Paintbot-An FPGA Based Monochrome Mural Painter

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Abstract- An approach of CNC machines are drastically varying these days. Extend of their applications have probably improved so that it could be easily implemented on our real life applications, one such as mural design works. Abstract paintings now seem to be common and skillful worker could only finish a design perfectly, but when considering perfection, cost may not hold in our hands. The Paintbot is an easily fixable mural painting CNC machine where its controller has developed using Spartan 6 FPGA board with software implemented using Verilog code and a position detector that sends coordinates from the input image. Hardware development involves building the main frame, the stepper motor and drivers, sensor circuitries and relay controlled piston of the air-brush for painting. The machine allows efficiency, time saving and low cost and the work could be completed with most satisfaction.

Keywords — Abstract paintings, CNC, Mural, Paintbot, Spartan 6 FPGA board, Verilog.

I. INTRODUCTION

Service robots are mushrooming most in developed countries, where the robotic mechanisms improve daily lifestyle. This is not only due to their simplicity, but because of its cost effectiveness, safety and efficiency [1]. A wall painting robot prototype is one such example for service robots. The prototype was designed to implement a CNC based mural painting machine that could be easily placed according to users need.

The prototype was started by designing a platform that could hold stepper motor and axis movement frame, the pneumatic control part was included in this frame only. In addition, this machine could be easily placed according to users need that includes a hardware frame which holds stepper motors, drivers, air brush for painting and a controller to control the direction of motion and color spray intensity.

To develop this system with reduced complexity, the system is made fixable. Once the area to be worked was chosen paintbot is kept fixed over wall. The support system was designed by considering all factors and in research with 3D printer mechanisms so as the connecting parts were also printed from fab lab [2].

Along with hardware design pneumatic controller should also have to be set up. From the review of wall painting prototype [3], a basic idea of how to interface paint controller with designed hardware is clearly mentioned.

Motion control system is a major subsystem responsible for the automation of paintbot. Success of a motion control is depended on its control algorithm. The control hardware used by existing systems shows complexity, leading poor control performance. FPGA have been used to create hardware circuity and is easy to customize which could not be performed by any microcontroller or a digital signal processor [4].

Main aim of this system is to implement linear interpolation technique to control the 2-axes of CNC machine.

1. To convert the given image to corresponding binary format and generate X and Y coordinates of each image portions using arm processor.
2. To send generated coordinates from arm processor to FPGA using SPI.
3. To store the received coordinates in FIFO.
4. To read the coordinates one by one and process it.

According to proportion in the coordinate generate the step and direction signal for the x and y axis stepper motors and in parallel, provide control signal to relay painting system.

II. RELATED WORKS

Various research works are still going in this area on how to make fully automated home painting robots by keeping stable and thereby reducing complexity in designing and implementing in our daily life. P. Keerthanaa et al., automatic wall painting robot [5] is one recent fully designed hardware system. The system was made cost effectively and reduces human efforts of painting interior walls. With the wheels attached at the basement, the system it is easy to paint around interior wall without any human support.

An improved design in automated wall painting was seen in a detailed study of robot design for interior wall painting [6] proposed by Mohamed Sorour. His presentation in

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interior wall finishing is a detailed description about wall painting utilizing all opportunities of Computer Aided Design (CAD) a model was designed. The model shows a fully functional flexible wall painting robot with its arm mounted on a wheelbase and allows 8 DOF for an efficient painting system.

Design and implementation of 3-axis linear interpolation controller in FPGA for CNC machines and robotics [7] and VLSI Implementation of High Precision Stepper Motor Using Verilog HDL [8], provides very basic idea of implementing hardware frame for the proposed system and also supports software development for motor control.

Face detection and conversion for the initial stage of operation was based on the review of detecting face region in binary image [9]. Face is detected from color input image and is converted to a gray scale image, which is then de-noised using low pass filter. This image is then transformed to binary image by adaptive thresholding method.

Daisuke Hirooka et al., proposed an experimental analysis on pneumatic flow control valve [10], showing detailed description about pneumatic actuators its wide applications and suggest methods to control flow rate by controlling amplitude of particles.

III. System Overview

The system prototype has been separated into four parts. As already mentioned aims, first part includes processing the input image to suitable frame size and converting the image into binary format. Next, the converted image is transferred to a processor that detects each position from the converted binary array of image. The position values one by one are transmitted to FPGA and finally the control signal for stepper motor control and pneumatic control received from FPGA results in painting.

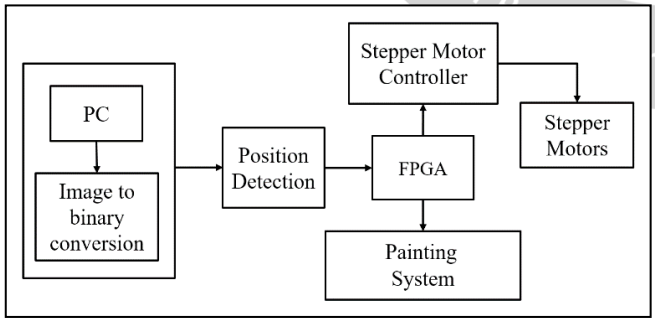

Fig. 1. System overview.

Figure 1 shows the system overview of the paintbot. Here position detection was done using LPC1769 arm processor. LPC1769 simply detects the two axis coordinate points and immediately sends to FPGA using SPI protocol.

IV. Proposed System

The proposed paintbot consist of both software and hardware controls.

A. Software control

The software control includes three stage of processing.

1.Converting an image,
2.Detecting position and
3.Processing coordinates.

1) Converting image: This process includes converting the input image into corresponding binary format were the background and light tone are converted to 1 and all the lines, sketches and free hands are converted to 0. This conversion for simplicity is done from an online site named dcode. One of the advantage of preferring online is to feel free for user to know how open our system is. In addition, we can set pixel quality and most important it will pad the converted image with 1 if the image size is smaller than our system hardware frame width. The system frame width is 50cmx50cm, which is approximately 2.7 ft^2.

Fig. 2. Image processing

Figure 2 shows one such processed image using dcode. Visible part of the converted image is binary 0 and all others are 1. The image now has converted to stencil format since the proposed system is focusing on monochromatic painting this type of conversion is most useful.

2) Position Detection: Image processed are set to 300x300 pixels which is suitable for a simple printing operation as the padding process is initially set according to this value. Now the generated binary 1's and 0's is like an array of size 300x300 which is sent as text file to LPC1769 arm processor. Program code designed to check zeroes in the array. Each time a zero is detected a corresponding x & y coordinates are generated.

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Algorithm: Position detection for motion controller.
Input: Text file of converted image.
Output: Detected positions coordinates.
Steps:
1. Assign an array of size 300x300 with the binary code generated.
2. Set a loop considering as y axis (vertical) and continues till 300 counts.
3. Inside that loop set another loop considering x axis (horizontal) and continues till 300 counts.
4. Within that loop check if the array of corresponding x and y values are equal to 0.
5. If yes, then call a function that enable SPI bus for transmitting the corresponding x and y values.

Fig. 3. Position Detection Algorithm.

Figure 3 shows the algorithm for finding coordinates from binary image using LPC1769 arm processor and send the result back to FPGA were motor control is achieved.

3) *Coordinate processing*: FPGA starts processing by receiving the x and y coordinate received from LPC1769. The values are stored in FIFO which is basically a sequential data buffer so the data received can be read in same sequence as it is received. Data received in DATAIN bus of FIFO is stored and waited until all data is received after that through DATAOUT bus of FIFO the coordinate values are send for motor control operation.

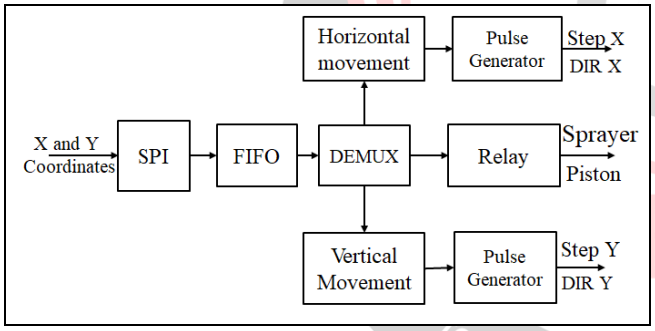

Fig. 4. Motion Control Block Diagram

Motion control system shown in figure 2 specifies the data flow from arm processor to motor through FPGA. Position detected is considered to be x and y coordinates where horizontal movements is being specified as x axis and vertical as y axis, which is send from buffer area in FPGA is processed and by using concept of de-multiplexer data are send to linear motions of stepper motor as pulses and along with the relay that control the valve connected from compressor for the spray paint to be achieved.

Algorithm: Motion control from received coordinates.
Input: Received coordinates.
Output: Motors movement and relay control.
Steps:
1. Start by initializing two variables x and y to zero.
2. Split the received input and assign it to x and y.
3. Compare it with previous input.
4. Set according to the value of x and y the movement of stepper motors through providing signals through the de-mux.
5. Provide signals to relay piston for the painting process to start.
6. Receive the next sequential input from FIFO and repeat from step 2 till all the coordinate is received.

Fig. 5. Motion Control Algorithm

Figure 5 clearly specifies the algorithm for the control of stepper motor and paint system. Movement of stepper motor that moves the rails will be always multiples of 0.167.

For example if the coordinates are found to be (15,3) then as per algorithm necessary steps are generated to drive motor and distance moved will be 15x0.167=2.505cm for x axis and 3x0.167=0.501cm for y axis.

B. Hardware control modules

Hardware modules includes painting system, axis frame and processor board with motor driver.

1) Painting system: Figure 6 shows block diagram of painting system.

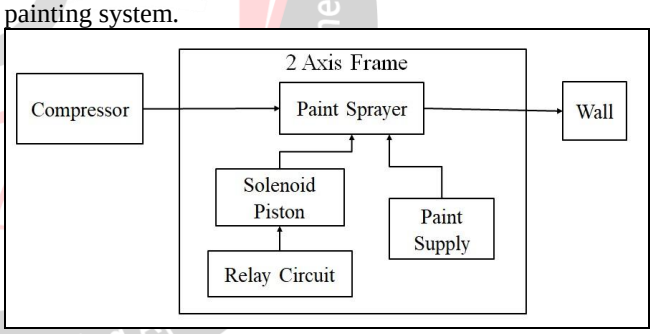

Fig. 6. Block diagram of Painting System

The painting system consist of a general 300 psi compressor, a mini push-pull solenoid piston with relay circuits and paint sprayer with paint supply of maximum capacity of 800ml. Piston movement is controlled by relay circuit. The set up was built on a 2 axis frame which includes stepper motor along with their drivers.

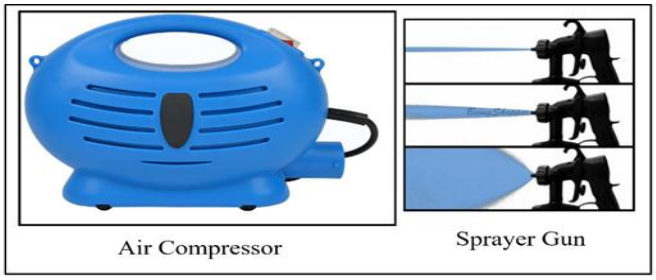

Fig. 7. Compressor and Sprayer gun.

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Figure 7 shows the compressor and paint sprayer gun used in paintbot. They are both interconnected with flexible pipe for easy movement of the system and a mini push-pull solenoid is being connected on trigger side of sprayer. The system is designed such that sprayer is kept OFF and solenoid piston connected with sprayer is made ON with relay circuit demands for the air pressure from the compressor. So that paint is dropped only if relay circuit gets active which in turns reduces paint supply.

2) Processor board with motor driver: The processor board is fully designed single module LPC1769 and FPGA Spartan 6 processors with necessary power supply lines provided for both processors. Its 4-layer PCB schematics and layout was designed using Orcad. Stepper motor is been controlled using motor drivers are also connected to the processor board TB6600 motor drivers where best suited for the system ass it has in built over current protection by limiting current from the source.

V. Prototype Demonstration

Paintbot was successfully set and for analysis purpose, several trial and error methods were also chosen to avoid paint clogging and overspread.

Fig. 8. Y axis with spray painter attached

For the Paintbot 2 axis frame was designed both for x axis and y axis. The figure 8 shows y axis frame attached with x axis frame and sprayer along with piston controllers has been implemented near to the wall for the painting process to start. Limit switches where suitably implemented on 4 points to avoid crashing of system.

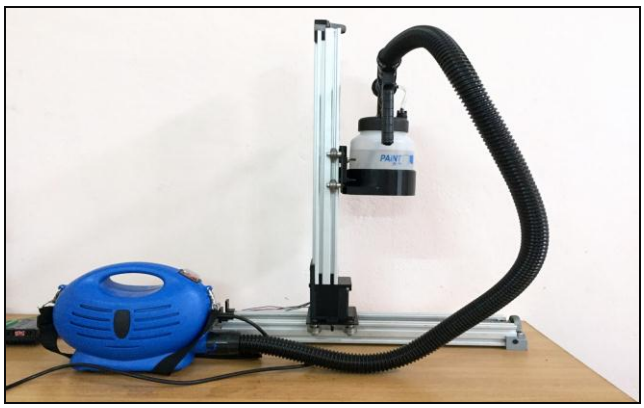

Fig. 9. Paintbot setup.

Figure 9 shows the demonstration of proposed system. Progressive works were done for getting better precision result.

VI. Future Work

Painting machine designed is flexible and its functional features can be expanded from simple home decoration to industrial world. The system expansion is one of the future work be done as the paint bot now designed can only work up to 2.5ft^2 area. Along with that, multi-color designing with automated color refill system is also considered.

Real time user and paintbot communication to be established in future results in viewing the progress of task while paintbot is doing its job. This may also reduce error possibilities and improves system maintenance by providing efficient feedback to user.

VII. Result

Horizontal and vertical movement of stepper motors are generated from pre found coordinate values. Two Nema 23 motors each 1.8^0 per step is used here and with a 10mm pitch lead screw coupled with stepper motor, both horizontal and vertical movement was made stable. Each pixel corresponds to an approximation of 5mm movement and the step pulse for this condition is being coded with stimulation as shown below

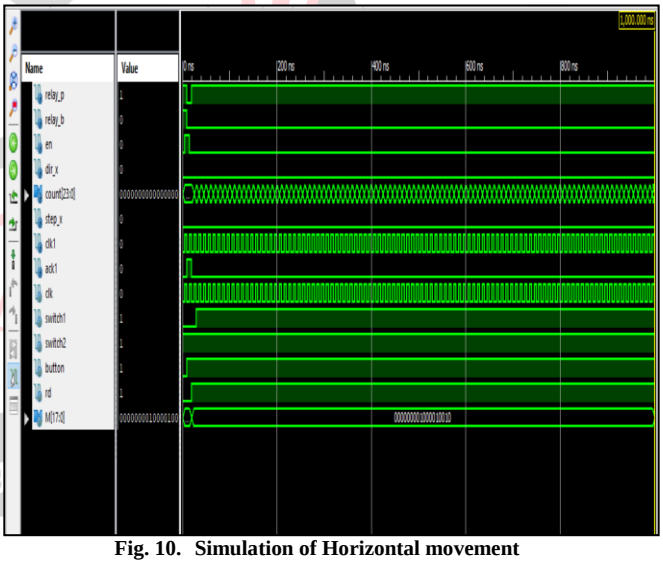

Fig. 10. Simulation of Horizontal movement

Figure 10 shows simulated result when a pixel is detected while read signal is high and for 5mm movement 534 steps are generated. This corresponds to x axis movement and after all pixels in a row is successfully moved single pixel movement of vertical direction stepper motor gets active, generating same step as for horizontal movement shown.

On successful completion of each movement corresponds to '0' paint is sprayed which is done with the help of push pull solenoid and the final image painted on the wall is shown below.

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Fig. 11. Painted Image on wall

The above figure 11 shows image painted on wall, just like dropping ink after finding correct position of dark portions.

VIII. CONCLUSION

The prototype of Paintbot was successfully build as shown in experiment setup. Now any image can be directly given for painting after completion of initial image processing, the coordinate points are sent for stepper motor motion which enables both horizontal and vertical movements and on successful reach of each detected position relay module is operated activating push pull solenoid and there by spraying of paint drop is done.

In general, the hardware and software of the proposed system was implemented. The objective of a monochromatic mural painting was successfully designed and in progress with the works for fully functioning robots working without human assistance. System analysis is still performing for developing a better efficient robot and in short, the paintbot prototype can act as platform for future research works.

REFERENCE

[1] V. J. Traver, A. P. del Pobil, M. Perez-Francisco, "Making Service Robots Human-Safe," International Conference on Intelligent Robots and Systems, 2000

[2] Cheng-Tiao Hsieh, "Development of an Integrated System of 3D Printer and Laser Carving," Microsystems, Packaging, Assembly and Circuits Technology Conference (IMPACT), 2016

[3] B Teoh and S.Ragavan, "FPGA based wall painting service robot prototype", in IEEE int. conf. on Recent Advances in Intell. Computational Sys., 2011, pp. 777-782.

[4] Dipali B. Bhatt, Hemant R. More, "CNC Machine Controller Using FPGA," *International Journal of Review in Electronics & Communication Engineering* Volume 2 - Issue 1 February 2014.

[5] P.Keerthanaa, K.Jeevitha, V.Navina "Automatic Wall Painting Robot," International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 7, July 2013.

[6] Mohamed Sorour, "RoboPainter – A detailed robot design for interior wall painting," IEEE International Workshop on Advanced Robotics and its Social Impacts,2015

[7] Mufaddal A. Saifee, "Design and implementation of 3-axis linear interpolation controller in FPGA for CNC machines and robotics," International Journal of Advanced Research In Engineering And Technology, Volume 5, Issue 9, September (2014), pp. 52-62.

[8] Richa Malhotra, Vishal Sharma, Vineeta Sharma, Nitika, "VLSI Implementation of High Precision Stepper Motor Using Verilog HDL," *International Journal of Innovative Research in Computer and Communication Engineering*, Vol. 4, , August 2016.

[9] Yumnam Kirani Singh, Vanlal Hruaia, "Detecting Face Region in Binary Image," IEEE Recent Advances in Intelligent Computational Systems, 2015.

[10] Daisuke Hirooka, Koichi Suzumori, "Experimental Analysis on Pneumatic Flow Control Valve Driven by PZT Vibrator," *IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 2010.*

 DOI : 10.18231/2454-9150.2018.0386