UNIVERSITI PUTRA MALAYSIA

COMBINATION OF LINEAR AND GRADIENT VECTOR FLOW FIELD DIGITAL MOSAIC RENDERING FOR AUTOMATED TILE PLACEMENT

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By

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Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

June 2018

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman : Sharifah Mumtazah bt Syed Ahmad Abdul Rahman, PhD
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Mosaic is a composite image generated by combining sets of small images together through the use of tiles. These tiles tessellate images with the purpose of recreating it in a mosaic form. The traditional method of generating a mosaic requires a design to be intuitively obtained from nature, occurrences or paintings, and a working surface be prepared, before tiles are glued to the surface. The process is time consuming and labour intensive. In recent times, mosaic are being generated digitally through the use of computational tools. The linear mode of rendering mosaic digitally, has been in use for a very long time. Its advantage include better tile coverage area due to lesser space between tiles, but it does not represent curved surfaces properly. This makes the mosaic have an unpleasant physical appearance. This led to the rendering of mosaic in a non-linear form.Gradient Vector Flow (GVF) field algorithm has been employed to tackle the limitations of linear mosaic rendering, because of its advantages of better similarity to a source image, better preservation of fine details, better distribution of grout, and better preservation of an image's global appearance. However, GVF has a problem of not enough tile coverage area. So an improved hybrid algorithm which combines the linear, and non-linear GVF digital mosaic rendering via image segmentation is proposed, to improve the overall tile coverage area and maintain a good similarity to the source image. There are three main contributions providedin this thesis. Firstly, an improved algorithm using hybrid GVF digital mosaic rendering. Secondly, this thesis evaluates the tile coverage area, and source image similarity of the output digital mosaic obtained from, the hybrid, linear and non-linear GVF digital mosaic rendering, using the percentage tile coverage area and Structural Similarity (SSIM) index respectively. The results show that, the hybrid has a better percentage tile coverage area than the non-linear, but lesser than the linear. Also, the hybrid and non-linear has the best SSIM. Thirdly, the thesis presents the physical tiling of the hybrid, linear

and non-linear GVF digital mosaic using a robot. This study can be applied in the field of arts to replicate images.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KOMBINASI PENTERJEMAHAN DIGITAL MOSAIC MEDAN ALIRAN VEKTOR LINEAR DAN GRADIEN UNTUK PENEMPATAN JUBIN AUTOMATIK

Oleh

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Mosaic adalah imej komposit yang dihasilkan dengan menggabungkan set gambar kecil bersama-sama melalui penggunaan jubin. Jubin-jubin ini memancarkan imej dengan tujuan menciptanya dalam bentuk mozek. Kaedah tradisional menghasilkan mosaik memerlukan reka bentuk yang diperoleh secara intuitif dari alam semula jadi, kejadian atau lukisan, dan permukaan kerja disediakan, sebelum jubin terpaku pada permukaan. Proses ini memakan masa dan tenaga kerja yang intensif. Dalam masa yang lalu, mozek dihasilkan secara digital melalui penggunaan alat pengiraan. Mod linear rendering mozek secara digital, telah digunakan untuk masa yang sangat lama. Kelebihannya termasuk kawasan liputan jubin yang lebih baik kerana ruang yang kurang antara jubin, tetapi ia tidak mewakili permukaan melengkung dengan betul. Ini menjadikan mozek mempunyai penampilan fizikal yang tidak menyenangkan. Ini membawa kepada pembuatan mozek dalam bentuk bukan linear. Algoritma medan aliran Gradient Vector (GVF) telah digunakan untuk mengatasi keterbatasan render mosaik linear, kerana kelebihan persamaan yang lebih baik terhadap imej sumber, pemeliharaan detail yang lebih baik, pengedaran yang lebih baik dari grout, dan pemeliharaan yang lebih baik dari global gambar penampilan. Walau bagaimanapun, GVF mempunyai masalah kawasan liputan jubin yang tidak mencukupi. Oleh itu, algoritma hibrid yang dipertingkatkan yang menggabungkan rendering mosaik digital GVF dan linier yang tidak linear menerusi penyepadatan imej dicadangkan, untuk meningkatkan keseluruhan kawasan liputan jubin dan mengekalkan kesamaan yang baik terhadap imej sumber. Terdapat tiga sumbangan utama dalam tesis ini. Pertama, algoritma yang lebih baik menggunakan rendering mosaik digital GVF hibrid. Kedua, tesis ini menilai kawasan liputan jubin, dan kesamaan imej sumber mozek digital keluaran yang diperolehi daripada rendering mosaik digital GVF hibrid, linier dan bukan linear, masing-masing menggunakan indeks liputan peratusan kawasan dan Struktur Persamaan (SSIM). Keputusan menunjukkan

bahawa, hibrid mempunyai peratusan jubin kawasan liputan yang lebih baik daripada non-linear, tetapi lebih rendah daripada linear. Selain itu, hibrid dan bukan linear mempunyai SSIM terbaik. Ketiganya, tesis ini membentangkan jubin fizikal mozek digital hibrid, linear dan non-linear menggunakan robot. Kajian ini boleh digunakan dalam bidang seni untuk meniru imej.

ACKNOWLEDGEMENTS

I remain grateful to the Almighty God for his blessed guidance, strength and courage during my Masters' Period.

I am grateful to my supervisor, Dr. Sharifah Mumtazah bt. Syed Ahmad Abdul Rahman for the opportunity given to me to carry out this research. Her consistent motivation, support, and guidance have been very important in the completion of my research. This research would not have been possible without her insightful conversation and recommendation.

I would like to express my sincere gratitude to my supervisory committee member, Dr. Syamsiah binti Mashohor for her constructive suggestions during my research period, and for the time dedicated to improve this thesis. Her valuable suggestions and comments have been helpful in the modification of this thesis.

I am also thankful to the management of the Computer and Embedded Systems Engineering laboratory for providing an excellent study environment throughout my study period.

In addition, I would like to appreciate my colleagues Fadi, Neam and Enas for their valuable assistance throughout my research period.

Finally, I would like to thank my parents who deserve my utmost appreciation. I am very grateful to them for the support and prayers. I also thank my sisters, cousin and friends for their love and affection. May the Almighty God bless them All.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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LIST OF ABBREVIATIONS

2-D	Two-Dimensional
3-D	Three-Dimensional
ASCII	American Standard Code Information Interchange
CVD	Centroidal Voronoi Diagram
D-H	Denavit-Hartenberg
DOF	Degree of Freedom
GPU	Graphical Processing Unit
GUI	Graphical User Interface
GVF	Gradient Vector Flow
HSV	Hue, Saturation and Value
HVS	Human Visual System
IP	Internet Protocol
LAN	Local Area Network
MSE	Mean Squared Error
PC	Personal Computer
PSNR	Peak Signal to Noise Ratio
RGB	Red, Green, Blue
ROI	Region of Interest
SCARA	Selective Compliance Articulated Robot Arm
SMT	Software for Mosaic Tiling
SSIM	Structural Similarity Index
SRM	Statistical Region Merging
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UR5	Universal Robot 5
V2	Version 2

CHAPTER 1

INTRODUCTION

This chapter provides a general overview on the subject of art mosaic. It highlights the differences between the conventional art mosaics, which is referred to, in this thesis as, the traditional art mosaic, and the digital art mosaic which remains the core of the study. In addition, the chapter points out the problem statement, objectives of the study, as well as, the scope of the research.

1.1 Background of Study

Mosaic is an ancient mode of art used some 4000 years ago or more (Nordhagen and Waage, 2014). It is basically a picture or art that comprises of small, customarily coloured materials (Carinemahy, 2011). The materials used in making a mosaic is known as tesserae, which is a Latin word for "cubes" or "dice" (Nordhagen and Waage, 2014). Tesserae is a small block of tile made of stones, glass, ceramics etc. (Carinemahy, 2011). Mosaic is often used to decorate building surfaces such as floors, walls and ceilings (Carinemahy, 2011). The images that appear on these surfaces give vivid picture about the culture, belief and interest during their period of creation.

(a) **(b)**

Figure 1.1 : Examples of art mosaic used for decorating buildings
(Oral and Inal, 2009)

The earliest known Greek symbolic mosaic dates from the end of the 5th century BCE. These mosaic have a similar look to contemporary vase paintings especially in their outline drawing, and use of dark backgrounds. Also, mosaics of the 4th century tend to imitate style of wall paintings. In late Hellenistic times, there was an evolution of a type of mosaic which could exactly reproduce the qualities typical of the art of painting. A breakthrough in the use of mosaic occurred in roman imperial time, where mosaic is developed based on aesthetic laws. The new rules of composition are governed by a conception of perspective, and choice of viewpoint different from those of wall decoration. The increasing use of strongly coloured mosaic materials stimulated the autonomy of mosaic from painting. A detailed history of mosaics is provided in ((Carinemahy, 2011); (Puglisi and Battiato, 2013)).Modern development in production techniques and materials is an indication that mosaic is very much in use in the new millennium. In addition, computer graphics has gained increasing popularity in contemporary mosaic. A deep understanding of the traditional method of mosaic production is needed as a background for creating digital mosaics and automating the mosaic tiling process.

1.2 Art mosaic forms

Art mosaics can be classified into two main forms; the traditional art and digital art mosaic. They are briefly explained in the sub-sections below.

1.2.1 Traditional Art Mosaic

This is an ancient form of mosaic creation. The materials needed for producing a mosaic traditionally include; a base which can be made of wood, terracotta, glass, net or even walls. Also, adhesives such as epoxy resins, cement based mortars, acrylic based adhesives are used to glue the tesserae to the base. Basic tools needed in the mosaic tiling process are; tile nippers, tile cutters, glass nippers, hammers, glass cutters, adhesive spreaders, grout spreaders etc. The various stages involved in its creation are:

i. mosaic design creating stage
ii. preparation stage
iii. mosaic tiling stage

The design creating stage involves, constructing a design from an imaginative thought and applying creative ideas and colours. The preparation stage consists of collecting information about the technical methods, obtaining tools and variety of materials. It also includes cleaning the working surface, checking that it is dry and smooth, preparation of mosaics parts and tools at a close and convenient location, and preparation of the glue. The mosaic tiling stage is made up of two basic methods; the direct method and the indirect method. In the direct method, the tiles are fixed directly in place onto the base, the right way up, and then grouted. The indirect method involves turning mosaics upside down on a sheet paper or grid nets, before being placed on the surface. Another indirect method involves constructing mosaic faced up on the medium, before being placed on the surface. Direct method is proper for an uneven surface and a small area, while indirect method is suitable for a large tiling area. There are several performance requirements that the mosaic tiling process must satisfy (Oral and Erzincanli, 2004). These include:

a) the mosaics parts must be set in the required position.
b) the distances between neighbouring mosaics parts must be uniform.
c) neighbouring mosaics parts have to be on the same level.
d) the glue has to be spread uniformly over the entire back of the mosaics parts, a special spatula could be used.
e) picking up a tile and checking that it is not cracked, chipped, stained, or otherwise defective.
f) the mosaics parts must be pressed evenly against the floor and the glue left to dry.

(a) **(b)**

Figure 1.2 : Traditional method of mosaic creation (Cayiroglu and Demir, 2012)

Mosaic tiling applications in recent times has taken a new form. It involves creating mosaic in a frame to avoid the tiles from breaking or slipping off the edges, with materials such as metal, concrete, wood, etc. that constitute the types of frame material. This manual form of mosaic creation involves the physical placement of tiles. Today, the adaptability of mosaic is more than its antique counterpart and it is long-lasting, but the method by which mosaic is made, and the time of its production process remain almost the same.

However, the pitfalls of the traditional method of mosaic creation cannot be overlooked. The process is time consuming and labour intensive. It also requires artistic skills to be done effectively, else, it could result to several production errors. The digital method of mosaic generation which is been employed today eliminates these pitfalls efficiently.

1.2.2 Digital Art Mosaic

This is the reproduction of the aesthetic essence of arts by means of computational tools (Battiato et al.,, 2007). In other words, it involves the rendering of digital images using computer based simulation. It does not involve physical tiling. The generation of a digital mosaic from a raster image can be formulated as a mathematical optimization problem:

given a rectangular region in a plane, a tile dataset and a set of constraints, find the number sites in the plane, and place tiles, one at each site, such that all tiles are disjoint, the area they cover are maximized and the constraints are verified as much as possible.

1.2.3 Tile Characteristics for mosaic rendering

The essential tile characteristics that needs to be taken into consideration for mosaic rendering include; position, orientation, shape and size.

Tile orientation refers to the angular position of tiles on a tiling surface. Tile orientation could be either linear or non-linear. Linear positioning requires no angular rotation of the tiles. Tiles are positioned in a regular manner. On the other hand, non-linear placement requires some form of angular rotation of the tiles. Linear placement of tiles is easy to implement but does not represent images perfectly, especially when dealing with images with irregular surfaces. Non-linear placement of tiles represent irregular surfaces in images efficiently, but it creates large spaces for grout between tiles, as compared to the linear form of tile placement. Tile orientation possesses a substantial visible impact on the total appearance of a mosaic. Some approaches position tiles by placing along parallel curves as seen in (Elber and Wolberg, 2003), some make use of a vector field (Battiato et al., 2008), while others utilize a direction field that is provided by the gradient of the Euclidean distance from the edges of an image(Hausner, 2001). It is therefore important that tiles are oriented non-linearly in order to properly replicate a source image. This influences the overall appearance of the mosaic.

The shape of a tile is another essential factor that contributes to the overall aesthetic quality of a digital mosaic. Old mosaicist made use of different shapes such as square, rectangle, hexagon etc. to realize a pleasant mosaic. Digital mosaicists imitate some of these shapes used by old mosaicists to tile their mosaic. In (Hausner, 2001) the author demonstrated a method to reproduce an ancient mosaic. He proposed solutions to the challenge of aligning square tiles with different angular positions while minimizing grout area. He utilized square tiles in order to simplify the problem to one of placing point particles and obtained realistic results. Other works that made use of square tiles in the rendering of its output mosaic include (Lai et al., 2006),(Y Liu, Veksler, & Juan, 2010) and (Sebastiano Battiato et al., 2008). This square shape of tiles is practical for actual tiling of the mosaic, as it is readily available in the market.

On the other hand, (Elber & Wolberg, 2003) made use of varieties of shapes in the reproduction of an ancient looking mosaic. They utilized square, hexagonal and diamond-like tiles along feature curves of an image, for the sole aim of maximizing the overall tiling area. Likewise, in (Dobashi, Haga, Yohan, & Nishita, 2002), (Faustino, Castorina, & Janeiro, 2005), the authors made use of hexagonal tiles to render their source image, with a stained-glass effect realized in their final results. In (Di Blasi & Gallo, 2005), the authors formulated a method to transform a raster input image into a good quality mosaic, and made use of square tiles in the optimization of the cost function of a good mosaic. They later cut tiles to realize variety of shapes, so as to minimize grout space. The same shape of tiles were used in (S Battiato et al., 2006) and (Di Blasi & Gallo, 2005).Another method proposed by(Sebastiano Battiato, Milone, & Puglisi, 2013) in the generation of an artificial mosaic utilized variable shapes in the rendering of their output mosaic. Also, in(Fritzsche et al., 2005), an interactive technique for creating a visually pleasing synthetic mosaic was proposed. The user could interactively define the shape of tiles to use to obtain the output digital mosaic.

The size of a tile is another important parameter that determines how good a mosaic appears. The tile size not only depend on the overall size of the image, but also on the peculiar size of objects within the image. A fixed tile size across the entire image has a customary appearance, while a variable tile size across the source image has a distinctive appearance. It is worthy to note that, if the tile size is not properly selected, some important details in the source image might be lost. In (Di Blasi & Gallo, 2005), the authors utilized fixed size of tiles in the transformation of an input image into a good quality mosaic. The results obtained has an impressive overall visual appeal, but limited in visual uniformity. The improved algorithm of Di Blasi and Gallo's work was proposed by(S Battiato et al., 2006), which also made use of fixed size of tiles, produced better results because of the efficient method used in detecting the directional guidelines of the source image. Also, in(Lai et al., 2006), fixed size rectangular and square tiles were employed over a mesh to attain near full tiling area coverage. The results obtained were also impressive. Likewise, in (S Battiato, Blasi, Gallo, Guarnera, & Puglisi, 2008), fixed size square tiles were used in the proposed algorithm for mosaic generation with gradient vector flow (GVF) field. It was observed that, with the utilization of fixed size tiles, grout space were evenly distributed.

On the other hand, in (Hausner, 2001), the author made use of variable size tiles to attain an impressive aesthetic impact on the output mosaic obtained. Many important features within the image were well-distinguished. In (Elber & Wolberg, 2003), tiles of variable sizes were utilized to render a traditional-like mosaic. From the results generated, the tiles grew larger as it approached the feature curves of the source image. There was a clear distinction between the foreground and background regions of the image. Also, in (Fritzsche et al., 2005), an interactive design of authentic looking mosaic using Voronoi structures was proposed. They employed a user-defined approach in the selection of tile size. The user is able to vary the size of tiles according to personal requirements and image features were properly differentiated.

(Dobashi et al., 2002), (Faustino et al., 2005)and (Sebastiano Battiato et al., 2013) also utilized variable size tiles and obtained good overall appearance of the output mosaic.

Also, grout contributes to the aesthetic element of the mosaic. Grout refers to the spaces in between tiles. According to (Abdrashitov et al., 2014), grout defines a negative space in which a mosaic is nested. The grout space between tiles, influences the overall appearance of mosaic either digitally or physically. A mosaic with little grout space have pleasant artistic look, while a mosaic with generally large grout space have poor physical appearance. Also, a non-uniform grout distribution gives rise to an unattractive mosaic outlook. This is because an unequal grout circulation distracts the observer from seeing the mosaic itself. On the contrary, a uniform distribution of grout in a mosaic gives a pleasant aesthetic effect. Regular tile shapes provides equal distribution of grout within the mosaic. In (Hausner, 2001), (Lai et al., 2006)&(S Battiato et al., 2008), regular shape tiles were exploited in the generation of digital mosaic, and a uniform distribution of grout was observed in the results.

1.2.4 Advantages of robotic tiling over manual tiling

i. Robotic tiling saves more time in terms of actual tile placement as compared to the manual method.
ii. It is more efficient as there are lesser errors encountered in tiling.
iii. It eliminates the large cost involved in acquiring skilled labour for the tiling process (Oral, 2009).

1.3 Problem Statement

The linear style of mosaic rendering(Kang et al., 2011)does not replicate images properly, especially curved surfaces within an image. This rendering style results in an artefact which distracts and prevents the observer from seeing the true picture depicted in the outlined mosaic. These artefact are horizontal and vertical lines obtained from rectangular grid of pixels (Hausner, 2001). Due to this problem, old mosaicist render mosaic in a non-linear form. Digital mosaicist also imitate the old mosaicist by rendering non-linearly(Hausner, 2001). The challenge posed by this approach is the excess grout between tiles which influences overall tile coverage area. From a literature survey, several methods have been proposed by digital mosaicists to solve this problem(S. Battiato et al., 2008), but from some of their results, it was observed that gaps were not well distributed and some important details within the source image is lost. Therefore, Gradient Vector Flow (GVF)field was employed to tackle this challenge, because of its advantages of better similarity to the source image, better preservation of fine details, better distribution of grout and better preservation of an image's global appearance (Sebastiano Battiato et al., 2013). GVF renders a source image in a non-linear form, however, it has a disadvantage of insufficient tile coverage area. So an improved GVF algorithm with hybrid mosaic rendering is proposed. This allows for foreground regions to be rendered in a non-linear form, while background regions to be rendered in a linear form. This tends to improve the overall tile coverage area and source image similarity. Furthermore, it has been observed that many works on digital mosaic rendering are not physically implemented. Therefore, the generated digital mosaic will be physically implemented via the use of a robotic arm.

1.4 Aim of the Study

To design a working system that renders a realistic mosaic image which is practical for robotic arm implementation.

1.5 Objectives of Study

The objectives of this study are:

1. To investigate the limitations of the UR5 robot.
2. To develop an improved algorithm using GVF with hybrid, linear and non-linear mosaic rendering to convert a source image into its mosaic representation while considering the robot limitations.
3. To evaluate and compare the digital mosaic results obtained from the conventional linear mosaic rendering, non-linear mosaic rendering and hybrid GVF mosaic rendering.
4. To implement the improved algorithm by physically placing tiles using a UR5 robot.

1.6 Scope of Study

This study focuses on the use of Two Dimensional (2-D) images for mosaic rendering, which the foreground and background regions can be easily distinguished. For the computer based simulation, the source image is tessellated by sorting tiles into different colours. Also, a 6-degree of freedom Universal Robot 5 (UR5) robot is utilized in the physical implementation of the digital mosaic and a slider system to accommodate tiles of size $22mm\ x\ 22mm$ for linear mosaic tiling, 18mm x 18mm for non-linear mosaic tiling, and the combination of both sizes for hybrid mosaic tiling, with the condition of no overlapping mosaic tiles. Furthermore, in the physical implementation of the digital mosaic, only three colour tiles will be used; the red, black and white tiles.

1.7 Thesis Contribution

Briefly highlighted in this section are the contributions in this thesis:

i. The thesis provides an improved algorithm using the hybrid GVF mosaic rendering.
ii. The thesis provided an overall framework for the mosaic rendering process.

1.8 Thesis Layout

The thesis is composed of five main chapters, whereby chapter one introduces the concept of art mosaic, which is grouped into traditional art mosaic and digital art mosaic. The chapter also highlights the problem statement, objectives and scope of the study. In chapter two, the review of previous works on digital mosaic rendering, and optimization techniques are provided. In chapter three, the methodology utilized are explained in details. Chapter four presents the experimental results and discusses the analysis of the results obtained. Finally, chapter five provides the conclusion and recommendation for future studies.

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