tool in carried out design solutions compared to digital tools [4,5,6]. Thus, it is important to have a quick translation of 3D model from paper sketches. Yet, this research is not progressively explored because this non-digital tool cannot generate input-responses in real time [6] and that is why the research is inclined on geometrical reconstruction from digital tools. The limitation and complex reconstruction from paper sketches that contain a lot of fuzzy information also make the process difficult. Regardless of these constraints, it is possible to substitute and improve the current practice in design process.

This ultimate goal of this research is to provide a complete digitalization at conceptual design phase. This system is intended to support and integrate conceptual sketching and 3D modeling task, by enabling a rapid conversion and visualization from 2D sketch to a precise 3D model.

The next section described about current issue in this research and followed by literature review of techniques commonly used in 3D reconstruction. Later, methodology and preliminary experiment are also illustrated. The expected outcomes are discussed as well in the following section. Finally a conclusion is addressed in the last part.

2 CURRENT ISSUE

Several important issues have been identified in this research. The first issue is related to the current practice in the design process and the second issue is about the capability of CAD system and SBM tools for sketching.

2.1 The iterative process in conceptual design stage

The general issue for this research is particularly relevant to the need of automatic conversion of 3D models from paper sketches. The common process after sketching requires the translation of the idea into a 3D model. This 3D model is essential because ordinarily it will be a mechanism of communication in design review session. Commercial CAD systems such as AutoCAD®, Rhino® and Solidworks® have become commonplaces for this modeling process. However, this process usually been created manually and separately from the sketches which lead to time consuming. First, pencil and paper is frequently used as a medium for sketching and several designs are usually presented. These sketches is discussed and evaluated in repetitive design review session to select the best among the proposed designs. Finally, a trained 3D artist will convert it into a 3D model. This tedious task possibly can hinder the efficiency of whole design process. Fig. 2 illustrates the current practiced by designer.

Fig. 2: The common step in design process

2.2 The deficiency of CAD and Sketch-based Modeling tool

CAD systems have a reputation in modeling task to support design process. In general, this system is designed for detail design in later phase, requiring accurate and detail geometric information to build precise 3D models. Apparently, it is not suitable for sketching activity and to be used in conceptual phase because CAD systems are too tiresome to allow quick expression of design ideas and will hinder designer's creative process.

Due to the CAD limitation, Sketch-based modeling tool were developed to expedite the process by providing the natural sketching interface that almost like traditional media. However, there has been little discussion about an adequacy of the tools because of the limited support for freehand sketching which can hinder the designer's natural way to express their idea creatively. It is almost impossible to create a natural 'pencil and paper' style interface, that mimic the way to designer's characteristic in portraying their idea at conceptual design phase. Other than that, the digital sketch tools is difficult to master by designers whether they are professional or practitioner due the steep learning curve that it is most possible in digital tools.

3 LITERATURE REVIEW

As mentioned previously, the direct conversion from paper-sketches become less interested to be explored due to the challenging tasks. All strokes information in the sketch is reduced to a batch of data points that need to be considered as equally important and cannot be simply ignored. Thus, this process is somehow found to be challenging and required many experiments and practices on the beautification of the sketch and in deriving the information from the 2D drawing.

Haron [7] has extracted the information from irregular line drawing which is junction, line and region. However, the work was not intended to get the depth value for each junction. The closest to our work, Chansri [8] has created an automatic single line drawing from overtraced paper sketches as a prerequisite step before reconstruction process. However, the image processing used unable to interpret a dash line. Shortly, Wang [9] has converted overtraced strokes from online sketch. These sketches are pre-processed into a tidy line beforehand.

Reconstruction is the task of creating a complete description of the 3D geometry based on the 2D drawing. Most of techniques used for 3D reconstruction starts from line drawing interpretation and have been initiated by [10,11,12,13]. Matondang [14] propose a new framework for 2D line drawing interpretation and our research shares the same objective which is intended to guess the depth value of each corner. Two main techniques are

used are line labeling and optimization based methods. Line labeling methods is not suitable for dealing inaccurate drawing and any missing entities. The optimization-based method is widely adopted because it can tolerate the ambiguous strokes and can produce result accurately. This method is optimizing the depth information and exploits the regularities to interpret 2D drawings.

Regularities are relationships between or within a set of geometric entities in a drawing that may be carried out over to 3D object. Since there is infinite interpretation of a 2D sketch as a 3D object, not all regularities are relevant for this purpose. Lipson [10], employed 13 regularities and reconstructed the 3D model from a single, inaccurate, 2D edge-vertex graph for planar objects. Even though it is claimed better than line labeling method, this algorithm just applicable to straight lines only and may results in an error when involved curved faces object. Kang [15] has selected the line orthogonality regularities to developed very fast vertex reconstruction algorithm to reform complex shapes. Nevertheless, it cannot be used with unconformity sketches and have disconnected points. Later, Yuan [16] has extracted depth information from 2D drawing using Automatic Relevance Detection (ARD) to select the most suitable regularities for the reconstruction process. Even so, somehow it was argued since the best regularities set should be based on cognitive not principles. Cantero [4], proposed the best regularities set that contains face planarity, symmetry and line parallelism further stated that minimum standard deviations of angles (MSDA) can be omitted. A hybrid method to reconstruct 3D polyhedral objects from 2D line drawing has been proposed by Lee & Fang [17]. But still no matter what optimization algorithm used, the ability of human perception to guess the Z or depth value is also the factor to influence and yield an accurate result of 3D object.

4 METHODOLOGY

This section presents a proposed methodology for 3D reconstruction from paper-based sketches. The input is a digitized two-dimensional sketch represents 3D object.

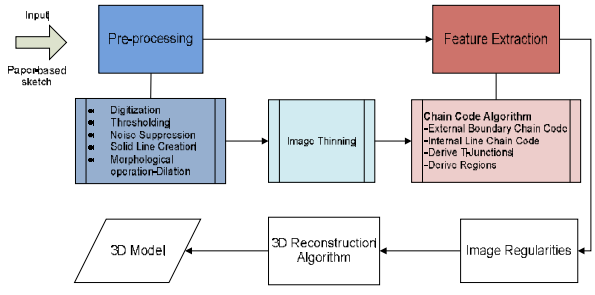

Fig. 3: Methodology of 3D reconstruction from paper sketches

There are four main steps as illustrated in fig.3; namely pre-processing, feature extraction, image regularities and 3D reconstruction algorithm.

Pre-processing is an essence step for further analysis to get accurate and desired result. The two-dimensional sketch is analyzed and ensures all the contents are treated equally. Next, the image needs to be binarized with suitable threshold value and here the process is quite straightforward. Noise suppression technique is then applied to eliminate the unwanted pixels before proceed to the next step. The sketches are usually rough and vague presented by any graphical features like shading, color and lines. One of the important features is line or also can be defined as strokes because it leaves many interpretations. This uncertainty line typically disturbs the solidness of the object. To solve this, a solid and clear line has to be derived by applying sliding neighborhood processing. Thinning process can be defined as iterative erosion to obtain skeleton is the final step in this phase. This will result a thinned image which is ready for the next phase.

Feature extraction has significantly use in image processing to extract useful information from input data. An identified technique suitable for this purpose is chain code representation. Introduced by Freeman [18], 8-connected chain code can be used to extract 2D geometrical entities; specifically junction, line and regions from line drawing and later can be extended for regularities identification. The algorithm will traverse from (0,0) coordinate on the thinned image to produce a list of codes ranging from 0 to 7 representing the direction of each pixels. Deriving a junction is the main idea for this work but it has to be started with lines extraction beforehand. When all lines in image are obtainable, those entities can be extracted and this information will be processed in the later stage.

Image regularities are the first step in 3D reconstruction. By default, the regularities such as line parallelism, face planarity will be exploited from the 2D drawing. The 2D vertices will maintain their X and Y coordinates and Z value is computed and must fit the compliance function. There are different regularities been used to remodel the 3D object however, not all is deployable for this purpose as some regularities can overlap with one another.

5 PRELIMINARY EXPERIMENT

In this section, some results of experiment on image processing are shown. The algorithm is implemented in Matlab R2010b by using some geometric shapes of sketches. Fig. 7 and 8 shows the interface of the prototype called 2D line drawing interpretation.

Pre-processing

The 2D sketch represent a 3D object is digitized and converting into binary image using Otsus method. Every

pixel with the lower luminance value than the threshold will be considered as dark and the rest pixel is changed to white. The result (Fig. 4) is the binary image with white pixels is shown as one and the dark pixels are shown as

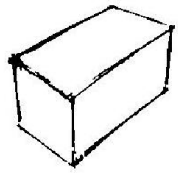

Fig. 4: The binary image

zero. To have a clean image, all pixels less than specified pixel value is removed.

In deriving the solid line from the ambiguous line of strokes, the sliding neighborhood processing can be used to cover the imperfection of lines. A small filter 3 X 3 size is used. This filter is overlay on the input image and slides from left to right and top to bottom in order to detect any presence of the object. Once it is found, all the eight neighborhood of the current pixel will be set to value zero. As a result, all discontinuity and gaps between strokes can be filled as presented in Fig. 4. If there is a case the solid line is not attainable as desired, a morphological operation such as dilation can be performed to make line thicker and automatically the uniform line drawing as shown in Fig. 5 is achievable. The accuracy of results somehow heavily depends on a

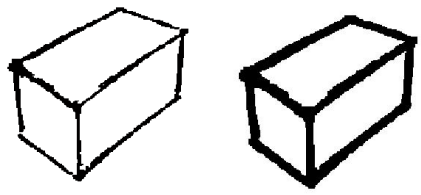

Fig. 5: The solid line sketch

type and size of structuring element in this operation. For this experiment, structuring element `disk` type has been used in order to preserve the originality of shape.

Thinning is a prerequisite step before feature extraction. A well-known Template-based Mark and Delete `Stentiford` algorithm is applied for this work. Even though this algorithm takes time because of the iterative erosion and uses several templates, it is claimed can produce an accurate result. A skeleton derived from the solid line usually contains extra branches at the intersection. This is definitely depends on the complexity of original sketches and how designers use the quality of lines. By shrinking those branches, a closed contour thinned image (Fig.6) is ready for chain code extraction process.

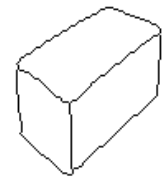

Fig. 6: The thinned image

Feature Extraction

Based on the Freeman chain code standard, this algorithm aims to derive junctions from 2D thinned binary image. To achieve this, external lines represents boundary of object is obtained first and followed by internal lines. Later, these lines can determine the junctions from the drawing.

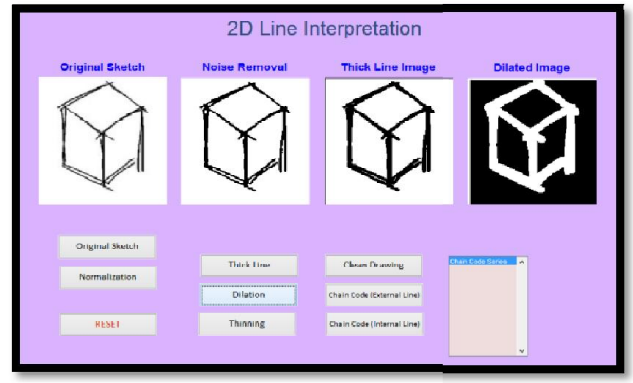

Fig. 7: Beautification of rough sketch

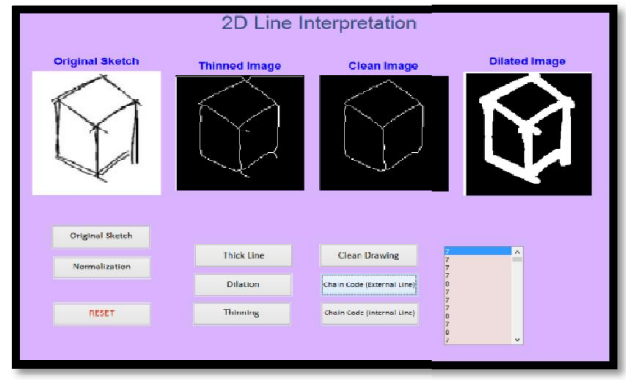

Fig. 8: Chain code lines extraction

Fig. 7 and 8 shows the interface of application called 2D line interpretation.

6 EXPECTED OUTCOME

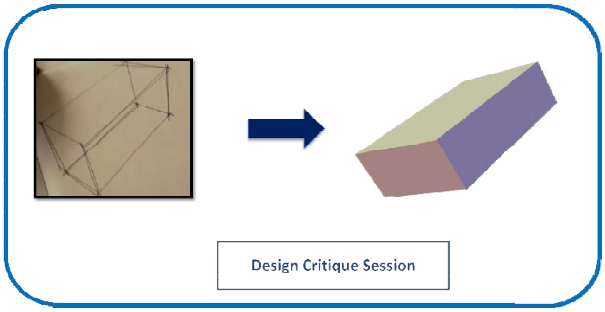

Fig. 9: A paper sketches is converted directly to 3D model

The aim of this research is to develop an automatic of 3D model reconstruction from conceptual sketches (Fig. 9). Contrary with tiresome current practices, this system is believed can shorten and improve the design process.

7 CONCLUSION

The major motivation of this research is to integrate all processes from sketches and 3D model reconstruction. This system is intended to be implemented during design review session at conceptual design phase. By simplifying the process and improve the modeling operations, it is supposed can facilitate and serve a wide range of assistance to designers. Understanding the particularities and designer's need are important issue in this research. Despite these challenges it is foreseen can speed up the design process.

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