PAINTING TOOL CONTROL AND SCENARIO FOR GONDOLA-TYPED FACADE MAINTENANCE ROBOT SYSTEM

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ABSTRACT

We have researched a gondola-typed building façade maintenance robot system. Its main goal is to paint reinforced concrete walls as fast and wide as possible. We applied a horizontal array of painting spray nozzles which have uniform heights. In order to apply them to the gondola robot, a painting scenario is designed. Basically, when the gondola robot goes from the bottom to the top of the wall, wall shape recognition is executed. While it goes down, the nozzles are turned on and off in accordance with the wall shape.

KEYWORDS

Gondola robot, building façade, maintenance, painting tool

1. INTRODUCTION

Building façade is a dangerous place for human workers. They rely on only some ropes to navigate on the façade. Many terrible falling accidents have occurred, and they have worked under a lot of mental stress. However, high-rise buildings have increased all over the world. Some of them are over 300 meter height. More façade maintenance is required.

There are many approaches to take human workers away from the dangerous working place, and robot technology has enabled it. A robot moves on glass wall using suction pad and pneumatic cylinders [1]. Gondola-typed robot system has been used widely because wire supports the robot body [2, 3]. Rail-guided robot system is another platform to navigate on the wall [4]. Purposes of the robot systems are also various. For example, they can clean curtain walls made with glass [1, 2] or windows [4]. Painting is another important job for building maintenance [3].

We have focused on the gondola typed robot system to paint on reinforce concrete wall. Even though it is sufficiently meaningful as an accident preventer, we also want to make the robot system valuable economically. Our approach is to paint wider wall fast with the gondola platform of conventional size. The widely used size is useful for the robot system because many supplies, parts, and actuators are sharable with existing gondola boarded by human. As we premise a professional robot gondola service company as our business model, sharing delivery system with conventional gondola is also important.

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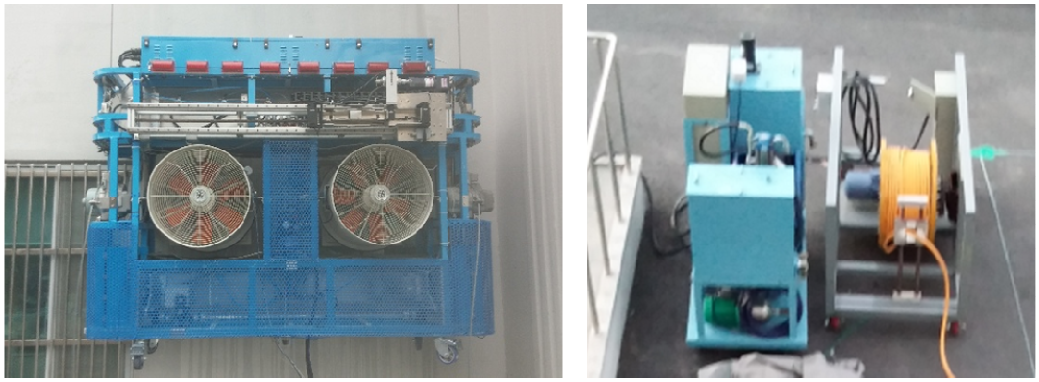


(a) (b)

Figure 1. (a) Gondola-typed robot system (G-BMR R6)
(b) Painting tool space

Fig. 1 (a) is our gondola typed robot platform. At top of platform, there are eight painting spray nozzles at uniform height. The nozzles are connected to an aluminium manifold block. Each nozzle is controlled with its air solenoid valve. The air compressor for valves is located between two suction fans. These fans provide contact force between the gondola frame and the wall. The paint pump is located on the ground as shown in Fig. 1 (b), and paint tube is connected between the gondola and the pump. We already tested with 100 meter long tube at 60 meter height building. Two endless winders at both sides of the gondola run on each wire ropes. Each speed is controlled in order to keep the balance of the platform.

Based on this approach, we proposed a painting tool system for the gondola robot system in this paper. We selected spray nozzle type tool system. In Chapter 2, details of our tool system will be introduced. Its usage will be shown in form of scenario in Chapter 3. With experiment, practical conditions for better performance will be discussed in Chapter 4.

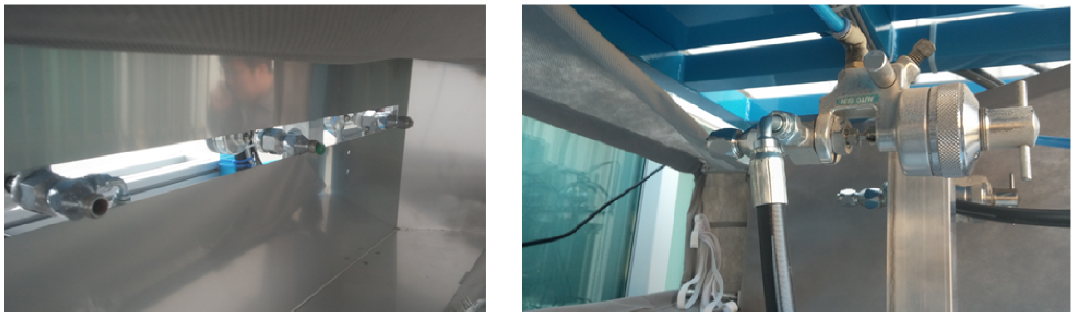
2. TOOL SYSTEM AND ITS CONTROL FOR GONDOLA ROBOT SYSTEM

The aim of our gondola robot system is to paint on RC (reinforced concrete) wall at 15 m^2/min. Because we use endless winders which are already accepted for gondola typed industrial machines, the vertical movement speed is fixed as 6 m/min. Therefore, we need to get at least 2.5 m painting width.

We have compared two types of painting tool. First is x-y plotter type tool type [3]. It is a frame that some nozzles move its inside. Therefore, there are two x-y coordination for gondola control. One coordinate is an x-y plane on building façade that the gondola navigates. The other is an x-y plane inside of plotter frame. The gondola should accept stop-and-go movement because the plotter needs time to cover the second x-y plane. On the other hand, this motion guarantees the static contact between the gondola frame and wall. It enables detail painting. Additionally, if necessary, real time tool change is also possible.

Second is an array of spray nozzles. The required motion for this tool is to move continuous speed from top to bottom. Its painting quality is combination of painting nozzle pressure and moving speed. Therefore, this tool system can paint faster than x-y plotter type, and it is more favourable in economic view. However, this system should use only one colour paint, and fixed type nozzle.

In order to get faster painting speed, we selected the second type tool system. Especially, in the process of RC building construction, this tool system is most suitable to primer coat. Many construction workers say that unmanned system of primer coat painting is also meaningful. It can also reduce the time that workers work on ropes.



(a) (b)

Figure 2. (a) The array of spray nozzles for G-BMR R6
(b) A spray nozzle and its air solenoid valve

Fig. 2 (a) is the array of spray nozzles heading to the wall. In order to reduce side effects of scattering paint rebounded to the wall, aluminium case covers around nozzles. This case also protect envelope of paint spray from disturbance of wind partly. Fig. 2 (b) is one of the painting nozzle. Paint is provided through the black tube, and air goes through blue tube. When we applied simple solenoid valves to the nozzles, the solenoid is often blocked by dried paint particles. After air solenoid valve is applied, the malfunction rarely occurs.

3. PAINTING SCENARIO FOR GONDOLA ROBOT SYSTEM

Our platform has a horizontal array of eight spray nozzles. They are activated when the gondola moves from top to bottom of buildings. If the gondola encounters an obstacle, corresponding nozzle will be stopped.

In order to find the obstacle, we have researched wall shape recognition [5-7]. We input distance between the wall and the gondola as system parameter. If somewhere on the wall is out of this limit, we stop the corresponding nozzle when the gondola tools are on that place. Additionally, if the balance of gondola is out of limitation, the entire nozzles are stopped.

In accordance with above tool strategies, painting scenarios has following procedures. First, the gondola robot system is checked initially on the ground. Second, the gondola goes to the top of painting area while wall shape recognition sensor data are gathered. Third, at the top, wall shape recognition algorithm is executed, and the location of windows and obstacles are described. Forth, the gondola goes down and starts to paint. Sixth, if a painting nozzles on the area of window or obstacle, it will stop painting. Finally, at the bottom of painting area, all tools stop to work. These procedures are shown with a flowchart in Fig. 3.

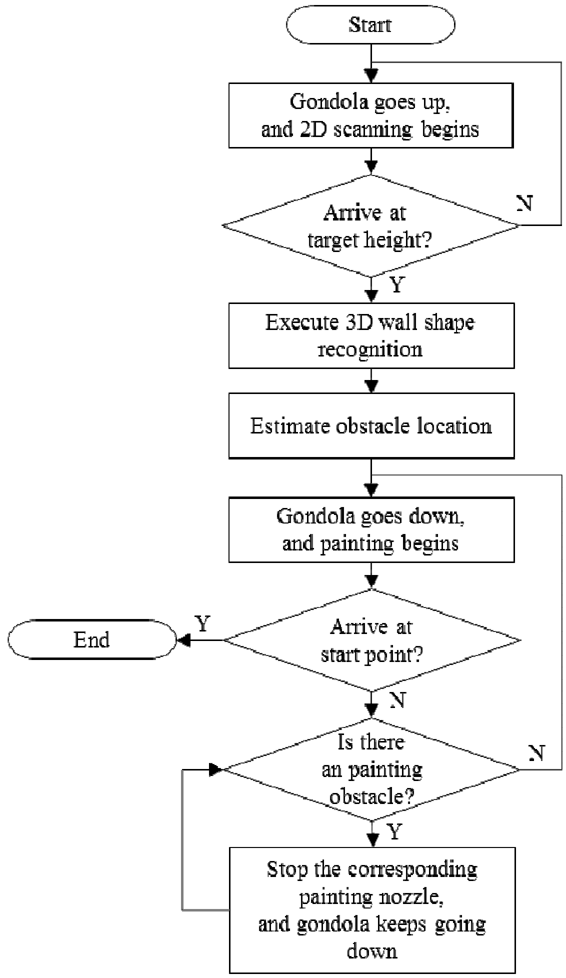


Figure 3. Flow chart for the tool control scenario

Figure 4 shows the output concept of proposed painting tool system. Figure 4 (a) shows a wall before painting. Orange line is outlines of each painting spray nozzles. For convenience, there are six nozzles as an example, so there are six areas. Blue squares are windows on the wall. The gondola should not paint on the windows. If some drops of paint approach on them, extra cleaning cost may be charged or compensation for the damage may be claimed. As the shown procedures above, the nozzles will stop on window areas.

Note that the tools are painting sprays. The edge of painted area is not deterministic. It differs in accordance with various causes such as wind speed, paint viscosity, ambient temperature, pressure of pump, and paint tube condition. Therefore, we decide to leave unpainted margin around window area to protect from unwanted paint. This margin will be painted by human worker through window. Because our main goal is to make human workers not to use rope to maintain the wall, this approach is acceptable. Figure 4 (b) is the state after paining. Orange colour is the painted wall. At the top of the wall, every nozzles starts painting, and on the window area, third, forth, and fifth paint nozzles stop. After the gondola passes window area, the stopped nozzles resume.

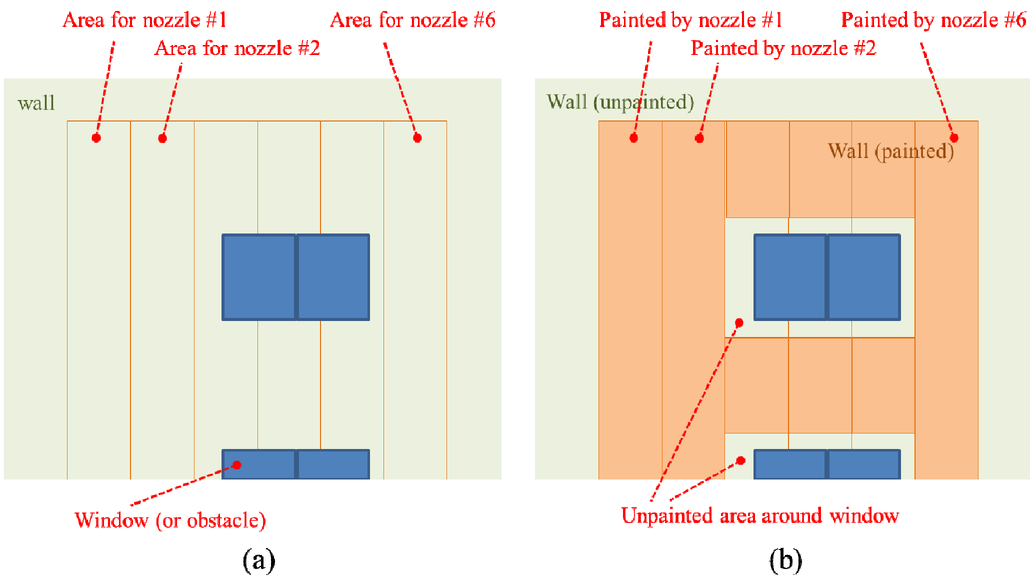


Figure 4. (a) Wall before painting execution
(b) Painting coverage in accordance with the proposed painting tool

4. EXPERIMENTAL RESULT

Control part of our system is divided to two controller. One is a Windows 7 single board computer, and it covers sensor processing, wall shape recognition, and GUI. The other is an AVR xmega128 which executes motion control algorithms of the gondola robot system. In a computer programming in Windows SBC, the program is implemented with MFC, and there is a timer callback function. After gathering every sensor data and setting parameters at each iteration, the algorithm decide which nozzle should be turned on. The collected data is ARS sensor, 2D laser scanner, and laser range finder. Additionally, there are some monitoring and fail-safe sensors such as wind velocity sensor and AVM (Around View Monitoring System) [9].

Figure 5. Wall painted by G-BMR with proposed tool system

We painted a wall of the BMR mock-up building at Hanyang University using the proposed painting tool and procedures. When the gondola robot met the windows, only first, second, and third tools are activated. The other tools stopped properly as shown in Fig. 5.

When the proposed tool scenario is applied, there is another factor to get more effectiveness. It is the location of the gondola hangers. As shown in Fig. 4, the gondola hangers were attached on the building parapet, and they are movable because they are fastening screw type hangers [8].

To get more effectiveness, it is important to reduce unpainted area. The top and bottom margin is determined by the nozzle on-off timing, and its performance is based on the wall shape recognition. The left and right margin comes from the gap between the painting nozzles, and it is fixed as mechanical design parameter. However, in the view of a post-processing, if the unpainted areas are concentrated to the one side, it will help human walkers to paint them. It can be accomplished with selecting appropriate location of hanger. Figure 4 is a good example. The left margin of the right window is narrow, and only simple painting is required. Additionally, if plural primer coats are acceptable, different deployment of hangers can get rid of both of left and right unpainted margin.

Figure 6. Wall painted by G-BMR with proposed tool system

However, Fig. 6 is an output caused with poorly tuned parameter. Left and bottom margin are acceptable. Post-processing through the window can cover them. However, top margin is too wide. Even though the margin can also covered, the painting tool control algorithm can reduce it with simple parameter tuning.

Right side of Fig. 6 was not painted because it was out of painting tool coverage. The reason is that the place is the corner of the building, and the gondola is block by side wall. The horizontal width of unpainted area is the width for endless winder. In order to paint this area, we are trying to apply 4-axis auto painting robot arm. By adjusting the position of the nozzle at the end of the robot arm, the corner will be painted. If the corner has complex structure, the gondola moves plural times to cover entire corner.

5. CONCLUSIONS

In order to get a more benefit-cost ratio, we applied a horizontal array of spray nozzles as the painting tool of the gondola-typed building façade maintenance system. With 6 m/min vertical movement speed, we could get about 15 m^2/min painting speed. On the other hand, this tool system is controlled only with on-off states, and we should endure unpainted area around windows on the wall. Our approach to reduce them is to get well-tuned wall shape recognition and gondola hanger location.

As a future work, we have another challenging problem. Even though spray-typed painting tools are fast and effective, they are prohibited in accordance with some environment regulations. It means we need a roller-typed paint tool is required, and it should be suitable to the automated and unmanned gondola-typed building façade maintenance robot system.

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