EXECUTIVE SUMMARY REPORT

Group 3 (The High Notes)
04/05/2024
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EXECUTIVE SUMMARY

After being given the task of building a robot for children in grades K-5 the team (The High Notes/Group 3) determined customer needs to be functionality, feasibility, aesthetic, and durability. The team had 2 main possible candidate designs, including a jukebox or a Kirby robot. By comparing both of the candidate designs in a customer needs table, the team settled on a Kirby robot that incorporates music and props into the design, while being programmed to follow a human by hand. The Kirby design was also more appealing to the target audience. Though it has a complex shape, its functionality and durability will not be affected. It is $30 and within the product specification dimensions.

The project was on schedule and set to be done with production by the first week of April, aiming for April 10, 2024, to be on track for testing before the showcase. This gave the team time to work through the testing process and fix any bugs that appeared. The cost of the Kirby-bot is around $30.00 including PLA costs and cost of all parts of the robot, such as the Arduino Uno board, wires, etc. The team has been productive and efficient in working together while aiming to complete this robot in a timely manner. There have been some difficulties such as faulty hardware and differing schedules that make meetings difficult, but the team has overcome them together.

The team made a lot of progress with executing the plan that was made at the beginning of the design process. Although there were many problems with designing, programming, and building the robot, the team narrowed the list of problems down to two- the right motor function and ultrasonic sensors interaction with the code and were able to fix them by the time of the showcase. However, to cast light on the teams' achievements, the 3D printed model properly fit all the mechanical components, is very sturdy, and mirrors the Kirby character it is modeled after. Besides the right motor and right ultrasonic sensor not working, the rest of the components performed as expected throughout the entirety of the fabrication process (such as the music, left motor, left and middle ultrasonic sensor, etc).

I. INTRODUCTION

The team plans to design and build a Kirby robot that is meant to provide entertainment for young kids from the ages of 7-13. The aim of this project is to provide entertainment as well as inspire young children to learn more about STEM. The inspiration for the robot will be Kirby, a character in a video game series that fights off villains to protect his planet using his various tools to guide him. The team will 3D-print the parts of the robot and the outer shell of the star, including the Kirby bot itself. There will be customization features as well to make this robot more engaging for the audience, younger kids in elementary school; these include a light-up wand and lively music. Ultimately, the goal is to present STEM in an entertaining manner and produce a functioning robot.

Project-based learning (PBL) is key for individuals to develop into independent thinkers and analysts, and this is important for the future of the workforce, where collaboration and critical thinking skills are necessary, as explained in a literature analysis conducted by Le Thi Kim Thu based on the importance of PBL at a university-level [1]. Going into the field of engineering specifically, Julie Mills and David Treagust discuss the significance of maintaining a balance between traditional teaching and PBL to ensure that students understand and apply the material, satisfying the industry needs [2]. An academic paper reflecting the importance of PBL in the engineering field written as a part of the undergraduate program at the University of Madrid, focuses on the different phases of the PBL process, developing their own competencies and eventually working with a team [3]. Overall, all of these academic papers summarize the importance of PBL as it relates to university education, as well as in the field of engineering.

Aside from the components used in the robot, many programs and devices contributed to its completion. The models that the robot used were designed and assembled in SolidWorks. Using SolidWorks, the team was able to make precise design choices based on the dimensions, features, and efficient placement of components for the design. Using a 3D printer, the team built prototypes for testing and troubleshooting the robot, before finally printing the main parts in different colors of PLA. MIDI file editing programs were also used for the mapping of the music that the robot plays.

II. PROJECT PLAN

PROJECT TIMELINE

The team's plans are right on schedule, and they are planning to complete the robot within the first week of April, aiming for April 10, 2024. By completing production of the Kirby-bot by April 17, 2024, the goal was to work through the errors and test to make sure all functions are operating and there were no errors until the showcase. The project was in working condition at the time and the team was working together, as well as communicating clearly, to make sure there were no last minute issues. The project plan was successful; producing a Kirby-bot that is functional and entertaining for young kids.

PROJECT COST

The total cost for the prototype is estimated to be $30.00, including costs of the PLA used for production and parts of the robot, such as the wires, batteries, wheels, motors, etc. The most expensive part of the robot is the PLA used for 3D-printing that costs around $9, followed by smaller costs of all parts of the Kirby-bot. Table 1 shows the costs of the Kirby-bot broken down from the beginning, as stated below.

Table 1: Costs Table

Part	Cost
Arduino Uno Board	$4.27
Motor Controller	$1.50
Screws	$0.09
Zip Ties	$0.15
DC Motors	$1.80
Ultrasonic Sensor	$3.50
Push Buttons	$0.06
420 g PLA	$8.40
Universal Wheel	$1.00
4 AA Batteries	$1.00
8 Male to Female Wires	$0.30
15 Male to Male Wires	$0.75
TOTAL	**$29.82**

TEAM STRENGTHS AND WEAKNESSES

All members of the team have been productive and efficient throughout this entire process. The software and hardware leads have been working together all semester towards a functional robot that fits the design and cost specifications, taking into consideration ideas and thoughts of all other members of the team. The test lead has been helpful in outlining the plans for assignments through the semester and providing the group general support, especially with wiring. The design has played an important role in designing the Kirby-bot itself using CAD software as well as provided extra support when necessary. The project lead has provided guidance and direction to keep the team on task. Ultimately, the team has worked closely together to produce a functional and entertaining robot, while dealing with hardships such as differing schedules and faulty hardware making production difficult.

III. PROTOTYPE DESIGN

ENGINEERING SPECIFICATIONS

The combined cost of all parts is expected to be less than $30. The expected size is 6” X 6” X 6”. The model should take less than two minutes to assemble. Due to the multiple ultrasonic sensors, this robot requires a 9-Volt battery to be powered. The song volume is set at 50 decibels, so it is enjoyable for the kids, without being too loud. There are 7 total 3D parts of the robot, such as the star top and star bottom, the 2 halves that make up Kirby, the 2 wheels, and the star rod.

FINAL CANDIDATE DESIGN

The team created a table describing their benefit analysis (Table 2). This analyses the importance of functionality ,which was weighted 40%, feasibility, weighed at 30%, aesthetics, weighed at 20%, and durability, weighed at 10%. After comparing the weighted scores of their two candidates, the Kirby Bot model and the Jukebox Bot model, they chose the former. They chose the Kirby Bot model because that one had a higher weighted score compared with the Jukebox Bot model. The Kirby Bot has a complex shape but is more appealing to its target audience (Figure 1).

Table 2: Weighted Benefit Analysis

	WEIGHT	RAW SCORES		WEIGHTED SCORES	
		Kirby Bot	Jukebox	Kirby Bot	Jukebox
Functionality	40%	8	7	3.2	2.8
Feasibility	30%	7	3	2.1	1.9
Aesthetics	20%	6	7	1.2	1.4
Durability	10%	4	5	.4	.5
TOTAL	100%	25	22	6.9	6.6

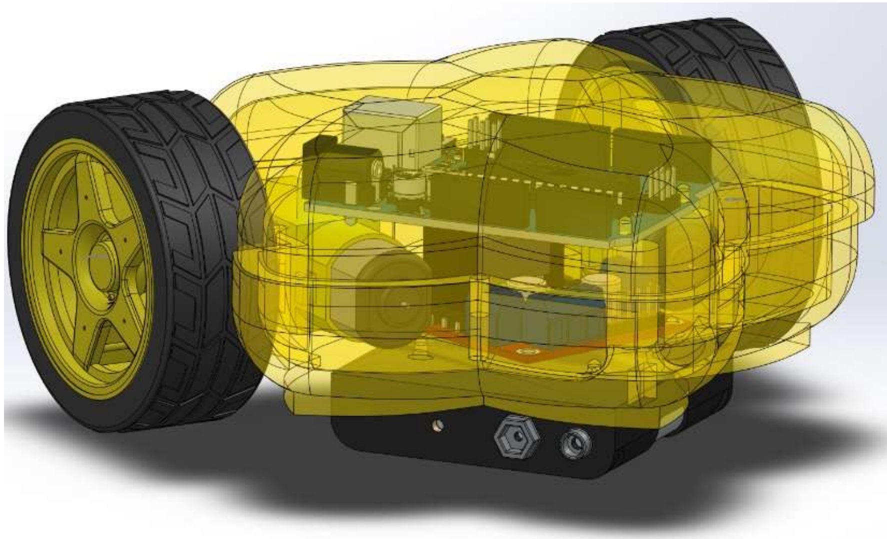

Figure 1: CAD model

CHALLENGES

The Kirby Bot has a complex shape, which led to difficulties in placing the components of the robot, such as the battery. As can be seen in Figure 1, the battery was originally supposed to be under the robot, but then the team finalized on putting it inside the star base to minimize safety concerns. The team had to place the components inside the star-shaped base, which can only be up to 6” X 6” X 6”. They also had faulty components that needed to be replaced, such as the Arduino and the electronic sensors that were being used during the testing phase.

IV. PRODUCT DEVELOPMENT

COMPONENTS

The components used in the final design are listed below:

Table 3: Components

Component	**Purpose**
2 DC Motors	Producing rotation of the wheels
L298N Motor Driver	Controlling the rotation of the motors
3 HC-SR04 Ultrasonic Sensors	Used for navigation; sensors detect hand movement
Arduino Uno	Executing sketch
9V Battery	Providing power to the robot
Speaker	Playing music from sketch instructions
Yellow LED	Blinks in rhythm with music

Each of the components functions in conjunction with another. The Arduino executes a sketch for the sensors and motors. There is a left, center, and right sensor. When an object comes near the center sensor, the Arduino responds by initiating both motors forward through the motor controller. When an object comes near the left sensor, the Arduino responds by initiating the right motor forward and the left motor backwards, making the robot move left. The opposite applies with the right sensor.

Additional functions include the speaker and LED. The speaker is connected to six analog pins on the board that each output a signal to play a particular sound at a specified frequency, enabling many instruments to be played simultaneously through one speaker. An LED is connected to these signals, so it also responds to the analog input by blinking in rhythm and accordance with the music.

ASSEMBLY STEPS

SolidWorks was used to design the robot, then it was 3D printed in 7 parts (2 wheels, two halves of the chassis, two halves of Kirby model, and one star rod. The steps for assembly of the robot are shown below.

1. Place sensors, motors, and Arduino Uno into chassis as shown in Figure 2.

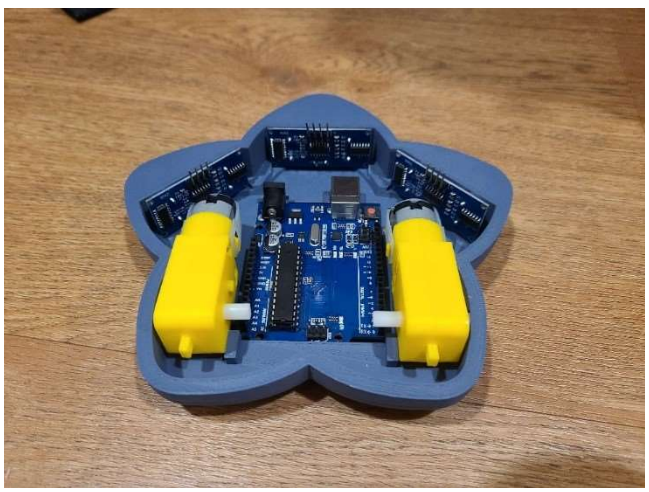

Figure 2

2. Add wires for motors, sensors, speaker, and motor driver. Referring to the perspective Figure 3, the left, center, and right sensors’ Trig pins correspond to pins 2, 4, and 10 respectively. The left, center, and right sensors’ Echo pins correspond to pins 3, 5, and 11 respectively. They are all connected via one Vin and one ground, going into the 3.3V pin and any available ground. The motors should be placed with the terminals facing inward. Connect the wires to the motors. Insert the motor pins into 7, 8, 12, and 13. Lastly, connect all six speaker wires into the analog pins in no particular order, then connect the remaining two ground wires to the board.

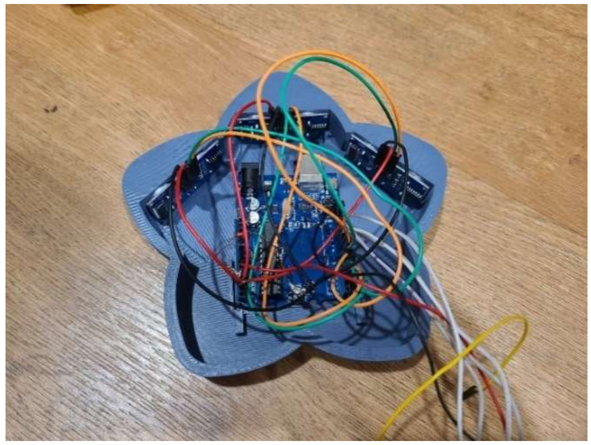

Figure 3

3. Place chassis lid and insert wires for speaker and motor driver through the top hole.

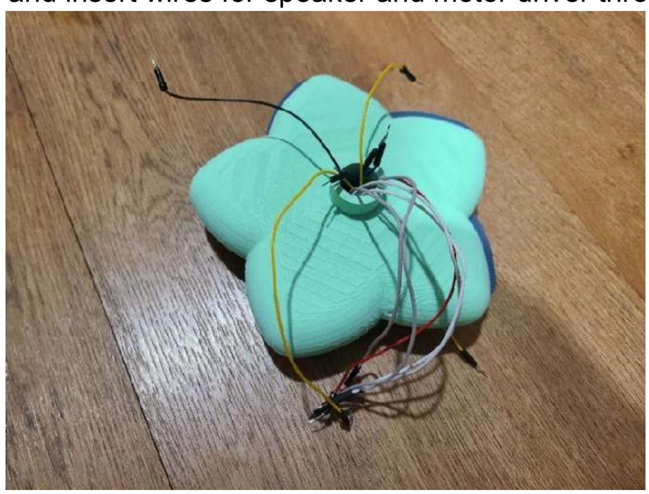

Figure 4

4. Wire motor controller and speaker into both sides of the Kirby model. Connect the wire at the end of the six analog wires to the left side of the speaker, then connect one ground wire. Connect pin 7 to IN1, pin 8 to IN2, pin 12 to IN3, and pin 13 to IN4. Then, connect the top and bottom left motor wires to OUT1 and OUT2, and the top and bottom right motor wires to OUT3 and OUT4 respectively.

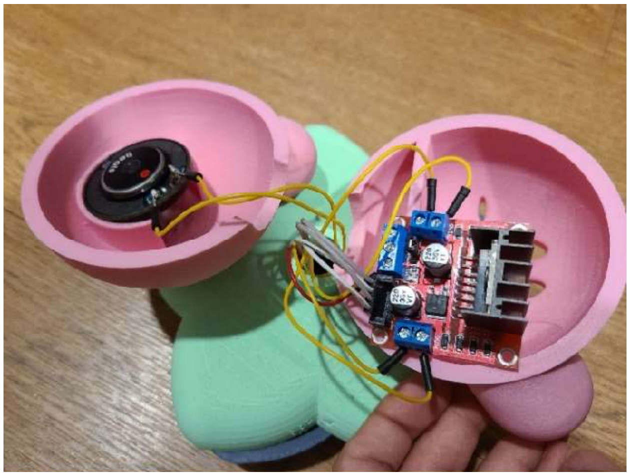

Figure 5

5. Close the Kirby model. Insert wheels to sides.

Figure 6

3D PRINTING CHALLENGES

Originally, the maximum length of any point on the robot was 5.5 inches due to the size constraint of the Flashforge Finder 3D printer. This caused the Arduino Uno to need to be stacked on top of the H-Bridge, inducing wiring complications for the team. This was found to be an oversight, as due to the nature of the hypotenuse of a square, the maximum length was actually 7.78in.

V. SOFTWARE DEVELOPMENT

PROGRAMMING CODES

The programming that goes into the robot's movement is comprised of two functions, one for music and the other for movement. The code used is a heavily modified version of Connor Nishijima's Miduino player and Gourav Tak's Human Following Robot code combined. For the music, a speaker emits six tones to produce polyphonic music. This is generated by taking advantage of hardware timers in the Arduino Uno. Normally, the Uno can only process up to three simultaneous commands to play a tone at once, absorbing all three hardware timers and leaving no availability for other actions; by "polling", however, or using only one hardware timer that interrupts at 20 Khz, or once every 50 microseconds, the illusion of multiple tones at once can be achieved. The interrupt routine determines which, if any, of the currently playing notes need to be toggled. The pins that each of the six inputs use are the analog pins, A0 through A6. These wires were bound together to all reach the speaker because this design does not include a breadboard. In the initial part of the code, an array of 94 values for frequencies is present. Then follows the array used to play the music. This was automatically generated by a program called Miditones by Len Shustek using MIDI files of the music of choice. These generated arrays are made up of set values that determine the frequency, duration, and voice type of each note. If the value is 0xF0, then it will stop the music. This is put at the end of the array to stop playing the music once it finishes. To create percussion, white noise can be emulated by creating a series of frequencies that play in quick succession. These percussion values are stored at frequencies above the 94 specified before. When the frequency in a note is above 16744hz, or C10, the following notes are a sequence of percussion instruments, such as bass drum 1 and 2, closed hi-hat, open hi-hat, and snare 1 and 2. These have to be manually added as they were not originally included in Miditones. Overall, the goal is to always have three songs play on loop. This part of the code takes up a large percentage of the flash memory. As for the robot's movement code, it is designed to follow a human target using three ultrasonic sensors. The schematic for pin placement is included in the image below. Assuming the ultrasonic sensors emit a frequency at the speed of sound, 343 m/s, the time it takes to receive is divided by 58 to find the distance in centimeters. These values are displayed in the Serial monitor while the code is running. The motors respond to these inputs by moving in the direction of the sensor that records the closest input within a certain range. If there is no recorded input within the maximum distance, 40 centimeters, then the robot will stop. If there is an object within the minimum distance, 5 centimeters, the robot will move backward. Since the design does not include a breadboard, the three wires for each sensor designated for ground and 5V need to be bound together to receive the one input. On an additional note, to create lights for the star rod that the robot will be holding, the team plans to connect the anode to the pin that generates music; the light will turn on when a note is playing on one of the six tone generators corresponding to six LEDs. The links to all the programming used are below.

https://gist.github.com/connornishijima/82add47400d60945bbe30205b907b9b1

https://circuitdigest.com/microcontroller-projects/human-following-robot-using-arduino-and-ultrasonic-sensor

The final combined code used in the robot along with comments describing its functions can be accessed below. The README file is also included.

https://gist.github.com/pinkious/0627b6a1e62100cab5ea017cf43cb7d2

FABRICATION VIDEOS

The first fabrication video created for the prototype, being for the Origami bot, there is confirmation of working hardware and response to input. The LCD display shows that the ultrasonic sensor can move backwards and forwards depending on the distance of an object from the sensor. This is simply a practical demonstration of the motors moving in accordance with a sensor. The code used for this video is different from the one currently used.

https://www.youtube.com/watch?v=2Jo6TvEkQoA

The second fabrication video is the demonstration of the code used in the final prototype. It demonstrates three working sensors and music and LEDS working in tandem. First, the robot can be seen moving in the direction of a hand. David explains that the robot moves according to which sensor is closest to the hand. In the latter part of the video, the robot's lights blink according to the frequency signals sent from the Arduino to the speaker. This results in the star rod blinking with the music.

https://drive.google.com/file/d/1OZb7gv-k-c-mY-oast411698tS3Iedd3/view?usp=sharing

SOFTWARE CHALLENGES

David encountered issues while working with the movement code with the music code and working with the robot's components. The most recent issue discovered with the movement code was that the ultrasonic sensor readings were displaying distance values far higher than intended. The team found that it was an issue with the board itself. There were also issues with finding a code that was capable of playing polyphonic music. Many of them would use all the hardware timers available for the Arduino Uno, making movement impossible. Others required another H-bridge or an external sound chip to function, both of which are unable to fit in the chassis. David settled on a system that involved soldering 6 inputs together to create polyphonic music by sending commands to have the Arduino play rapidly varying tones at 20 kHz. This means that there is no external hardware required to create music other than the speaker.

VI. PROTOTYPE TESTING

PROTOTYPE PERFORMANCE

The final prototype consists of 6 3D printed parts (2 star base halves, 2 wheels, and 2 Kirby figure halves) and the Arduino Uno kit components that are able to fit inside the 3D model. The dimension restrictions were followed, and the robot's stability is acceptable for the target audience. The final candidates functionality needed more work throughout the entire fabrication process because the ultrasonic sensors were not working with the code (the code kept crashing) and one of the motors did not run (it was assumed to be a problem with the quality of the wires or motor) but it was resolved with an increase in the voltage of batteries used, and a correction in the code. The robot is very safe because the body of the robot (Kirby and the star) has no sharp edges, and it weighs under 4 pounds. All in all, the robot is fully functional after much trial and error.

PRODUCT SPECIFICATIONS

Focusing on the product specifications, the robot weighs about 420 grams (0.93 pounds) in PLA plus ~400 grams (0.88 pounds) in machinery, making the robot under 2 pounds when totally assembled. The power requirement will be satisfied by a 9V battery, and max speed has been determined to be 2 meters per second. The robot's dimensions are 5.98in x 5.81in x 5.06in making the robot within course engineering specifications. Regarding the musical performance, the robot will play 3 songs at 50 decibels.

Table 4: Robot Specifications

Specification	Measurement
Weight	~820 grams
Power	9 V battery
Dimensions	5.98in x 5.81in x 5.06 in
Materials	~40 parts
Song Volume	50 decibels
Speed	2 m/s
3D printed parts	7 (star top and bottom, Kirby halves, 2 wheels, star rod)
Cost	$29.82

PERFORMANCE ISSUES

As stated above, one problem with the robot was the technical issues with the ultrasonic sensors and the code. When the code was run with the robot the team built, the serial monitor kept crashing after it sensed motion in front of the right ultrasonic sensor, however the middle and left sensor worked as expected. The team believed that the problem lied within the quality of the ultrasonic sensor itself and saw that a feasible solution would be to get a new ultrasonic sensor. However, after doing that, the problem was not solved but an error in the code was found and fixed, along with a replacement of the battery pack with a 9V battery. The team considered using less ultrasonic sensors to prevent errors in the robot's movement but after many adjustments they seemed to all work so the final candidate has 3 ultrasonic sensors. Additionally, one other problem was the difficulties with getting the motors to work. There was no function in either of the motors, however, after the wires were tugged on, the left motor began to work. This led the group to believe that there was hardware problems that were keeping the right motor from working. A proposed solution was to move the working left motor to the right side, however that did not fix the issue, so the problem was somewhere between the outputs on the H-bridge, the wires connecting the H-bridge and the motor, and the motor. Due to this, we used a new H-bridge and changed the batteries and the problem was resolved.

VII. RECOMMENDATIONS

Nearing the deadline for the final candidate some adjustments had to be made to ensure that the product was done by April 17th. The team reconsidered the use of designing multiple props due to time constraints and the feasibility of it. The star rod prop was the only prop made (as opposed to the hammer and microphone) in order to give attention to high priority tasks.

Looking toward the future, if the team were to mass produce our product, the first step would be to find a factory that supports the production of large-scale additive manufacturing methods. The next step would be to create molds of each 3D printed model part and inject polypropylene into them (due to its wide heat range, flexibility, and cost-effectiveness). The 3rd step would be to design a PCB for the robot. Next, an assembly line would have to be hired to wire and solder the components into the robot and then assemble the wheels, motor's, chassis, and Kirby model. Finally, the last step would be to glue/screw the Kirby and the Star Base together. This makes it so the consumer does not have to do any assembly themselves.

VIII. CONCLUSION

The Kirby design was chosen because it best satisfied the team’s chosen customer needs. It is multi-functioning because it can follow a hand, play music, and hold light-up props. The motivation for the project was to entertain children with a toy that incorporates STEM. The final candidate is low cost, utilizes Arduino Uno components, and is within product specifications. The team used their individual specializations (such as 3D printing, wiring, software, leading, and testing) to collaborate on making a robot that is fully functional and ready for a product market (given the resources needed to support mass production are available).

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