Automatic Record Flipper

ECE 445

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Team 20

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1. Introduction

1.1 Problem and Solution

Vinyl records have experienced a significant resurgence due to their warm, analog sound quality and the unique tactile experience of physical media. The global vinyl record industry, valued at $1.5 billion, is projected to grow by $900 million by 2030, demonstrating sustained consumer interest [3]. However, most modern record players require manual flipping of the record once the side of the record is done playing, and older automatic record-flipping systems—once popular in jukeboxes and early automated setups—are bulky and have long been discontinued. This leaves vinyl enthusiasts with the inconvenient task of manually flipping records mid-listening experience, disrupting the music listening experience, especially during continuous playback or social gatherings [4].

This project aims to address this gap in modern record player functionality by designing an automatic record flipper that retains the analog charm of vinyl while enhancing convenience, making the experience more accessible and enjoyable without sacrificing the physical engagement of handling records. The design employs an ATmega328 microcontroller to precisely control three servo motors that manage the flipping mechanism. A critical component of the design is the use of a hall effect sensor strategically placed near the tonearm's natural resting position, paired with a small magnet attached to the tonearm itself. This setup ensures accurate detection of when a side of the record has finished playing and the record is ready to be flipped, as the tonearm must return to its resting position in order to flip the record.

Upon detection of the tonearm, the microcontroller activates three servo motors to conduct a carefully choreographed sequence where the record is held, gently lifted, rotated 180 degrees, and then precisely reseated onto the turntable. While our prototype uses a budget-friendly Crosley Cruiser Premier record player, a player which requires manual placement of the tonearm at the start and end of playback, our design is intended for integration with mid-range record players with automatic tonearm movement functionality, though currently tailored specifically for compatibility with our budget-friendly Crosley Cruiser Premier. These mid-range models feature automatic tonearm mechanisms capable of autonomously positioning the tonearm at the start of the record and returning it to rest upon completion of the side of the record, making the entire playback experience completely autonomous when paired with our flipping mechanism and an additional triggering device that signals the record player to automatically move the tonearm.

By combining a carefully designed PCB to control three servo motors, reliable electronics, and thoughtful sensor integration, our automatic vinyl record flipper significantly modernizes and enhances the vinyl listening experience, providing both reliability and ease-of-use while preserving the beloved analog aesthetics.

1.2 Visual Aid

Figure 1: The Crosley Cruiser Premier record player

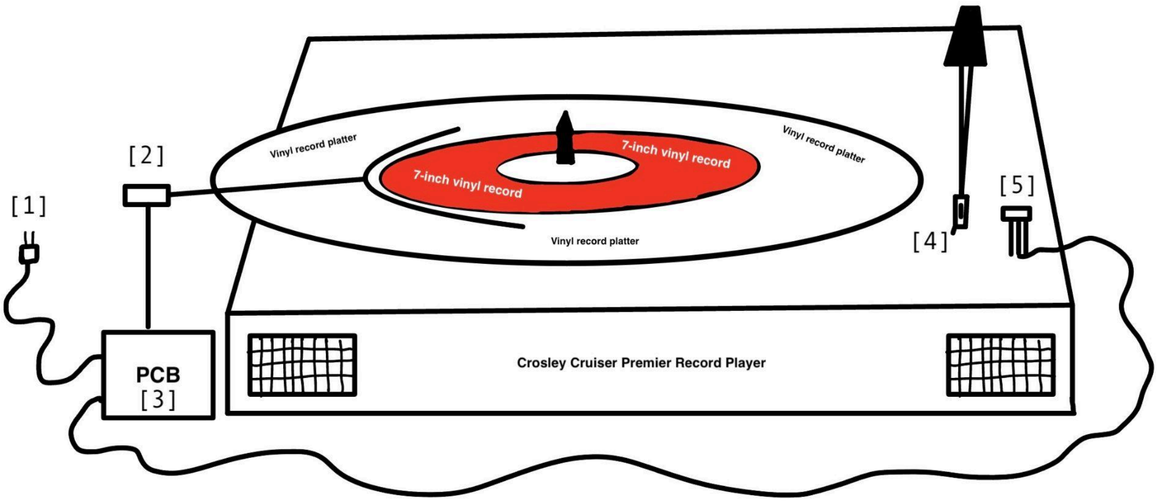


Figure 2: An overview of the system

[1] Power Supply – Power provided by a Dell AC adapter

[2] Flipping Mechanism – Utilizes three servo motors for horizontal movement, lifting, and flipping the record.

[3] PCB with Built-in Microcontroller – Controls the flipping mechanism, coordinating motor actions.

[4] Magnet – Attached to the top of the stylus to interact with the Hall effect sensor.

[5] Hall Effect Sensor – Detects the proximity of the magnet, signaling the PCB to initiate the flipping process.

1.3 High Level Requirements

Time-Constrained Flipping Sequence:

To establish an acceptable duration for the record-flipping process, we conducted user testing with a sample size of seven individuals to determine the point at which the flipping sequence felt noticeably slow. Results indicated that a duration of up to 35 seconds was acceptable before disrupting the listening experience. Additionally, we considered user familiarity with digital music interruptions, such as advertisements on streaming platforms.

Spotify Free ads typically range from 15 to 30 seconds, and YouTube ads last between 15 to 20 seconds, occasionally extending to 30 seconds. HBO Max includes six minutes of advertisements per hour, equating to approximately 10% of viewing time. Applying this percentage to a vinyl record that holds approximately 10 minutes of music per side, the equivalent ad time would be one minute, exceeding our flipping duration. Given these considerations, we have determined that a **25-second flipping process** ensures a minimally disruptive experience, aligning with common digital music interruptions.

Accurate flipping of the record:

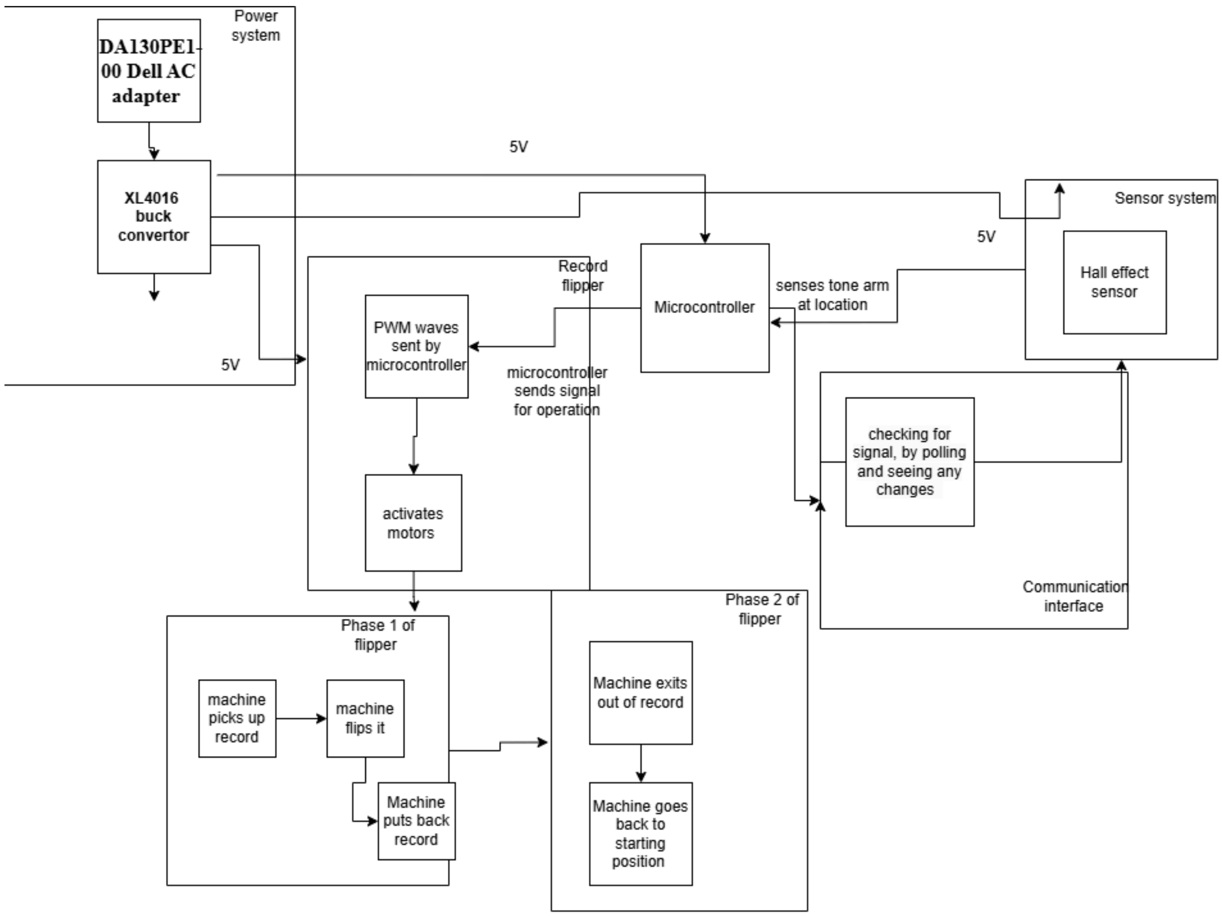
For our automatic vinyl record flipper to match the reliability of vintage jukeboxes—characterized by a Mean Time Between Failures (MTBF) of 100,000 hours—the flipping mechanism must operate with near-perfect accuracy [17]. Our calculations assume that each flip takes 25 seconds, which means the device performs 144 flips per hour, or roughly 14.4 million flips over the course of 100,000 hours. With an expectation of one failure per 100,000 hours, the failure probability per flip is approximately 6.94×10^{-8}, or about 6.94 failures per 100 million flips. In practical terms, this translates to an accuracy of approximately 99.9993% per flip. Given these numbers, our design requirement is that the flipping mechanism effectively operates at 100% accuracy, ensuring the system meets the high reliability standards expected for such applications.

Accurate Tonearm Detection:

The Hall effect sensor is crucial for detecting the tonearm's position and triggering the flipping mechanism precisely at the right moment. The sensor's reliability directly impacts the system's performance. If it fails to detect the tonearm accurately, the flip may not initiate on time, causing playback interruptions, or it may activate too early, risking damage to the stylus and record. To maintain jukebox-level reliability and ensure seamless operation, the sensor must function with an accuracy of 99.9993% per detection, which we will consider as 100% accuracy, aligning with the failure rate threshold calculated above. This precision ensures the flipping process is consistently triggered at the correct moment, preventing disruptions and maintaining the integrity of the vinyl playback experience.

2. Design

2.1 Block Diagram



2.2 Subsystem Overview

2.2.1 Power System

This subsystem houses the power system that will power the entire system in order to function properly. The power system will be able to power the entire operation of the project without causing harm (i.e. short or burn any components during operation). The power system will be powering the motors used to flip the vinyl record, the microcontroller which controls the entire operation of the project, and the Hall effect sensor which will scan for the moment to begin operation. The subsystem will deliver a constant DC voltage to the entire system at a voltage level compatible with all other subsystems whilst not causing any damage.

2.2.2 Record flipper system

This subsystem will handle the flipping of the vinyl record, in which it will do three steps. The system will first receive a signal from the microcontroller to begin operation. Once it receives a signal, it will use a grabber attached to motors which will grab onto the record, completing the first phase of operation. In the second phase of operation, the flipper system will then move up and flip the record, out of range from any obstruction which may impede the process. The flipper will then put back the record in the correct position, using Servo motors. Once the record is flipped and is in the proper position, the record player will automatically begin playing the vinyl record via the pre-installed auto-stop and auto-start functions.

2.2.3 Sensor system

This subsystem will consist of a Hall effect sensor near the location of the tone arm's resting position when the tone arm is done reading the vinyl. It will be situated right above the tone arm and will be able to detect when the tone arm is finished playing via a magnet that will be attached to the top of the tone arm. When the sensor detects that the tone arm is in its resting position, it will emit a voltage signal to the microcontroller, telling it the tone arm is in its resting position and that the record flipper system is ready to be activated. The flipper will activate itself and flip the vinyl after receiving the signal from the microcontroller.

2.2.4 Microcontroller system

This subsystem will be the brains of the entire project's operation, it will receive and send signals to each of the components to instruct them when to begin operation and know when a component has finished operation. The microcontroller will act as the method of communication between each component and will be able to make the component operation transition smoothly. The operation of the project would follow a linear order, where the Hall effect sensor attached to the tone arm will send a signal to the microcontroller, which will then be transmitted to the vinyl record flipper to begin operation. Once the vinyl record player has finished operation, the auto-start function built into the record player will automatically begin playing the other side of the vinyl record.

2.3 Subsystem Requirements

2.3.1 Power System

The power system will be sending out to the entire system a nominal DC voltage of 5V with a variance of $\pm$0.1V. How this will contribute to the design is it will be the driver that our system needs in order to function. From being sent out to our microcontroller that will be outputting power to it. We also are outputting power to the motors that will also be needing a voltage that is around 5V as well but will also need high current at around 6A for all three to simultaneously work at the same time. For this subsystem, we will be using the **XL4016 buck converter** which we already own that can transform a supplied voltage from a **DA130PE1-00 Dell AC adapter** hooked to the wall which will produce enough voltage and current for the entire project's subsystems to function correctly.

Requirements	Verification
Provide adequate but limited voltage for the entire system which should be 5 volts.	Read the input voltage for all the subsystems to ensure it is at 5 volts or around that range.
Provide adequate current of about 6 total amps to the motors which will ensure smooth operation	Read the input current provided to the motors during operation and ensure it is within the standard operating current

2.3.2 Record flipper system

This system's importance is it will contribute to the flipping accuracy and also flipping time constraint of our design. The system will house three () servo motors (Miuzei) that will each need to draw a voltage of about 4.8-6V which our system's power system will provide. We will also need to make sure that the clamp will provide enough force and support to lift and hold our vinyl record, which for reference the vinyl will weigh about 120-150 grams. We also need to make sure the force of the clamp will not damage the record, so as not exceeding the 150 grams of force. From looking at the datasheet of the servo motor, we can determine that the motors do indeed have enough power (9.4 kg-cm torque at 4.8V) to handle flipping the vinyl record and complete the intended operation for the record flipper subsystem.

Requirements	Verification
All 3 servo motors must rotate from 0° towards 180°	Using our Power supply and microcontroller we will power the servo motors and apply a PWM wave to the motors that we will check if they are able to rotate in the degree of motion mentioned The PWM modulation should be done slowly and also make sure the transitions are smooth
The system must go to the location of the record player and also flip it to where there is very minimal movement	We will apply measurements to make sure that the motors in company with the brackets that the machine shop will make for us, will be able to fit through the record player first We will then have our motors move in order to correctly flip the record player We will then have our motor move in to

	position for where we want to hold the record player
Test that the motors are able to support the weight of holding the record player	We must first make the flipper system hold onto the record player and make sure that the base of the system is sturdy enough to not change direction in any sort of way
Make sure that any type of force applied by the flipper system ensures that it does not hurt or damage the flipper system	We must first check for the condition of the record, check for any types of scratches or anything. Operate the flipper system's functionality to the record

2.3.3 Sensor system

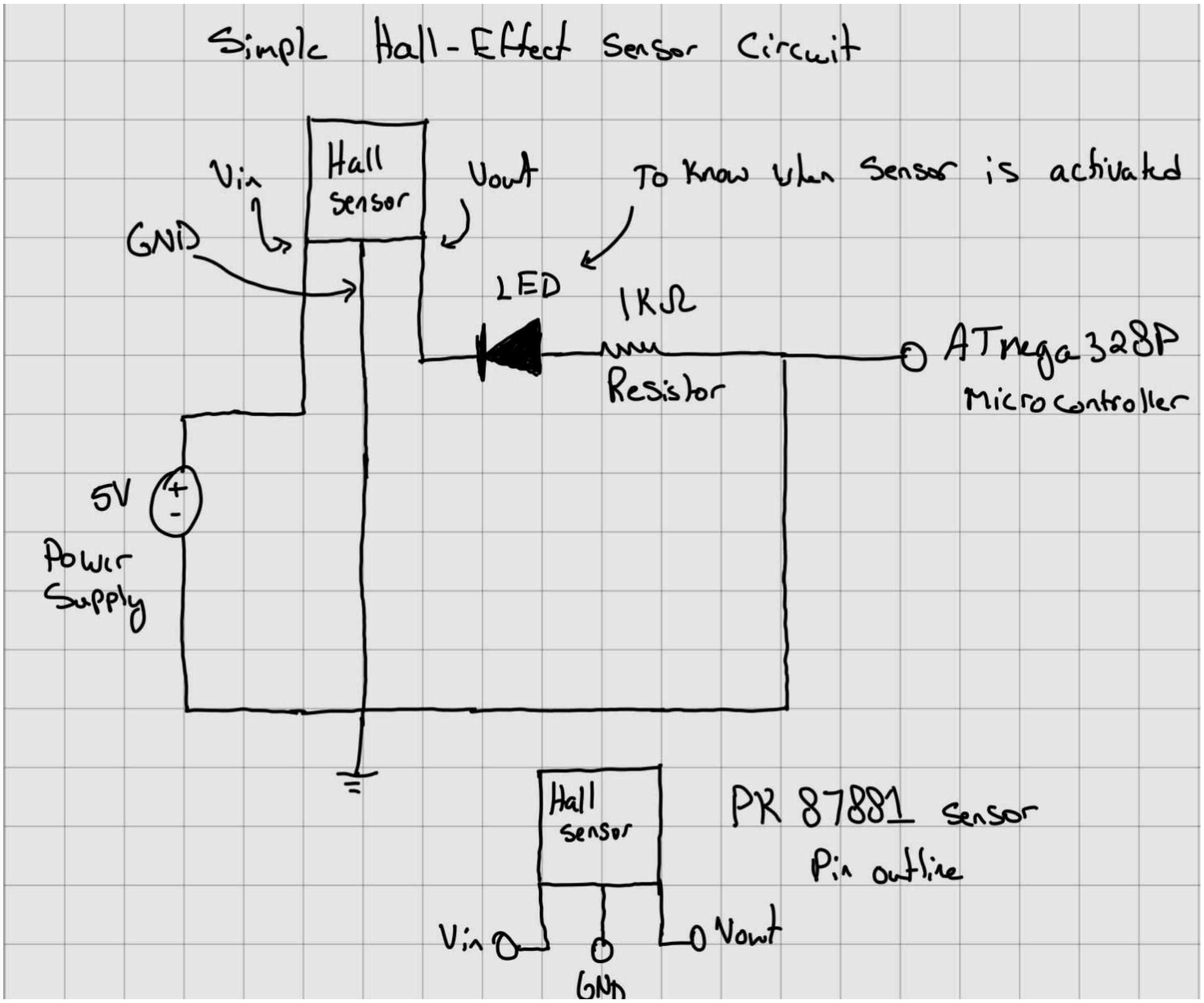
This subsystem will consist of a sensor that will be located right above the tone arm and will be able to detect when the tone arm is at its rest position to signal the flipper to begin operation. From the data sheet, it is apparent that the sensor **PK87881** contains three pins, one for V_{DD} (supply voltage), one for the GND (ground), and lastly, one for the V_{OUT} (which is for the output voltage). The sensor system will be powered by the power system, receiving the nominal voltage of 5V which will be attached to the V_{DD} pin of the sensor. Once the sensor has received a strong enough magnetic signal (around 150 Gauss), the output voltage (V_{OUT}) will match that of the input voltage (V_{DD}). We plan on attaching a disc shaped $\frac{3}{8}$ $inch$ diameter, $\frac{1}{4}inch$ thick grade N52 magnet to the tone arm, which will act as the signal emitter for the Hall effect sensor to know when the tone arm is at its resting position. The magnet will emit a magnetic field of 151 Gauss when it is within $\sim\ 0.62\ inches$ from the sensor, and anything below that distance will result in a higher magnetic field, meaning that the sensor will be activated. We do not have to worry about any higher magnetic field, as the sensor does not have a maximum operating limit of magnetic field per the datasheet. For the magnet, we propose to use the PO - P1315208 Bob Wallace, 3/8 x 1/4 Neodymium Magnet (available in the ECEB workshop store) which should have a weight of approximately 0.01 lbs, light enough to be attached to the tone arm without hindering its performance. In the end, we hope to have the Hall effect sensor receive a signal from the tone arm’s magnet which will then send a signal to the microcontroller, telling it that the tone arm is at its resting position and to begin the operation for the record flipper since the tone arm will no longer be in the way of the flipper’s operation, not hindering it.

There should not be any interference from the electronic components of the vinyl record player flipper to the sensor, thus the sensor will not accidentally trigger. This is because the sensor needs a minimum 50 Gauss magnetic field to activate at room temperature and since every component we are using for the project uses low current (at most 200mA), the magnetic field produced by the electronic components will be much less than the minimum field required by the sensor to activate. Accounting for the distance between the electronic components and the sensor, which will be about a dozen inches or even more, we know that the great distance weakens the magnetic field signal output from the electronic components, thus we can safely assume that the distance will negate any magnetic field from the electronic components to the sensor.

Combined with the fact that the strongest type of magnet of our sizing choice needs to be within one inch of the sensor to activate it, we are sure that no accidental triggering of the sensor will occur. We believe from the previous calculations in this section, that no magnet from the vinyl record player will accidentally trigger the sensor (that is if we use older vinyl players because they utilize magnets for reading the record which are situated at the base of the tone arm). Modern vinyl players like ours use electronic signals instead, which as we’ve stated, use low current thus they will not accidentally trigger the sensor.

The hall-effect sensor utilizes a locked turn on mechanism, where if it receives a strong south pole magnetic field signal it will turn on and remain on until it receives an opposite north pole magnetic field signal which it will then deactivate. Since we will be using only one magnet and want the sensor to activate once during the entire operation, because we will be flipping the record once to its opposite side to play, we do not need to make any modifications to the sensor circuit and can leave it to a simple design. If we want to place another record into the flipper, we could simply turn off and then turn on the power for the sensor to reset it and restart operation, which we do not need to automate since switching the record will require intervention which would also include restarting the system.

Requirements	Verification
The sensor is able to detect when the tone-arm's magnet is within a reasonable distance (< one inch) to detect the record has finished playing.	The record finished playing and the tone-arm is in its resting position when the signal to begin operation begins.
Ensure the sensor does not send a signal to begin operation when the tone-arm is not in its resting position.	The sensor does not have any false triggering from any magnetic fields (any magnetic field with a magnitude of 50 Gauss or above from the sensor's position) imposed on it other than the magnet attached to the tone-arm which determines the tone-arm is in its resting position.



Simple Hall-Effect sensor circuit

2.3.4 Microcontroller system

The microcontroller we will be using is the ATmega328P, which will be powered through the system's power supply. The microcontroller has an operating voltage range of 2.7V to 5.5V. It needs to handle response times quickly and efficiently; we expect that once our tone arm reaches position, the signal will be received and sent out in our system in under 2 seconds.

The ATmega's primary function is to control the servo motors using PWM (Pulse Width Modulation) signals. Our system will first receive a signal from the Hall effect sensor, which will trigger the microcontroller to activate the flipper subsystem. The servo motors will have a set PWM signal that indicates their starting position.

Using the microcontroller, we can program it to elongate or shorten the PWM wave, which will correspond to the rotation of the servo motors. After the flipper subsystem has completed its operation, the microcontroller must return the motors to their starting positions.

Requirements	Verification
Be able to send correct PWM waves for the servo in order to control it	We must first hook up the microcontroller, make sure everything is powered on, and then we must use an oscilloscope in order to properly check the PWM waves and if they are able to be adjustable in width which is what we want
Be able to properly take in signals in order to start the functions (I.E. flipper subsystem starts moving)	We will check for the input port of the ATmega Controller and make sure that we are receiving the signal and show that the Microcontroller did it's function properly
Make sure that the movement is sequential and is consistent every single operation	Program the microcontroller to do the first part of the movement, which would be to go in to pick up the record, flip it and put it back. It must be repeated a number of times in order to make sure that the functionality is consistent and can be repeated a number of times Program the Microcontroller to do the second

	part of the movement, where it will consistently be able to go back to its starting position as if it's a little off, it will mess up the consecutive processes. This step must be repeated a number of times in order to make sure that

2.4 Tolerance Analysis

The most critical aspect of our automatic vinyl record flipper project is ensuring the accurate and secure seating of the record's center hole onto the 45 RPM adapter after insertion, lifting, and flipping phases. Since we are using a 7-inch record spinning at 45 RPM, we require a 45 RPM adapter—a circular disc positioned on the central spindle of the turntable. This adapter increases the spindle diameter from approximately 7 mm to 37 mm.

For horizontal alignment and accurate insertion of the record onto the spindle, we utilize the DSservo DS3235 35KG Coreless Digital Servo. This servo is commonly selected for its high torque and precision in remote-controlled applications. It features a pulse width range of 500–2500 μs, providing a total pulse width span of 2000 μs, and achieves a total rotation of 270 degrees. Crucially, the DS3235 servo also has a dead band of 2 μs. The dead band in servo terminology refers to the range of input signal variation within which the servo does not respond or move. This characteristic impacts the precision of positioning, introducing an inherent angular error.

To quantify the angular error caused by the servo's dead band, we calculate the servo's angular resolution. Given a 270-degree rotation range corresponding to the 2000 μs pulse width span, we find the angular resolution per microsecond as follows:

Angular resolution per μs = 270° / 2000 μs = 0.135°/μs

Using this resolution, the angular error caused by the 2 μs dead band can be calculated:

Dead band angular error = 2 µs × 0.135°/µs = 0.27°

The vertical movement and flipping actions are controlled by two additional servos – the Miuzei DS3218 servos. Each DS3218 servo has an identical pulse width range (500–2500 µs) and total rotation (270 degrees) but features a slightly larger dead band of 3 µs. Applying the same calculation method as above, we determine the angular error for these servos:

Dead band angular error = 3 µs × 0.135°/µs = 0.405°

Next, we must translate these angular errors into linear displacement at the 45 RPM adapter level to assess practical impact. Our 7-inch vinyl record's center hole diameter is 38 mm, while the Crosley Cruiser Premier's 45 RPM adapter diameter is 37 mm, yielding a radial clearance of ((38 mm - 37 mm) / 2) = 0.5 mm. This clearance defines our allowable tolerance for accurate seating.

Considering the adapter radius of 18.5 mm (half of the 37 mm adapter diameter), we convert angular errors into linear displacement. For the horizontal servo (DS3235), this calculation is:

Linear displacement = 18.5 mm × sin(0.27°) ≈ 18.5 mm × 0.00471 = 0.087 mm

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For the lifting and flipping servos (DS3218), the linear displacement calculation is similar:

Linear displacement = 18.5 mm × sin(0.405°) ≈ 18.5 mm × 0.00707 = 0.131 mm

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By conservatively summing these displacements to account for worst-case cumulative errors, we obtain a total potential linear displacement:

0.087 mm + 0.131 mm = 0.218 mm

This combined error remains within our available tolerance of ± 0.5 mm, suggesting the existing adapter is theoretically adequate. However, practical considerations such as mechanical wear, backlash, and servo nonlinearities could further increase real-world misalignments.

To mitigate potential real-world variances and ensure robust and reliable operation, we will be designing a custom 45 RPM adapter featuring a gentle taper (trapezoidal shape). This tapered design would guide the record towards accurate alignment even in the presence of slight deviations. It will have the following dimensions:

- Top Diameter: Approximately 36 mm (smaller to funnel and guide the record)
- Bottom Diameter: Standard 37 mm
- Height: 5 mm
- Taper angle = arctan ((37 mm − 36 mm) / 25 mm) = arctan(0.1) ≈ 5.7°

This gently tapered 45 RPM adapter ensures reliable centering, compensating effectively for minor servo and mechanical variances, thus significantly improving overall operational robustness and reliability.

3. Cost Analysis

3.1.1 Individual Components

Walmart:

Component (quantity)	Manufacturer	Cost ($)	Link
Vinyl record player (1)	Crosley	$35	Link

Record Swap:

Component (quantity)	Manufacturer	Cost ($)	Link
7-inch vinyl record (2)	Scepter Records	$2.5 ea. (total $5)	N/A

ECEB Workshop:

Component (quantity)	Manufacturer	Cost ($)	Link
Miuzei 20KG Servo Motor High Torque RC Servo motors (3)	Miuzei	Workshop lent	Link
DSservo DS3235 35KG	Stemedu	Workshop lent	Link

ECEB Self-Service Shop:

Component (quantity)	Manufacturer	Cost ($)	Link
PK 87881 Hall-Effect Sensor (1)	Honeywell	SERVICE SHOP	SERVICE SHOP

ECEB SMD Request:

Component (quantity)	Manufacturer	Cost ($)	Link
Atmega328p microcontroller (1)	Atmel	SMD Request	SMD Request

ECE Supply Center Shop:

Component (quantity)	Manufacturer	Cost	Link
PO - P1315208 Bob Wallace ⅜ x ¼ Neodymium magnet (1)	Bob Wallace	$2.99	Link

AliExpress:

Component (quantity)	Manufacturer	Cost	Link
XL4016 voltage regulator (1)	XLSEMI	$3.78	Link

Amazon:

Component (quantity)	Manufacturer	Cost	Link
DA130PE1-00 Dell AC adapter (1)	Dell	$26.88	Link

3.1.2 Labor Cost

The average salary of an Electrical or Computer Engineering bachelor's degree graduate of University of Illinois at Urbana-Champaign is about $98,473 (average salary between electrical engineering and computer engineering majors per the 2021-2022 academic year).

The project length starting from the fourth week of the semester (when the team contract was finalized) is until the final demonstrations is about two months and a week length, for the sake of simplicity, we will round the work length to two months as the team will not work on some days due to examinations and/or religious observances. Considering the salary of a UIUC

ECE graduate is $98,473 yearly, which translates to about $8,206 monthly, the labor cost of employing three UIUC ECE graduates to work on this project for two months would equate to:

$8,206 (monthly salary) * 3 (three employees) * 2 (two months labor time) = $49,236

The combined cost of the entire project with the projected student labor cost and component cost comes to about $73.65 for the individual purchased components and $49,236 for anticipated labor costs which totals to $49309.65

3.2 Schedule

Week	***Task***	***People***
March 10 – March 16	Test a 5V DC power regulator system (ADALM2000) Validate individual subsystems on the breadboard and build circuit Convert validated circuit into a PCB design on KiCad and pass audit Finalise motor design for machine shop **PCB Order**	Mohammed & Alfredo Mohammed & Alfredo Riyaan Alfredo
March 17 – March 23 (Spring break)	Initial programming of microcontroller Verify hall effect sensor and magnet interaction on breadboard	Alfredo & Riyaan Mohammed

March 24 – March 30	Receive built flipping mechanism from ECE Workshop and test with breadboard and power supply Initial PCB Soldering Test PCB with simple microcontroller program, flipping mechanism, and power system Debug and refine PCB design and pass audit Address any issues with power system and flipping mechanism	Everyone Mohammed & Riyaan Everyone Riyaan & Alfredo Mohammed & Alfredo
March 31 – April 6	**PCB Order** Programming complete microcontroller program Re-soldering PCB if needed Testing of PCB with complete microcontroller program, hall effect sensor, power supply, and flipping mechanism Debug and refine PCB design and pass audit	 Alfredo & Riyaan Mohammed & Riyaan Everyone Everyone
April 7 – April 13	**PCB Order** Re-solder PCB if needed Fine-tune motor movement sequences in program	 Mohammed & Riyaan Alfredo

	Debug microcontroller program	Everyone
April 14 – April 20	Enclose PCB in record player housing with all components connected Test and debug final system	Everyone Everyone
April 21 – April 27	Mock demo	Everyone
April 28 – May 4	Final demo Mock Presentation	Everyone
May 5 – May 9	Final Presentation Final paper	Everyone

4. Ethics and Safety

4.1 Safety

Our project design incorporates a linear DC voltage regulator, and due to the presence of risks associated with overheating and potential fires due to said regulator, we've decided to adopt a set standard of safety when handling the power subsystem component of the overall design. For our project, we will be implementing the 1100 IEEE Emerald Book standard for handling the powering and ground electronic equipment, which should provide adequate guidelines for a safe and robust power system, reducing downtime, failures and electrical hazards which may be present in the project.

Throughout the creation, testing, and finalization of the project, we will be adhering to the University of Illinois' laboratory safety guidelines which prioritize proper handling of electronic components and safe usage of said material. As part of Illinois' safety guidelines, we will be conducting all laboratory work with the proper personal protective equipment (PPE) and ensure proper storage of all project components in the storage area allocated for the team for this semester.

4.2 Ethics

We assert that this team will maintain intellectual and ethical honesty in our endeavors. In accordance with IEEE code (IEEE), section 1, parts 1-6, we will not by any means cut any corners and we will use the most accurate data we note down. If any behaviors happen that would benefit the individual, team, or project but also hinder the progress of society, they will be discarded in favor of honest work towards the betterment of society. Specifically noting down, we will "seek, accept, and offer honest criticism of technical work, [acknowledge] and correct errors, [be] honest and realistic in stating claims or estimates based on available data, and [credit] properly the contributions of others", to quote the IEEE code of ethics.

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