1. INTRODUCTION

Drawing is one fundamental human behavior; it is still a very important skill for communication and innovation in modern society. Many people experienced difficulty with drawing, which requires the information process of visual or spatial perception in the right hemisphere of the human brain [1]. In this study, we aim at utilizing computer support to assist people’s visual perception during their drawing practice. To this end, we propose to use AI technology based on CNN (convolutional neural network) model to recognize what people draw, and then output CG (computer graphics) according the recognition result. We apply this proposed solution to support the practice in creating design patterns like the tessellation. Our work includes four contributions in-below: (1) recognition of the user’s original drawing based on our trained AI model; (2) generation of new visual design by incorporating the result of recognition into the pattern called tessellation; (3) a digital interface to interactively provide the drawing recognition and tessellation generation; (4) our work is the first trial to realize the innovation tetra proposed by Dr. H. Shiizuka. A cross validation shows the theoretically accuracy of the train AI model. The result of a questionnaire-based evaluation shows the practical usability of the support system, and also advise us future improvement to reach various user requirements.

Keywords: Tessellation, Tessellation generation, Computer graphics, AI-based recognition, Interactive art design
2. TESSELLATION AND ITS DRAWING SUPPORT

In the second section, we study the visual patterns in the tessellation samples, and then define process methods to create a new tessellation. For a better understanding, we created several tessellation examples in Figure 14, Figure 15 and Figure 16 in Section 4.

2.1 Related Work about Tessellation

It can be traced to the Sumerian civilization (about 4000 B.C.) in which tessellations were used as decoration for buildings like temples [5]. From the Middle Ages to the 19th century, a group of intellectuals left numerous documented research work to explain the geometric structures of tessellation based on mathematics [6].

Tessellations also appear in many modern art and design works. M.C. Escher (1898–1972), one of the most renowned tessellation artists, created many famous tessellation artworks, left viewers a deep impression about the nature of visual perception, and the geometrical infinity and patterns. Escher’s way of creating tessellation is not easy for non-professionals to learn. David Bailey [7], analyzed Escher’s artworks from a simple perspective. He studied the similarities between the Penrose puzzle [8] and Escher’s tessellation work, and decomposed some tessellations as the combination of repeatable tiles, which are in the form of simple geometry such as triangles, squares. Embedding different graphics into the tile could create new styles of tessellation. Similar to David Bailey’s work, we try to break the process of creating tessellation into a few steps and use computer support to generate tessellation tiles.

The use of a computer can create a similar pattern or create a better tessellation pattern. Computers can learn and create graphics, but they may not be able to create higher-quality graphics than humans, which may be leading to meaningless and poor-quality images. So still need to manually correct and improve. Computers can assist users to complete and give certain planning opinions. Through the support system, users and designers can create more beautiful patterns; the so-called as a system advised drawing of Tessellation based on the artful thinking process.

Figure 1 shows a process of the system supported drawing. We propose an application scenario that the user sends the original picture to the system, and the system then sends the automatically generated image such as the tessellation back to the user.

2.2 The Definitions of S-curve Tessellations

There are many kinds of shapes on tessellation, here we pick one of them as the main shape, called the S-curve in David’s research [7], or S-edge [2].

Here a S-curve Tessellation is a set of square matrices as the basic geometric shape. Taking the center of the matrix and four points unchanged, the curve passes through the center of each side to form a twisted pattern. Different radians produce different effects.

The S-curve shape looks like irregular, but symmetric. It can be used to create more interesting patterns by filling appropriate drownings inside the shape. It is also possible to fill the computer generated images into the shape as a single tile, and duplicated tiles to be organized in different spatial patterns, which result in a tessellation design.

2.3 The System Support for Tessellation Drawing

First, the user selects a tessellation graphic shape on the interface, then adds some strokes or draws a picture directly on the figure. The system will find the most similar picture in the database. And then it gives the recommended form as design suggestions to the user, through the user interface, the user modifies the design based on the suggested sample graphics. Finally, the user can not only modify it repeatedly but also select other graphics until the system gives satisfactory graphics. According to the pictures drawn by the user, the system finds the pictures with higher similarity, compares and processes the pictures in the database, and presents them to the user as the final picture selection.
A Support System for Artful Design of Tessellations Drawing using CNN and CG

The input is an image of the original drawing, e.g., when the user selects the image of the fish for creation, the original data drawn by the user is input into the system for recognition. Figure 2 shows the result of the recognition is closer to the fish in the database, as an attainable recommendation. And then the tessellation of the picture (fishes) will be embedded into tessellation pattern.

3. TECHNICAL PROOF OF CONCEPT

In this section, we discuss the experiment and prototype of system advised drawing of tessellation. We train a drawing classifier to recognize the visual objects in drawing, and demonstrate a system advised drawing based on the classification result.

3.1 Outline of the System

Figure 3 shows the system outline, which consists of three components or called modules, i.e., drawing classification, generation of tessellation, and user interface, which interacts with the user to give the advices.

A user without artful training and skill draws a picture such as a fish, a bird, a flight, or a balloon, etc. The classification module, which has been trained by a dataset to a CNN model, classifies the drawing of the user, and sends the output to generation of tessellation module. The module is made by a generation program using image processing libraries and reference image database. It generates a number of tessellations as candidates for the final results and provides those candidates to the user, through the interface module. The user checks the output candidates and input some points representing his/her wish for improvement, based on the points, the generation module will regenerate the candidates until the user satisfies. The procedure of computer supported drawing is outlined below.

1) The original drawing is taken as input.
2) The drawing classification is based on one of models that have been trained.
3) The image classification output the classification metrics that classifies the original drawing.
4) The reference image is selected from database according to the classification metrics, and then the system generates the tessellations by using the reference image.
5) The tessellations are then output.
6) After checking the output, the user may input request for improvement, which leads regeneration of tessellations

The processing loop from step 1 to 6 repeats until the loop is interrupted by the user.

3.2 Classification of User’s Input Images

We use Sony Neural Network Console [3, 4] for the classification, which is a convenient deep learning tool to quickly prototype AI models.

3.2.1 The Training Dataset

In this experiment, we prepared totally over 175 images with input being the shape of 28-by-28 pixels; and the output is either 0, 1, 2, 3 to represent the 4 classification categories of bird, face, fish and flower. Some examples are shown in Figure 4 which are drawn in the level without art professional training.

We also prepared totally 38 images with input being the shape of 28-by-28 pixels and the output is also either 0, 1, 2, 3 to represent the classification result. Some examples are shown in Figure 5.

3.2.2 The Convolutional Neural Network Model

To implement the image classification, we construct a CNN (Convolutional Neural Network) and tune parameters based on the Neural Network Console.

The neural network (as shown in Figure 6) starts with Multi-Scalar and Image Augmentation and CNN layers, then layers for max-pooling operation, Tanh activation function operation. We used LeakyReLU and Softmax as activation functions to normalize the output. We also used categorical cross entropy as loss functions.
The CNN layer maps the features of image data in tensors-like matrix with four dimensions. It employs the convolution mathematical operation to construct the neural network. The image augmentation is employed to create more variations of training images by random rotation, shifts, etc. in a certain range.

We have tried to change the model using less or more layers, and tune the parameters to increase the accuracy, and we found the network model shown in Figure 6.

### 3.2.3 The Learning-Curve

The constructed neural network model is trained over multiple epochs. During each epoch, the training data set is completely parsed to tune the model.

The Figure 7 shows the learning curve to the network model discussed above. It is achieved by using the data set of training and validation mentioned above. The x axis is the cost of training time, totally 100 epochs is set. The y axis for dash line (in red) is the validation error. Along the learning curve, the validation error is decreasing, and its minimum value is achieved at the 100th epoch.

### 3.2.4 The Evaluation Metrics

The best trained model is selected according to the confusion matrix [9]. Figure 8 shows the evaluation metrics, and the calculation is given in below. Here the $TP_i$, $FN_i$, $TN_i$, and $FP_i$ denote the true positive, false negative, true negative, and false positive for each of the 4 categories.

- **Average Recall**
  \[
  \text{Average Recall} = \frac{\sum_i (TP_i / (TP_i + FN_i))}{4} = 0.9268
  \]

- **Average Precision**
  \[
  \text{Average Precision} = \frac{\sum_i (TP_i / (TP_i + FP_i))}{4} = 0.92312
  \]

- **Average Accuracy**
  \[
  \text{Average Accuracy} = \frac{\sum_i ((TP_i + TN_i) / (TP_i + FP_i + TN_i + FN_i))}{4} = 0.9268
  \]

- **F-Measure**
  \[
  \text{F-Measure} = \frac{2 \times \text{Recall} \times \text{Precision}}{(\text{Recall} + \text{Precision})} = \frac{\sum_i (2 \times TP_i / (2 \times TP_i + FP_i + FN_i))}{4} = 0.9265
  \]

**Figure 4**: Examples of Training Data Set

**Figure 5**: Examples of Test Data Set

**Figure 6**: The Classification Model (created during the experiment based on Neural Network Console)

**Figure 7**: The Learning Curve (generated during the experiment based on Neural Network Console)

**Figure 8**: The Confusion Matrix (output during the experiment based on the Neural Network Console)
3.3 Generation of Tessellation

3.3.1 Function Design

The steps above helped recognize the original creation the user drew (e.g. fish, birds, etc.). Making tessellation while immature original ones may impair the artistry. Therefore, an image close to the creation drawn by the user is created by a person with professional skills in advance and is prepared in a database.

The system extracts an image from that database that is close to what the user has drawn. The image is transformed and then embedded in the Tessellation pattern.

The extracted image is subjected to various changes and embedded in Tessellation, various possible variations such as angle adjustment and size adjustment are created.

The tessellations then are presented to the user up to the specified limit by the user, who will select what he/she likes and enter the improvement opinion.

3.3.2 Procedure for Tessellation Generation

The procedure of tessellation generation is outlined in-below.

1) Extract images from the image database based on user input.
2) Apply affine transformation to the image. Make variations of the image.
3) Embed the images from various angles in Tessellation while rotating etc.
4) Ask the user to select the created Tessellation and start again the procedure from Step 1 based on the conditions re-entered by the user on the improvement opinion.

3.3.3 Prototype System

The database is built based on the images which are created by a master’s degree holder in the art department. Various image processing is applied to digitalize the original drawing images using Python and image processing library.

There are some technical issues which have been dealt with in the prototype.

1) The shape of Tessellation is not rectangular, so a series of cropping and stitching operations are required to match the exact neighboring Tessellation cells.
2) The output of the trained CNN model is required to be connected to a procedure.
3) It is desirable to scan the original photographs (creature of user), since those taken by the camera because they tend to contain noise.

3.3.4 Generation of Tessellation

The screenshots show the results of the execution.

Figure 9 shows (a) and (b), a bird or a fish is generated based on whether the user was drawing a bird or a fish.

The sub-figures (a) and (b) in Figure 10 shows the tessellation of fishes and birds respectively, which are generated by embedding the generated birds to a tessellation farmwards.

3.4 System Architecture

The system architecture proposed in [10] is used to implement the computer supported drawing of tessellation. Figure 11 shows the system interface design consists of a canvas panel and advice panel. When a user draws on the canvas, the system keeps on updating the advices accordingly. The interface periodically monitors user’ drawing, and then send it to the advice maker. The advice maker generates the advice for next drawing action based on the classification results.
The advice generation is based on the random selection of images which are associated with the words output the classifier. The advice operator contains the function to add changes to the canvas according to the advice, such as replacing the current drawing by the recommended image.

After finishing the drawing of the tessellation unit, the system then reproduces the unit of tessellation design into a tessellation artwork.

Based on the database of drawing advice, the proposed system has more advanced functionality including the image classification, and generation of new images. To improve the drawing recognition, we plan to collect more drawings from the volunteers, and other exiting drawing datasets (such as Google’s Quick Draw [11]) can be utilized to train the model for recognizing more drawings. And to improve the quality of new image generation, we plan to invite volunteers, who are good at drawing, to contribute the images to enrich the advisable database. Based defining more association between words and images, learning from users’ behavior can also be a feasible direction to make the advice more personalized.

3.5 Evaluation Survey using the Prototype System

To provide stronger evidence, we have conducted a survey. 11 participants who are not art professionals were selected as the representatives of the targeted user. We asked them to design tessellation using the prototype system. They answered a questionnaire, based on their impression on the prototype. Among the participants, 4 were female, 7 were male, 2 were over 40 years old, and the rest were between the ages of 20 and 40, three of them are interested in art but with less practice, other participants have no experience with art. They come from various majors, such as Computer Science and Engineering, or Language and Literature. No one is major in art.

3.5.1 The User Interface of the Prototype System

Figure 12 shows the four steps to use the prototype system.

1) Draw a tessellation tile image on the canvas below.
   User can start by drawing an image of fish, bird, flower, or face on the digital canvas, then click the button to trigger process to recognize the drawing.

2) Recognized tessellation tile image.
   The system returns the reignition result include the label and score. It also recommends images with a score greater than or equal to 0.3, which are in the same categories that are top ranked. The system will recommend two images at most in the current interface.

3) Tuning the parameters to generate tessellation.
   In this step, the user can select the number of rows and columns to construct the framework of the tessellation. Then, user can select the recommended image to be filled into the tiles. User can also change the direction of the image in each tile.

4) Generated tessellation.
   User can click the ‘Generate’ button in the last step, and the system will automatically generate a candidate tessellation image. If the user is not satisfied, they can go back to any of the previous steps and repeat again to create different tessellation pattern.

3.5.2 Summary of survey results

Figure 13 is showing the statistic result of the response about the 5 assessment questions, with the score ranging from 1 to 5.

Figure 12: The Prototype User Interface of the Support System for Artful Design of Tessellations Drawing

Figure 13: The table of Average Assessment Score based on the Questionnaire Response
from negative (-1.0) to neutral (0.0) to positive (1.0). Participants also provide their anonymized personal profile and the comment about the prototype system. Please pay main attention to the column in red color that shows the average score for each assessment question. The rest columns show the variance of the evaluation score given by participants with difference background.

The dark cells in the first column in the heatmap shows high positive score. Most of responses give high score that the can understand the interface; they can use the interface to generate tessellation patterns; and they think the system can help non-art professionals to design tessellation. The majority of the evaluation are positive. And there is no negative average score. The image recognition is voted to be insufficient. This is due to the current limitation of small training data set which includes only four categories, and limited drawing style contributed by very small number of volunteers.

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The comments from 11 survey participants indicate that most of the participants are interested in this system. About the recognition, the fishes, birds, and flowers are relatively easy to be recognized than the face. They suggest increasing the number of categories and recognition accuracy. This is due to the insufficiency of the training data set. We will continue to add more data later, including more people’s hand-drawn data to improve the recognition rate.

4. FEASIBLE APPLICATIONS

In this section, we introduce possible applications by using the generated tessellation. This work shows a practice of system advised drawing of tessellation. According to a series of methods, tessellation can also be integrated into life, such as commercial advertising, product packaging design, and shopping mall marketing.

The proposed approach can be applied to many scenarios and can even play a certain role in children’s art education. Children can draw new images, obtain new image samples through tessellation, and combine the styles given by the computer to modify the images. They want repeatedly to eventually generate new patterns.

The tessellation represents the geometric combination of tessellation through periodic and aperiodic patterns. Its repeated combination gives people deep visual impression in mind. It is attractive since many people like geometric visual affect in minimalist styles. In luxury bags and branded clothing, many geometric elements are often used. We can tile the tessellation tiles on the surface of the object. According to the changes in the pictures inside, we can display the arrangement and combination of different things. According to the content of the arrangement and combination, we can spell out many different images, or even combine them into a story set. Commercial products advertise the effect.

4.1 Application of Two-dimensional Tessellation

Tessellation can be made as to the graphic design on the 2D surface by geometrically organizing pieces of tessellation tiles through different patterns. The tiles combined within a tessellation have translational symmetry and rotational symmetry. The tessellation in the periodic pattern makes people feel comfortable. By using a package which printed in the tessellation pattern, it can bring comfort to people by using geometric aesthetic packaging. The Penrose tiling [8] is an example of an aperiodic tiling, with repeatability and tiling and decorative characteristics.

It is applied to the fields of packaging and clothing design and has elements in the design art, e.g. Figure 14 repeating design style, tessellation is also a repeating design element. Through the different contents of tessellation, various patterns can be combined to enrich the design content. We can put tessellation pictures on the real thing to associate. The shape of tessellation is very close to the square, so the effect of collage is very similar to square and diamond, and it can also produce different visual effects according to the change of tessellation pattern.

Through the system software, we can stitch the different tessellation tiles that have been drawn into groups, and there will be unexpected effects. As shown in Figure 15, this tessellation is currently completed by hand drawing, but it is possible to imagine that such beautiful pictures are automatically generated after drawing with the system.

![Figure 14: Two-dimensional product interface design by using tessellation](image-url)
4.2 The Application of 3D Tessellation

Tessellation is easier to implement on two-dimensional pictures, but there are some difficulties in three-dimensional implementation. We need to consider the radian and angle of the object, and then tile the tessellation according to the volumetric surface of each object.

If we put tessellation on a three-dimensional building and add with the color screen, the color pattern can be changed constantly, and the tessellation patterns can also be changed at any time. The eye-catching advertising effect is very impressive. (such as Figure 16)

Tessellation is easier to implement on cylinders and cubes. We can imagine the tessellation tiles surrounding the building, which changes according to the festival or advertising. Compared with two-dimensional, three-dimensional effect can show spatial effect and dynamic visual effect.

4.3 Possible Applications of Tessellation in Art Education

Tessellation can not only be used in commercial design, but also in online art education. Our proposed approach is to provide a software system mainly for the non-art professional users, especially children and adults who are the beginners interested in art painting.

5. DISCUSSION AND CONCLUSION

The purpose of this research is to study art design utilizing artificial intelligence and IT technology. Specifically, we helped even beginners and those who have never specialized in art learning to create an original art pattern called Tessellation. An AI-based CNN model is used to classify the original drawing of the user, and a program based on image processing library is used to generate candidates of Tessellations.

This research has the following contributions.
1) Recognition of the user’s original creation by a recognition program based on artificial intelligence.
2) Support of the various tessellation-based art designs by incorporating the original creation of the user into the pattern called tessellation.
3) The user can create a tessellation-based art that he/she likes while interacting with the support system, gradually learn the interestingness and sensation of the art, and incorporate it into a better tessellation creation.
4) Dr. H. Shizuka proposed a concept called *Innovation Tetra*, [12] which can be regarded as the basis of *artificial kansei* [13]. This research was realized as the first system prototype of the concept.

The *Innovation Tetra* has 88 combinations by combining 4 different approaches. Each becomes a concept for the construction of a computing model. This time, we have performed the following four processes.

1) Inductive operation,
2) Deductive operation,
3) Abductive operation,
4) Transilient operations.

More specifically, we first used deep learning (CNN) to recognize images which were hand-written by users with little artistic skills. This is an inductive approach.

We then use the recognized objects as the basis for generating the artistic pattern tessellation. Using an algorithm-based image generation presents the user with tessellation candidates as output which is a deductive approach.

There is also a third approach, i.e. an abductive operation. Within the upper limit of the number of candidates specified by the user, different tessellation candidates are generated by changing the parameters of the image generation algorithm (program). Then, the user confirms whether or not there is something he/she wants to express or likes among those candidates. If there are no satisfied candidates, the parameters are changed randomly and free transilient is performed to recreate another kind of Tessellation candidate.

The significance of this research can be used as a support tool for designing people such as studying art for beginners, product planning for companies, design of packages and advertisements, and design of supermarkets and towns. And to some extent, it can be used by art professionals as an auxiliary tool for artistic expression.

As for future work, we will further deepen research in the following directions:

1) Expanding the categories of recognizable creations

The current prototype system can recognize four categories of drawings with high accuracy, but with those four categories, the accuracy achieves certain accuracy. We need to extend amount of the categories and increase date set to improve the accuracy of recognizing the drawings of different users.

2) Improvement of response to user requests

Currently, the system provides simple set of parameters for user to interactively generate tessellation. We need to increase the variety of the tunable parameters.

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