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System Design Considerations for Autonomous Wall Painting Robot

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Abstract

Wall painting is a repetitive, exhausting and hazardous process which makes it an ideal case for automation. Painting had been automated in automotive industry but not yet for the construction industry. There is a strong need for a mobile robot that can move to paint interior walls of residential buildings. In this paper, the conceptual design of an autonomous wall painting robot is described consisting of an arm that scans the walls vertically and is fitted on a mobile robot base to give the lateral feed motion to cover the painting area. The design objective is to satisfy the criteria of simplicity, low weight, low cost and fast painting time. Ultrasonic sensors are fitted on the arm and the mobile base to adjust the motion limits and maneuver in the room area. A control system is designed to guide the arm motion and plan the mobile base motion.

1. Introduction

The development of service robots became popular recently due to the fact that the society needs robots to relax humans from tedious and dangerous jobs. In Egypt, as well as other developing countries, the increasing population stimulates the construction-related activities such as interior finishing and painting. Painting is classically done by humans and generally requires exhaustive physical efforts and involves exposure to dangerous chemicals. Chemicals can seriously impair the vision, respiratory system and general health of the human painter. These factors make painting an ideal candidate process for automation. More than 100,000 apartments are built annually in Egypt, with an average painting area of 40 million square meters (based on an average 100 m2 apartment area with 400 m2 painting area). The surface area of painting is more due to the renovation work and expected population increase in the future. This demand imposes challenges that will hardly be met using human painters only in the next decade. Therefore, development of a painting machine that can perform the painting task with minimum human intervention is needed and will improve the quality of painting. The need for an autonomous painting robot is both clear and strong.

Automated painting had been realized successfully in the automotive industry to paint millions of cars in the assembly lines. This industry uses spray painting and the robotic system is fixed in the assembly line. The domestic painting robots should be different in the sense that robots should have mobility so that it can move to paint the fixed walls. Also, the domestic painter robots should use roller instead of spray which is the common practice in the market to attain customer satisfaction. In the open literature, few systems were reported to serve the task of wall painting. A full scale mechanism for ceil painting was introduced by Aris et al. [1], having 3DOF without considering those of the platform and a working envelope of (84x72x122 cm). Ceiling area of 46m2 were painted in 3.5 hours which is 1.5 times faster than manual painting. However, this robot is bulky and has small work space and designed to paint the ceiling only.

Kahane et al. [2] and Warszawsky et al. [3] developed a robot for interior finishing tasks of painting, plastering, tiling and masonry. They used a standard robot arm with 6 DOF (Degrees Of Freedom) with 1.7 m reach and 30 kg payload. Their robot was mounted on 3 wheeled mobile robot which gives another 3 DOF. The robot can move between workstations and deploys four stabilizing legs at each site. This robot cannot be used in residential buildings due to its 500 kg heavy weight. A reduction in painting time of about 70% was reported for wall painting compared to human painting, and claimed to increase extra 20% if ceil painting is included.

A scaled down model for interior wall painting using multi-color spray were implemented by Naticchia et al. [4,5,6]. They also used a standard robot arm with 6 DOF, with 0.4m reach and 4 kg payload. They proposed to fix it on a 2 DOF hexapod for lateral motion though this was not experimentally verified.

Sorour et al. [7] described a full scale wall painting robot, composed of a simple two link manipulator fitted on a mobile platform. The system worked but with slow painting rate. Their work was motivated by the fact that painting arm need not to be a 6 DOF arm, since it is overqualified for the painting job, and hence it was replaced with a simple 2 link arm.

In this, paper, we show the conceptual design of a new painting robot based on the realization of the drawbacks of the design of system described in [7]. The design modifications are made for both the painting arm and the mobile base to satisfy the system requirement. This paper is arranged as follows, the next section discusses the basic system requirements and economic and technical considerations. In section 3 the robotic system module design is presented. Section 4, describes the control of the mobile platform and the control algorithm of automated painting is described. Conclusions are finally given in Section 5.

2. System Requirements

At first, we have to make explicit statement about the assumptions needed for the robot operation and can be summarized as follows:

1. The robot moves on flat terrain and no inclination.
2. The painting wall is vertical, smooth and flat without any obstructions, such as windows or hangers.
3. The painting fluid is supplied by a human user to a tank in the robot.
4. Roller maintenance and cleaning is also left for user.
5. The walls to be painted are instructed by the user through a suitable interface.

The motion requirements of the robot arm is shown in Fig.1 which shows the basic need to move the roller vertically for painting and the need for horizontal motion to make direct contact with the wall and to depart from the wall.

Figure 2 shows the motion requirements of the robot base for placement of the whole robot and maneuvering. The robot needs to move parallel to the wall to make lateral feed motion and to move normal to the wall to start and depart the painting process.

The need to rotate is essential to adjust the robot orientation against the wall.

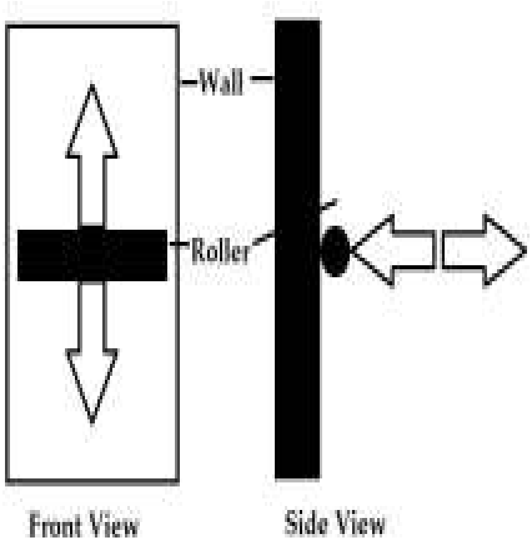

Fig.1. The motion requirements for the painting arm.

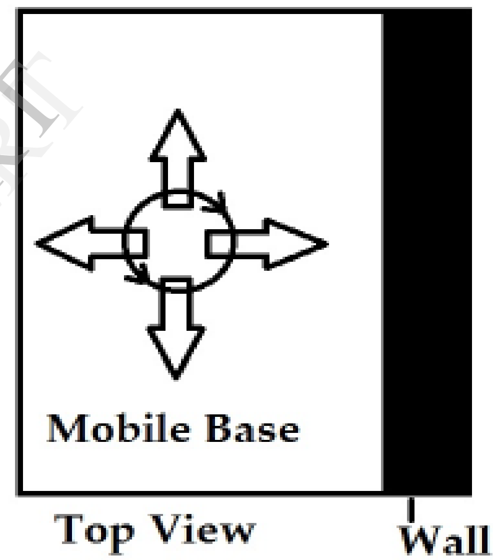

Fig.2 Motion requirements for the mobile base.

The system requirements and specifications can also be summarized as follows, the robot should:

1. Paint the walls in a once-through fashion vertically from top to bottom.
2. Be stable and not to flip over during painting or maneuvering.
3. Paint the walls and the ceilings.
4. Have painting speed higher than that of human painter (0.15 m2/min).
5. Have light weight, less than 35 kg (excluding painting liquid), so that it can be carried by a single human.
6. Have foldable structure to fit into a single bag for human to carry conveniently.
7. Have simple interface for non-technical users.

8. Have affordable price so that painting cost does not exceed 50% of the cost of human painters.

The economic considerations are important for the system marketing. The unit is not intended to replace humans completely, but to assist it to finish the painting task faster. Therefore, the price should not exceed that of manual painting by 50 %. Therefore, we consider that daily rental charges should account for that factor. Price range one day le 700 $100 x20 =2000, that means max price USD $ 20,000. The human user should be prompted and warned against system errors. Change and refill of paint should be typical functions for the user interface.

3. Conceptual System Design

The system modules can be described as shown in Fig.3, which consists of an arm motion control module, motion planning module, paint feed module and a user interface module. Another painting quality inspection module is intended in the future using vision system. In our conceptual framework, the robot structure should have a vertical scaning mechanism attached on top of a mobile base that allows for lateral feed motion of the robot.

- **Arm**

For the arm, and referring to Fig.1, the required motion is 2DOF, vertical motion and motion into the direction normal to wall surface. There are several solutions for such motion such as making a simple multi-link mechanism for the vertical linear motion. The normal motion can be made by the arm mechanism or through the base. The simple two link mechanism used in [7] will be used but replacing slow stepping motors with fast dc servo motors.

- **Mobile Base**

The mobility requires fitting the arm on a mobile base, and referring to Fig.2, it is required to have 3 DOF as indicated that is two planar moving directions and one for rotation to adjust robot pose relative to the wall plane.

Although a simple two wheel differential drive can achieve this motion requirements, it will take long time for the robot to make the lateral feed motionn after each vertical roller stroke. Therefore it is better to use the three wheel or four wheel arrangement. Although three wheel arrangement seems a good choice, in the sense of easier control, but due to the expected high loading on the wheels whether due to weight or dynamic forces of painting, the wheel slippage will be problematic. Hence four independently driven wheels is the preferred choice although this will complicate the control algorithm, but it will ensure suitable system maneuverability during the painting process.

With four individual motors for every omni-directional wheel, this mobile robot can change its orientation while its translational motion. The three alternatives for mobile base structure are compared in Table 1.

Table 1. Alternatives for Mobile Base Configurations

Structure	Maneuverabilit y	Control	Cost
2 Wheel Dif.Drive .	Low	Easy	Low
3Wheel Drive.	Medium	Medium	Mediu m
4 Wheel Drive	High	Comple x	High

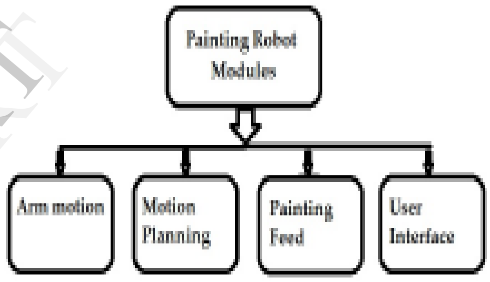

Fig.3. The modules of the painting robot.

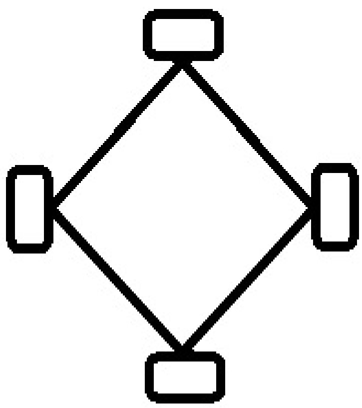

Fig.4. The arrangement of wheels on the mobile base.

The motion limits of the arm and the mobile base is sensed through using ultrasonic range sensors. The sensors are attached to the vertical scan end effectors to know the limits of painting stroke and are also attached to the base to detect the walls.

- **The Painting Feed Module**

A standard commercial module is used that make automatic painting fluid feed to the roller. The responsibility of ensuring enough amount of painting fluid and controlling its color is left for the human user at this stage, though it can be improved in the future to generate some messages for the user when the fluid is below the limits. The feed painting mechanism works on a supply of DC voltage and pumps the liguid throug a hose to the roller.

- **The Graphical User Interface**

The user interface should be made graphical for ease of use especially for non technical users. A touch screen with basic function and sample error message alerts is designed. A simple PC104 industrial computer will be used together with a touch screen. The major requirements of the interface are to:

1. Point to the wall needed to paint, controlling the number of paint layers.
2. Option to set the painting speed for considerations related to quality and paint viscosity.
3. Option of setting the wall/ ceiling painting.
4. Option for the method of motion planning.
5. Option to stop painting for roller cleaning or paint refill.
6. Option to work in team with other robots and or working with a supervising robot.

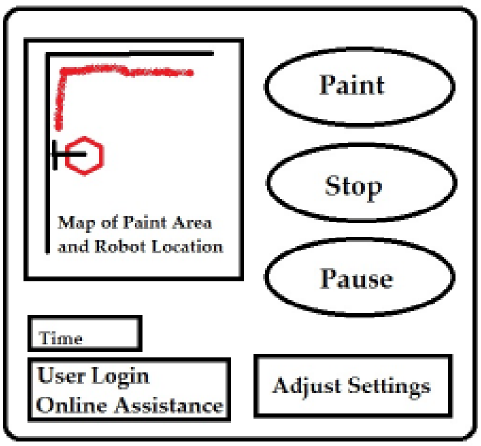

Fig. 5. Graphical User Interface.

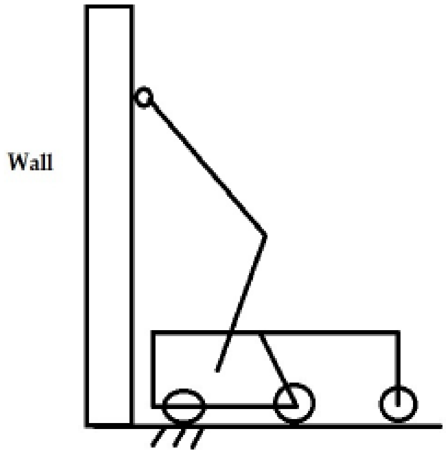

Fig. 6. Painting Robot Skeleton.

4. Control System

The two link robot arm is now made through ball screw joint drive as shown in Fig.7.

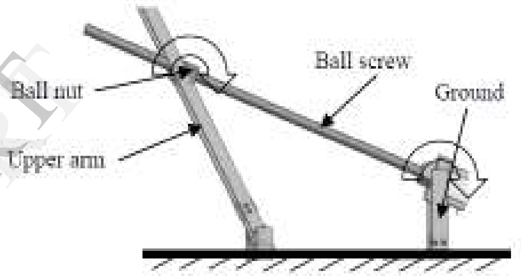

Fig.7 . Ball screw joint drive.

The specification of the joint drive mechanism is summarized in Table 2.

Table 2. Joint Driving Mechanism Specifications

Item	Description
First joint stepper motor ratings	2.12 Amp/phase, 2 N.m holding torque, 1.8 degree/step.
Second joint stepper motor	2 Amp/phase, 0.65 N.m holding torque, 1.8 degree/step.
Stepper motor size	Nema 23
Micro-stepping driver	50 VDC max. supply voltage, 4.2 A.
Ball nut and screw	16 mm screw diameter, 5mm pitch, 760 Kg.f load rating.

Two of the joint driving mechanisms are installed at each joint of the two link arm mechanism.
The algorithm assumes the platform is initially positioned somewhere in the middle of the room

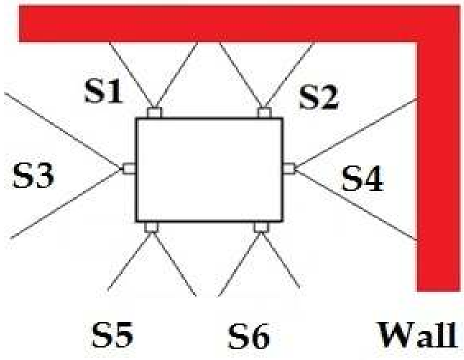

Fig. 8. Schematic representation of ultrasonic sensors as position and orientation feedback devices.

and facing the wall to be painted. The ultrasonic sensors shown in Fig.8, is used to measure the robot distance from the surrounding walls.

The control algorithm indicated by the flowchart shown in Fig.9 starts by scanning the front side of the platform using two front ultrasonic sensors, then according to the indicated distances it will move forward or backward till one of the sensors indicate the required value of, at this point we have reached our position in x and y directions and still have to adjust the platform's orientation.

After that it scans both sides of the platform in search for the nearest beginning of the facing wall. Then the platform moves toward it until the corresponding side range sensor indicates a clearance value of 5cm, then adjusts its orientation again. At this point the robot is ready to start painting the first strip of the wall with a width of 21 cm.

By finishing this strip the platform moves laterally a distance of 20cm (software adjustable), readjust its orientation and start painting the next strip and so on. An overlap of 1cm between every two successive paint segments is required to maintain paint continuity, and this overlap is adjustable based on experiments. The rear sensors are used to ensure that the robot does not hit any obstacle while it is maneuvering backwards. It should be noted that the interface of human user to select the wall is not yet implemented and will be done in future work.

The experiments ensured that the robot arm can do the vertical scan successfully and can adjust its location and feed through the width of the walls.

The current robot arm is designed to be stable so that the robot does not flip over while painting, but we intend to add a stabilizing wheel on the back side as schematically shown in Fig.6.

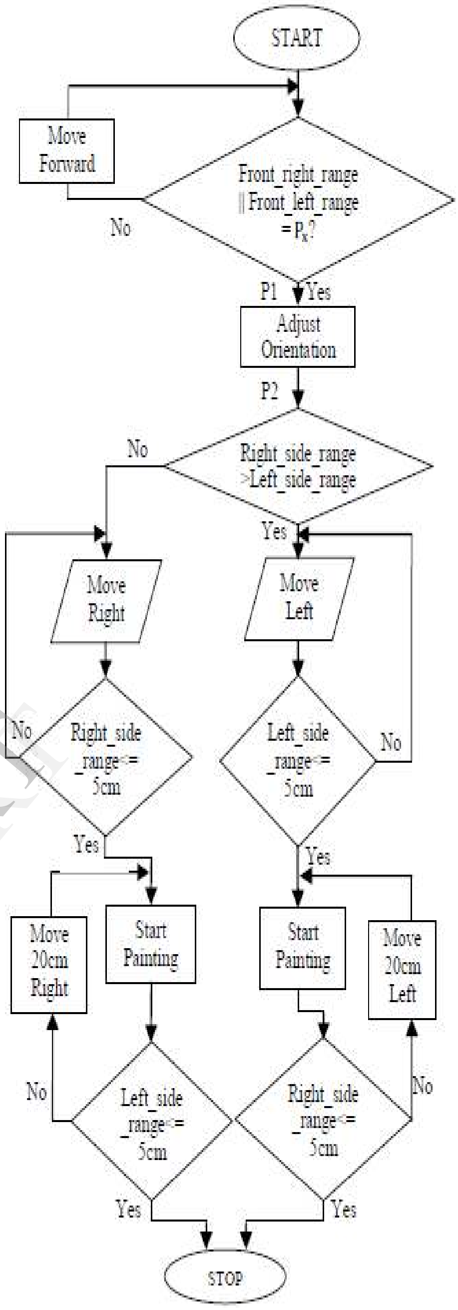

Fig.9 The robot control algorithm.

The current speed of the vertical arm is slow and this will be modified through changing the stepping motors with fast dc servo motors. The robotic arm design presented in past sections has been implemented in full scale as shown in Fig.10.

Fig.10. The robot real photograph.

5. Conclusions

The conceptual design of a mobile painting robot to be used for painting interior walls of building had been described. The robot uses a roller fed with painting liquid and keeps contact with the walls. The robot enables the roller to scan both vertically and horizontally the painted walls. The robot can maneuver to adjust itself in front of the wall.

The criteria for system design had been outlined and the system was implemented and tested. However, there is much scope for system improvement in the future to increase the painting rate and simplify the system design.

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