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Original

A Novel Robotic System for Painting with Eyes / Scalera, L., Seriani, S., Gasparetto, A., Gallina, P.. - 91:(2021), pp. 191-199. (3rd International Conference of IFToMM Italy Online 9-11 settembre 2020) [10.1007/978-3-030-55807-9_22].

Availability:

This version is available at: 11368/3065712 since: 2023-11-28T15:08:26Z

Publisher:

Springer Science and Business Media B.V.

Published

DOI:10.1007/978-3-030-55807-9_22

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A Novel Robotic System for Painting with Eyes

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Abstract. In this paper we present the preliminary analysis and results of a novel robotic system that allows a user to paint with eyes, using an eye tracker device and a collaborative robot. Eye tracking is a sensing technology that allows a computer to detect where a person is looking (point of gaze). This technology is used to control the motion of a collaborative robot that paints on a canvas based on the detected input. Results show the feasibility of the robotic system and its possible future application as a tool for artistic and creative painting by people with disabilities who cannot use their hands, or that have lost the control of all or part of their muscles.

1 Introduction

Nowadays, robotic painting is becoming a widespread technology often adopted by artists as a tool to imitate human painting and to develop novel forms of expression. In the recent years, several examples of machines and robots equipped for painting purposes can be found in the literature. In most of the cases, the motion of the robotic system is planned on the basis of image processing algorithms and computational models that aim at reproducing a non-photorealistic version of an input image.

Examples can be found in the work of Tresset and Leymarie [23], where a robotic installation capable of drawing sketches of people by extracting salience lines from images is presented, and in the painting robot developed by Lindermeier et al. [9] capable of creating brush strokes based on non-photorealistic techniques and visual feedback. Further examples are given by Song et al. [19], who developed an artistic pen drawing system for arbitrary surfaces, and by Karimov et al. [8], who implemented a Cartesian robot with a mixing device capable of creating full-color images with artistic paints in a human-like manner. Furthermore, Scalera et al. developed Busker Robot [16,18], an automatic robotic system for watercolor artworks based on several image processing techniques [17]. Other recent examples of artistic robotic painting include the interactive system

capable of producing realistic artworks using image segmentation presented by [7], the airbrush robotic painting system proposed in [15], the adoption of mobile robots for spray painting described in [4, 26], and the robot that paints artworks using the palette knife technique presented in [2].

In the majority of these cases, the interaction between the robotic system and the human artist is limited to the choice of software and hardware parameters, and the painting process is mainly handled by the algorithm and based on a starting input image. Only few examples of robotic painting systems remotely controlled by humans can be found in the literature, mainly related to robotic telemanipulation, such as in [12]. An interesting example of remote human-robot interaction for artistic purposes is given by the neurorobotics painting through brain-computer interface presented in [22]. The system allows to measure the brain activity of the user and associate the recorded cerebral signals into simplified movements of the robot.

Within this framework, eye tracking is another technology that can be adopted to tele-operate a robotic manipulator. Eye tracking allows a computer to know where a person is looking and represents a simple and effective interaction method for people who are left with minimal motor abilities [1, 11]. An example of the adoption of eye movements as a brain-machine interface to control the motion of a robotic arm can be found in [10], whereas in [5] the eye-tracking technology is adopted for the teleoperation of a mobile robot.

In art, the eye-tracking technology is used by the multimedia artist Graham Fink to create figurative portraits composed of lines on a screen with impressive results [6]. Eye-tracking data are also used for abstract painterly rendering in [14], where a model of human perception is adopted to process images by highlighting only meaningful information. However, these rendering techniques have not been applied to real painting robots yet. To the best of the author's knowledge, no examples of robotic painting systems that use eye-tracking data for artistic painting can be found in the present literature. In this paper we present the preliminary analysis and results of a novel robotic system that allows a user to paint with eyes, using an eye-tracker device and a collaborative robot. A scheme of the robotic system is shown in Fig. 1. The system has been first presented at Trieste Next (Italy), Festival of Scientific Research, from 27 to 29 September 2019. During the festival the system was tested by the public with great interest. The proposed system can in future be exploited as a tool for creative painting by people with disabilities who cannot use their hands.

The paper is organized as follows: Sect. 2 describes the eye tracking technology. Section 3 presents the novel robotic painting system, whereas Sect. 4 reports the algorithms for data acquisition and path planning. Some preliminary results are shown in Sect. 5, whereas the conclusions of the paper are discussed in Sect. 6.

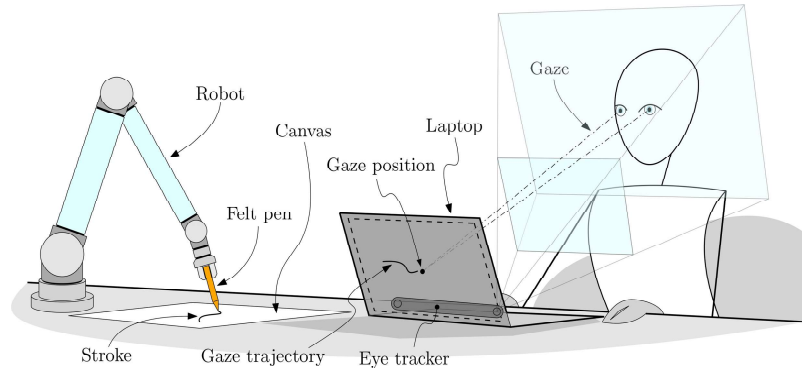


Fig. 1. Scheme of the robotic system for painting with eyes.

2 Eye Tracking

Eye tracking is a sensing technology that allows a computer or other device to record the movements of the eyes and to know where a person is looking (point of gaze). This technology allows an easy and natural interface between a human and an external device, and can be applied in several fields. In psychology, the study of eyes movements provides insights in cognitive processes, attention, behavior and decision-making. In the computer field, eye tracking can facilitate the learning of software as well as enhance the visual experience in video-games and augmented graphic displays. However, the most important application of eye tracking is to provide communication and interaction for people that have lost the control of all or part of their muscles. Indeed, eye movements are preserved in many movement disorders leading to paralysis (or amputees) from stroke, spinal cord injury, Parkinson’s disease, multiple sclerosis, and muscular dystrophy among others [10].

The eye movements on unchanging images can be classified in two main categories: *saccades* and *fixations* [13, 14]. Saccades are discrete and rapid movements of the eyes that are directed in a goal-oriented fashion to scan one part of an image at a time. Fixations are stabilizing motions, which allow to pause over informative regions of interest. The majority of visual processing takes place during fixations. Other types of eye movements are possible, such as smooth pursuit and vestibulo-ocular ones, but the saccades and fixations play the largest role in gathering information from static images [14].

The eye tracker adopted in this work is a Tobii Eye Tracker 4C, which can be easily mounted to a laptop or a monitor. The eye tracker works with near infrared (NIR 850 nm) illuminators that create a pattern of infrared light on the eyes. The cameras of the eye tracker take high resolution images of the user’s eyes and of the projected pattern, whereas machine learning and image processing algorithms determine the eyes’ positions and gaze point on the screen with a frequency of 90 Hz [21].

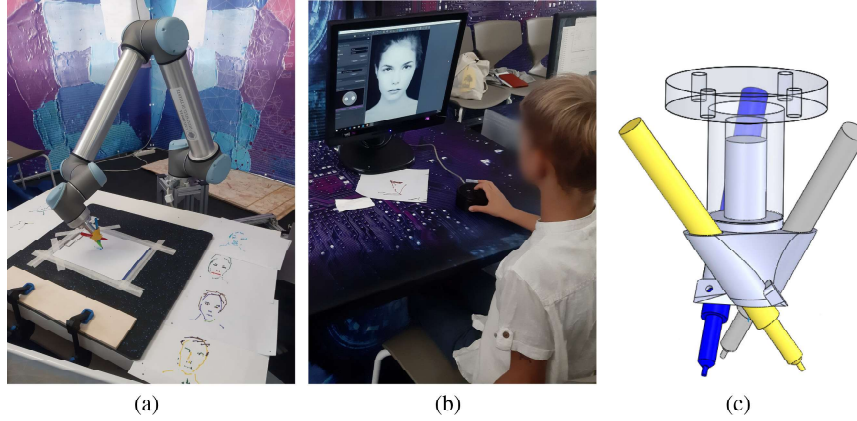


Fig. 2. The robotic system equipped for painting at Trieste Next 2019 (a); a subject painting with eyes (b); custom 3D printed support for felt pens (c).

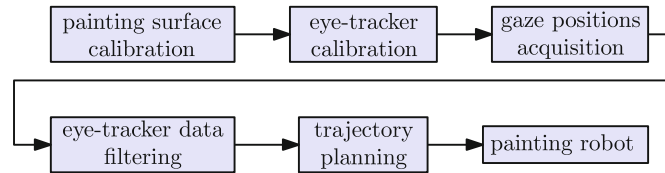


Fig. 3. Flowchart of the system.

3 The Robotic Painting System

The robotic manipulator chosen for the system is an industrial robot UR10 by Universal Robots with 6 degrees of freedom, available at the Robotics Lab of University of Trieste, Italy. The manipulator can hold a maximum payload of 10 Kg and has a working radius of 1.3 m. Since it is a collaborative robot, it can be used alongside an operator without the need of protective barriers. The robot is equipped for painting with a custom 3D printed support for felt pens, as shown in Fig. 2. This tool allows the robot to use three felt pens of different color and to switch from one to the others with simple rotations of the wrist. The robot performs the painting on a planar surface, which position and orientation with respect to the robot base are calibrated prior to starting the painting task, in a way similar to [18]. In particular, by acquiring at least three positions of the end-effector with a felt pen touching the painting surface, the approximating plane with minimum-square error is computed.

The robotic system is controlled in Matlab. The commands for the robot are written in the UR Script Programming Language and sent to the robot controller using the TCP/IP protocol. The trajectories are planned in the Cartesian space using standard trapezoidal motion laws and imposing the maximum speed and acceleration. Figure 3 reports a flowchart of the robotic painting system.

4 Data Acquisition and Path Planning

The process of painting with eyes is based on the observation of a test image shown on a screen, whose main features have to be focused with the eyes' motion by the subject who is painting. This strategy has been adopted to help the users in following the main contours of an image with eyes. We adopted images of people taken from the website "This person does not exist" [20]. These images are generated by a StyleGAN (generative adversarial network) artificial intelligence based on an analysis of portraits. However, the system can be used without a test image as well.

Prior to starting the eyes-painting process, the eye tracker is calibrated by looking at a sequence of points displayed on the screen one after the other. This process measures the characteristics of the subject's eyes and calculates personal differences such as where the pupils are located in relation to the cornea. After the calibration is completed, the data acquisition is started. A graphical user interface developed in Matlab allows to log the gaze positions acquired by the eye tracker.

The acquired gaze positions are composed of both saccades and fixations eye movements, as described in Sect. 2. Before sending the data to the robot, each segment need to be filtered, in order to remove the contributions given by the fixations, which create problems in the robot motion and in the painting due to the multitude of points very close to each other. For this reason, two different approaches are considered: a moving average filter, and an interpolation with B-spline curves.

The first approach is an analysis tool that smooths out data by considering a simple sliding-window spatial filter. This sliding filter replaces the center value in the window with the mean of all data values in the window. With this approach the agglomerations of points due to the fixations are smoothed but not completely removed, and the results are highly dependent on the size of the considered window.

The second approach consists of an interpolation with B-spline curves [3]. This technique adopts piece-wise cubic polynomial functions to interpolate intervals of data, called knots of the spline. Cubic B-spline interpolation ensures C^2 continuity for the entire curve and it is usually adopted in the trajectory planning of industrial machines and robots to achieve acceleration continuity and smoothness [24, 25].

After filtering of eye-tracker data, either with moving average filter or with B-spline interpolation, the gaze coordinates are scaled within the painting surface limits and sent to the robot controller as command strings. The acquisition of gaze positions continues in parallel with the painting process, and new strokes are painted as soon as the robot completes the previous ones. The time needed for painting depends on the number of lines and their length, and extends from few minutes to one hour.

5 Results

Figures 4(a) and 5(a) shows two examples of test images from [20]. Images (b) report eye-tracker raw data, where fixations and saccades can be identified. Images (c) and (d) are obtained from (b) by filtering data with moving average,

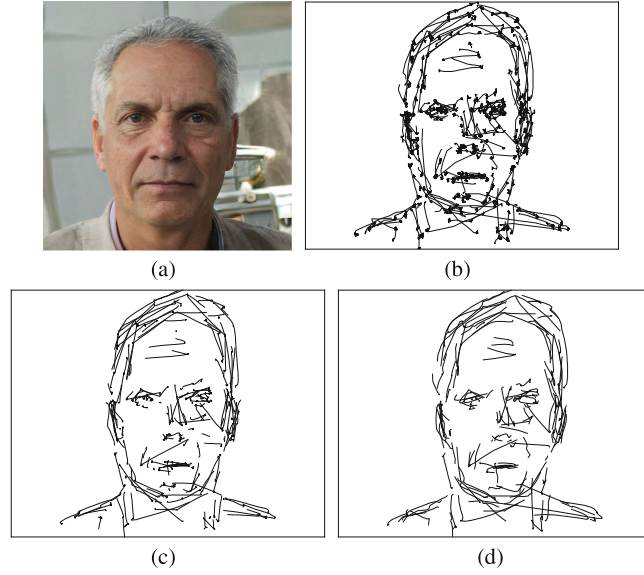


Fig. 4. Test image 1, from [20] (a); eye-tracker raw data (b); filtered data with moving average (c); data interpolated with B-spline curves (d).

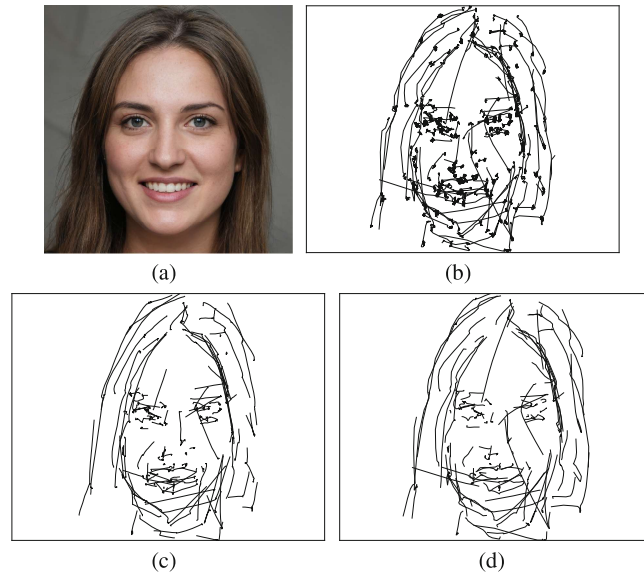


Fig. 5. Test image 2, from [20] (a); eye-tracker raw data (b); filtered data with moving average (c); data interpolated with B-spline curves (d).

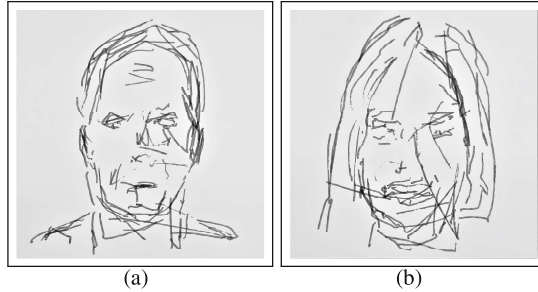


Fig. 6. Images drawn by the robot based on eye-tracker data using test image 1 for (a), and 2 for (b).

and by interpolating the data with B-spline curves, respectively. Finally, Fig. 6 reports the images drawn by the robot using the eye-tracker data of Fig. 4(d) and 5(d), with B-spline interpolation. The image processing described in Sect. 4 allows to remove fixations and to smooth the paths that the robot end-effector has to follow. More specifically, the strokes appear more refined and areas where blots of color were apparent are less conspicuous, resulting in a considerably more polished artwork. In the future, further techniques will be developed and applied to eye-tracker raw data to enhance the aesthetic appreciation of the results. In particular, alternative algorithms will be used for the smoothing of robot paths and to fill the image with color. Furthermore, brush painting techniques will be applied [18], and quantitative metrics will be introduced for the analysis of the painted results.

6 Conclusions

In this paper we presented the preliminary analysis and results of a novel robotic system that allows an user to paint with eyes, using an eye tracker device and a collaborative robot. The gaze positions detected by the eye tracker are filtered with different techniques and converted into paths that the robot end-effector has to follow to paint on the canvas. Results show the feasibility of the system and its possible future application as a tool for artistic and creative painting by people with disabilities who cannot use their hands, or that have lost the control of all or part of their muscles.

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