Low Cost Embedded Device for Animatronic Control

Dominic Holloman, Computer Engineering

Kevin Worsley, Computer Engineering

Mentor: Dr. Mohamed E. Aly

Kellogg Honors College Capstone Project

Background

Animatronics are an integral part of many amusement park rides, museums, and children's toys. The animatronics in amusement parks are large, complex devices costing anywhere from thousands to millions of dollars. The sacrifices made for mass produced children's toys are often seen in the animatronics' features and behaviors. The goal of this project is to create a low cost, entertaining children's animatronic toy capable of responding to the user's emotions. Using commercial off-the-shelf parts (COTS), this project's design allows for visual, physical, and auditory feedback based on the user's emotions.

Objective

Make an autonomous, interactive, children's toy capable of emotional detection and responding with lights, sounds, and animations while keeping the final toy price less than $75.

Requirements

A sample of the toy's requirements is shown below. Additional requirements (such as "Safety") include: all electronics be concealed within the toy's enclosure and the toy must remain below 40°C.

Requirements

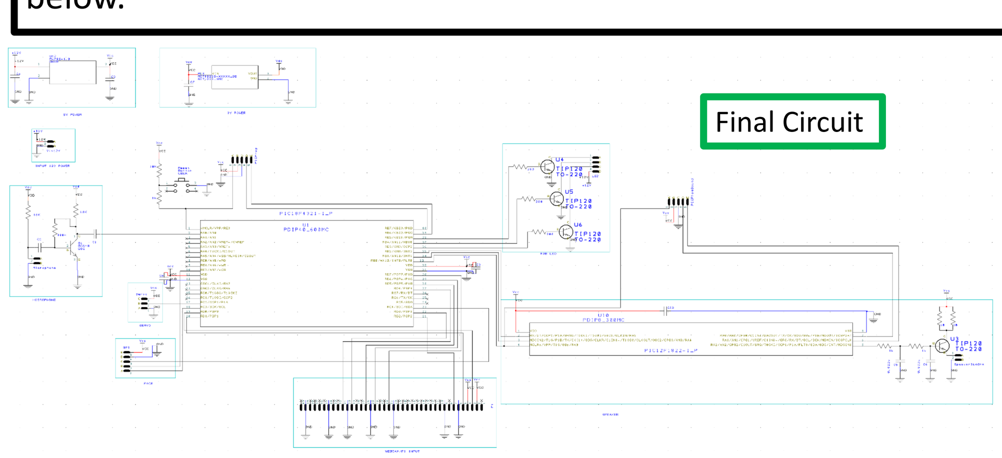
1.0	The toy shall detect emotions
1.1	The toy shall detect facial expressions
1.1.1	It will have Computer Vision and expression detection.
1.1.1.1	Computer Vision will be achieved through a web camera
1.1.1.2	Expression detecion will be achieved through machine learning
1.2	The toy shall detect audio events
1.2.1	It will have a microphone.
2.0	The toy shall react based on input
2.1	The toy shall have multiple reactions
2.1.1	It will be achieve through preset reactions saved on a microcontroller.
2.2	The toy shall react physically
2.2.1	It will move along one axis.
2.2.1.1	This will be achieved with a servo.
2.2.2	It will play sound effects.
2.2.2.1	This will be achieved with a speaker and a microcontroller.
2.2.3	It will display lights.
2.2.3.1	This will be achieved with RGB LEDs.
2.2.4	It will display facial animations.
2.2.4.1	This will be achieved with an LED Dot Matrix.
2.3	The toy shall have a default state
2.3.1	The toy will display a "sleeping" state
2.3.1.1	This will be achieved through animations.
3.0	The toy shall be low cost
3.1	The toy will be less than $75
3.1.1	The controller board will cost less than $15

Design

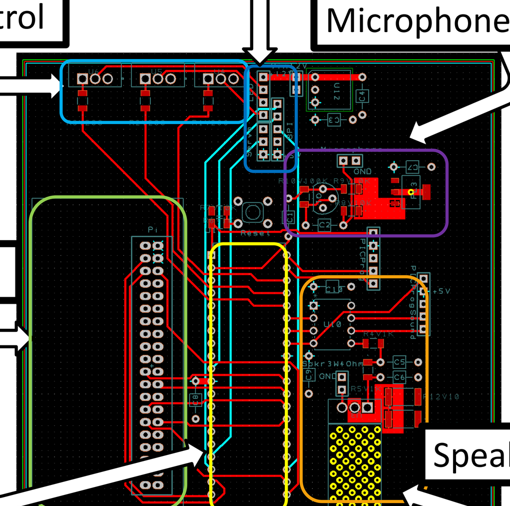
During the design phase, each system was physically prototyped on a breadboard and its functionality was confirmed. Initially, the emotional recognition, master control and sound systems were to be implemented on an FPGA+ARM processor. Due to out-of-date drivers from the manufacturer, a new system was designed using a Raspberry Pi Zero as the machine learning processor and 8-bit PIC microcontrollers as the peripheral controllers. A PIC18F4321 acts as the main processor, controlling the RGB LEDs, servo, LED Dot Matrix, microphone and interfacing with the Raspberry Pi Zero. A secondary PIC12F1822 is used as a Direct Digital Frequency Synthesis (DDFS) audio controller, creating sinusoidal signals for audio output. This PIC12F is controlled by the PIC18F. The final circuit is shown below.

After designing and prototyping each system, a PCB was routed. To reduce costs, this circuit was implemented on a 3.75" x 3.75" two-layer PCB. To reduce heat, a small heatsink was created using vias for the TIP-120 IC used as an audio amplifier. The final PCB (with and without power/ground planes visible) is shown below.

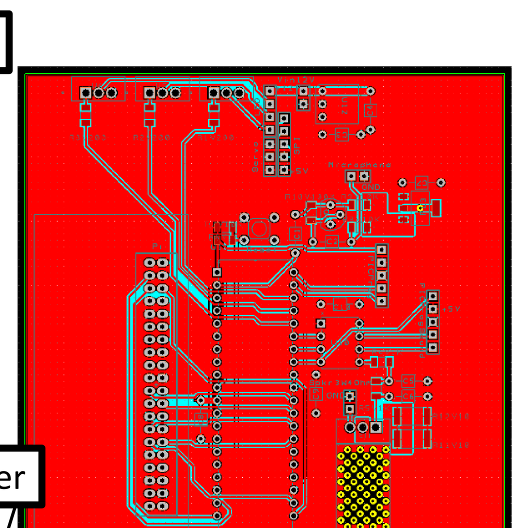
Once the PCB was routed, a 3D model of the toy was created for 3D printing. The first version is shown below.



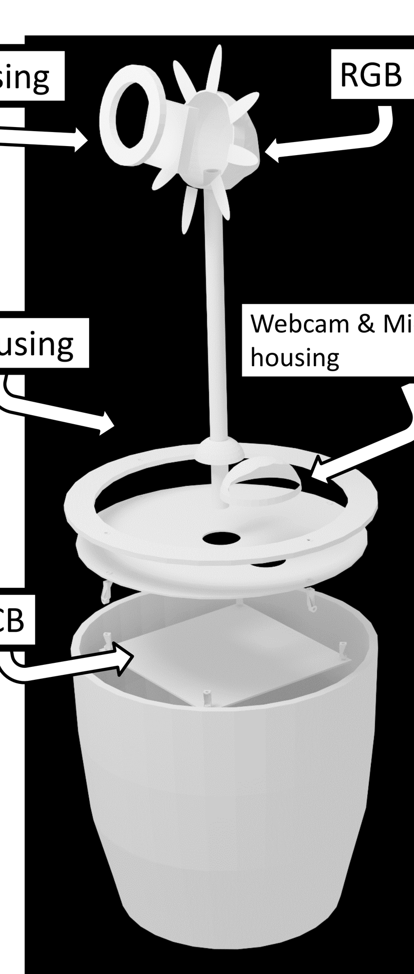
Final Circuit



PCB without Power/Ground Planes



PCB with Power/Ground Planes



3D Model

Cost Analysis

A component price breakdown for the current design is shown below. The full toy (not including plastic for 3D printing and PCB price) costs $50.71. The majority of this cost (19.72%) is due to the Raspberry Pi Zero. The next most expensive items are the servo (11.73%) and webcam (10.81%). The design, when adding an additional $10 for PCB manufacturing (based on a quote from jlcpcb.com) and $10 of 3D printer filament (based on 1kg = $20), the total price of the toy is $70.71. While the toy's price to manufacture is below $75, if sold on the market, the price would be greater than $75. Therefore, this toy design does not meet the price requirement.

This price could be reduced in later variants by redesigning the systems with the highest costs. A price breakdown by system is also shown below. The "Emotional Response" system takes almost a third of the budget. Reworking this system is the most critical when attempting to reduce the price.

If the emotional recognition, master control and sound systems were combined into a single chip (as in the design described in the previous section), the price could further be reduced, as could the PCB area.

Shown below are other, popular children's robotic toys with their initial release price listed beside them. The toy designed for this project includes more functionality for less money.

Component Price Breakdown

Item	Description	Quantity	Cost	% of Cost
R-78E5.0-1.0	DC DC CONVERTER 5V 5W	1	$3.26	6.43%
MCP1825ST-3002E/DB	IC REG LINEAR 3V 500MA	1	$0.51	1.01%
CR1206-JW-201ELF	RES SMD 200 OHM 5% 1/4W	3	$0.30	0.59%
CR1206-JW-102ELF	RES SMD 1K OHM 5% 1/4W	3	$0.30	0.59%
CR1206-JW-103ELF	RES SMD 10K OHM 5% 1/4W	3	$0.30	0.59%
CR1206-JW-104ELF	RES SMD 100K OHM 5% 1/4W	1	$0.10	0.20%
CR2512-JW-100ELF	RES SMD 10 OHM 5% 1W	2	$0.90	1.77%
TIP120	TRANS NPN DARL 60V 5A	4	$2.56	5.05%
PIC18F4321-I/P	IC MCU 8BIT 8KB FLASH	1	$3.47	6.84%
PIC12F1822-I/P	IC MCU 8BIT 3.5KB FLASH	1	$1.10	2.17%
1825910-6	SWITCH TACTILE SPST-NO	1	$0.10	0.20%
BC548CTA	TRANS NPN 30V 0.1A	1	$0.22	0.43%
SR215C104KAA	CAP CER 0.1UF 50V X7R	6	$1.20	2.37%
FG14X7R1H334KNT06	CAP CER 0.33UF 50V X7R	2	$0.64	1.26%
FG24X7R1H224KNT06	CAP CER 0.22UF 50V X7R	2	$0.58	1.14%
3968	General Purpose Speaker 3W	1	$4.95	9.76%
Raspberry Pi Zero	-	1	$10.00	19.72%
609-3243-ND	CONN HEADER VERT 10POS 2.54MM	5	$1.40	2.76%
CMA-4544PF-W	MICROPHONE COND ANALOG	1	$0.77	1.52%
LED Dot Matrix	-	1	$1.99	3.92%
PJ-037B	CONN PWR JACK 2.5X5.5MM	1	$0.58	1.14%
12V 1A power supply	-	1	$2.78	5.48%
COM-12021	LED RGB STRIP - 1M (price 5")	1	$1.27	2.50%
169	SERVOMOTOR RC 5V	1	$5.95	11.73%
USB Webcam	-	1	$5.48	10.81%
TOTAL			$50.71	100.00%

System Price Breakdown

System	Cost	% of Cost
Dot Matrix	$1.99	3.92%
Emotion Recognition	$15.48	30.53%
Master Control	$5.37	10.59%
Microphone	$1.69	3.33%
Movement	$5.95	11.73%
Power	$8.17	16.11%
RGB LED Control	$3.49	6.88%
Sound	$8.57	16.90%
TOTAL	$50.71	100.00%

Boxer *Boxer*

$60

WowWee *RoboSapien*

$100

$70.71

WowWee *RoboRaptor*

$120

Anki *Cozmo*

$300

Future Work

Due to COVID-19, work has been delayed on this project. The next steps for this design include another design pass through for the toy's CAD model to make it more appealing to children, finish the emotional response coding, and to assemble a full prototype.

In later iterations, the price will be reduced through redesign- the three microcontrollers can be swapped for a singular microcontroller, the microphone circuit can be simplified, and the speaker circuit can be simplified. The webcam can also be switched with a custom circuit which may be less expensive. Another improvement could be to shrink the PCB by reducing spacing between components and using only surface mount components. After thermal analysis of the original PCB design, an alternate, smaller version can be created if the thermal requirement is met by the original design.