Robotics in Construction Industry

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Abstract
Automation through robots is not a new concept. Many of the manufacturing and service sectors are adopting most sophisticated robots to increase productivity and reliability. Construction industry which is most unorganized and labour intensive is no different. Robots are employed to map the construction site, to lay bricks, to fulfill materials as required etc. But still the modern huge structures and buildings are painted by human laborers. The chemical paints, working height poses high threat to the safety of painters. Adopting a Robot may eliminate these problem by working at great heights and improving the tangible benefits like productivity of painting process, reducing manpower, reducing construction lead time and construction costs thereby improving quality, work conditions, safety. Along with reviewing the development of automated wall painting, two new concepts of light weight, easy to handle exterior wall painting robot is discussed in this paper.

1. Introduction
The construction industry plays a very important role in national and global economies. In India investment in this sector contributes 6.5% of Gross Domestic Product (GDP) growth. Every Re.1 investment in the construction industry causes Rs.0.80 increment in GDP as against Rs.0.20 and Rs.0.14 in the fields of agriculture and manufacturing industry, respectively. Such an important sector is facing many challenges [9]. One such major hurdle is skilled labor shortage. With the advent of vertical development in construction industry the life risk to laborer’s has increased exponentially. These factors contributed to the shortage of laborers. It is the responsibility of the construction company to ensure safety of its working crew. We have numerous regulations regarding the same from concerned departments. These problems can be better addressed with automation through robots.
However, the degree of automation in construction and allied process are far less than in any other industries. Construction involves major allied processes like excavation, material handling, brick lying, floor finishing, wall inspection, Painting etc. Major advancements are seen in robotic control, sensing, vision, localization, mapping, and planning modules can ensure these jobs are done both accurately and precise.
Much of the processes like site mapping, brick laying, and material handling are automated in modern days [1]. But the most important finishing process the exterior wall painting has seen negligible automation and sophistication. Fig 1 shows the risk the painters take while working at heights. It’s also a fact that many lose their life while doing these works. Adopting semi or complete automation with
artificial intelligence and expert systems would be a solution for problems of these kinds ensuring much better monitoring and controlling of the entire process.

Fig:1 – Showing how painters toil risking their life

Numerous efforts in this regard are already done to considerable scale. But still none of the system is readily used in construction with ease. As many concepts discuss spray painting which we feel, may not suit exterior walls. Hence an alternate concept of automated roller painting is discussed in this paper. The concept is still in the CAD stage and hence only the concept is discussed without many details.

2. Literature survey

Many ideas and conceptual models are worked out by many engineers few of which are discussed below.

“TAISEI” painting robot [3] was designed to paint vertical surfaces, both textured and smooth finishes, with automatic detection and avoidance of windows. The robot section posses 8 spray guns [3].

"TAMIR", a 6 Degree of freedom (DOF) interior wall finishing robot developed by Warszawsky and Kahane performs painting, plastering, etc. with an average reach of 1.7m and end effector payload of 30 kg. The mounting platform adds another 3 DOF.

A robot for interior wall painting with multicolor spraying was implemented by Naticchia and claimed to work in full scale with utmost performance. The robot "Pollock#1" having 6 DOF, fixed on a 2 DOF hexapod (horizontal movement) ,with an average reach of 0.4 m and a maximum payload of 4kg[2]. Automatic wall painting robot[5] by P Keerthana and team, a interior wall painting robot which is heavy and involves many mechanical parts, hence weighs more and movement will be difficult.

The concepts discussed above uses spray painting technique. The spray painting needs suitable masking to cover the non painted or the adjacent areas which may not be possible with high rise building walls as it adds to the cost of labor and masking materials. Also the spray painting is difficult to control on a single line/edge i.e. nearby wall edges, window frames or any kind of obstructions. The rollers on the other hand can be controlled for edges and uniform consistent coat.

3. Methodology

The road map for building this conceptual model is discussed as a major interest of this paper. The concept is first transformed into a CAD model using PROE WF4.Here we have discussed two models, one which utilizes an I section rail as shown in fig 2 and another one suspended from steel cables as shown in
fig 3. But both the models utilizes roller painting only. The suitable concept out of two will be built making use of various other details as discussed below.

3.1 Paint rollers
Paint rollers absorb and hold more paint and cover more surface area than the brush. The paint brushes produce stray marks whereas the rollers don’t. A Paint Roller is ideal for painting smooth walls. Rollers are available in various sizes like 7 to 18 inches. The selection is always made depending on the application i.e. the surface area to be coated and number of pass.

3.2 Control system
The Robot consists of mainly two section, Robot section and control section. The Robot section paints the wall and the control section controls the vertical and lateral movements of the robot section. A control system also controls the various movements of the arm, wrist, and body in appropriate directions as programmed and performs the overall task and handling unaccounted situations. Robot programming can be divided into four major types and among them we have adopted Playback Robots with Continuous Path Control [8].

3.3 Playback with continuous path Control
Playback control records motion sequences in a work cycle and uses a controller with memory to record locations and other parameters, and then plays back the same during program execution. Once a particular area is covered the roller will be moved to the next location, where the robot is expected to repeat the same path or cycle, hence the continuous path control is preferred. Each joint is controlled by mechanical stops. Feedback control is used to ensure the individual joints achieve the specified locations and to stop any possible damage to the robot by any obstruction.

3.4 Permanent magnet DC motors
Permanent magnet DC motors(PMDC) are quite suitable for controlling the joints as they are more efficient and most importantly they can be battery operated up to 10 HP. PMDC motors are most suitable for intermittent and light-to-moderate duty.

3.5 Frame
A low carbon steel I section beam (Size-W 4 x 13) is chosen for the frame as it is structurally stable and can house the sliding mechanisms thereby its web and flanges acts as rails for small roller mechanisms.

3.6 Jointed arm configuration
Jointed arm configuration resembles human arm, as straight links/members are joined to form human shoulder, elbow and wrist like structure. The joints are free to rotate to any specified angle with the help individual stepper motors connected to each joint. The end effector here is the paint roller used to spread the paint over the wall. The up and down wrist bend movement gives the necessary motion to the roller for initial angle setting if any.
3.7 Metering pump
Metering pumps deliver a precise volume of fluid with respect to time. However volume can be adjusted based on the requirement. The metering pumps have the capacity to pump 0.038 to 78 liters per minute. In painting a constant volume flow is required and hence can be set for the same.

3.8 Pipe
A nylon pipe 6-10 mm in diameter can be used to carry the liquid from the pump to the roller end. The pressure involved may not be very high but the working environment demands a strong and stiff pipeline. Hence nylon will be suitable.

4. Time analysis
To paint a wall of 1000 sq. foot the time required may be approximately 3 to 3.5 hours with a normal 4-5 inches brush and one painter working. Much of the time is consumed in dipping the brush time and again into the paint bucket. An overall performance of a day will be approximately 2000-2500 sq.foot with 8 hours shift. The painting time also has cleaning involved, as the paint scatters all around the paint area. These issues can be addressed partly when a roller is used instead of a brush. The roller is much wider than the brush and ensures more spread for a single dip. The number of dips into the paint bucket required will be reduced many times. It is observed that with rollers used it is possible to paint approximately 3000-3200 sq.foot per 8 hours shift. The productivity can still be improved when the paint is continuously pumped to the roller eliminating dipping process.

5. Conceptual CAD model
The CAD model of the conceptual wall painting robot is as shown in the fig 2 and fig 3. The model is prepared from Pro-Engineer-WF4. The concept in the fig 2 shows I section rails, robot links/arms, and paint roller, roller holder, slide able housing for control system. The horizontal beam will slide over the two vertical columns (I section) using suitable mechanisms which in turn are controlled by the control system/unit. The stepper motors drives all mechanisms controlling the Robot movements. The rotary movements are converted to linear motions wherever necessary using appropriate mechanisms. The links/arms are also driven by stepper motors of lesser capacity comparatively. To keep the model simple none of the motors are shown in the picture.
The paint bucket or the reservoir with properly mixed ready to apply paint can be kept stationary and at a distance from the robot. The pipe reel of sufficient length can be used to reach any location within the wall as the paint is pumped at higher pressure.
The pump used is a metering pump where a fixed or set volume of liquid is pumped at constant rate, similar to one used in Bosch PPR 250[7].
It is mandatory to offset the entire setup at a distance from the wall to be painted. The spacing can be done with the same type beam at horizontal position placed perpendicular to the wall. The entire set up can also be thought of as hanging with suitable hanging mechanisms namely a specially designed hook and spacers etc.
The concept shown in the fig 3 has slightly different mechanism compared to the previous one. The robot arm and the control mechanisms move through a cable via suitable rollers. The rollers are controlled by the control system on board the system. The control system controls the direction and position of the paint head. The bottom support forms the hanging rigid base. The entire setup is hanging from the top portion of the wall where it is fixed and can be slided to different position. This cable hung setup is very easy to use and convenient to transport.

Fig 2: The CAD model of conceptual automated roller painter
In addition vacuum grippers can be used in the bottom support so that it firmly stands against the wall along with its own weight.

6. Working Principle

The conceptual model carries a roller brush, a pump, flexible pipe line, paint bucket/tank, a support structure and suitable mechanism to guide the roller through the painting area. Initially the roller end will be guided through the painting area by a teach pendant thereby programming is done by lead through method. The movements are recorded in the robots memory for subsequent play back during painting, the speed of working can be controlled via individual controllers. When the robot arm is pressed against the wall and starts rolling, the pump starts supplying the paint to the roller. The roller end rolls down and back again via the same path for uniform coating. After one cycle the roller is moved to the next position hence covers the entire programmed area.

Once the programmed area is finished the roller end has to be moved through to the new area. The process can be repeated until the complete wall is painted. The roller end mechanism needs to move lengthwise at the same time pressed against the wall. The lateral movement is possible by a sliding head sliding on the beam.

The concept involves a robot arm which is a jointed arm configuration which houses individual stepper motors for each joint. The stepper motor is controlled by the central control system. The control system decides the speed direction and various other parameters based on the program and working conditions.
7. Conclusion
The concept discussed above is an automated, consistent and dip free painting process. Fine details are to be included while building the physical model. Conventional manual painting process poses workers life under risk. Statistics shows many accidents occurred during painting process. A robot not only eliminates the risk of painters but also works efficiently. Spreads paint over more area in less possible time. Hence saves lot of time and number of laborers required. The application of BOSCH PPR 250[7] enables clean and safe painting atmosphere.

The cost of equipment may be more in comparison to the conventional manual brush/roller painting. But the cost of the equipment is justified by improvement in productivity and reduced number of laborers required to paint the given area. The majority of the painting equipments are hired from building contractors and therefore the entire cost will not be borne by one. The equipment when maintained well can be used to paint many buildings hence shares the overall cost involved

7.1 scope for future development
The concept uses continuous path control system but the same can be replaced with intelligent control system wherein the robot scans the area to be painted and decide the set of actions on its own. The roller arm can be equipped to work with multiple colours, but it makes the robot complex and heavy. Given its commercial exploitation complexity in design can be justified.

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