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Automatic path-planning algorithm for realistic decorative robotic painting

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ABSTRACT

In this paper an innovative algorithm to reproduce non-uniform, photorealistic, gray-scale images on large surfaces, using an ordinary industrial spray-painting robot is proposed.
The algorithm splits the process into a set of iterative steps with decreasing spray-gun stroke diameters. Thus, it can efficiently build up the image starting with large strokes to paint the larger details of the image. Then, with increasingly smaller strokes, it can paint the rest of the smaller details.
The target image is segmented and a tool-path is computed. A set of critical points in the image is then chosen to avoid oversaturation and used to implement an algorithm to calculate spray-gun operational speed at each path point. Eventually, such conditions lead to a linear system which is solved using an ordinary least squares method. Depending on the image to reproduce, this methodology promises to be far more efficient than painting processes where the image is built entirely at the smallest detail level. For this reason, it would be particularly suitable for large building façade decoration, for example.

1. Introduction

Nowadays, robotic painting is a very important process in industry; it spans from automotive to manufacturing, even to art. In the vast majority of applications the spray painting technique is used rather than others, i.e. brush painting. Indeed this technique couples very well with automated systems, and can be very efficient. Normally, the painting process aims at obtaining a uniformly painted surface of arbitrary shape. It is worth noting that, some aspects of robotic painting were left behind, in particular those concerning non-uniform painting. An ordinary example of this kind of painting is a photo, or a drawing. At present, no automated methodology or algorithm aimed to replicate an accurate copy of a digitized image (be it a photograph or something less realistic) on a large surface by means of an industrial spray-painting robot has been proposed. The purpose of this work is thus to present an innovative methodology and algorithm to tackle this challenge.

Several branches in the industry could be positively affected by this methodology, especially where decorative and/or functional painting is required. Automotive and furniture industries, particularly in the high-end segments, can present the need for this type of operations, and up to now this was generally met with the aid of highly skilled artisans or with complex masking systems (which, in turn, needs other professionals as well). It goes without saying that these procedures often impose great cost and time. Another promising branch is the one involved in construction; some companies (Cité-Création, in Lyon, France, http://cite-creation.com) use classic techniques like fresco and trompe-l'oeil to decorate buildings and homes, this mainly in an attempt to increase quality of life in crowded and dull city environments. Along the same line, in a less artistic way perhaps, industry buildings often need signs, text or warnings on walls or machinery, and while on small surfaces decals can be used, with larger surfaces this becomes impractical. The history of painted furniture is as old as society in itself, dating back to at least ancient Egypt; in modern times the interest in this kind of art has somewhat subsided due to high costs, but examples are still present. If, though, the process were to be completely automated and robotized, cost would lower substantially.

At present, the mechanics of the spray painting are well understood, for example Balkan and Arikan [1], Ellwood et al. [2] and Conner et al. [3] presented models for the flow rate flux of a paint gun and for the paint deposition in spray painting. Chen et al. [4] experimentally analyzed the paint coating characteristics for uniform velocity with overlapping paths, whereas Fogliati et al. [5] provided a numerical CFD analysis of the paint deposition process. Elliot et al. [6] provided a model for the

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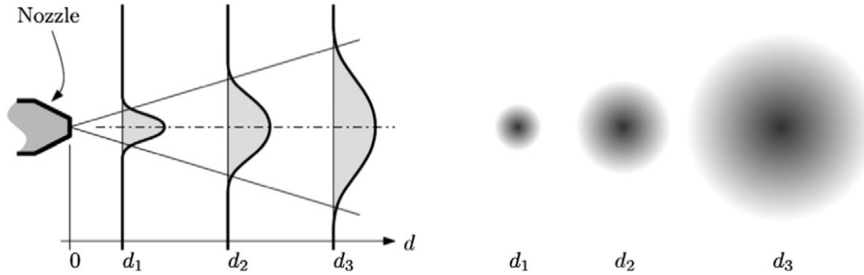

Fig. 1. Spray-paint cone morphology. The cone originates from the nozzle, and at various distances (for example d_1, d_2 and d_3) an indication of the cross-sectional paint distribution is visible in gray, along with the resulting stroke on the canvas (on the right). For clarity purpose, the distributions are normalized over the maximum value of each curve.

fluid-dynamics effects of spray-painting with a rotary nozzle. Atkar et al. [7] published a work on robotic uniform spray-painting in automotive. Robotic spray painting is also widely acknowledged; in normal industrial practice the manual teaching methods (see Baldwin [8]) are widely used. Chen et al. [9] propose a review of the current state of the art in the automatic path planning for industrial robotic spray-painting. Artistic, non-uniform painting by means of autonomous or automatic systems has been a subject of research in the last two decades, mainly since the work by Haeberli [10] on the virtual representation of images using pictorial, abstract styles. A crucial reference for our work paper is the concept highlighted by Hertzmann [11], in which the painting is carried out (virtually) with progressive decreasing-size strokes, following the footsteps of Haeberli. A series of different artistic painting robots are presented in literature, a few examples of which are in [12–14]. All these are not adequate since they tend to produce artistic-looking, non-photorealistic paintings.

The best example of system used to reproduce photo-realistic images on a surface is the printer, in its various forms. The problem of this system is that it operates essentially dot-by-dot, regardless of the detail sizes in the image. This translates in very long painting times if the surface is large. Moreover, the resolution is ultimately established by the hardware in the print head, which is a big limitation in flexibility.

For these reasons, in this paper an innovative methodology to reproduce photo-realistic images on surfaces by means of a fully automatic robotic spray-painting process is proposed. The method is centered on the concept that with a spray-painting robot we can achieve a wide range of stroke sizes; this can be exploited by using the larger strokes to paint the large details, and the smaller strokes for the smaller details. Efficiently calibrating this process leads to virtually any outcome, from low-detail and hi-speed to slow-speed but high-detail executions. The core of the methodology is an adaptive, smart algorithm that uses techniques like Voronoi diagrams, convolution and ordinary least squares

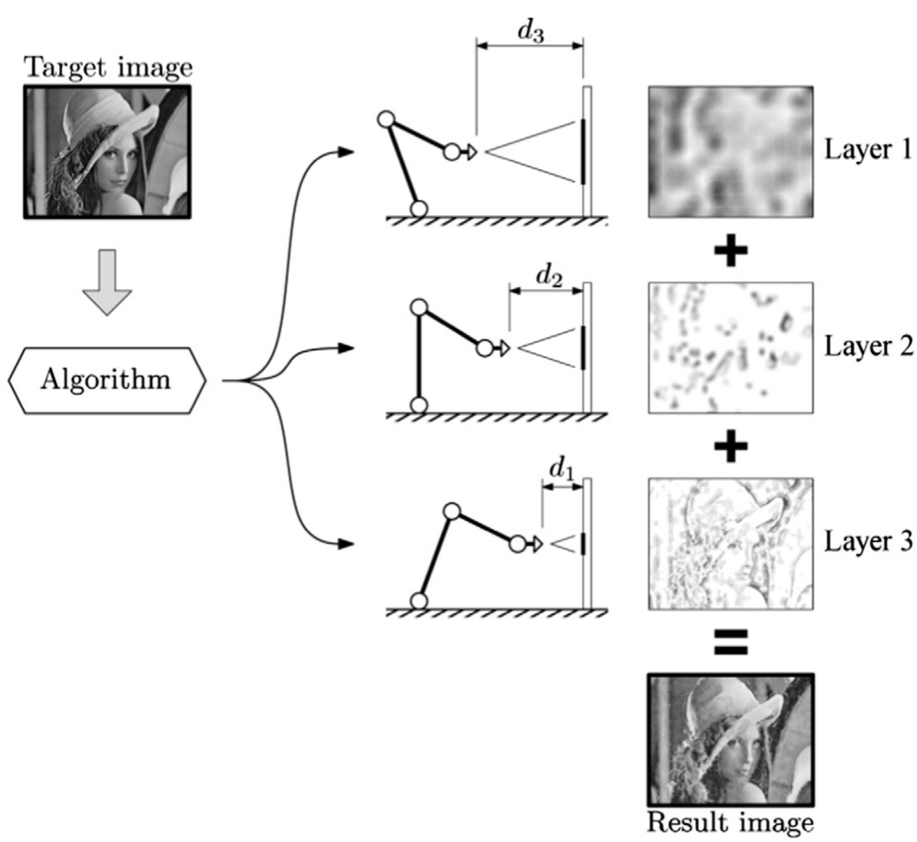

Fig. 2. The proposed methodology. The image (upper-left) is fed into the algorithm, which, according to the spray morphology and mechanics, splits the paint execution in a series of consecutive tasks, each of which takes advantage of a different stroke size, and operates mostly on details of matching size. The progressive execution of these steps generates the resulting image. Note that $d_3 > d_2 > d_1$.