UNIVERSITY OF NOTRE DAME

Paint by Bits

High Level Design

Tim Bontrager, Sarah Divel, Kelsey Han, Elizabeth Huschke

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Table of Contents

1 Introduction

The paint-by-joystick design project was introduced by ADEC. The premise of this project is to create a system in which a user utilizes a joystick that controls a robotic device which dispenses paint on to a piece of paper. Our goal is to design a cost efficient and user friendly system that improves the quality of life of the individuals at ADEC.

2 Problem Statement and Proposed Solution

ADEC provides a range of services for people with developmental and physical disabilities to help them "live, learn, work, play, and achieve the same as anyone else,"[1] including family services, employment services, supervised group living and supported living services, and day services.

One of the goals of ADEC's day services in particular is to provide adults living with developmental disabilities with meaningful days by helping them to discover their natural abilities and interests. Many of ADEC's clients enjoy painting, but some lack the motor skills necessary to grasp and maneuver a paintbrush. Currently, ADEC employees have to manually assist clients by holding the client's hands on the canvas. This is not in keeping with ADEC's mission of independence for its clients. The goal of this project is to create a system that can take the role of the second hand, giving independence back to ADEC's clients. They will be able to control a painting utensil using a joystick in order to create a painting on their own.

Our proposed solution can be divided into four broad areas. The first area is the user interface, where the client will manipulate a joystick. The user interface will also include an LED alert system that will give necessary information to the user about if the power is on, if the "paint brush" is in motion, etc. This will optionally be paired with an LCD screen to convey appropriate messages. The second area is a microprocessor unit, which will receive signals from the user interface, as well as feedback from the dispensing unit. The third area is a color dispensing unit. This unit will be physically placed onto an easel, and will dispense a coloring agent onto the canvas. The fourth area is the power supply unit which will deliver the appropriate voltages to each component.

[1] adecinc.com/our-services

3 System Requirements

Table 1. Overall System Requirements

Overall System Requirements	
General	Must be able to distribute color across a canvas. Must be able to lift paintbrush off of canvas. Must be driven by a joystick Must be able to interface with motors that control plotter
Safety	Must not be electrically "hot" Must protect users from getting caught in motors Must not overheat and cause fire Motors must stop when carriage reaches the edge of the frame Must not short if splashed with paint
Power	Must operate from 12 V battery and wall plug
Cost	Must not exceed $500 to design and produce
Size	Must be approximately 2' x 4' in dimension
Weight	Must weigh less than 30 pounds
User Friendliness	Must be operable by handicapped persons Must be transportable Must be sturdy enough to withstand normal use

4 System Block Diagram

4.1 Overall System

The system will have four major subsystems. The first to be discussed will be the user interface, the second will be the microprocessor, the third will be the paint-dispensing unit, and the fourth will be the power conversion unit. Figure 1 shows the overall system block diagram that represents what will be implemented.

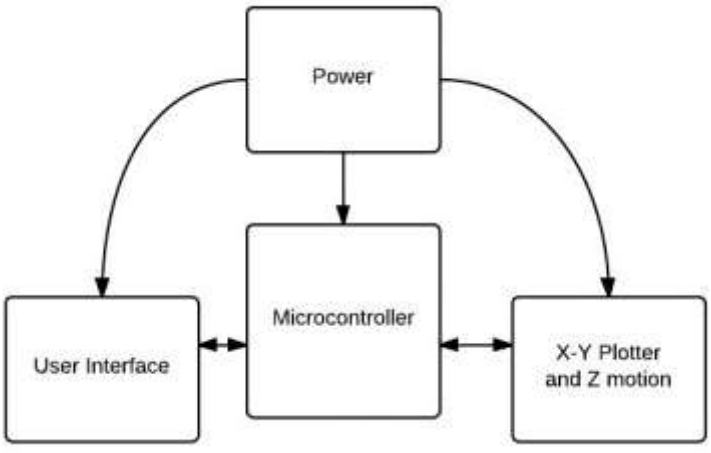

Figure 1. System Block Diagram

The user interface consists of the joystick, LED indicators, and buttons that the user can interact with. Figure 2 shows how the user interface will connect to the microcontroller as well as what the inputs and outputs on the microcontroller will look like. The power block will include a 12 V rechargeable battery plus a 5 V regulator that will power the microcontroller and other low voltage devices.

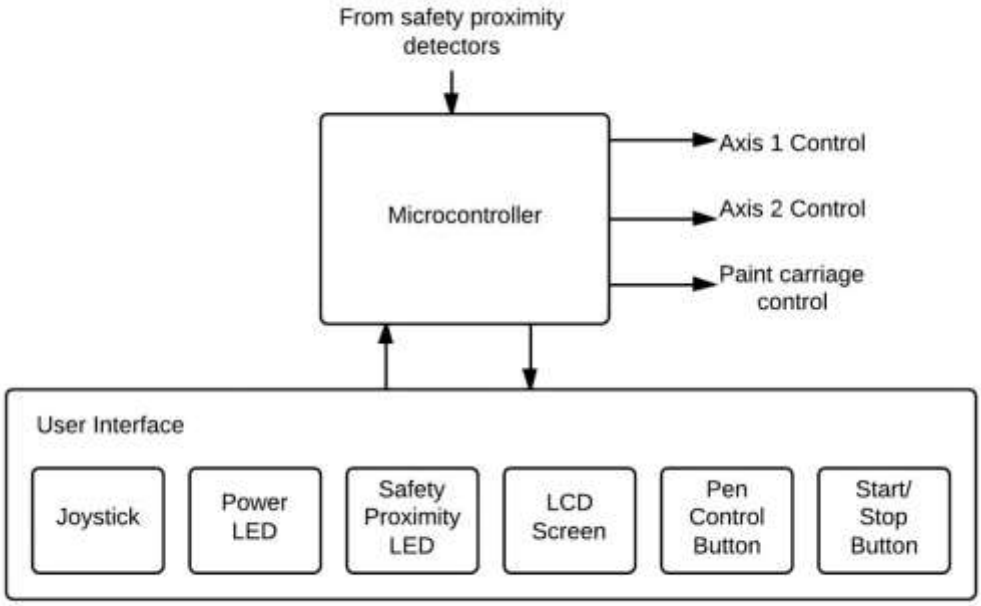

Figure 2. User Interface and Microcontroller Block Diagram

The microcontroller to be used is a PIC32. It will read signals that indicate when the motors are too close to the edge via the proximity detectors. The microcontroller will then take appropriate action. The joystick will also control the X-Y plotter by connecting directly to the microcontroller. The microcontroller will send out signals to control both axes of motion in response to movements of the joystick.

The last subsystem to be discussed is the paint-dispensing unit. This subsystem can be described by the block diagram in Figure 3.

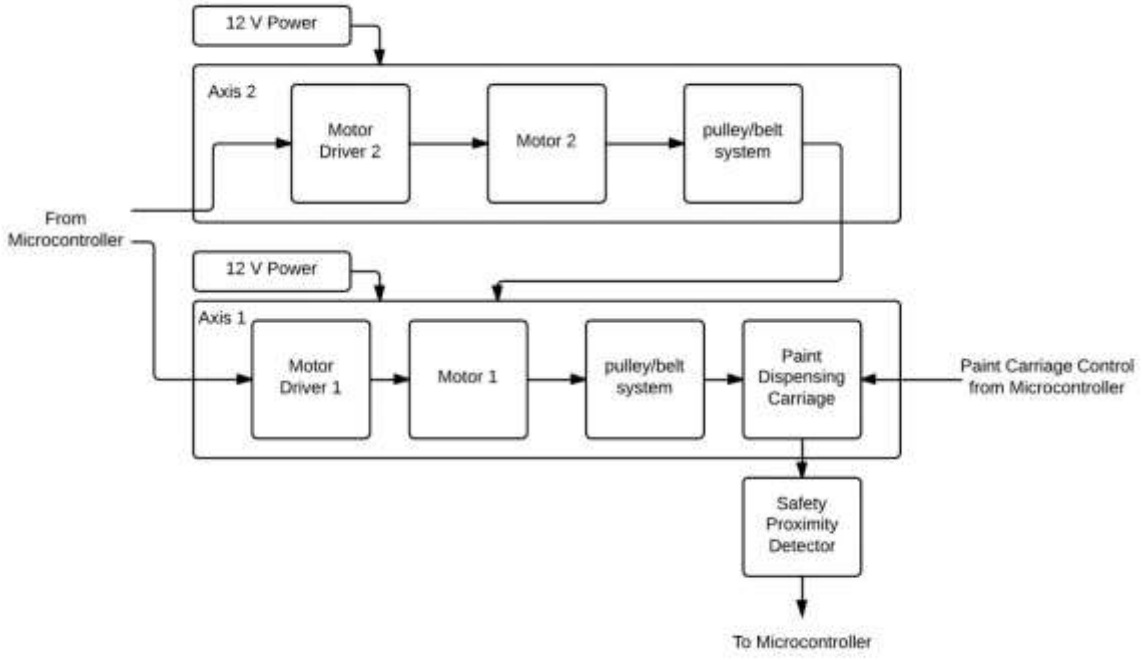

Figure 3. XYZ Motion Block Diagram

This subunit fulfills the design requirements of size, weight, and the functionality of dispensing paint to canvas. This subunit can itself be broken down into two more subunits. The first to be discussed will be the x-y plotter, and second will be the paint dispensing mechanism.

The motors that will be used are Amico 24V 200 rpm motors. These motors require a maximum of three amps. This presents a safety hazard, so the motor housing will be encased in a non-conductive material. All wiring will be shielded to minimize the chances of a user touching a hot wire.

4.2 Subsystem and Interface Requirements

The X-Y plotter will require a 12V rechargeable battery for each motor controller. The motor controller powers the motors, so no additional interfacing is required for the motors or frames. A plug in wall adaptor will generate this signal. Additionally, the safety switches on the frame, the paint dispensing unit, user display and the microcontroller will require 5 V to operate. This will be supplied by feeding the 12 V power line through a 5 V regulator.

The joystick is essentially a pair of potentiometers, with one reading the X displacement of the joystick, and the other reading the Y. By placing a voltage across the potentiometer, and then varying the wiper's position, different voltages are presented to the microcontroller. The maximum allowable voltage on the input pins is 5V, so a 5V signal across the joystick is needed. This will be done using the same voltage source as the microcontroller. Finally, the interfacing between the microcontroller and the joystick uses an on-chip ADC. This will be programmed using a PIC32, and will allow for direction control and speed variation.

4.3 Future Enhancement Requirements

In the future, the team plans to improve upon the initial design, recognizing that multiple design iterations are necessary to create the final, marketable product. While the group has analyzed the project and developed a design to create a successfully functioning prototype in the allotted time, potential future improvements were identified to increase the usability and portability of the system..

Part of ADEC's mission statement is to help clients "live, learn, work, play, and achieve the same as anyone else"[2]. While the device, as designed, will enable ADEC clients to paint on their own by using a joystick to control a paintbrush, the end result may seem to be more of a video game rather than actually painting. Therefore, one future enhancement requirement involves updating the user interface so that it mimics real painting. While a joystick will still be the underlying method of controlling the X-Y motion, an additional unit will be placed on top of the joystick in which the painter can rest their wrist and hold an actual paintbrush. As the painter's arm moves, the joystick will move and control the movement across the canvass.

As part of improving the design to simulate actual painting, another future enhancement involves replacing the marker in the color dispensing unit with an actual paintbrush. This would also require a paint palette or another method of switching colors and cleaning the paintbrush. This enhancement must include several safety mechanisms to prevent paint and water from damaging the electronic systems.

The current design requires the system to lay flat on a table. This design makes it somewhat difficult for one individual to transport the system on their own due to the various components of the frame and axes, battery, joystick, and connecting wires. A final future enhancement involves making the system able to tilt at approximately a 70° angle with the horizontal, similar to how easels are tilted. This enhancement requires that all forces are taken into account so no components are displaced when the axes move. It would also be beneficial to consolidate the system to improve the painter's independence to relocate the system if they desire.

5 High Level Design Decisions

5.1 Color Dispensing Unit

The purpose of the color-dispensing unit is to apply color to the canvas as the unit is moved by the X-Y plotter. The unit will slide along a dowel, which will provide support and stability. A belt clamp will connect the unit to the moving belt. The color application will be achieved through the use of a felt tip pen or marker.

It is also desired, though not essential, to enable raising and lowering of the felt tip pen or marker, allowing users to draw non-continuous lines. One way to implement this functionality is to use a solenoid that will raise and lower the pen. A push/pull solenoid from Adafruit has been identified to serve this purpose. It would be powered by the 12V motor power supply and

[2] adecinc.com/our-services

switched by the microcontroller via a power transistor in response to a pushbutton input from the user interface.

5.2 X-Y Plotter

The purpose of the X-Y plotter is to move the color-dispensing unit around the canvas. To meet the design requirements, it must be lightweight, but still large enough to allow a full canvas to be painted. Additionally, the X-Y plotter must be able to support the color-dispensing unit without sagging into the center. This will be done with the use of metal or plastic dowels, giving strength to the supported machine while maintaining a lightweight frame.

The X-Y plotter will consist of two axes for motion. The first axis will be connected to the color-dispensing unit, and will travel across the canvas. This axis will be based off of the design generated during the first semester. It will consist of a dowel, placed between two and five inches above the canvas. This dowel will support the color-dispensing unit, allowing it to move across the canvas. The color-dispensing unit will also be attached to a belt, running below the dowel. This belt will be attached to a motor at one end of the axis, and a pulley at the other. By varying the direction and speed of the motor, one axis of linear motion will be achieved. In order for motion to be smooth and controlled, the pitch of the pulley must match the pitch of the belt, and a pulley must be able to be mounted onto the motor. Because the color-dispensing unit will be powered, a wire will be run to the color-dispensing unit along this axis.

The second axis of motion will be placed perpendicular to the first one, and will run parallel to the left and right of the canvas. Because of the need for greater stability, this axis will consist of a linear slide on each side of the canvas. Each of these slides will have a mobile carriage, and the first axis will be mounted on top of these carriages. A motor-pulley system will move the linear slide up and down the sides of the canvas. In order for this axis to be properly integrated with the first axis, it must be able to smoothly move both ends of the first axis.

The motors to be used are AMICO 200RPM 24V motors. These motors pull a maximum of 3 A. The motors will be run at a maximum of 12 V, since 200RPM is too fast for this design.. A HB-25 motor driver from Parallax controls the motors. Input power to the motor driver will be 12V. The motor draws up to 3A (motor driver is capable of supplying 25A). Logic input to the motor driver is a single pulse sent from the microcontroller. The pulse time can be anywhere from .8 ms to 2.2 ms, with 1.0 ms representing full reverse, 1.5 ms representing off, and 2.0 ms representing full forward. Intermediate values represent scaled speeds, achieved through pulse width modulation of the output signal to the motor.

In order to fulfill safety requirements, and to protect the motor from damage, switches will be placed at the end of each axis. This will send a signal to the microprocessor indicating when the carriage has reached the end of the axis. The microprocessor will then turn off the motor.

5.3 Joystick Interface

The joystick interface connects directly to the microcontroller which in turns transmits signals to the X-Y plotter to move the paint dispensing unit in the desired direction. The directions implemented include up, down, left, or right across the page.

This input will be implemented by using both an analog joystick as well as a digital joystick. The digital joystick is able to send signals depending on which way the joystick is moved. It is useful in testing the mechanical system. However, it is limited in movement. Therefore, an analog joystick will also be implemented in order to get all directions of movement. An analog to digital conversion is necessary for this step so that the system knows how much to move in the X and Y directions. The digital Atari joystick chosen does not require power because the implementation is based on completing a circuit. The analog joystick can be powered off of the 5 V provided to the microcontroller.

The joystick outputs can be directly connected to the I/O ports of the microcontroller. When implementing the digital joystick, the change notification interrupts will be used. The analog joystick does not require an interrupt. Instead, constant polling will be used to test which direction the joystick is being moved. From there, the microcontroller will send the appropriate signal to the motor control, based on the signal.

When implementing the subsystem, the joystick will be connected to the I/O ports via jumper cables. In a custom board design, a simple header pin will be mounted on to the board so that the joystick can be inserted directly onto the board.

6 Open Questions

Before committing to a low level design, several open questions involving wire management, safety, and the overall system layout must be addressed.

6.1 Wire Management

This design involves several wires connecting the X-Y plotter and paint dispensing unit to the microcontroller. Careful consideration must be used in managing the wires to ensure no components are disconnected as a result of the system movement.

6.2 Safety Considerations

Because the proposed system involves several moving parts and potential for minor to severe errors, the team must carefully consider all safety concerns and solutions to alleviate these concerns.

The first safety concern involves ensuring that the user does not derail the color dispensing unit by attempting to run it past the boundaries. The team has considered various methods to sense position, including IR sensors or switches, which prevent the user from moving the system past the position limits. Of these position sensors, we must consider which best suits the needs of our system.

Furthermore, the team must also determine the best way to indicate operational states to the painter. Some options considered include flashing LED lights to indicate when an error state has been entered or an LED display to write text messages to the user displaying the exact error. One concern for the flashing light implementation is that the painter may become frustrated since they are not given exact information about which error state has been entered. On the contrary,

one concern of providing the text messages is that the user may attempt to solve the problem without reading a user manual and potentially harm the system or themselves.

6.3 Overall System Configuration

The team has discussed several overall system configurations of where the user interface is in relation to the X-Y plotter. While much time of the design process was spent on the technical realization of the system, it is recognized that the system must be comfortable and operable by handicap persons to be effective. Both stationary and adjustable configurations for each user have been considered. It is yet to be determined what the best configuration is for the intended uses.

7 Major Component Costs

Table 2. Component Costs

Category	Part	Price
X-Y Plotter: Both Axes	Motor (x 2)	2 x $20.62
	Pulleys (x 4)	4 x $10.00
	Timing belt (x 2)	In Storage Closet
	Pin for free pulley (x 2)	In Storage Closet
	Metal strapping (to hold motor)	Donated
	Motor driver (x 2)	Donated
X-Y Plotter: Axis 1	Dowel	In Storage Closet
	Frame	$35.00
X-Y Plotter: Axis 2	Linear Slides (x 2)	2 x $38.99
	Carriages for linear slide (x 2)	2 x $3.65
Power	12 V rechargeable battery	$23.99
	5 V regulator	$0.67
Position Sensors	Switches	Donated
	IR Sensors	4 x $14.95
Microcontroller/Board	PIC Microcontroller	$11.03
	Board	$50.00
User Interface	Joystick	In storage closet
	LCD screen	$34.99
	Indicator lights	$1.00
	Pushbuttons	In storage closet
Paint Dispensing	Solenoid	$9.95
	Marker	$0.50
	Total	**$393.45**

8 Conclusions

This paint by joystick design poses a particularly difficult mechanical challenge. In order to make the device usable by an audience that include those with special needs, usability and safety concerns should be some of the top priorities. The design process for this mechanism focused on the customers and on making reasonable decisions that are in the capabilities of the team members.

This design document includes the initial design decisions made by the team. As issues arise, there is possibility of redesign. The focus is to make the design as close to the original design as possible in order to meet the goals set at the beginning of this process. The paint by joystick mechanism created by Paint by Bits seeks to be a system that is, reliable, enjoyable, and usable by people with disabilities.

9 References

Price references were obtained from Digikey and related sites. Google searches were used frequently to find various parts. The most used resources were the data sheets that came with each of the parts that were included in the design.