

AN INTERACTIVE EDUCATIONAL DRAWING SYSTEM USING A HUMANOID ROBOT AND LIGHT POLARIZATION

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ABSTRACT

In this paper we propose an educational robotic system for teaching kids at nursery schools how to write and draw simple shapes. Our system uses the humanoid robot NAO to draw shapes appearing on a computer screen. The system uses light polarization property for fast detection of the screen despite of its content. We also propose a mapping from the image domain to the robot space.

Index Terms— NAO, Polarization, Educational

1. INTRODUCTION

Robots were initially designed to aid human carry out tasks that are repetitive, difficult, or dangerous. A robot can be much more accurate, reliable, faster and stronger than a human but till now, it cannot do everything done by a human. For instance, teaching a kid at a nursery school how to write or draw is a task that intuitively fit a human more than a robot. However, the recent emergence of toy-like humanoid robots makes it promising for a robot to mimic the teaching process as a toy-like robot is more attractive for a kid than a real teacher and can lead to a better performance. Educational robotic was used by da Silva et al. [1] for game purpose for kids, as Lego MindStorms was used to make the kids experience situations of urban traffic, leading to reflections on what attitude to take in view of typical situations. This paper focuses on drawing and writing educational robotics.

For writing and drawing robots, Yussof et al. [2] used a robotic arm to write the Latin characters. Their method was based on dividing any character into several straight or curved segments where each segment is responsible for one movement for the used robotic arm. In their system, the robotic arm was connected directly to the computer that accepts the characters from the user. Balaganesh et al. [3] designed a robotic arm to help the handicapped people with the writing. The input to their robot is based on speech recognition. Calinon et al. Kwok et al. [4] designed a 5 degrees of freedom (DOF) drawing robot that aims at

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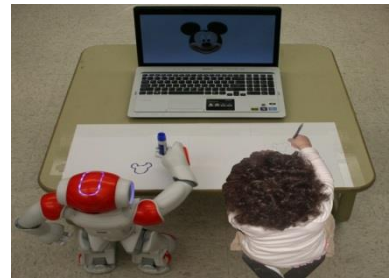


Fig. 1. The proposed interactive educational drawing system.

studying Chinese painting and calligraphy. Calinon et al. [5] presented an entertaining application for drawing human portraits using a *Fujitsu* humanoid robot. Their approach is capable of detecting humans only. Their system pre-drawing processing consists of a Haar-like features tracking stage that detects a human face in the image and feed it into Canny edge detector based contour extraction stage. The extracted contour is then fed into an image binarization stage that uses morphological operation to remove salt and pepper noise. Their work was extended by Chyi-Yeu Lin et al. [6] who used a 3 DOF hand humanoid robot and more sophisticated image pre-processing to generate a better quality image. Gommel et al. [7] used a Kuka robotic arm to develop a human portrait drawer to be used inside a museum to auto-portrait visitors. Jean-Pierre et al. [8] used a 6 DOF robotic arm to develop the entertaining “artist robot” that is used to draw portraits for the visitors of a park. The robotic arm is connected to an external computer for image processing and trajectory calculation. In [7] and [8], the system was based on using a robotic arm that was relatively big in size and does not fit many environments. Chatzis et al. [9] presented a quantum-statistical approach towards trajectory-based robot learning by demonstration. They exploited their method to teach the humanoid robot Nao [10] to draw the character 8. They used kinesthetic during their experiments rather than vision.

In this paper we used a Nao H25 Aldebaran humanoid robot [10] and a laptop to build an interactive educational system to teach nursery school kids how to draw as shown in Fig. 1. Nao is 57 cm tall and has 25 DOF. We used 1 DOF (head pitch) for capturing the images of the surrounding scene, 1 DOF (right hand) for holding a pen

and 3 DOF (right shoulder roll and pitch, and elbow roll) for drawing the object of interest that is segmented out of the captured scene on the fly using light polarization, as Nao is equipped with a pair of cameras that are aligned vertically on its head and we attached to each camera a linear polarizer. These polarizers are perpendicular to each other and will play a significant role in the segmentation process as will be described in section 2 and section 3. Compared to similar related work [5, 6, 7, 8], our system is less complex, more general and smaller in size. Moreover, it is a humanoid toy-like which makes it fit better when dealing with kids. Also our code is written in c++ and embedded on the robot Nao through linux cross-compiling which speeds up the operation.

2. LIGHT POLARIZATION

Light plays an important role in the process of image formation, as an image is formed when light is reflected from an object in space into an image sensor. In the process of image formation, the object 3D shape is converted into 2D information. The 3D shape information of the object is carried by the light wave propagating from the object to the image sensor, and hence we can exploit the properties associated with the light to recover the 3D shape of the object after the process of image formation. From the perspective of wave propagation, light is an electromagnetic wave [11] that is characterized by several properties among which are intensity, spectrum, and polarization. The intensity is a measure of the magnitude of the oscillating electric field associated with the light, the spectrum is the frequency range over which the electric field oscillates, and the polarization is a measure of the direction at which the electric field oscillates in space. Recently, the polarization property has been used beside intensity and spectrum properties in the field of imaging emerging the terminology polarization imaging and polarization cameras that are capable not only of measuring the spectrum and magnitude of the electric field associated with the light, but also its direction in space. While the intensity and the spectrum can inform us about the materials, polarization can give information about surface shape, conductivity, refractive indices, and roughness [12]. Polarization imaging has been used for many applications in machine vision [19], remote sensing [12], biomedical imaging [13] and industrial control [14].

In this paper, we exploit light polarization to make fast segmentation for the image appearing on the Liquid Crystal Display (LCD) of any laptop. Our method depends on the phenomenon of the emission of linearly polarized light from any LCD as a conventional LCD is based on using two crossed sheets of linear polarizers to achieve high contrast ratio [15]. A voltage controlled liquid crystal is sandwiched between these crossed polarizers [16]. The bottom polarizer is lit by an unpolarized backlight. Only the light components whose electric field is parallel to the axis of the bottom

polarizer will pass resulting in having a linearly polarized light leaving the bottom polarizer towards the liquid crystal having an electric field direction parallel to the axis of the bottom polarizer i.e., perpendicular to the direction of the top polarizer. When the voltage controlled liquid crystal is at the voltage-off state, nothing will happen to the direction of electric field of the light incident on it. Thus, the electric field of the light incident on the top polarizer will be perpendicular to the direction of that polarizer axis, and hence the light is blocked and the screen is black. On the other hand, when the voltage applied to the liquid crystal exceeds a certain threshold, reorientation occurs to the directors of the liquid crystal and it works as a half-wave retarder that rotates the direction of the electric field incident on it by 90° . Thus, the direction of the electric field of the light leaving the liquid crystal will be parallel to the direction of the axis of the top polarizer, and hence, the light leaving the top polarizer is linearly polarized with the direction of its electric field parallel to the direction of the top polarizer axis as shown in Fig. 2. Now when putting an external linear polarizer in front of the LCD, light will pass through it with maximum intensity if its electric field direction is parallel to the LCD top polarizer. Furthermore, the light will be completely blocked if the external polarizer is perpendicular to the top polarizer. Having the external polarizer in any other direction will give intensity less than the maximum intensity according to Malu's law [17]:

$$I(\theta) = I_o \cos^2(\theta), \quad (1)$$

where I is the intensity of the light leaving the external polarizer when making an angle θ with the top polarizer with I_o being the light intensity leaving the external polarizer when having an angle of 0° with the top polarizer.

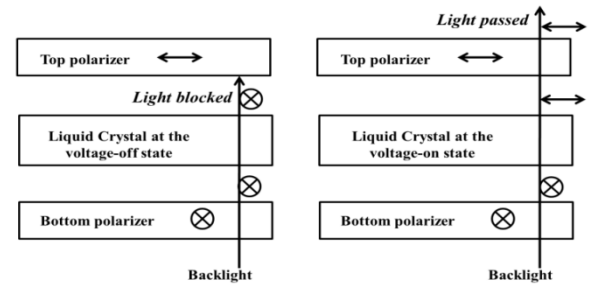


Fig. 2. LCD at voltage-off state (left) vs voltage-on state (right).

3. DETECTION FRAMEWORK

Our detection problem can be formulated as having Nao viewing with his upper camera (Fig. 3(b,d)) a scene containing a laptop and wants to draw with his hand the image appearing on the laptop LCD. The first step to do this is to segment the LCD from the whole scene which is normally very complex (a class room or an office). This problem is hard because the images on the screen are varying and the background is complex and also is varying;

in addition the location of the laptop on the table can also change. To solve these problems we propose attaching to the lower camera a linear polarizer which is perpendicular to the top polarizer of the LCD. The scenario is as follows: first Nao captures an image using his lower camera (Fig. 2(a,c)), then rotates his head pitch till the upper camera can see almost the exact scene previously seen by the lower camera as shown in Fig. 2(b,d). Using equation (1), the angle θ between the light leaving the LCD and the light entering the lower camera is 0° so the image of the LCD is blocked and hence is completely black as shown in Fig. 2(c). Thus we have from the upper camera a scene that is repeated for the lower camera but with the LCD part completely black which make it easy to detect despite of the displayed image. The blacked LCD in the lower camera image can now be detected easily from the surrounding using template matching and then the same region of interest is cropped from the upper camera image as in Fig. 2(e). The output of the cropping is turned into black and white using thresholding as shown in Fig. 2(f). The contours are then extracted from the black and white image using opencv [18]. The main contribution in our detection framework is in using the polarizers to detect the LCD screen despite of the image displayed and the background complexity.

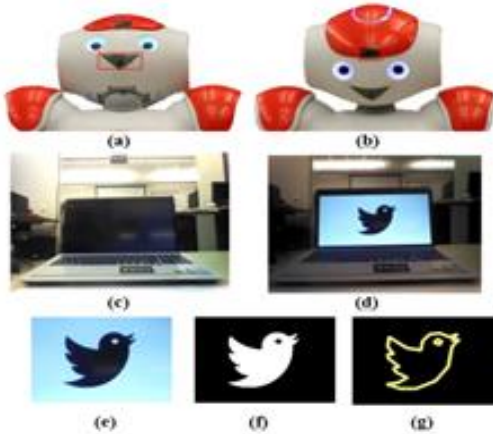


Fig. 3. NAO using his (a) lower and (b) upper cameras to capture the same scene. (the red boxes indicate the active camera in each position). (c) The image captured by the lower camera in which the LCD image is blocked. (d) The image captured by the upper camera. (e) Cropped part of the upper camera image. (f) Black and white version of (e). (g) The contours extracted from (f).

4. TRANSFORMATIONS

In this section we describe how the points of the lines and curves that we want the robot to draw can be transformed from the image domain to the robot's joints angles so that we can produce the proper movement of the arm to draw the same lines and curves on a piece of paper. This transformation is done over two stages, the first one is to transform each point from the image domain to the paper domain and then the second one is to transform each point in the paper domain to the corresponding robot's joints

angles that will move the robot arm, and hence the pen, to this point on the paper.

4.1. From image domain to paper domain

We use a linear transformation to relate the image domain to the paper domain using the following equations:

$$x_p = x_{pmin} + \frac{x_{pmax} - x_{pmin}}{y_{imax} - y_{imin}}(y_{imax} - y_i) \quad (2)$$

$$y_p = y_{pmin} + \frac{y_{par} - y_{pmin}}{x_{imax} - x_{imin}}(x_{imax} - x_i) \quad (3)$$

Where (x_i, y_i) is any point in the image domain and (x_p, y_p) is the corresponding point in the paper domain. The values $x_{imin}, x_{imax}, y_{imin}$ and y_{imax} are the minimum and maximum values of x_i and y_i for all the points of the lines and curves we want the robot to draw in this image and hence they will change from one image to another. $x_{pmin}, x_{pmax}, y_{pmin}$ and y_{pmax} are the boundaries of the selected region in the paper for the robot to draw in. To maintain the aspect ratio of the shape that we are drawing we replaced y_{pmax} in the transformation by y_{par} which is chosen such that:

$$\frac{y_{imax} - y_{imin}}{x_{imax} - x_{imin}} = \frac{x_{pmax} - x_{pmin}}{y_{par} - y_{pmin}} \quad (4)$$

Solving for y_{par} we get:

$$y_{par} = y_{pmin} + \frac{x_{imax} - x_{imin}}{y_{imax} - y_{imin}}(x_{pmax} - x_{pmin}) \quad (5)$$

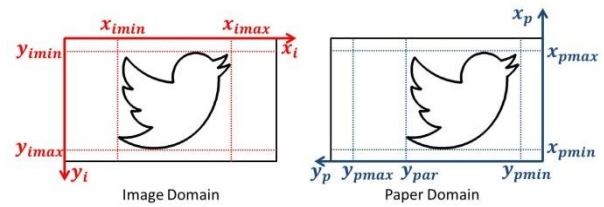


Fig. 4. The transformation from the image domain to the paper domain.

4.2. From paper domain to robot's joints angles

The robot will raise his right arm parallel to the paper and then use his shoulder roll and elbow roll angles to reach the required point on the paper. We need to transform the point (x_p, y_p) in the paper domain to the angles S and E which represent the right arm shoulder roll and elbow roll angles respectively as shown in Fig. 5. We start from the reverse transformation namely from S and E to (x_p, y_p) :

$$x_p = a \cos(S - \delta) + b \cos(S - \delta + E + \theta) \quad (6)$$

$$y_p = a \sin(S - \delta) + b \sin(S - \delta + E + \theta) \quad (7)$$

where a and b are the lengths of the upper arm and forearm respectively while δ and θ are the angles resulting from the offset “ d ” between the shoulder joint and the elbow joint in the y direction as shown in Fig. 5. To find the reverse transform we start by squaring and adding equations (6) and (7) which lead to:

$$x_p^2 + y_p^2 = a^2 + b^2 + 2ab\cos(E + \theta) \quad (8)$$

Then we can solve for E to get:

$$E = -\theta + \cos^{-1}\left(\frac{x_p^2 + y_p^2 - a^2 - b^2}{2ab}\right) \quad (9)$$

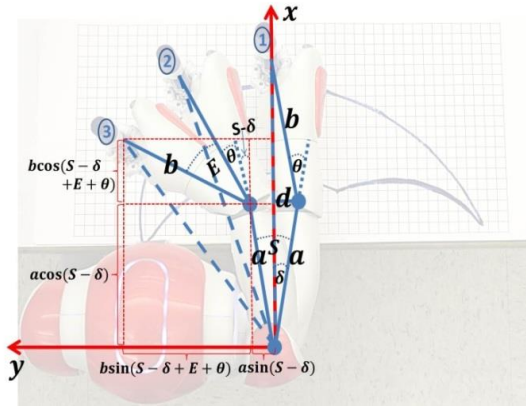


Fig. 5. The transformation from the paper domain to the robot joints angles.

To get S we expand the cosine and sine functions in equations (6) and (7) in terms of $(S - \delta)$ and $(E + \theta)$:

$$x_p = (a + b\cos(E + \theta))\cos(S - \delta) - b\sin(E + \theta)\sin(S - \delta) \quad (10)$$

$$y_p = (a + b\cos(E + \theta))\sin(S - \delta) + b\sin(E + \theta)\cos(S - \delta) \quad (11)$$

Solving equations (10), (11) for $\cos(S - \delta)$ and $\sin(S - \delta)$ by multiplying equation (10) by $(a + b\cos(E + \theta))$ and equation (11) by $b\sin(E + \theta)$ then adding and subtracting we get:

$$\cos(S - \delta) = \frac{x_p(a + b\cos(E + \theta)) + y_pb\sin(E + \theta)}{a^2 + b^2 + 2ab\cos(E + \theta)} \quad (12)$$

$$\sin(S - \delta) = \frac{y_p(a + b\cos(E + \theta)) - x_pb\sin(E + \theta)}{a^2 + b^2 + 2ab\cos(E + \theta)} \quad (13)$$

Dividing equation 13 by equation 12 and solving for S we get:

$$S = \delta + \tan^{-1}\frac{y_p(a + b\cos(E + \theta)) - x_pb\sin(E + \theta)}{x_p(a + b\cos(E + \theta)) + y_pb\sin(E + \theta)} \quad (14)$$

Equations (9) and (14) will be used to transform any point on the paper plane (x_p, y_p) to the angles S and E that will move the pen to this point.

5. EXPERIMENTAL RESULTS

In our experiment, Nao is standing in front of a laptop displaying an image and his task is to segment the laptop screen from the complex background despite of the contents of the image and then analyze this image to extract the contours and draw them so that a kid sitting beside Nao can mimic what Nao is doing. Nao showed to be attractive for all of the kids that participated in our experiment and hence captured their attention and enabled them to learn fast.

The values of “ a ” and “ b ” mentioned in the previous section were used as 10.5 and 11.37 cm from the documentation of Nao. Also the offset “ d ” is 1.5 cm and hence δ and θ are calculated as 8.21 and 15.79 degrees respectively. These are constant values that were calculated only once. The region of drawing in the paper is shown in blue in figure 6. We selected within that region the rectangle shown in red to be the limits of our drawing area with x_{pmin} , x_{pmax} , y_{pmin} and y_{pmax} equal to 15.5, 20.5, -6 and 6 respectively. These values controlled the region of the paper that Nao can draw in without walking. Of course, Nao can walk a step to the left, right or back to move that rectangle in case he needs to draw several images.

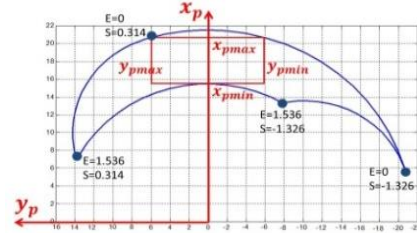


Fig. 6. The drawing region for Nao.

The experiment was repeated with the laptop in different locations on the table and with different backgrounds and different images. The detection of the screen in the image captured by the lower camera was perfect because of the polarization that led to 99% success. The only failure that happened occurred when the background scene was almost completely black, which is a non-realistic case that we tried just to test the system’s limitations. The derived analytical mapping was also successful and accurate as can be seen in Fig. 7 which shows some of the results drawn by Nao.



Fig. 7. Some of the results drawn by Nao

6. CONCLUSION AND FUTURE WORK

In this paper, we have presented an interactive educational system for drawing using the humanoid robot Nao. The paper has two main contributions; a fast and accurate method for detecting LCD screens regardless of the contents and an analytical transformation from the image domain to the robot space. Our system showed to be a useful educational tool for normal kids. In the future, we intend to extend our work to include kids with autism.

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