Measuring and Positioning System Design of Robotic Floor-tiling

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Abstract –

The research of floor-tiling robots aiming to replace the artificial floor tile installation, which is a trend in the development of construction automation. Modular design of the robotic floor-tiling system used embedded PC as the main controller, which has several advantages, such as reliable system performance, convenient modular communication, and simple function improvement. The measuring and positioning system of robotic floor-tiling consists of multiple subsystems. The task calls of each subsystem are allocated in real time through control flow and control algorithms. Feasibility of the measuring and positioning system is proved by test run and the future works are discussed.

Keywords –

Robotic floor-tiling; Control system; Embedded PC; Modular design

1 Introduction

Floor-tiling is a project in the construction industry that is labor intensive, highly repetitive, and testable to the skills and body of workers [1]. There are large quantities of tiles to be consumed and an increasing trend every year all over the world [2]. The environment of floor-tiling process is fully filled with mud, dust, noise, and vibration. Workers will squat or kneel on the floor when installing tiles [3]. If we rely entirely on the workers to set such large quantities of tiles, it will cost a lot of manpower and labor time, also can be physically harmful to workers [4]. Therefore, developing robotic floor-tiling to replace artificial floor tile installation will play a key role in the future of construction industry [5].

To use robotic floor-tiling instead of manual floor-tiling, the robot system must have the advantages in floor-tiling process such as higher efficiency, better quality, lower cost, and so on [6].

In the following of this section, the process of artificial floor-tiling is analyzed first, and then a floor-tiling robot system frame that can fulfill measuring and positioning function is designed.

1.1 Artificial Floor-Tiling Process Analysis

Thinset tiling method is one of the most widely used method in the current floor-tiling. Thinset tiling is also called dryset or drybond tiling [7], it uses a blend of cement, fine sand, and a unique blend of special additives to install tiles on an even substrate surface [8]. Fig.1 shows the thinset tiling process, this method can be described as the following steps [9]:

1. Level substrate by self-leveling epoxy or self-leveling cement.
2. Hold a notched trowel at a slight angle, push down and away to spread the thinset mortar to substrate surface or to tile's back evenly and following the same direction.
3. Set tiles and spacers, plug wedge into spacer to leveling tiles.
4. Repeat thinset spreading, tile setting, spacer setting and tile leveling till all tiles are installed, then grout joints and further clean the room.

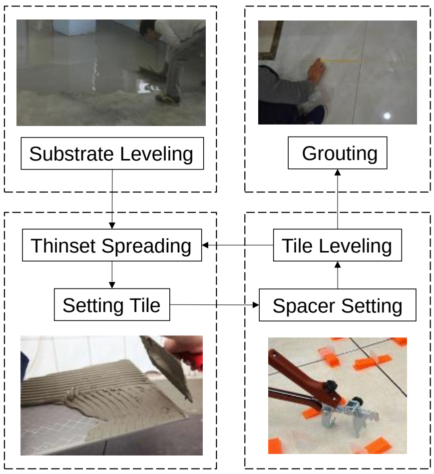

Figure 1. Process chart for thinset tiling

Thinset tiling has the following advantages compared to traditional thick-bed tiling:

- Less steps and easy operation.
- Lower cost and higher efficiency.
- Stronger bonding strength.
- Use less material and save more space.

Therefore, a floor-tiling robotic measuring and positioning system frame is designed based on thinset tiling method.

1.2 Frame Design of Floor-Tiling Robot System

The measuring and positioning system is the most critical component of the floor-tiling robot. By analyzing the artificial floor-tiling process, the measuring and positioning system can be divided into several subsystems to realize the precise placement of tiles [10]. Fig. 2 shows a general floor-tiling robot's measuring and positioning frame diagram, it basically consists of the following subsystems [11]:

- HMI (Human Machine Interface), which is the medium for information interaction between the control system and the operator.
- The main controller, which is responsible for sending control commands to and receiving statuses from the slave controllers of the subsystems.
- The mobile platform system, which is a crucial part of the floor-tiling robot to achieve a wide range of operations.
- The actuator system and robotic arm system, which contribute to the grabbing and placing of tiles.
- The sensor system, which is the key part of the floor-tiling robot, in order to implement measurement and carry out positioning functions when tiling.

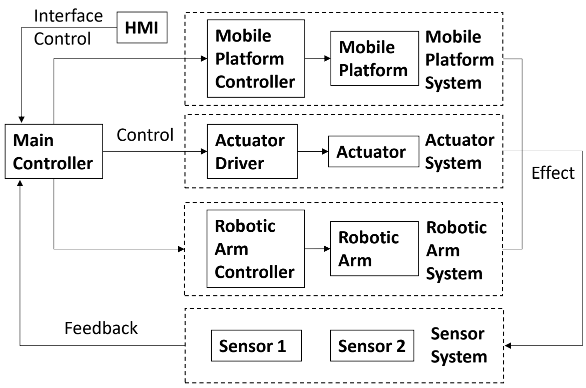

Figure 2. General floor-tiling robot's measuring and positioning system frame diagram

2 Hardware Platform Design

In this section, the hardware part of each subsystem is built according to the previous general floor-tiling robot's measuring and positioning system frame diagram, and the communication of the whole hardware platform is established through various communication modules [12].

2.1 Subsystems

According to the suitable measuring and positioning method used by the floor-tiling robot, the system is divided into the following five subsystems, which are introduced separately.

2.1.1 Point Laser Measurement System

The point laser measurement system contains two sets of measurement modules. Two sensor heads mounted on the end tool can measure one edge of a tile at the same time, and obtain relative position deviation data. Precise positioning function is achieved through position correction algorithm.

As shown in Figure 3, IL-300 is used as sensor head, which has 30 micron repeatability, ±0.25% F.S linear accuracy, 300mm reference measurement distance, and the measuring range is 160 to 450 mm from the laser head. The IL-1000 and IL-1050 are used as amplifiers, and the two amplifiers are plug-in connected to save connection cables and space. The DL-EN1 communication module is used to transmit laser measured data.

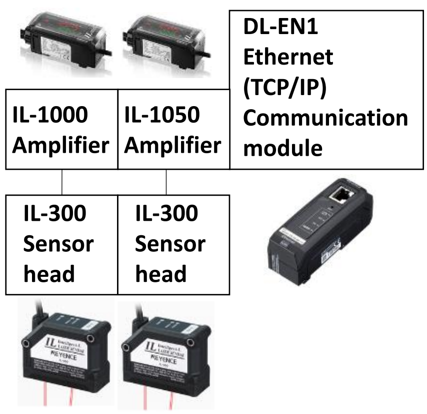

Figure 3. Point laser measurement system frame diagram

2.1.2 Pneumatic System

The using of pneumatic system with the suction cup is the most suitable method for grasping and placing tiles or other flat objects.

As shown in Figure 4, four suction cups with a diameter of 25mm are used for the pneumatic system to grab and place 300mm×300mm tiles with the weight of about 2 kilograms after calculation and selection. The assembled vacuum generator can monitor the air pressure in real time and control it by switching the supply valve and destruction valve. The air source uses an air compressor and a filter valve is installed at the outlet to clean the air to prevent dust from clogging the vacuum generator.

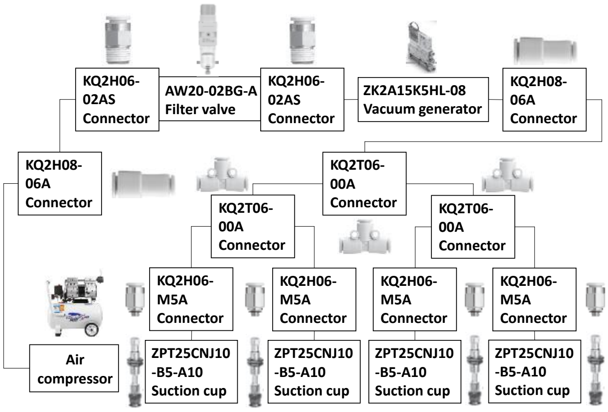

Figure 4. Pneumatic system frame diagram

2.1.3 Main Controller and Terminal System

The German Beckhoff modular products are used for the main controller and terminal system, which have the characteristics of reliable performance, fast transmission rate and convenient installation and disassembly.

As shown in Figure 5, the embedded PC is used as the main controller, which most of the algorithms are compiled and written into. The embedded PC coordinates the work of each subsystem controller. The power system can provide a stable 24V DC power supply, which can not only supply power to the embedded PC, but also support the power requirements of other subsystems. The subsequent terminals are responsible for information interaction with the communication modules of each subsystem, and the multiple subsystems are combined into a complete measuring and positioning system design of robotic floor-tiling.

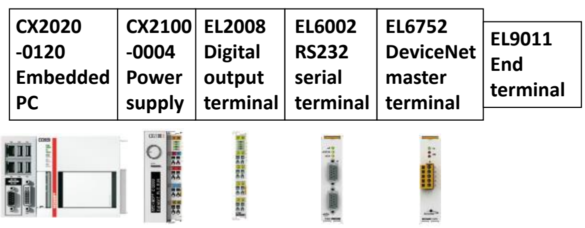

Figure 5. Main controller and terminal system frame diagram

2.1.4 Robotic Arm System

Figure 6 is the robotic arm system frame diagram. The Yaskawa industrial robot products are used in the robotic arm system. The GP7 industrial robot has six axes of freedom and a load of 7 kilograms, which can meet the requirements of tile measuring and positioning. Each action of the robotic arm is programmed by the teaching programmer and written into the YRC1000micro control cabinet. MOTOPLUS software is used to write the protocol for the data exchange between the control cabinet and the Beckhoff embedded PC, the protocol is programmed on the computer and eventually written into the control cabinet.

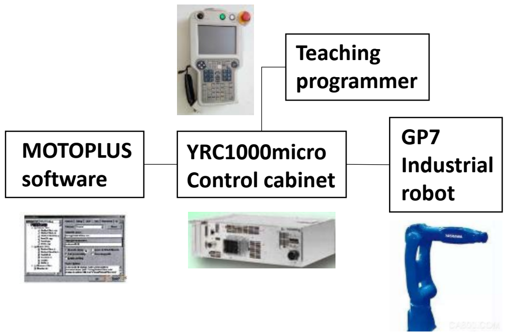

Figure 6. Robotic arm system frame diagram

2.1.5 Mobile Platform System

The mobile platform has a load capacity of 200kg, Figure 7 shows the mobile platform system frame diagram. The mobile platform system uses an STM32-based control board. The movement program in the control board sends drive commands to the four servo drives. Each servo drive drives a servo motor connected to a Mecanum wheel for rotation. The Mecanum wheel is one kind of omnidirectional wheel. The mobile platform based on the Mecanum wheel has a minimum turning radius of 0mm, it is flexible in movement and can move laterally. And the control board is equipped with a wireless module, the mobile platform can be controlled through the remote control.

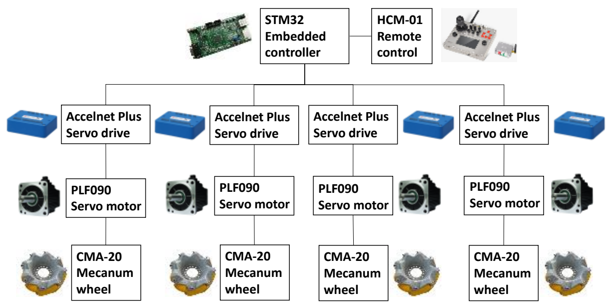

Figure 7. Mobile platform system frame diagram

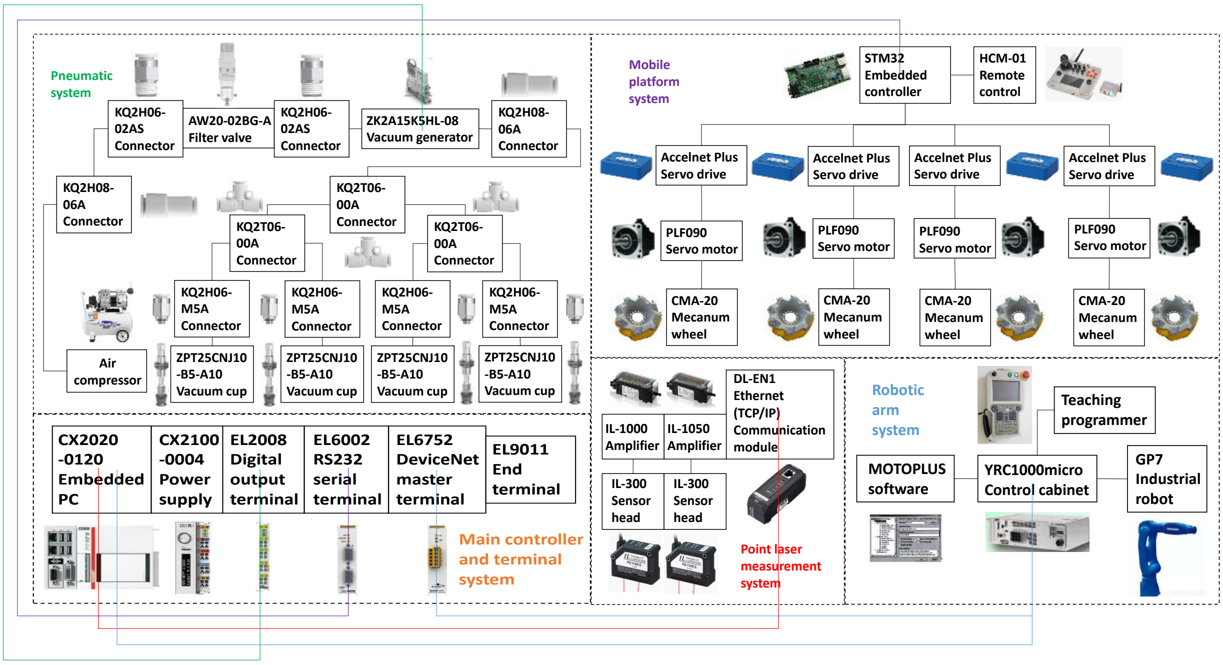

Figure 8. Measuring and positioning system's module communication frame diagram

2.2 Module Communication

As shown in Figure 8, there are several ways to communicate between subsystems.

The main controller controls the vacuum generator in the pneumatic system by EL2008 digital output terminal, and supply valve and destruction valve in the vacuum generator is controlled by the digital output, the communication cable is indicated in green.

Communication between the main controller and the point laser measurement system is realized by Ethernet TCP/IP, and TCP/IP has the advantage of reliable data transmission. The communication cable between the CX2020-0120 embedded PC and the DL-EN1 is indicated in red.

The main controller and terminal system and the mobile platform system is realized by serial port RS232. RS232 is one of the most commonly used serial communication methods, which is suitable for data transmission in non-real-time application conditions. The communication cable between the EL6002 serial terminal and the STM32 embedded controller is indicated in purple.

There are two communication ways between the main controller and terminal system and the robotic arm system. One is the Ethernet TCP/IP, which is used for robotic pose transmission, and the other is the fieldbus DeviceNet. The DeviceNet has the characteristic of high real-time performance, which is used for the transmission of motion commands sent to the robot by the main controller. Both communication cables are indicated in blue.

3 Software Environment Establishment

After the hardware platform of the robotic floor-tiling system is built, the software environment should be established in the system. The software design can be completed in three steps. The principle of tile measuring and positioning is analyzed firstly. Then, the task assignment is performed to figure out which tasks each subsystem needs to complete in a complete measuring and positioning process. Last, the control flow is developed so that each task can proceed in the order.

3.1 Tile Measuring and Positioning Principle

Figure 9 shows the schematic of tile measuring and positioning. Firstly, the end tool picks up the tile 2 and moves along the yellow arrow. When the laser spot of one point laser sensor moves from the ground to the tile 1 and another sensor head's laser spot still shoot on the ground, the end tool will slightly rotate along the orange arrow and continue to move along the yellow arrow until both laser spots shoot on the tile 1's edge. The good parallelism of the gap between two tiles is achieved by this method.

Secondly, the end tool moves back and forth along the green arrow, so that the two laser sensors can measure the range between the two red lines on the tile 1 and determine the placement position of the tile 2. In this way, the good linearity of a row tiles can be achieved.

In the process of measuring and positioning, the good levelness of the end tool is guaranteed by a gyroscope mounted on the end tool. And the relative position of the tile 2 to the end tool can also be calculated through the two laser sensors data. When laying the second row of tiles, the same method can be used for measuring and positioning by rotating the end tool 90 degrees clockwise.

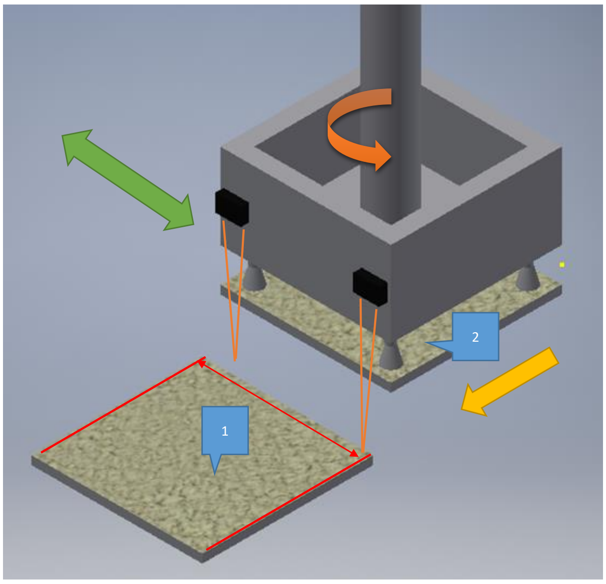

Figure 9. Tile measuring and positioning schematic

3.2 Task Assignment

According to the tile measuring and positioning principle. The process of robotic floor-tiling is divided into the following tasks to complete:

- Reference tile measuring.
- Reference tile calculation.
- Tile picking.
- Tile measuring.
- Tile calculation.
- Target position calculation.
- Tile placing.
- Return to starting point.
- Mobile platform movement.

3.3 Control Flow

The control flow is the actual flow and order of instructions and data between subsystems in the measuring and positioning process for several tasks. Figure 10 is the control flow chart of measuring and positioning process, for example in reference tile measuring task, the main controller sends movement instruction to the robotic arm. By the control flow, system tasks can be executed correctly and orderly.

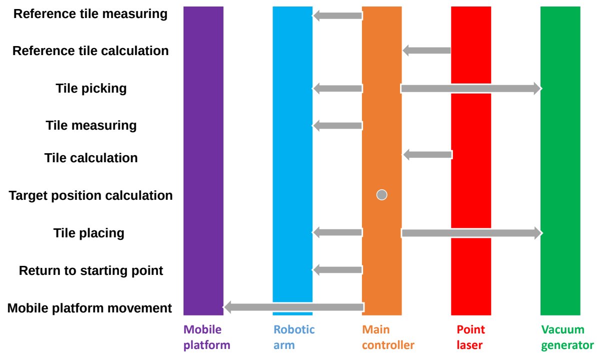

Figure 10. Control flow chart of measuring and positioning process

4 System Test and Results

Before the measuring and positioning test of the robotic floor-tiling, it is necessary to adjust the jump value of the point laser sensors. The jump value of the point laser sensor is the basis for recording the posture of the robotic arm which includes 6 parts: X, Y, Z, Rx, Ry, and Rz in the Cartesian coordinate system. And when the laser spot moves from the upper edge to the lower edge of the tile or reversed, the hopping signal generated by the point laser sensor will cause the robot to automatically record the current posture as a reference value for the test. In this test, the laser sensor has an optimum jump value of 4.2 mm.

Figure 11. Measuring and positioning test of robotic floor-tiling

The measurement and positioning test of the tile is shown in Figure 11. After placing the reference tile, the robotic arm continuously sets 10 tiles according to the position of the reference tile, and the posture of robotic arm will be recorded. Comparing the actual position with the theoretical standard position of the 10 tiles estimated from the reference tile position, the data results can be obtained in Table 1. The linear deviation range is within 0.5mm, and the rotation deviation range is within 0.2°. Results meet test expectations.

Table 1. Tile position deviation in measuring and positioning test

Tile number	X deviation (mm)	Y deviation (mm)	Z deviation (mm)	Rx deviation (°)	Ry deviation (°)	Rz deviation (°)
1	0.420	0.339	0.194	0.125	0.112	0.157
2	0.376	0.491	0.104	0.112	0.194	0.171
3	0.108	0.110	0.178	0.123	0.146	0.120
4	0.466	0.191	0.266	0.123	0.107	0.121
5	0.217	0.151	0.261	0.135	0.195	0.152
6	0.379	0.240	0.339	0.181	0.119	0.140
7	0.175	0.124	0.499	0.165	0.109	0.163
8	0.124	0.173	0.154	0.171	0.140	0.155
9	0.479	0.205	0.483	0.196	0.136	0.191
10	0.258	0.396	0.485	0.199	0.102	0.126

5 Conclusions and Future Works

This paper describes a design of measuring and positioning system for robotic floor-tiling. This system uses embedded PC as the main controller to exchange data with subsystems through various communication terminals. In the system, the main controller communicates with the robot controller via Ethernet TCP/IP and DeviceNet field bus, which can ensure the correctness and real-time of data transmission. And the connection between the main controller and the point laser measurement system is also Ethernet TCP/IP which can ensure the reliable measuring data transmission. RS232 serial port is used to control mobile platform that can save costs and meet non-real-time communication requirements. And digital output is simple and efficient enough to control the opening and closing of the supply valve and the destruction valve in the vacuum generator. The test shows the measuring and positioning system has a high precision. And this system can be seemed as the basis for the subsequent research of the floor-tiling robot.

In future works, the point laser sensors need to be replaced by other sensors, and the measuring and positioning principle also need to be improved cause the low process efficiency. More subsystems need to be added to complement the functionality of the entire robotic floor-tiling system.

References

[1] Navon, R. Process and quality control with a video camera, for a floor-tilling robot. *Automation in construction*, 10(1):113-125, 2000.

[2] Baraldi, L., & by ACIMAC, M. M. E. S. World production and consumption of ceramic tiles. AMERICA, 1(9.2):7-7, 2016.

[3] Lichtenberg, J. The development of a robot for paving floors with ceramic tiles. *Proceedings of the 20th International Association for Automation and Robotics in Construction*, 85-88, Eindhoven, Holland, 2003.

[4] Apostolopoulos, D., Schempf, H., & West, J. Mobile robot for automatic installation of floor tiles. *In Proceedings of IEEE International Conference on Robotics and Automation*, pages 3652-3657, 1996, April.

[5] Wong, J. K., Li, H., & Wang, S. W. Intelligent building research: a review. *Automation in construction*, 14(1):143-159, 2005.

[6] Baharudin, M. E. Development of Automatic Floor Tile Laying Machine. Universiti Sains Malaysia, 2007.

[7] TCNA.(n.d.). Thick-Set/Thick-Bed. Online: http:// www.tcnatile.com/faqs/71-thick-setthick-bed.html.

[8] C-Cure (n.d.). ThinSet 911, dry-Set Portland Ceme nt Mortar. Online: https://www.c-cure.com/doc/ds/ ds_thinset911.pdf

[9] FloorsTransformed. (n.d.). Applying The Thinset Mortar. Online: http://www.Floors-transformed.co m/thinsetmortar.html

[10] King, N., Bechthold, M., Kane, A., & Michalatos, P. Robotic tile placement: Tools, techniques and feasibility. *Automation in Construction*, 39:161-166, 2014.

[11] Vähä, P., Heikkilä, T., Kilpeläinen, P., Järviluoma, M., & Gambao, E. Extending automation of building construction—Survey on potential sensor technologies and robotic applications. *Automation in Construction*, 36:168-178, 2013.

[12] Chatila, R., & De Camargo, R. F. Open architecture design and inter-task/inter module communication for an autonomous mobile robot. *In Proceedings of IEEE International Workshop*, pages 717-721, 1990, July.