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Computer-assisted robotic tiling of mosaics

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SUMMARY

This paper describes the development of a system that is capable of tiling mosaics using a robot according to requirements of the individual customer. The art of mosaic, in one form or another, has been practiced manually for thousands of years. Modern developments in materials and production techniques could be found as evidence that mosaic is very much alive in the new millennium. It is very costly and also difficult to find skilful people to tile mosaic. Therefore a computer-assisted robotic system has been constructed and applied. To activate the system a particular algorithm has been developed and successfully applied on an available SCARA robot.

KEYWORDS: Mosaic; Robot; Tiling; Marble.

1. INTRODUCTION

For thousands of years marble has been the symbol of craftsmanship and structure in all kinds of communities. It has enhanced colour and pleasure in human lives and although it's used in different places it has never lost its natural beauty. Civilized people haven't been able to escape from it's colour, pattern and strength.

Mosaics are designs or pictures created by embedding small pieces of glass, stone, terracotta, pieces of marble, etc. into a bed of cement or other form of fixative. This form of decoration is often used for panels or on floors, but is especially effective on curved surfaces, such as ceilings and vaults. Mosaics can be found both indoors and outdoors. The art of mosaic, in one form or another, has been practiced for thousands of years. Modern developments in materials and production techniques are evidence that mosaic is very much alive in the new millennium. Mosaic – the artistic and expressive medium in it's own right – has an immense decorative potential. Computers and new programs are of course ideal for designing contemporary mosaics, and are increasingly used for that purpose.[1–3]

A good understanding of the manual work is needed as a background for automating the corresponding task making (tiling) mosaics in the present case. Consequently, the following section will specify the performance requirements from the mosaics tiling operation; describe the manual work methods, including the tools needed for them; and present the work inputs, as measured in a field study.

2. ANALYSIS OF THE MANUAL WORK

The manual mosaic tiling process involves three stages: (i) preparatory work, (ii) tile setting proper and (iii) additional tasks. A manual mosaic tiling process is shown in Figure 1. The preparations include 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.

Mosaics can be tiled by direct or indirect method:[4] Direct method (pieces are glued directly to the base to be decorated); Indirect method (pieces are stuck to contact paper or glued to other paper right side down).

The tiling of mosaics parts must satisfy the following performance requirements:

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

The progressive industrialization of mosaics, with the increasing use of production-line methods, made it possible to employ a less skilled workforce, thus culminating in the almost total decay of the ancient and glorious mosaic tradition.[5] Unfortunately, the manual tiling method is not a fast and flexible process as much as necessary, because, each customer has different requirements, such as colour, style, size, etc. Each mosaics style requires special mould or drawing on paper to tile the pieces in a right position and orientation. Computers and computer programs are ideal and available for designing contemporary mosaics. There-

Fig. 1. Manual mosaic tiling.

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fore, in order to meet customer demands, flexible robotic systems are necessity to tile various style mosaics.

3. A ROBOTIC SYSTEM FOR TILING MOSAICS

Modern robot manipulators, and kinematics mechanisms, in general, are typically constructed by connecting different joints together using rigid links. The kinematics of a robot manipulator describes the relation between the motion of the joints of a manipulator and resulting motion of the rigid bodies that form the robot. Most of the modern manipulators consist of a set of rigid links connected together by a set of joints. Any type of the joints mechanism can be revolute, e.g. prismatic, helical, cylindrical, spherical and planar joints.[6]

In this study, a SCARA robot has been used for automatic mosaics tiling. The SCARA robot is a four-degree of freedom (DOF) robot, with three revolute joints and one prismatic joint. The first 3 revolute joints are all in the same plane. This means that the structure of the robot supports the weight of the robot up to the third joint, rather than the joint actuator. The fourth prismatic joint must still support the weight of the prismatic link. Therefore, the first two joint motors can be really powerful, and consequently heavy, which will allow the robot to move extremely quickly. A SCARA manipulator can move up to 10 times faster than articulated robots. These robots are the best for planar type tasks, or $2\frac{1}{2}$ degree works, such as pick and place or assembly line sorting. A schematic representation of the robot is shown in Figure 2. Different techniques have been used for positioning of the robot end effector, e.g. forward kinematics and inverse kinematics.

3.1. Forward kinematics

The forward kinematics of a robot determines the configuration of the end-effector, given the relative configuration of the robot.[6] If the values of the joint variables are known or measured, the position and orientation of the end-effector in the Cartesian base coordinate system can be uniquely determined. The kinematic equations are used in the forward directions.[7] Forward kinematics can be determined using plane geometry. For given lengths (l_1, l_2), point coordinates of the end effector are uniquely determined by two variable joint angles (q_1, q_2). The representation of the joint angles is shown in Figure 3. The equations q_1 and q_2 are the "forward kinematic" equations of model links. The coordinates px and py are mathematically calculated as denoted in Equations (1) and (2):

$$p_x = l_1\,Cos(q_1) + l_2\,Cos(q_1 + q_2) \qquad (1)$$

$$p_y = l_1\,Sin(q_1) + l_2\,Sin(q_1 + q_2) \qquad (2)$$

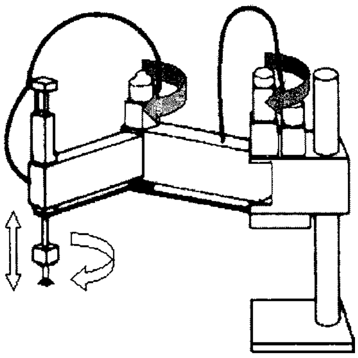


Fig. 2. A SCARA robot.

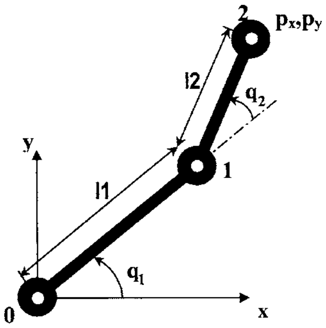


Fig. 3. Example of the planar revolute manipulator.

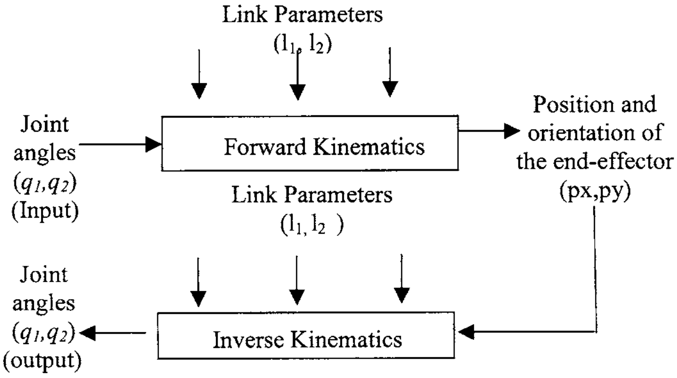


Fig. 4. Forward and inverse kinematics of the robot.

Inverse kinematics is the problem of determining the required joint angles that will achieve a desired manipulator position and orientation.

The robot would be given a point (p_x, p_y) in space on which to place end-efector. In the fact, the controller would be given both an end-effector position and an orientatiton. This is called an inverse solution.[9] A block diagram indicating the relationship between the forward and inverse kinematic problem is shown in Figure 4.[10]

3.2. Inverse kinematics

Inverse kinematics is the problem of determining the required joint angles (q_1, q_2) that will achieve a desired manipulator position and orientation. The joint angles are calculated to put the end effector in the defined position an orientation. For the 2 DOF robot, the reverse solution can be derived by solving Equations (1) and (2) for q_1 and q_2. Angles of q_1 and q_2 are calculated using Equations (4) and (6), respectively.

$$Cos\ q_2 = \frac{p_x^2 + p_y^2 - l_1^2 - l_2^2}{2 l_1 l_2} \qquad (3)$$

$$q_2 = ArcCos\left[\frac{p_x^2 + p_y^2 - l_1^2 - l_2^2}{2 l_1 l_2}\right] \qquad (4)$$

and

$$\tan q_1 = \frac{(p_y(l_1 + l_2\ Cos\ q_2) - p_x l_2\ Sin\ q_2)}{(p_x(l_1 + l_2\ Cos\ q_2) + p_y l_2\ Sin\ q_2)} \quad (5)$$

$$q_1 \times ArcTan\left[\frac{(p_y(l_1 + l_2\ Cos\ q_2) - p_x l_2\ Sin\ q_2)}{(p_x(l_1 + l_2\ Cos\ q_2) + p_y l_2\ Sin\ q_2)}\right] \quad (6)$$

These equations, given a desired position and orientation for the end-effector, determine a set of joint variables that achieve the desired position and orientation. q_1 and q_2 angles also can be calculated using an iterative solution. A special computer program that includes this purpose must be developed and used.

Fig. 5. The SCARA robot.

4. EXPERIMENTAL PROCEDURE

A SCARA type robot was used for the purpose of pick and place (Figure 5). An ordinary vacuum suction cup was used as an end effector for handling marble pieces.

The technical specifications of the SCARA robot are:

First Arm rotation angle (Shoulder) $(q_1) = 200°$
Second Arm rotation angle (Elbow) $(q_2) = 215.652°$
Wrist rotation angle = 450°
First Arm length = 250 mm
Second Arm length = (147) mm
Z axis course (up and down) = 75 mm
Movement accuracy = 1 : 4096
Accuracy = 1 mm

Software is necessary in order to tile the pieces of mosaics in a desired orientation and location using the robot. For this purpose software, called Software for Mosaics Tiling (SMT), has been developed and successfully applied. A flowchart of the software algorithm is shown in Figure 6 and a screen image of interface of the software is shown in Figure 7.

The sizes of the mosaics parts (*a*: *width*, *b*: *length*), the amount of the mosaics in rows (*N*) and columns (*M*), and spaces between mosaics parts are the input of the software. SMT calculates the coordinates in x and y axis using Equations (7) and (8) as denoted in Figure 6.

$$x[u, j] = x[i, j] + (a + space) \quad (7)$$

$$y[i, j] = y[i, j] + (b + space) \quad (8)$$

Then, q_1 and q_2 angles are calculated using Equations (4) and (6) by SMT to place the marble pieces in the required location (*x* and *y*). The result of the calculation is then marked using the robot's software format. Walli 2,5[11] (i.e., the control software of SCARA robot) reads the result and starts to tile the parts of the marble. During the application of the software (SMT), as an example, two different sizes of

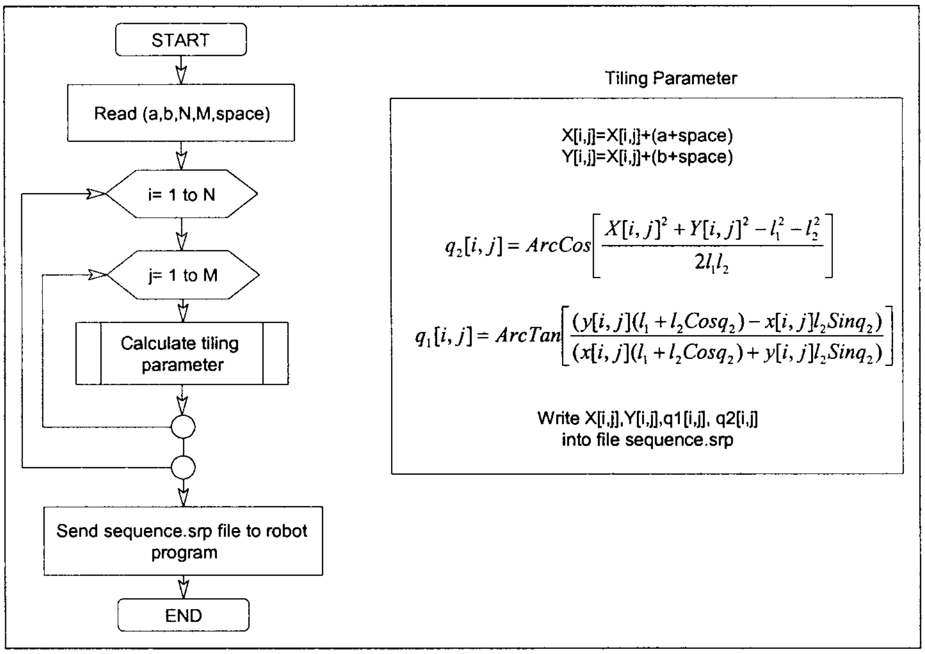
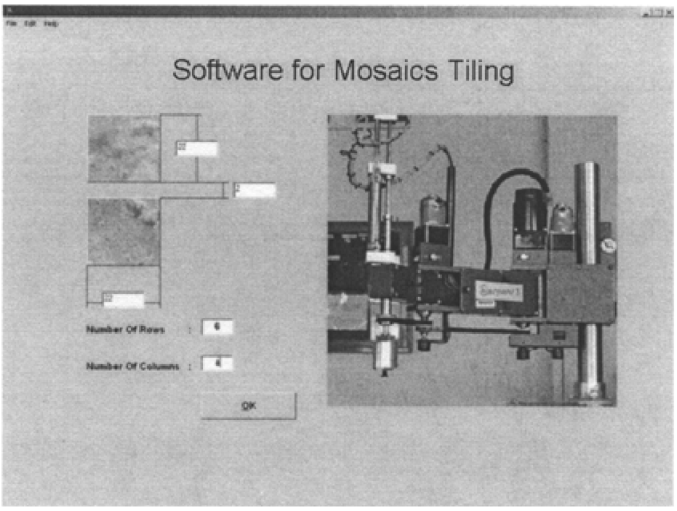


Fig. 6. Flowchart of the SMT.



Software for Mosaics Tiling

Number Of Rows : 6

Number Of Columns : 4

Fig. 7. Screen image of SMT.

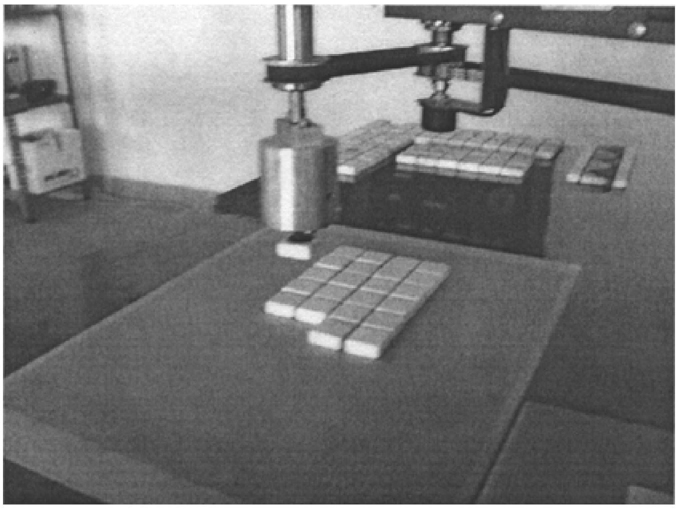


Fig. 8. Mosaics using pieces of marble of the sizes of 22 × 22 mm.

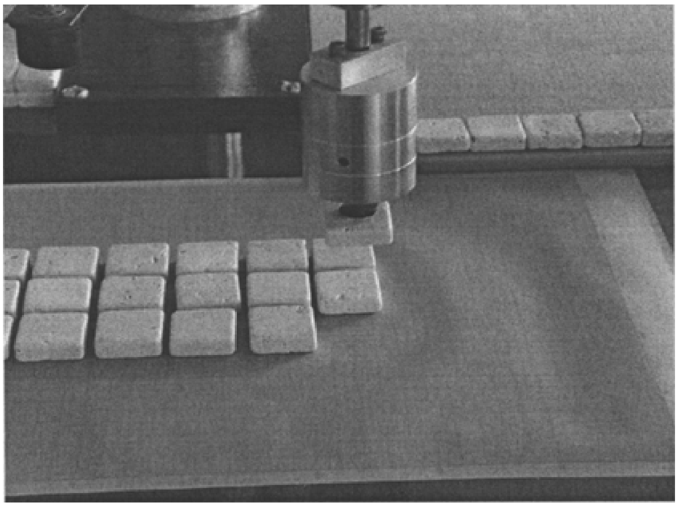


Fig. 9. Mosaics using pieces of marble of the sizes of 30 × 30 mm.

pieces of the marble have been used. The mosaics using pieces of marble with the sizes of 22 × 22 mm 4 × 6 matrices is shown in Figure 8. The other configuration, mosaic tiling with 3 × 6 matrices using pieces of marble with the size of 30 × 30 mm, is shown in Figure 9.

5. DISCUSSION

Computers are, of course, ideal for designing contemporary mosaics, and are increasingly used for design purposes. The use of mosaics decorations have been known for centuries and countless examples of mosaics decoration are available all over the world.

Mosaic pieces (marble parts, square cut) with various sizes are placed in a required orientation. The piece of mosaics could also be tiled with different angles to obtain complex figures. The working envelope of the robot was relatively small, therefore small pieces of marble have been used. For that reason, small mosaics have been made during the application of the system. The software (SMT) which has been developed could be used with the robots with a relatively large working envelope.

According to the result of this study it can be envisaged that the robots could be used for making mosaics compatible with the diversity of the customer's requirements. The expectation from the robotic tiling mosaics could be expressed as:

- Faster production
- Eliminating mould-making operation
- Reducing labour mistakes
- Reducing labour cost
- Production complex figures
- Flexibility for meeting the customer desires

6. CONCLUSION

Mosaics is a beautiful and unique craft, using the elements of colour, texture and design to create complex entities from many simple pieces. Mosaic art is becoming popular again, and can be seen in public pieces of large decoration, displays in bars and restaurants, and pieces of function and beauty for the home. A system have been developed and successfully practised to make mosaics. Further researches are going to be carried out by the authors to be able to make more complex and colourful mosaics. The mosaics with various colours and orientations would be made in future works and the results would be shared with people who are interested in such endeavours.

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