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Development of tiling automation for custom mosaic design

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ABSTRACT

Mosaic is the art of design creation from tesserae, and for custom mosaic design the individual tesserae are assigned to certain positions unlike forming a random pattern. The variety of designs makes it difficult for automatic tile assembly; consequently, manual assembly is typically found in practice. This paper presents the development of a tiling automation to support custom mosaic design from uniform size square tiles. The system follows a product flow concept that the tesserae are sorted first to form a row prior to be assembled to a mosaic moving slowly on a conveyor. It allows a simple point-to-point movement for assembly. The complexity shifting from toolpath generation to tile sorting is handled in two steps: acquiring tiles needed for a row and rearranging the tiles according to the order. A shortest distance criterion has been applied for determining dispensing sequence. Hardware and software have been developed to illustrate the proposed tiling automation.

1. Introduction

Mosaic is the art of design creation that has been with human being since ancient time. Small pieces of material, called tesserae, are assembled together on a bed of cement, clay or other types of adhesive materials to form a decorative covering surface used in various places ranging from floor to ceiling, and for both interior and exterior [1]. An image appearing on the surface tells a story about culture, belief, interest and/or way of life occurring during its construction period.

Tesserae, which typically are, but not limited to, square cut, are made from marble, stone, glass, ceramic, terracotta, etc. They can be arranged in various ways, and from visual line movement (andamento) that illustrates through grout flows, different styles of mosaic work (opus) have been introduced [2]. Opus regulatum, opus tessellatum and opus vermiculatum are examples of tiling styles when tesserae are placed parallel vertically and horizontally similar to a chessboard, parallel in either direction similar to weaving a fabric, and along the edge of key figures respectively.

A creation of a custom mosaic design is usually done in 3 steps. First, the image of an intended design is rendered for reproducing an image in a mosaic-like style [3], and according to shape, size and color, cells on the mosaic-like image are matched next with available tiles in a stock [4]. These tiles are then assembled to mimic the mosaic-like image in the last step.

The first two steps can be done manually or automatically on available commercial programs. For the manual process, a user makes a decision which types of opus he/she wants and then draws a map of tessellating tiles with selected tile colors. For the automatic process, the input image is inserted to the mosaic rendering commercial program. The program transforms the image to different styles of tile placements and colors as the user selected. For the third step, manual mosaic assembly is still commonly seen in practice.

Generally, there are three ways to manually assemble mosaic tiles [5]. The first one is known as a direct method that individual tesserae are directly placed onto a prepared surface. The second and third ways are known as indirect methods that tesserae are assembled onto media such as papers or grid nets before these subassemblies are placed on the surface. The two indirect methods are different on that the tesserae are faced down onto the medium for the second method and are faced up on the medium for the third method, also known as a double indirect method. Direct placement is appropriate for small area and for uneven surface while indirect placement is suitable for tiling large area. Indirect placement also allows the subassemblies of mosaic to be prepared in advance at the factory which helps shorten tiling time on the site. The advantage of double indirect method over the indirect method is the workers can observe the work during the creation process. Overall, the manual mosaic assembly, especially the direct method, is very fastidious, time consuming and requires more skills to finish the product. It hinders the tile manufacturers to quickly respond to the need of customers for custom mosaic design.

Although mosaics have been used for quite a long time, tiling automation remains relatively new. Complexity resulted from tiles'

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shapes, sizes, colors and their intended positions makes automatic assembly a challenging task for custom mosaic design. A limited number of researches have been done on tiling automation. Furthermore, they are not ready for production due to fabrication speed or high capital investment required for full implementation. This has motivated the development of a tiling automation presented in this paper and a focus has been given to assemble uniform size square tiles to form opus regulatum custom mosaic design from a digital image. The proposed system is capable of performing the three activities: mosaic rendering, tile color matching, and mosaic tile assembly but the main contribution is in the tile assembly process.

2. Tiling automation

Tiling automation has been reported for both direct and indirect methods. Mobile robots with omni-direction wheels have been introduced for direct floor-tiling [6, 7]. They were capable of lay down tiles one by one on a floor. Handling mechanism and jointed arm have been applied in these robots for delivery of a tile to its assigned location. Machine vision has been integrated into the systems to inspect the quality of tiles and to control the placement.

The application of robotic arm has been researched also for the indirect tiling methods. A jointed-arm robot with four-degree of freedom was controlled by computer to pick up and to place similar square cut marbles piece by piece at their assigned locations [1]. The system was also capable of tiling rectangular cut marbles and of reorienting marbles to create various patterns. Software for control robotic arm's movement was developed in-house. The system was further improved for both hardware and software [8]. An end effector was installed with multiple vacuum cups for handling many identical marble pieces at the same time to speed up tiling process. In term of software improvement, different repeated tile patterns that require two or more different types of marble were made available for selection after the geometric relationships between different marbles in the patterns were identified. Similar implementation has been reported for a Cartesian robot with four degrees of freedom [9]. Besides, automatic tiling from a computer image has also been introduced [4]. Image processing technique was applied to convert the image to be a mosaic-like image and to match the color of each of its pixels with available tile colors. The size of the mosaic-like image was determined from tiling area and tile size, and color matching was done on RGB color system. A path movement file was created for six-degree of freedom robotic arm that handled prearranged square tiles piece by piece from a tile charger magazine. Research in this area has been extended to mosaic assembly from unorganized tesserae. A vision system has been applied to recognize incoming tesserae that appear randomly and to match them with their intended positions [10,11]. On a commercial side, a gantry robot has been introduced in a mosaic tiling machine that assemblies mosaic color by color [12]. During the process, tiles are prearranged by color and installed in magazines. The robot picks up one magazine at a time, moves to the working area and places tiles row by row according to the tiles' color.

These indirect tiling systems have been developed under fixed position product assembly concept that tesserae are brought in for stationary mosaic assembly. It is suitable for tiling a complicated pattern that contains various tile shapes, sizes and orientations. The complicated part is in the toolpath generation for 3D movement of the robotic arm because each tile has its individual position.

Recently, another tiling automation has been introduced for assembly mosaic from uniform size square tiles. It follows product flow assembly concept that being-assembled mosaic moves instead of being stationary. For this tiling automation, tiles are arranged into a pattern row by row before being assembled to a mosaic placed on a conveyor. 3D movement has been split and assigned to both a robotic arm and mosaic assembly. This tiling automation system composes of main band module for moving being-assembled mosaic, lateral band modules for preparing tiles, and pick and place module for mosaic assembly [13]. Each lateral band module consists of bunkers for storing tiles, a conveyor, sliding units for reorienting the tiles released from the bunkers to face down before reaching the conveyor, and sorting unit. One bunker is for one color. The tiles are dispensed from the bunkers according to their positions on each row. The released tiles are delivered to the sorting unit by the conveyor. They are secured at the positions at the sorting unit before the pick and place unit picks up and assembles them on the main band. Toolpath is simplified by limiting the movement of the pick and place unit to a repeated point-to-point movement on a plane. To shorten sorting time, multiple lateral band modules have been introduced to handle the use of several tile colors.

3. System development

Presented in this section is the system development of a mosaic tiling automation that is capable of assembly uniform size square tiles to form custom mosaic design from a digital image.

3.1. Research concept

Unlike assembling patternless mosaic that tiles are placed randomly, assembling custom mosaic design requires each individual tiles to be placed at particular positions to form an image or pattern. Three key factors involved in arranging and placing these tiles are the number of colors used, the number of tiles for each individual colors and their intended positions. The complexity increases as the number of tiles and colors increase. The fixed position product assembly concept can be applied, but tile by tile placement becomes a tedious complicated task and requires several toolpaths for a robotic arm's movements. The product flow assembly concept is more suitable for assembly of uniform size square or rectangular tiles because having similar tiles allows several of them to be assembled simultaneously and speeds up the process. The existing system, however, consider all three factors together in one step which means that the tiles are released from the storages according to their orders in a row as illustrated in Fig. 1. When the number of colors is large forming a row consumes time because some tiles require long traveling distances. A long sorting time is handled in this system by the introduction of several shorter lateral lines of which each line is assigned for a few colors to serve the increase of tiles colors. This increases investment cost unavoidable.

This research follows the product flow assembly concept also but simplifies the sorting process by considering the three factors in two steps (Fig. 2). The first step focuses only on the acquisition of the tiles required for a row. Therefore, only the colors used and the number of tiles for these colors are considered. The tiles needed to form the row are dispensed from their storages and put on a carriage, also in a single row receiver slot format. Distances between tiles and available positions on the carriage are considered, and shortest distance criterion is used to decide the releasing order. By ignoring their intended positions, the tiles can be delivered much faster. The second step is for reconfiguring them according to their assigned orders. It is simply done by picking up them all together but they are released according to the order onto a moving conveyor at different times. The arranged row of tiles is