JOURNAL OF APPLIED INTELLIGENT SYSTEMS & INFORMATION SCIENCES
VOL. 5, ISSUE 1, PP. 33-41, MAY 2024.
Available at: https://journal.research.fanap.com/
https://doi.org/10.22034/JAISIS.2024.441014.1078

DESIGN AND IMPLEMENTATION OF AN ARTIST ROBOT WITH HUMAN-INSPIRED DRAWING BEHAVIOR

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ABSTRACT

Although drawing is usually interpreted as a hobby, it could come with several benefits for mental health. Hence, planning to enhance this skill is crucial, especially for children. Given this importance, educators use different tools to teach drawing to children. Furthermore, modern technologies such as artificial intelligence and robotics could make educational tools more attractive. Previous drawing robots either performed a specific design or behaved unnaturally. Hence, this work focuses on the design of a novel intelligent drawing robot that can artistically draw any picture. For this purpose, we apply a human-inspired contour extraction method for the robot. In this step, to make the method suitable for the drawing process, we use some post-processing techniques. As another contribution, the robot is designed based on low-cost and off-the-shelf components to be accessible to anyone. Moreover, to make the robot more ready for drawing contours, we apply a calibration technique. The experimental results show that the designed robot can draw desired subjects based on the provided pictures. Also, it will be discussed that how this work could be beneficial for any educational institute to use low-cost intelligent drawing robots for learners.

Keywords: Drawing Robot, Robot Design, Human-like Contour Extraction.

1. INTRODUCTION

Studies have shown human brain works well in terms of capturing and interpreting visual information (Yang et al., 2022). Hence, drawing is one of the oldest approaches for humans to express their information within the visual arts (Wallis, 2019). Nowadays, drawing is usually considered an interesting skill for children. Because they can express their ideas and express themselves using their images. Moreover, drawing can improve the memory and creativity of children. Also, researchers showed cognitive skills could be empowered by performing drawing tasks (Van Sommers, 1984). Thus, the art of drawing should be included in the curriculum of children.

Using technology is one of the most popular mediums for teaching kids. There are a variety of apps and websites that can help kids learn drawing skills (Yadav et al., 2021). However, they did not have physical embodiment. Drawing machines (Coelho et al., 2019) could tackle this issue. Drawing machines are devices/mechanisms/instruments that draw or assist in drawing tasks. Readers may note that drawing gradually makes an image by sequential contours. Accordingly, an inkjet printer should not be considered as a drawing machine.

We categorize the drawing machines into two groups. The first category includes kinetic sculptures (Coelho et al., 2019) and drawing robots to create predefined shapes (Naomi, 2020; Song et al., 2018). On the other hand, intelligent drawing robots (Hsu et al., 2017) that can draw any given picture are considered in the latter group.

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RECEIVED: 1 FEBRUARY, 2024; **ACCEPTED:** 14 MAY, 2024; **PUBLISHED ONLINE:** 28 MAY, 2024

Accordingly, intelligent drawing robots should include an intelligent module to extract the contours (or edges) of a given picture (Hsu et al., 2017; Huang et al., 2016). Image processing researchers have proposed several edge detection algorithms, and each of them is proper for specified applications. However, because the conventional edge extraction algorithms did not consider artistic features, they might not achieve proper contours for drawing a picture.

Nevertheless, according to the literature (Gao et al., 2020; Hsu et al., 2017; Huang et al., 2016; Wang et al., 2020), most intelligent drawing robots use conventional edge detection algorithms (such as (Canny, 1986)) for line drawing art. These approaches capture the edges with no image understanding. Hence, from the point of view of human-robot interaction, such drawing robots could not behave naturally. To tackle this, (Li et al., 2019) presented a state-of-the-art human-inspired contour extraction approach. They showed the outputs of the proposed method are better matched with the human behavior in boundary detection.

In this work, we design and implement a novel intelligent drawing robot (hereafter named “Rasmbot”) to perform drawing pictures with the state-of-the-art human-inspired contours extraction method presented in (Li et al., 2019). For this purpose, we used several post-processing methods to make ready the outputs for the robot path-planning process. Moreover, in this work, we try to design the robot with low-cost and off-the-shelf components so that anyone can implement it easily. Additionally, this work tries to address the question of whether a low-cost robot could visually convey the targeted subject to users or not.

The rest of the paper is structured as follows; Section 2 presents the overall design of Rasmbot. The robot’s components and their functions are introduced in this section. The implementation process of the robot is presented in Section 3. Then, Section 4 presents a calibration technique to make the robot more accurate in drawing tasks. The experiment results are presented in Section 5. The paper ends with discussions and conclusions in Section 6.

2. SYSTEM DESIGN

In this section, we present the design of Rasmbot. The structure of this robot includes an application and a device; see Fig. 1. The application is an interface between the user and the device. The user specifies the picture to be drawn, and the application, after analyzing the user’s request, sends commands to the device. The robot’s device consists of a body and a parallel manipulator.

To achieve a low-cost robot, for actuators, we considered three off-the-shelf RC servo motors. Also, for the robot’s control board, an Arduino Mega 2560 R3 (O'Connell, 2020) that has an accessible market was considered. The other robot’s parts were designed based on 3D printing and Laser cut techniques so that they can be made at a low cost.

According to the design, the robot’s body is fixed and covers a control board, three motors, a driver board for motors, and a socket for a power source. For drawing a curve, two of the motors actuate a scara parallel manipulator (Figielski et al., 2007) to move a pen on a sheet. Another motor moves the robot’s manipulator in the vertical direction (to place and remove the pen on the sheet). The parallel manipulator makes a friendly shape for grasping the pen. Fig. 2 illustrates the 3D design of the robot device.

The Rasmbot’s application converts the given picture to an artistic line art. Moreover, in this step, the obtained contours are ordered into several independent stroke lines. For each stroke of the art, the application defines the drawing motion with respect to time. Accordingly, the application records the motions of all strokes with an equal step time as discretized motion signals. Following that, the application sends the recorded data of each stroke to the control board placed in the robot’s body.

The communication between the application and control board is established based on the USB serial protocol. Because the control board has a limited buffer memory, the application sends the data of the desired strokes sequentially. Indeed, it sends the data of a single stroke to the control board and waits to finish the drawing of that line. Following that, the application sends another stoke.

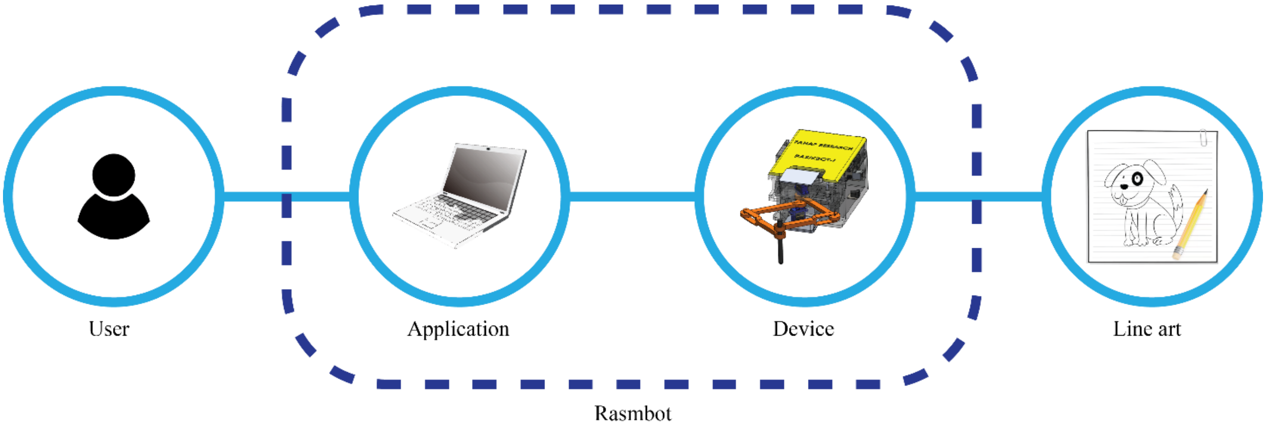


Fig. 1: The framework for using Rasmbot

The control board, according to inverse kinematics of the scara parallel manipulators, converts the strokes drawing motions to suitable commands for the actuators; see Fig. 3. Accordingly, for the position of $\underline{r}_{OC} = [x_{OC} \quad y_{OC}]^T$, the desired angles for the motors (q_+ and q_-) are extracted as (Bourbonnais et al., 2014):

$$\sigma = \|\underline{r}_{OC}\| = \sqrt{x_{OC}^2 + y_{OC}^2} \tag{1}$$

$$\underline{h} = \frac{\sqrt{4l^2 - \sigma^2}}{2\sigma}\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}\underline{r}_{OC} \tag{2}$$

$$\underline{r}_{OA_\pm} = \begin{bmatrix}x_{OA_\pm}\\ y_{OA_\pm}\end{bmatrix} = {\underline{r}_{OC}}/{2} \pm \underline{h} \tag{3}$$

$$q_\pm = \tan^{-1}\left(\frac{y_{OA_\pm}}{x_{OA_\pm}}\right) \tag{4}$$

where $l = 0.1$ m. According to the desired angles for the motors, the driver commands are extracted; and meanwhile, the commands are sent to the motors' driver to generate PWM signals for the RC servo motors (readers may note the RC servo motors have internal position controller and are commanded with the PWM signals). While the driver module is connected to a power source, the driver according to the received commands directs the power to the motors with PWM signals. Finally, the motors move the robot manipulators, and the desired curves are generated.

3. IMPLEMENTATION

As mentioned before, the application of Rasmbot receives the desired picture. In this application, the method presented in (Li et al., 2019) was developed in Python to extract the boundaries of the given picture artistically. Indeed, this method brings intelligent behavior to the robot so that it extracts the picture contours similar to human behavior. The other algorithms for designing the drawing motions and the application's GUI were developed in MATLAB.

It should be mentioned (Li et al., 2019) generates thick lines. However, for drawing them, we need the lines with a width of one pixel. Hence, to convert the thick lines into thin ones, we applied several morphological techniques (such as opening, erosion, dilation, closing, and skeletonizing). Comparison indicated the skeletonize technique yields better results with less error. Thereafter, we used the raster-to-vector conversion method presented in Abedinzadeh Shahri and Daei Niaki (2022) to make the desired drawing lines smooth. As the next step, the obtained path lines were sorted in such a way that the pen's overall movement was minimized. Moreover, similar to the aforementioned method, the robot's motions were designed for tracing the desired lines with a constant speed.

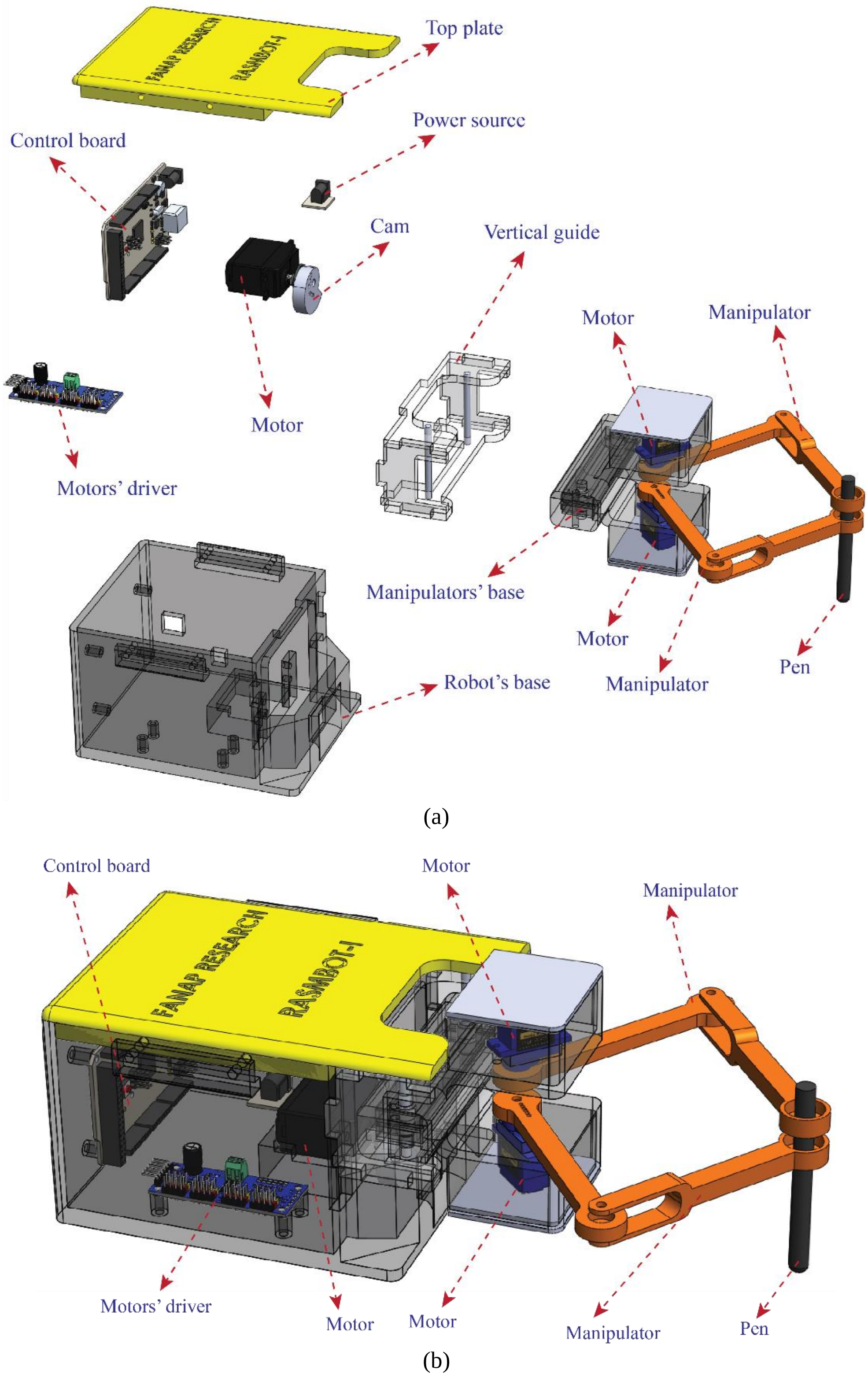


Fig. 2: 3D illustration of the robot’s components and the assembled device.

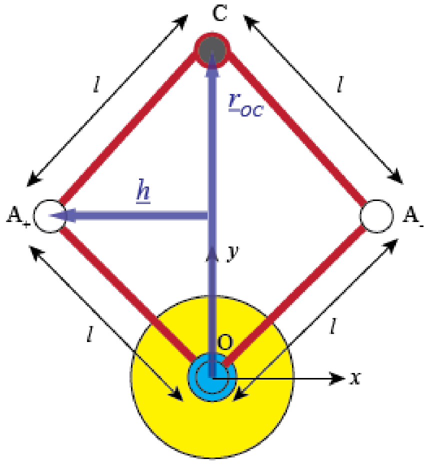


Fig. 3: The kinematic of the parallel manipulator

For fabricating most 3D-designed parts of the robot, we used an Ender3-V2 3D Printing machine. For this, the PLA filaments with a 0.2 mm nozzle were used. A few 3D parts were fabricated with the laser-cut technique. The other parts were prepared from off-the-shelf components.

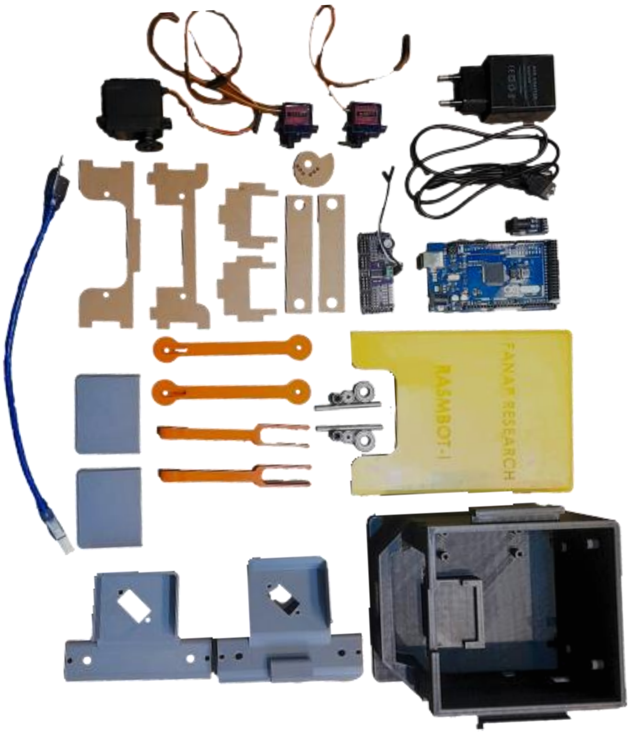
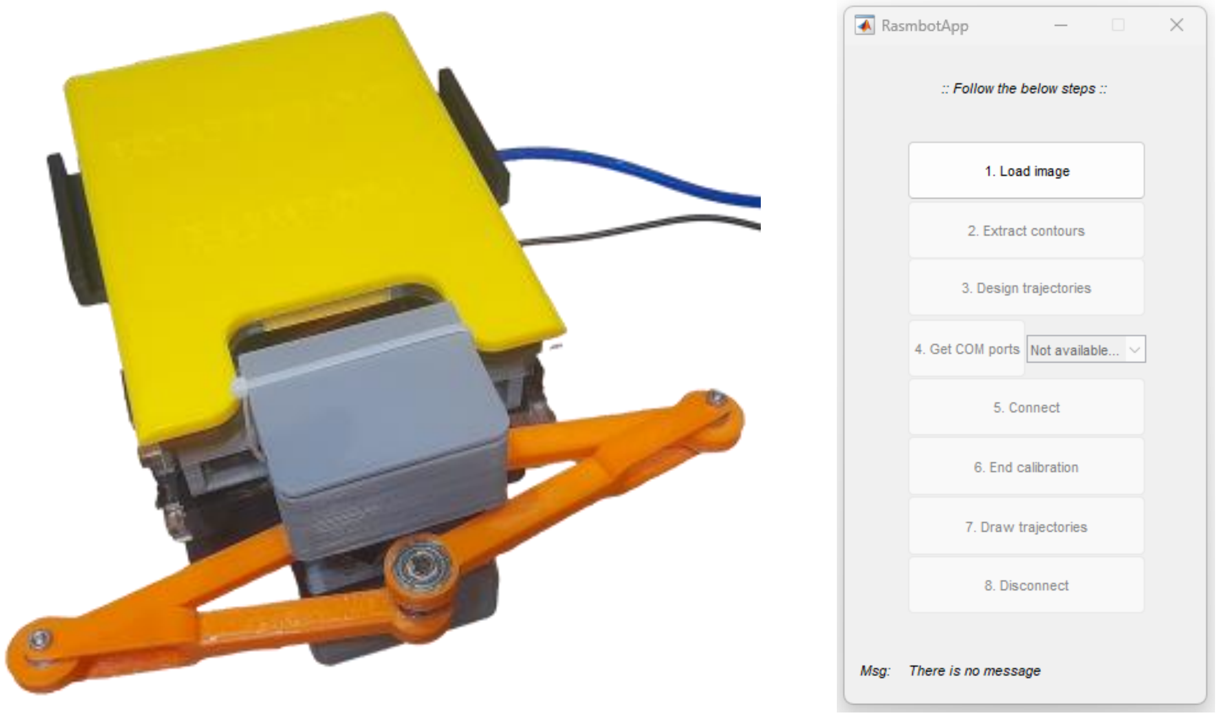


Fig. 4: The components used for the implementation of Rasmbot

For the control board, we used an Arduino Mega 2560 R3 (O'Connell, 2020). We used two mini-RC servo motors for the horizontal movement of the manipulators. Moreover, for the vertical movement, we used a medium-sized RC servo motor. All RC servo motors were driven with a PCA9685 module. Fig. 4 presents all components used for the robot’s device. The implemented robot is shown in Fig. 5.

4. CALIBRATION

Usually, due to fabrication and assembly errors, the motions of robots deviate from the designed motions (Marwan et al., 2017). To tackle this, we applied a calibration technique to the path planning module used in the robot’s application. In this approach, we designed a path to cover the drawing area. Fig. 6a shows the designed path and robot performance for tracking that. After tracing the designed path, we measured the tracking error for 256 points of the path. Accordingly, we fitted two 3rd-order polynomial functions for the measured deviation errors on the X and Y axes to anticipate the deviation behavior. Accordingly, for each position, the application modified the control command to overcome deviations and reach the manipulators to better positions to draw the designed path. Fig. 6b shows the tracking improvement due to applying the calibration technique. The measured results indicated that before applying the calibration technique the RMSE (Root Mean Square Error) for positioning the 256 points was 0.3971 cm, and the modified commands reduced the RMSE to 0.312 cm.



Msg: There is no message

Fig. 5: The implemented robot: The left and right subfigures show the robot's device and its application UI.

5. EXPERIMENTS

In this section, we demonstrate the drawing performance of Rasmbot. For this, we considered three images for different subjects (fish, seagulls, and shoes) and sent them to Rasmbot, see Fig. 7a. Firstly, the application extracted the contours of the pictures; as shown in Fig. 7b. Then, the extracted contours were smoothed by the method presented in Abedinzadeh Shahri and Daei Niaki (2022), as shown in Fig. 7c. Accordingly, the application extracted the motion signals for drawing the contours. Thirdly, the motion signals were sent to the control board. The control board converted the strokes' motions to the actuators's motions, as shown in Fig. 7d. Finally, Rasmbot drew the contours on the sheets, see Fig. 7e. Thereafter, 10 adults (over 18 years old) were asked about the subject of the drawn contours. Almost all people recognized the target of the drawn pictures (i.e., fish, seagulls, and shoes).

6. DISCUSSIONS

In this work, we targeted the question of whether Rasmbot with low-cost components could visually convey the targeted subject to users or not. The investigation study on a small population indicated Rasmbot (with low-cost components) could draw any given picture in a human-inspired manner. It should be mentioned because the selected low-cost RC motors could not sense their exact position, in this work the robot's accuracy was not measured.

Rasmbot includes a parallel manipulator to move its pen. However, to design a manipulator for a drawing robot, instead of the parallel configuration, one can consider a series configuration. However, in the series configuration, the weight of a motor is added to the manipulator. This might diminish the drawing accuracy. Also, according to the human pen grasping style for drawing, at least two fingers of a hand grasp the pen in a parallel configuration. Hence, for Rasmbot, we targeted the parallel configuration with two arms for the manipulator to make the robot's embodiment friendly.

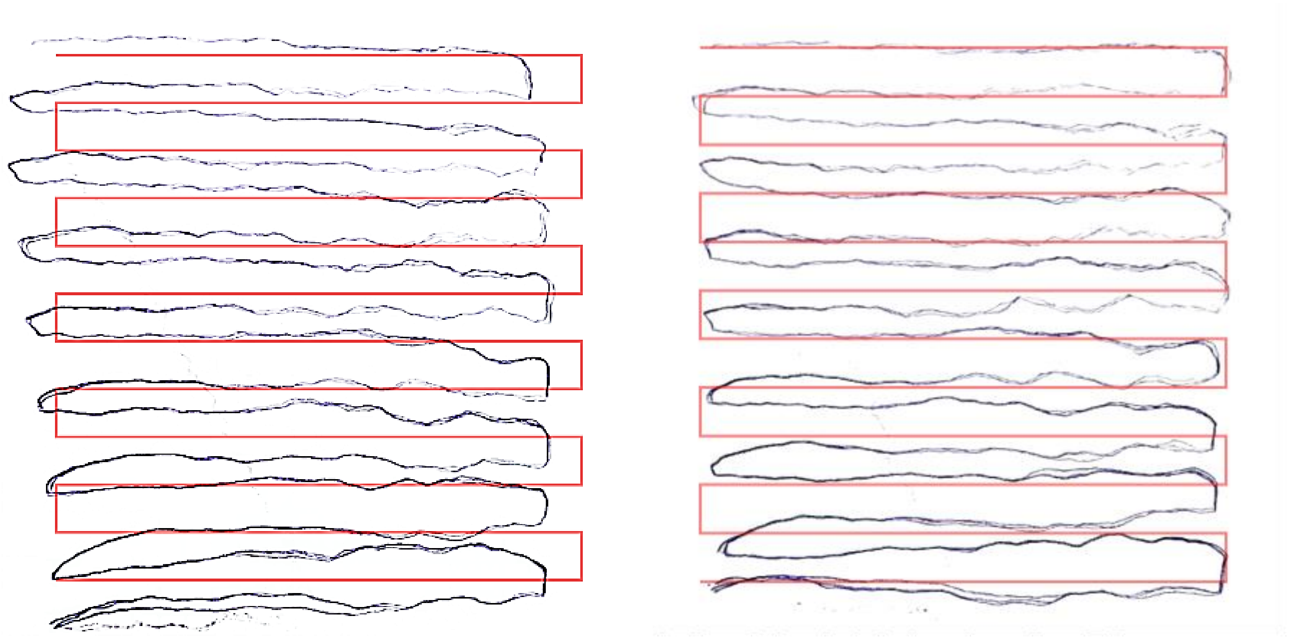

(a) (b)

Fig. 6: The calibration process: The red and blue lines in both sub-figures show the desired and drawn path by the robot, respectively. The left and right subfigures are for the before and after applying the calibration technique.

In the robot, functions of drawing trajectories were defined for tracing the lines with a constant speed (according to the motor's limitation). However, considering some human behavioral features (such as the power law and isochrony principle (Bennequin et al., 2009)) in motion planning could make the robot's performance more friendly.

The Rasmbot's application, after receiving a picture, begins commanding the device to draw the contours of the picture. However, for educational use, it is better to develop another intelligent module to describe the features of each contour in a simple way for users to make them ready to follow the drawing task.

In this work, we used a calibration technique to compensate for a few fabrication and assembly errors. The experimental results showed the presented technique could improve the accuracy of the robot in tracking the defined trajectories. However, after applying the calibration technique, errors appeared in tracing the path. The residual errors are the results of using low-quality RC servo motors and backlash existence in the motor coupling and pen gripper parts.

7. CONCLUSIONS

In this work, we presented the design and implementation of a smart drawing robot (Rasmbot) to be used for different applications. For educating drawing, one of the early steps is drawing the subject with simple lines. Rasmbot has two features for this purpose: 1- it intelligently draws a subject in a picture with outlines that are similar to what an artist chooses, and 2- it tries to smooth the lines to make them simple for drawing. Accordingly, Rasmbot could help students develop their creativity and problem-solving skills for drawing different subjects. Moreover, for entertainment, Rasmbot can be used as an interactive robotics artist for users. Nevertheless, the experimental results showed the design approach considered for Rasmbot is effective for implementing a robot for drawing any pictures in a human-like artistic way. Because Rasmbot was designed based on low-cost and off-the-shelf components, we think the approach presented in this work could be considered as guidelines and might be beneficial for researchers and administration in educational institutes to use robotics technologies for teaching drawing skills.

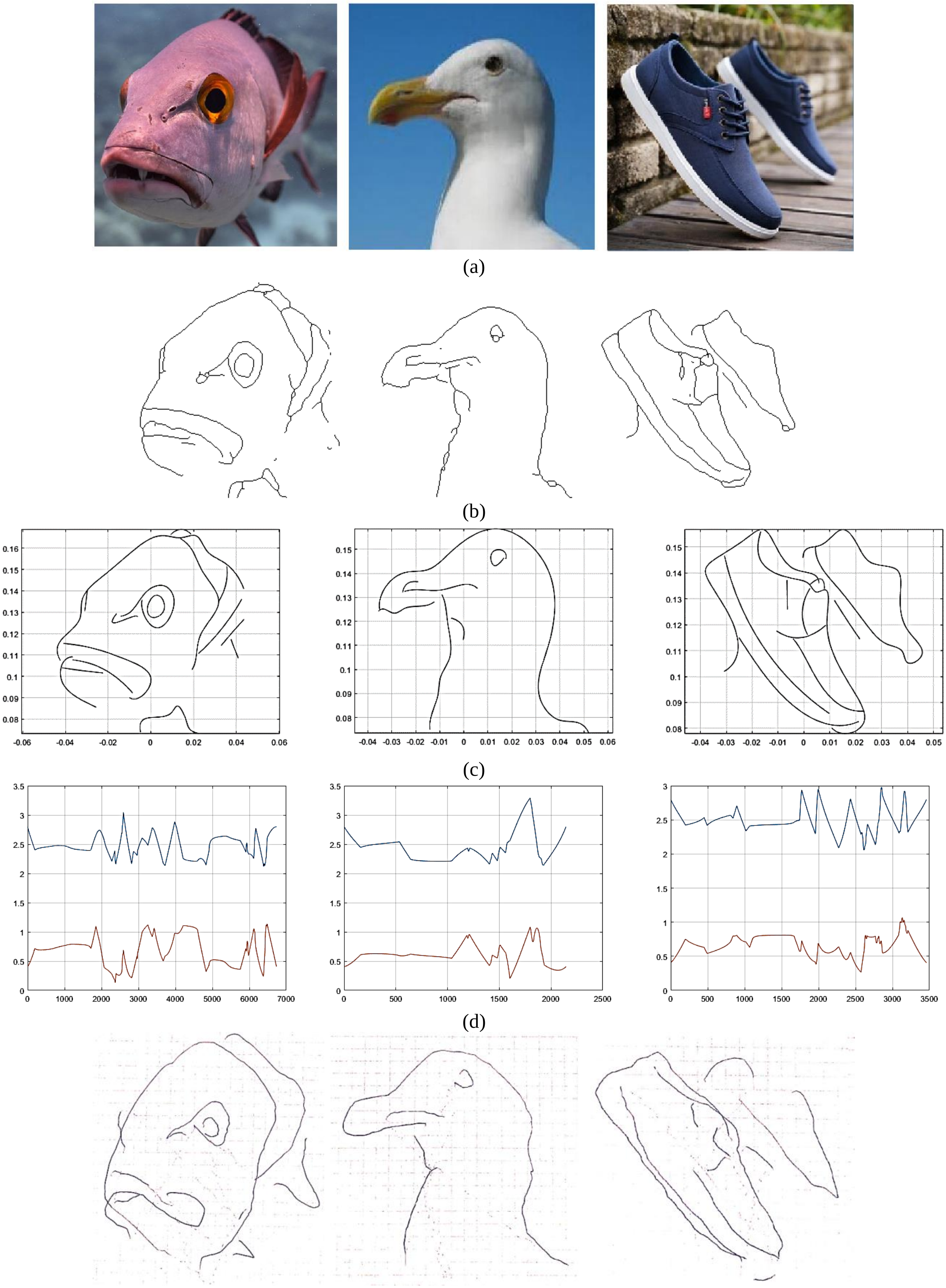


Fig. 7: Experiment results: (a) shows the given pictures. (b) and (c) illustrate the extracted and smoothed contours, respectively. The motions designed for the robot's motors are presented in (d). Finally, (e) shows the drawn pictures by the robot.

For future work, we will focus on improving the UX of the robot. For this, we plan to design another drawing robot with a compact design. Also, we will develop the robot's application in a mini-PC placed internally in the Rasmbot's body. Moreover, we plan to equip the robot with an Internet of Thnings module to be controlled via the Internet and Bluetooth. Additionally, we will use more accurate servo motors for the manipulator to make the robot more accurate in drawing tasks.

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