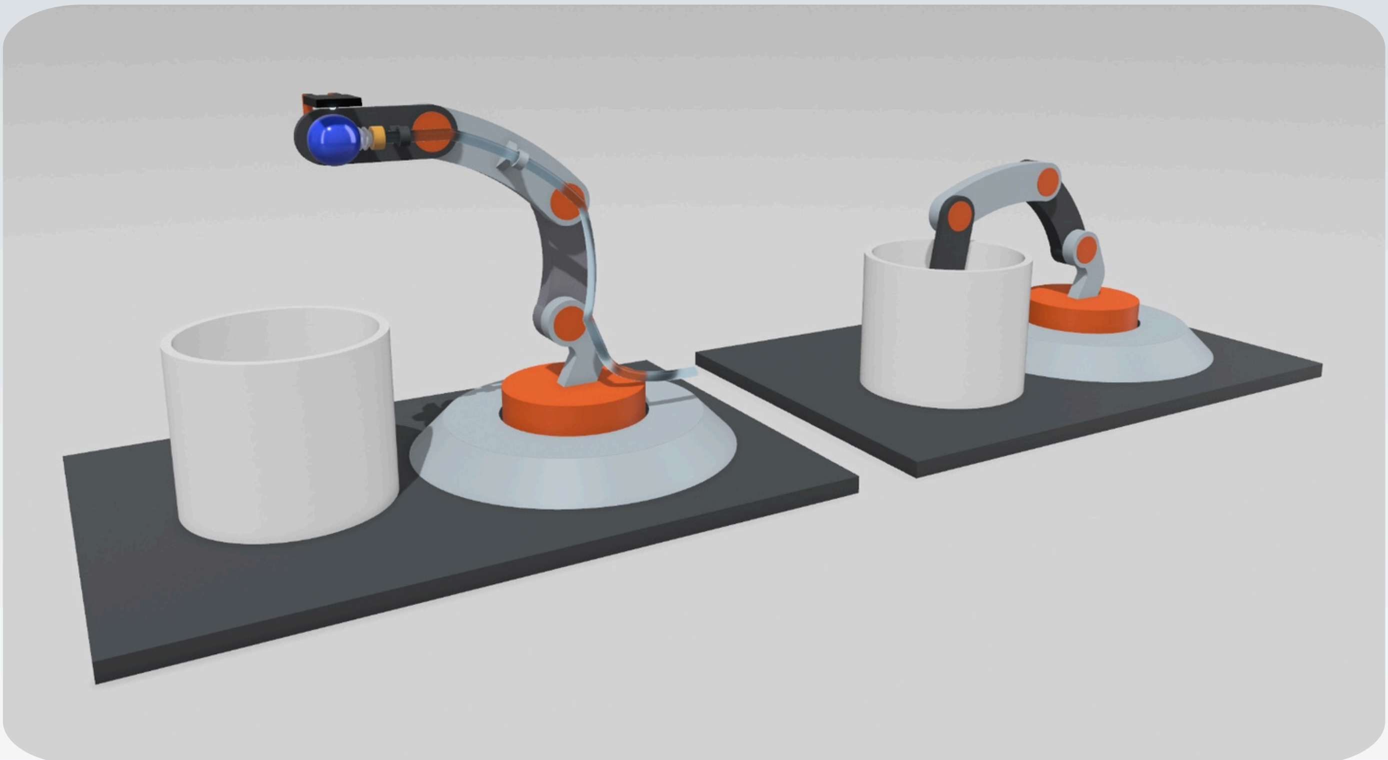
VACUUM SORTER



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ABSTRACT

This project focuses on the development of a robotic sorting arm designed to identify and categorize red, blue, and yellow balls into distinct bins using the **SHAKTI SoC** as the central processing unit, which is implemented on a **Nexys Video FPGA board**. Our proposed solution will utilize the **APDS-9960 sensor**, in order to sense the presence and arm's distance from the ball, moreover the same sensor will be used to detect the color of the balls, after one is picked up. We will not be using a traditional mechanical gripper assembly, instead, we will use a **vacuum suction gripper** to reduce the number of joints, actuators, sensors, and complexity/size of our firmware.

The system combines **advanced hardware, sensor integration, and efficient algorithms** to achieve precise and **autonomous sorting**. This document outlines the algorithm, hardware components, IPs used, and the detailed operation flow of the robotic sorting arm.

PROPOSED SOLUTION

Our robotic sorting arm is designed to autonomously identify and categorize red, blue, and yellow balls into distinct bins. The core strengths of our solution lie in the use of the **APDS-9960 sensor** for both proximity and color detection, eliminating the need for separate IR and color sensors, and the adoption of a **vacuum suction gripper** instead of a traditional mechanical gripper. To realize the arm we are to use **MG90S servo motors** alongside an **MG995 servo motor**. Having a higher stall torque and a full 360 degree of rotation the MG995 is better suited to handle the overall load of the arm assembly, the remaining servos are used to control the hinges at each joint of the arm.

These choices lead to a **simpler, more efficient, and compact design** with **fewer moving parts, reduced firmware complexity, and improved reliability**.

KEY FEATURES & ADVANTAGES

1. **APDS-9960 Sensor for Dual Functionality**
    - Has features such as advanced gesture detection, proximity detection, digital ambient light sense (ALS), and color sense (RGBC), while also incorporating an IR LED for proximity sensing.
    - We utilize it to act as a **proximity sensor** (to detect the ball's presence and measure its distance from the vacuum suction gripper's current position) and a **color sensor** (to classify the ball after it is picked up), while also using the **ALS,** to measure the same under different lighting conditions.
    - Reduces the need for multiple sensors, simplifying the implementation by reducing the number of sensors and firmware size.

2. **Vacuum Suction Gripper for Ball Handling**
    - A traditional **mechanical gripper** requires more actuators and joints, is more bulky and heavy, and would be more complex to maneuver inside the collection bin to pick up the ball. Instead our system uses a **vacuum suction** mechanism to pick up balls, the benefits of this are.
        - **Fewer mechanical joints and actuators,** leading to **lower hardware complexity and power consumption.**

- **Faster and more secure grip,** reducing the chances of dropping or misplacing the balls, also requires far less precision to pick up a ball compared to the mechanical gripper.
- **Simplified firmware** due to fewer actuators and sensors to control, also no need for complex maneuvers we need to code, which is needed in the case of a mechanical gripper.

3. Central Processing Unit – SHAKTI SoC on Nexys Video FPGA

- The robotic arm is controlled by the SHAKTI SoC, providing efficient processing power for real-time control, sensor interfacing, and sorting logic execution.
- **Customizable architecture** allows optimization for embedded robotics applications.

4. SHAKTI SoC on Nexys Video FPGA

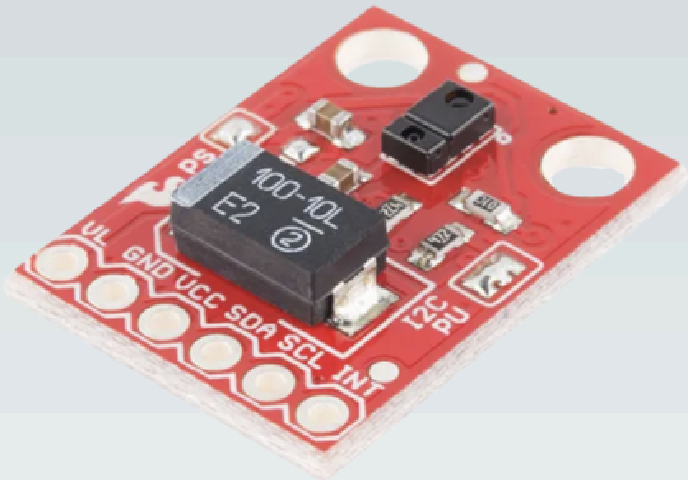
- The **SHAKTI processor**, based on the **RISC-V ISA**, is implemented on the **Nexys Video FPGA board**, which features the **Xilinx Artix-7 XC7A200T FPGA**.
- This setup provides a high-performance and customizable processing platform.

5. Efficient Sorting Mechanism

6. Optimized Firmware & Algorithm

DETAILED DESIGN PLAN

1. APDS-9960 - Color & Proximity Sensor - ₹301.00
https://robu.in/product/apds9960-rgb-gesture-sensor-detection-i2c-breakout-module/



APDS-9960 Specifications:

1. Operational Voltage: 3.3V
2. Ambient Light & RGB Color Sensing
3. Proximity Sensing
4. Gesture Detection
5. Operating Range: 4-8in (10-20cm)
6. I2C Interface (I2C Address: 0x39)

Color and Ambient Light Detection

- The APDS-9960 sensor provides red, green, blue, and clear light intensity data. Each R, G, B, and C channel has a dedicated 16-bit data line where each produces data simultaneously.

Proximity Detection

- The proximity detection utilizes an IR emitter and Receiver to transmit an IR pulse, receive, and provide us with a reading ranging from 10 cm to 20 cm.

Choosing the right threshold value for different colors

- Start by choosing a colored ball.
- Note the room ambient brightness C, and the value for R, G, and B.
- Repeat the observation with other balls of the same color.
- Vary the brightness of the room until there's a significant value difference.
- Note the room ambient brightness C, and the value for R, G, and B again.
- Repeat the observation with other balls of the same color.
- Once you cover the maximum possible range, tabulate the values.
- Repeat this with other colored balls.
- For every ambient brightness range, set the thresholds and detect them appropriately.

Sensing color logic

- Start by choosing a color to detect.
- Define different ranges of ambient light and check for the color value to detect is greater than or equal to the threshold, while the remaining two colors are less than the threshold.
- After defining them for all the cases end by defining a default case doing nothing.

2. MG90S Servo Motor: Actuator - ₹199.00

https://robu.in/product/towerpro-mg90s-mini-digital-servo-2-2kg-0-08sec-13g/

MG90S Specifications:

1. Weight: 13.4 g
2. Dimension: 22.5 x 12 x 35.5 35.5 mm approx.
3. Stall torque: 1.8 kgf·cm (4.8V) (4.8V), 2.2 kgf·cm (6 V)
4. Operating speed: 0.1 s/60 degree
5. Operating voltage: 4.8 V - degree (4.8 V), 0.08 s/60 degree (6 V) 6.0 V
6. Dead band width: 5 µs

Why use this?

- The arm hinge mechanism requires an actuator that is:
  - Light in weight, metal gears with durability.
  - Ability to turn precise rotation angles and stay at that position.
  - Produce enough torque to move the arms of the assembly.

3. MG995 Servo Motor: Actuator - ₹212.00

https://robu.in/product/towerpro-mg995-metal-gear-servo-motor/-mini-digital-servo-2-2kg-0-08sec-13g/

MG995 Specifications:

- Weight: 55 g
- Dimension: 40.7 x 19.7 x 42.9 mm approx.
- Stall torque: 8.5 kgf·cm (4.8 V), 10 kgf·cm (6 V)
- Rotation Angle: 120deg. (+- 60 from center)
- Operating speed: 0.2 s/60º (4.8 V), 0.16 s/60º (6 V)
- Operating voltage: 4.8V to 7.2V
- Dead band width: 5 µs
- Stable and shockproof double ball bearing design
- Metal Gears for Longer Life
- Temperature range: 0ºC – 55 ºC

Why use this?

- The arm hinge mechanism requires an actuator that is:
  - Light in weight, metal gears with durability.
  - Ability to turn precise rotation angles and stay at that position.
  - Produce enough torque to move the arms of the assembly.

Positions and PWM signal:

- -90 degree - 1ms pulse
- 0 degree - 1.5ms pulse
- 90 degree - 2ms pulse

4. Kamoer EDLP600-12A - ₹301.00

https://robu.in/product/kamoer-12v-0-3a-600ml-min-diaphragm-pump-model-edlp600-12a/

Pump Specifications:

- Model: DLP600-12A
- Operating Voltage: 12V DC
- Current Consumption: 0.3A
- Flow Rate: 600 ml/min (liquid): ≥1000 ml/min (gas)
- Maximum Positive Pressure: ≥0.05 MPa
- Maximum Negative Pressure: ≥0.04 MPa
- Power Consumption: 5W
- Noise level: ≤65 dB
- Weight: Approximately 65g
- Dimensions: 63 mm (L) x 27 mm (W) x 27 mm (H)
- Operating Temperature Range: -10°C to 55°C
- Humidity Range: <85% (non-condensing)

Features:

- **Maintenance-Free Operation:** designed for durability without the need for regular upkeep.
- **Compact Design:** A small footprint allows for versatile installation in space-constrained environments.
- **Low Noise Level:** operates quietly, making it suitable for noise-sensitive applications.
- **Robust Construction:** built to withstand various environmental conditions, ensuring long service life.

Why use this?

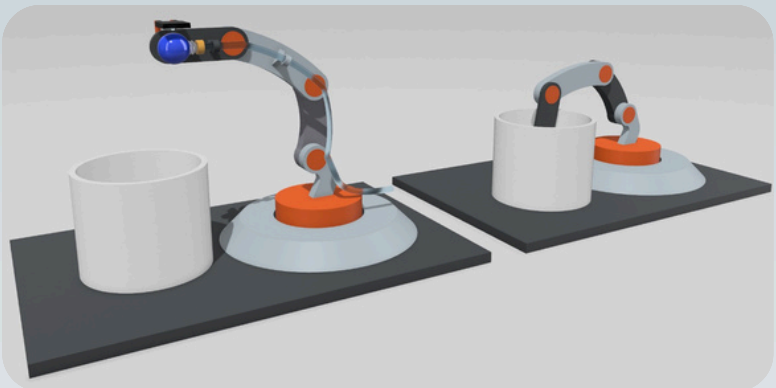
- This pump is attached to a flexible tube to be used as a vacuum suction gripper, which will be used to pick up the colored balls.
- This pump facilitates both fluid suction and discharge, enabling enhanced control over the arm's pick-and-drop manoeuvers with the ball.
- This pump offers the highest flow rate in terms of its size, cost, and power consumption, while also being quiet, making it perfect for our use case.

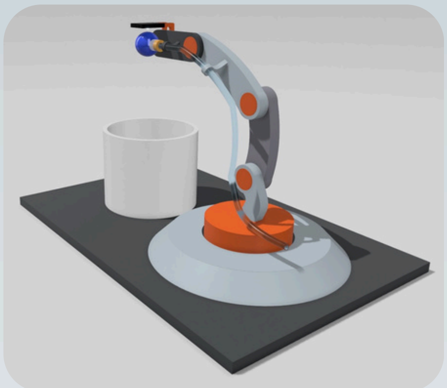
References

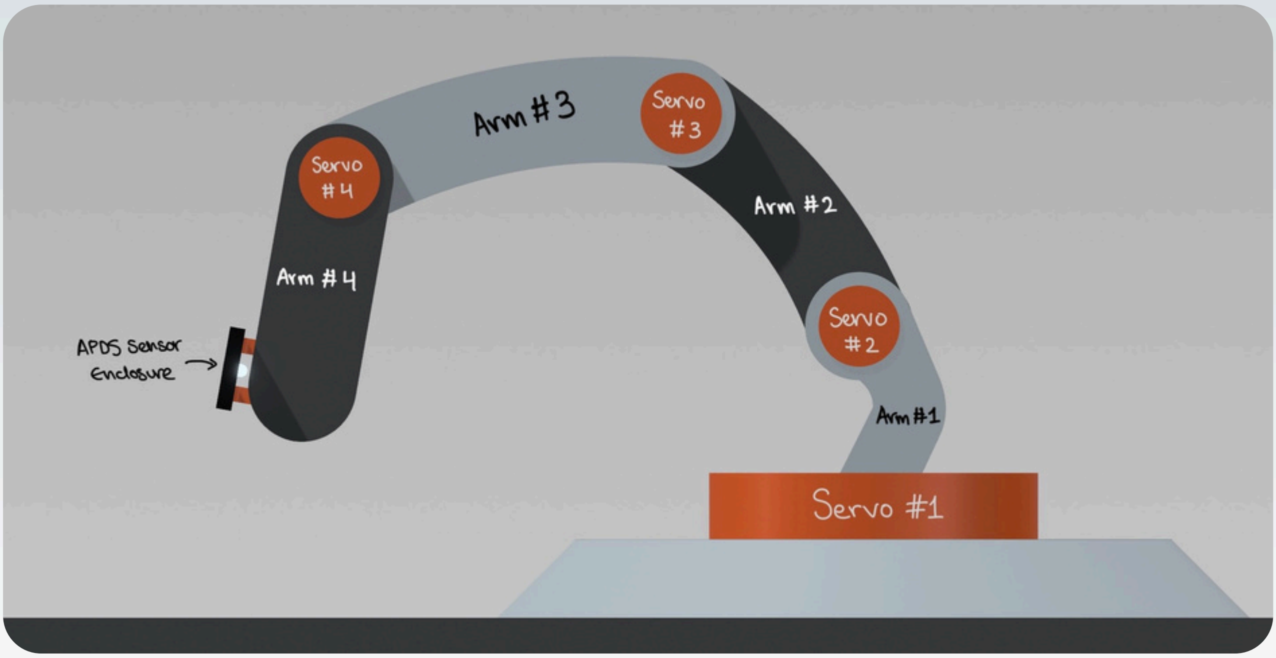
- Below is a video link of a demonstration of an older Kamoer pump with a much lower flow rate (300ml/min):
    - https://www.youtube.com/watch?v=cO10nBr_Ne0

- Below is a video of a vacuum suction gripper and its demonstration, which uses a comparable GB370 5v motor pump, with a flow rate of 1000ml/min. In the video, the gripper is shown to be able to pick up objects such as a smartphone with ease, so picking up the plastic colored balls will not be an issue.
    - https://www.youtube.com/watch?v=Gmdvx8TKWOQ

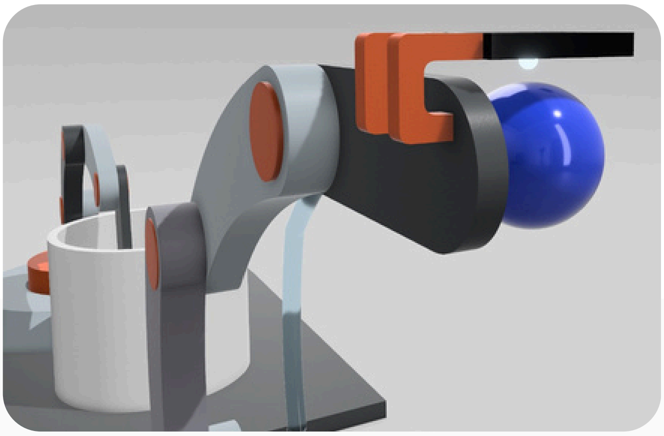
MECHANICAL DESIGN

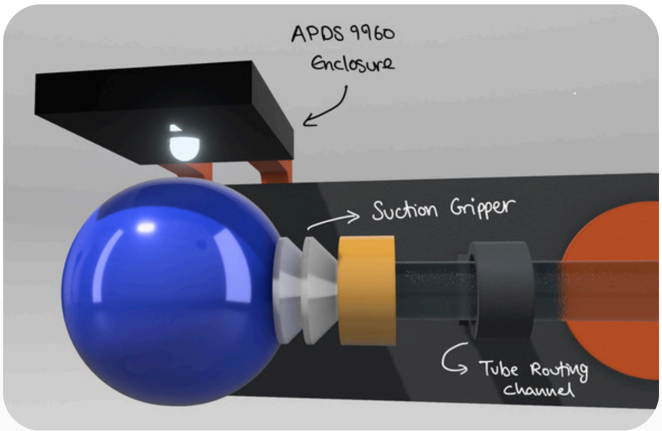






Servo 1 is a **MG995 Servo Motor**, whereas servos 2, 3, and 4 are **MG90S Servo Motor**. The **depth** of the arm is controlled by servos 1, 3, and 4 while the simple **front and back** motion is controlled by servos 1 and 2.





The **APDS-9960 sensor** will be placed in a **dark enclosure** to **reduce the effects of ambient light and reflections** on color and object detection.

The enclosure is attached to Arm 4, and is positioned in such a way that the APDS-9960 sensor can be used to **detect the presence and distance of the ball** while the sensor is **parallel to the bottom surface of the collection bin.**

It is also positioned in such a way that when the plastic ball is picked up by the vacuum suction gripper, it **can also detect the color of the plastic ball**, while the arm is still in motion to its next destination.

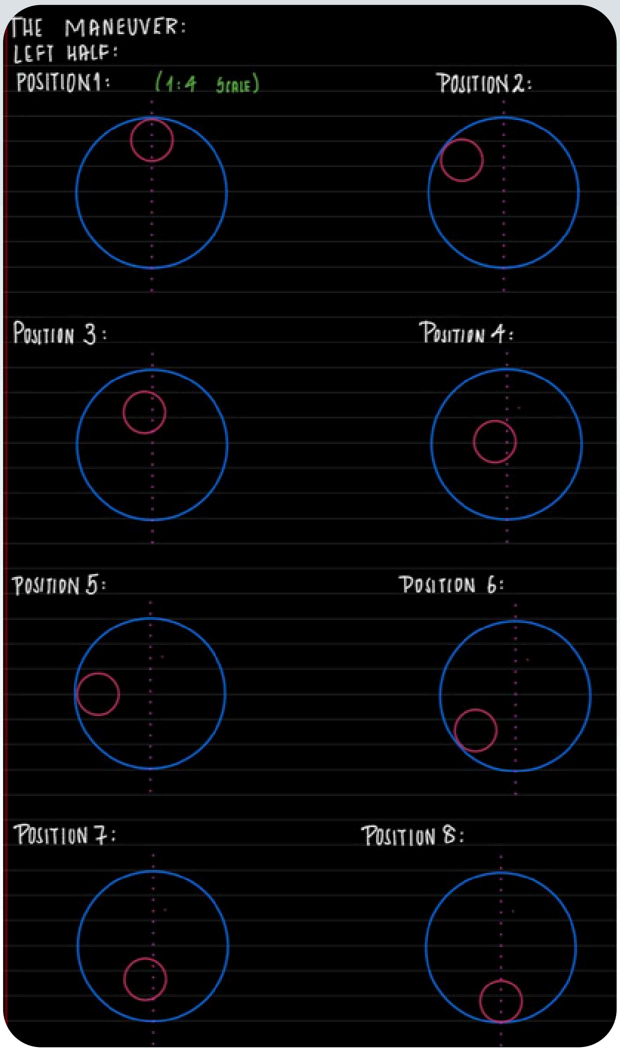
The enclosure has cutouts for the sensor itself and for a **white LED**, which will **properly illuminate the object's surface** whose color the APDS-9960 Sensor will determine.

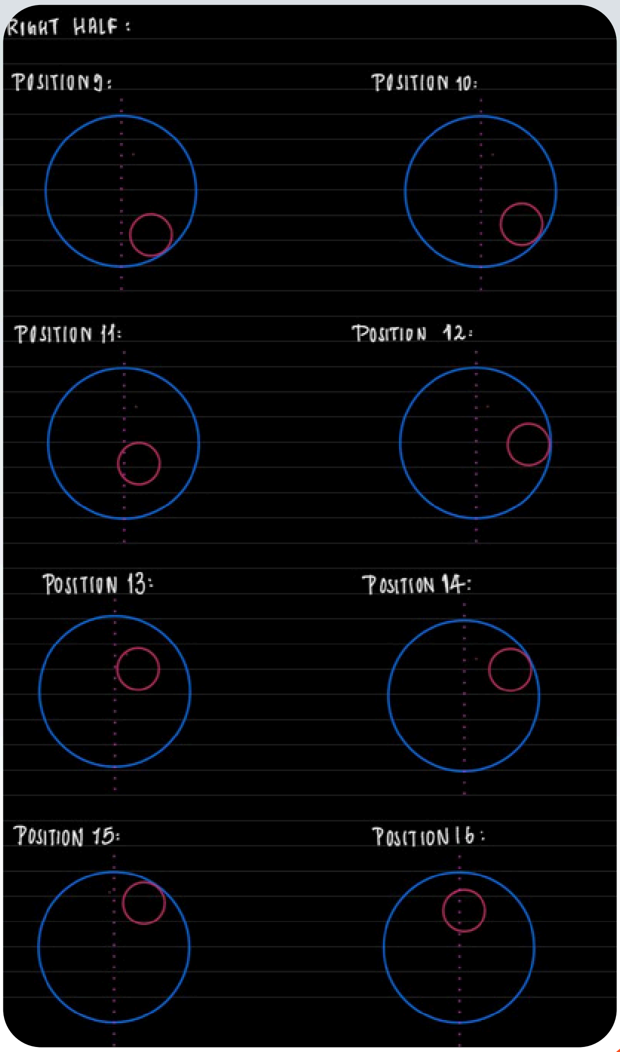
The arm has conveniently placed a **routing channel** along the arm mechanism for the silicone tubes of the vacuum suction gripper mechanism.

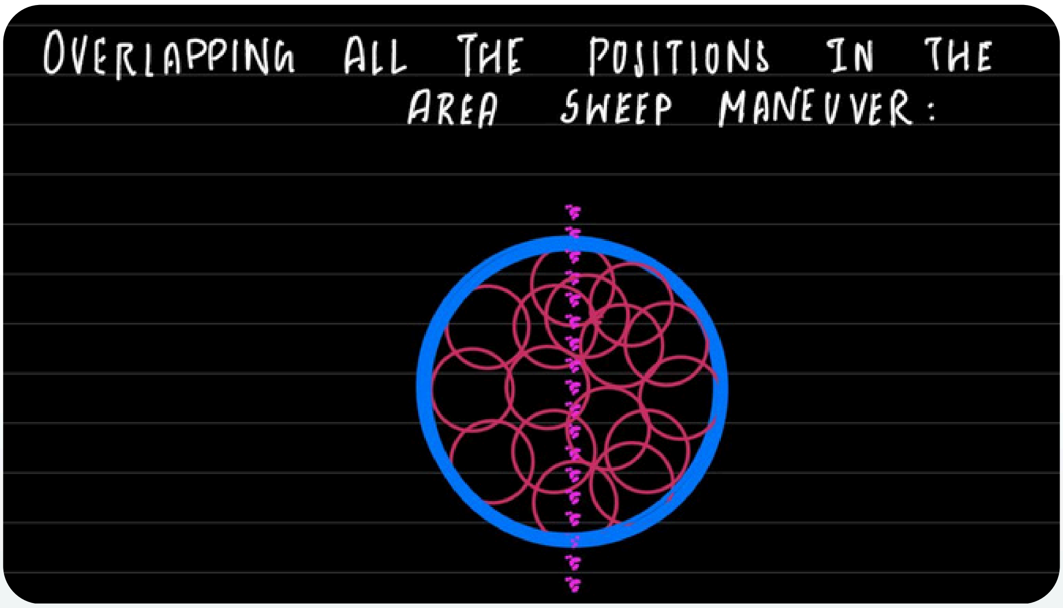
SCANNING THE FLOOR

A height threshold is to be taken before the maneuver with an empty bin which will be used later **to detect the presence of balls**, during the maneuver this is the height at which the **APDS-9960** will be maintained.

Here's what the **"Area Sweep Maneuver"** is, which consists of 16 steps or positions.







Here's the maneuver rendered in Fusion360:

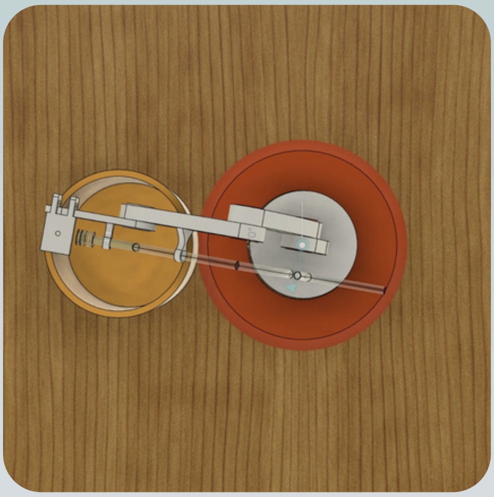
- The collection bin and plastic ball are all to scale.
- The collection bin's interior has a radius of 10 cm, and a height of 8 cm
- The plastic ball is of 2.5 cm diameter

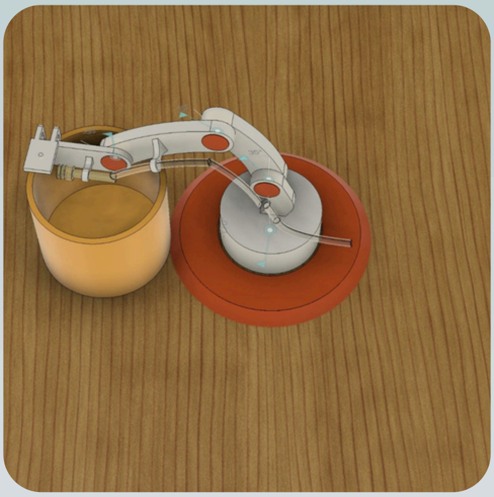
The arm mechanism will have a total of **4 points of articulation** (Indicated by the Orange Circles), which will all be controlled with the use of **servo motors.**

- One point of articulation will be the rotation at the base of the arm, the rest will be used to get the vacuum suction gripper in place to pick up the colored balls.

The angles at each of the articulation points at each position are to be mapped with the servos.

POSITION 1:





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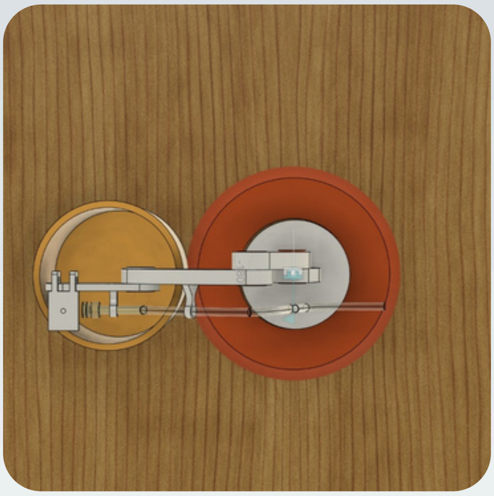

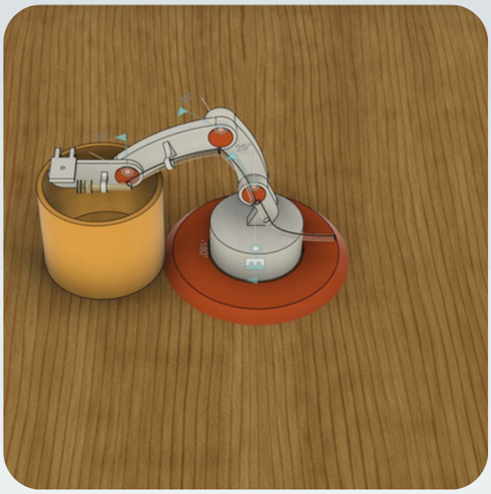

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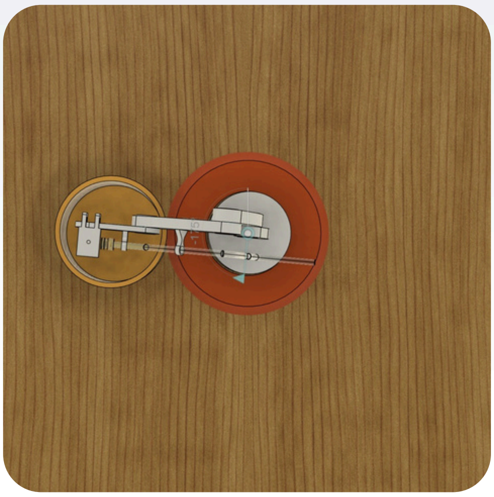

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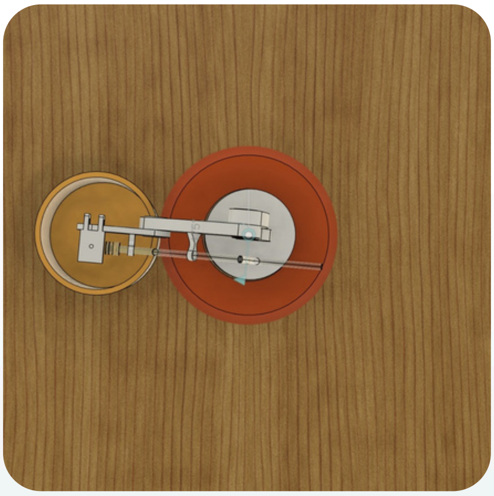

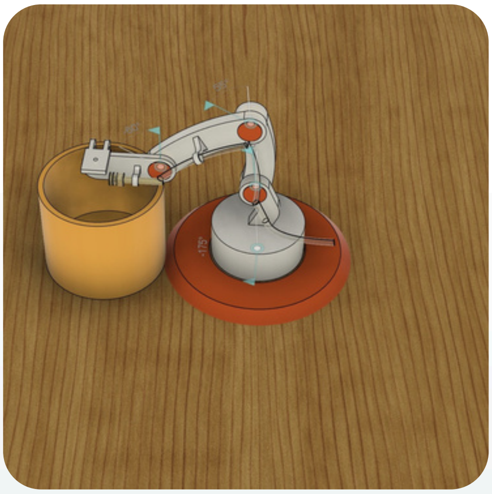

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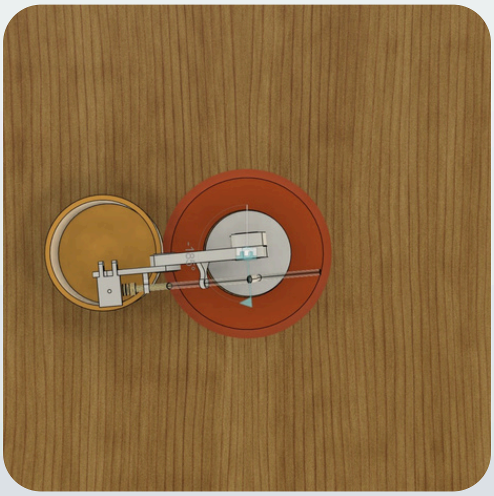

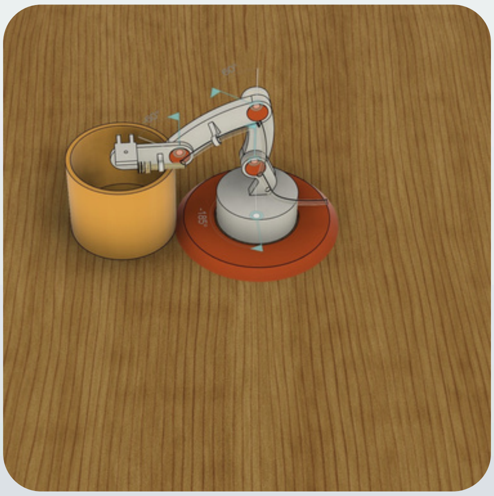

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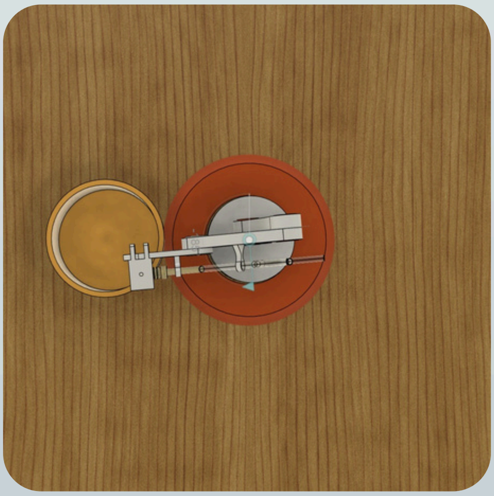

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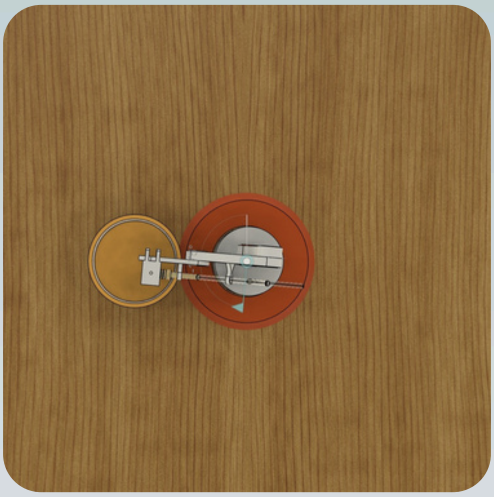

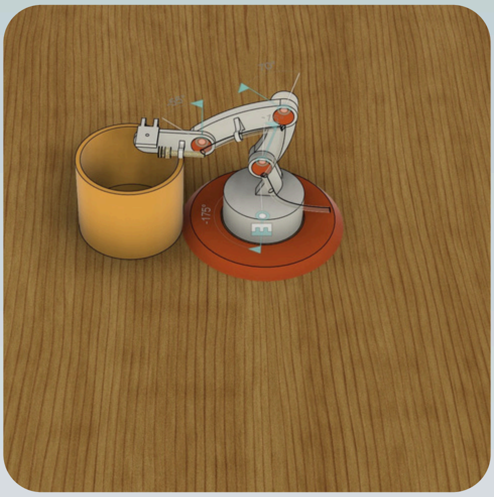

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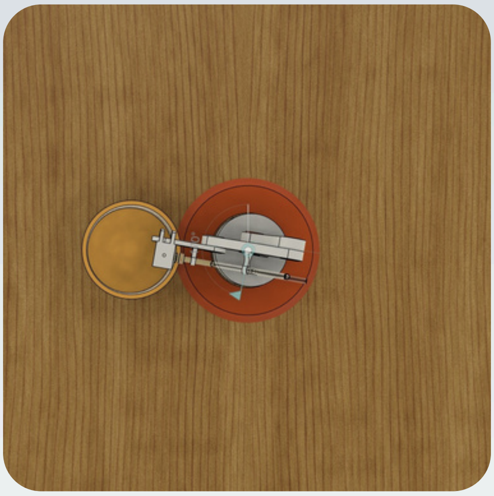

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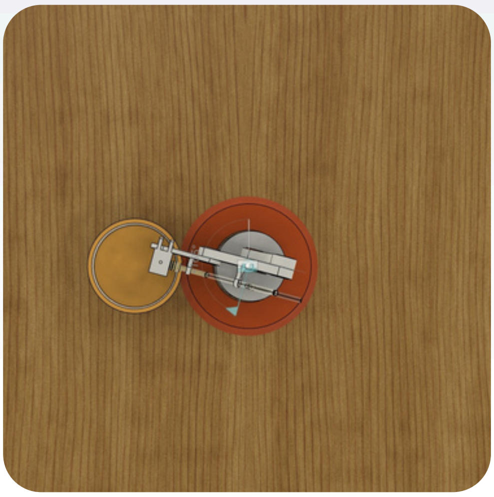

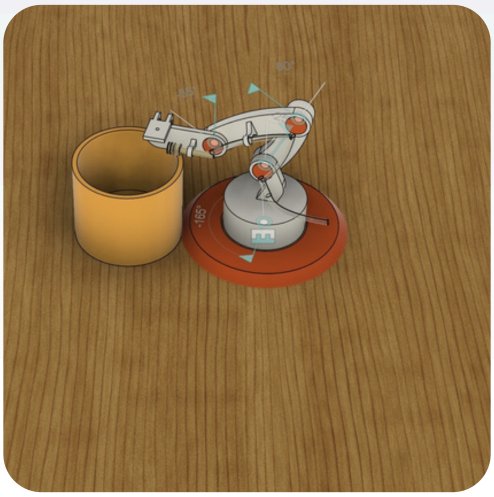

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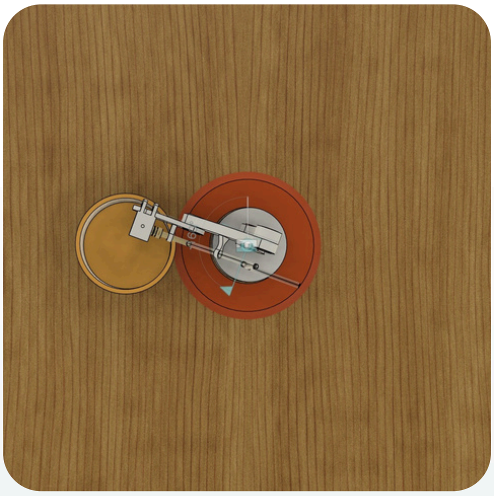

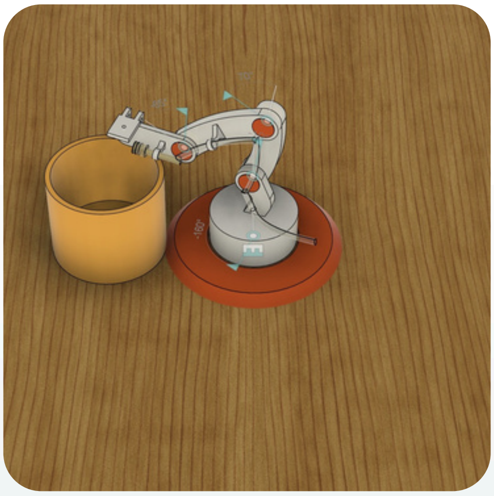

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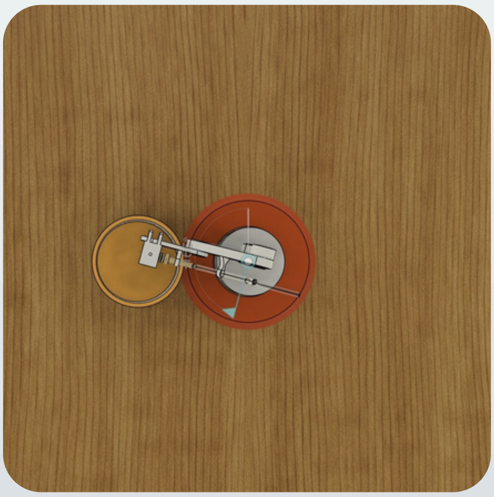

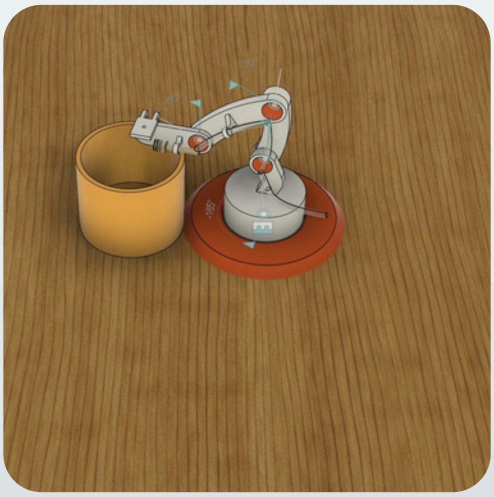

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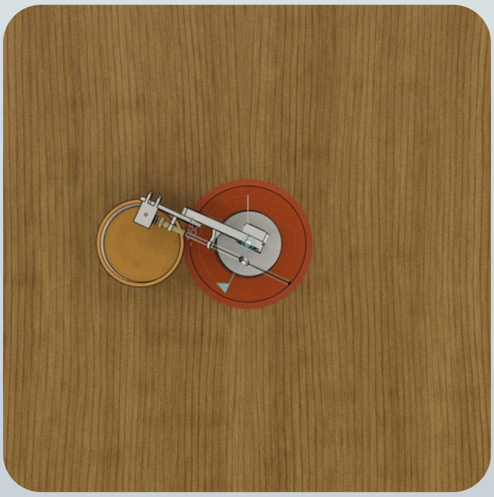

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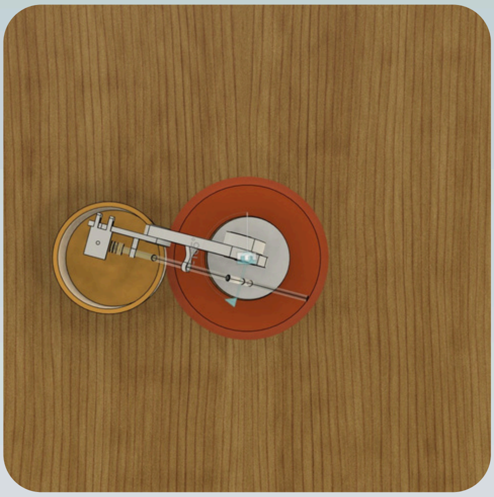
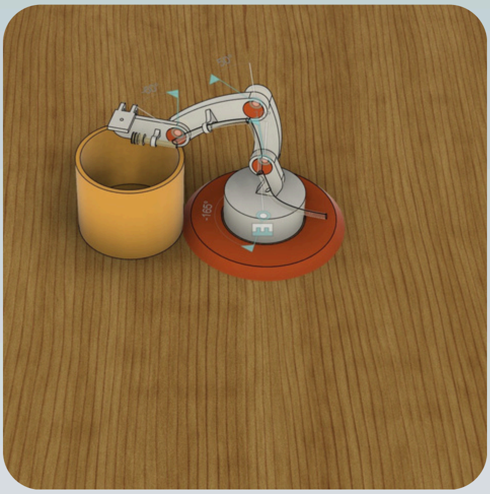
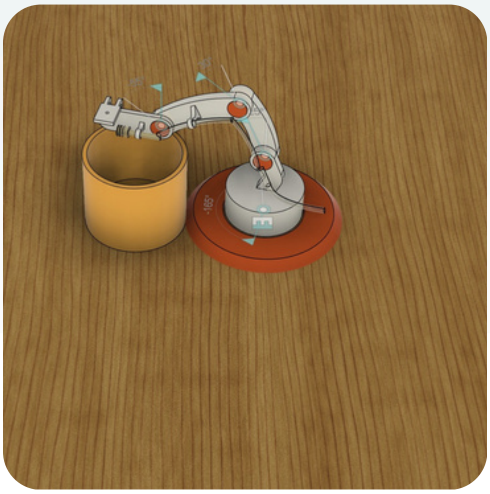




POSITION 14:

POSITION 15:



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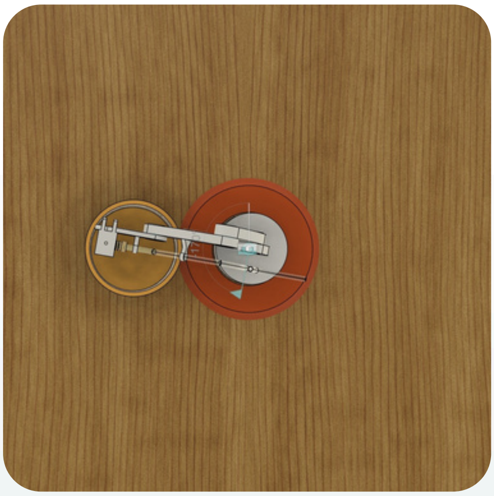
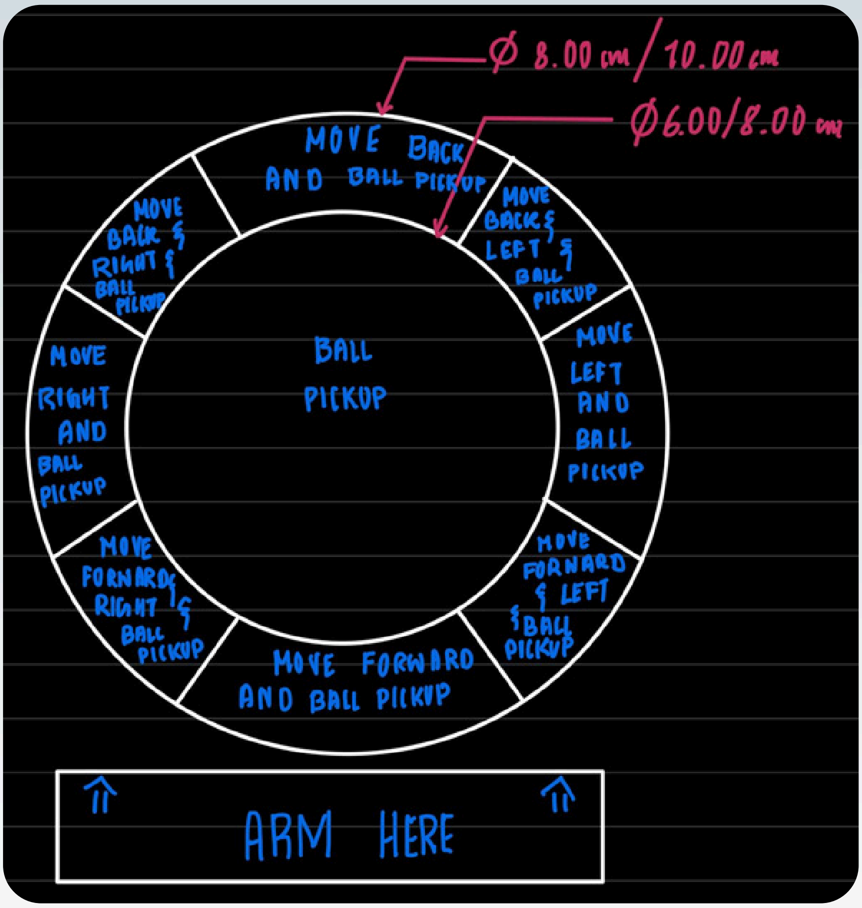


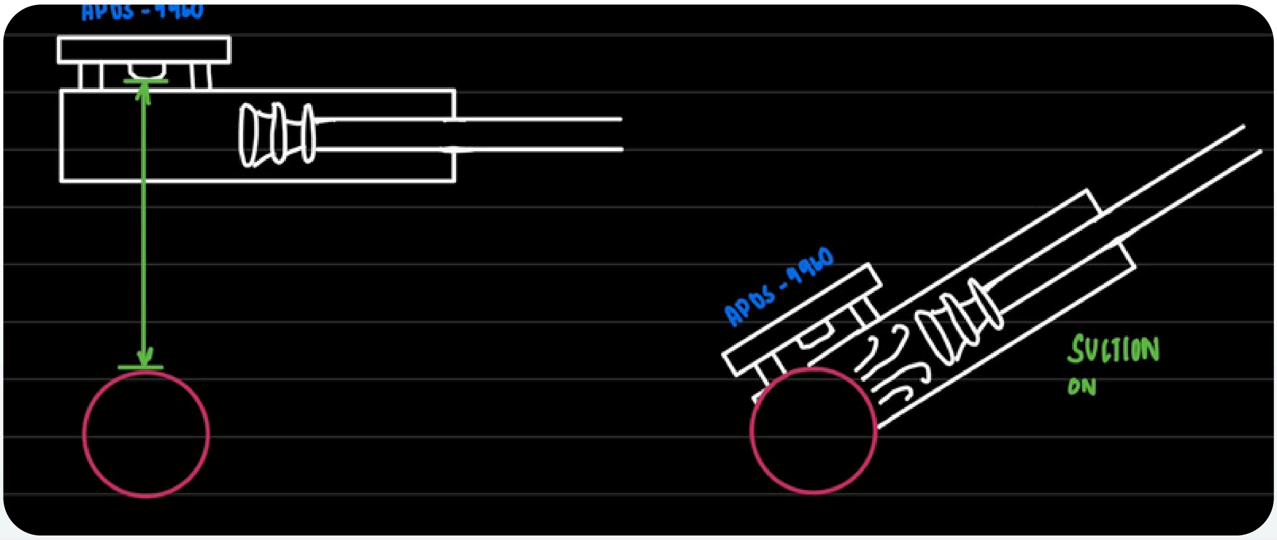
BALL COLLECTING LOGIC

The bin has been marked into the following regions to avoid the suction assembly contacting the edges. These regions are to be identified solely based on the angular positions of all the servo motors.



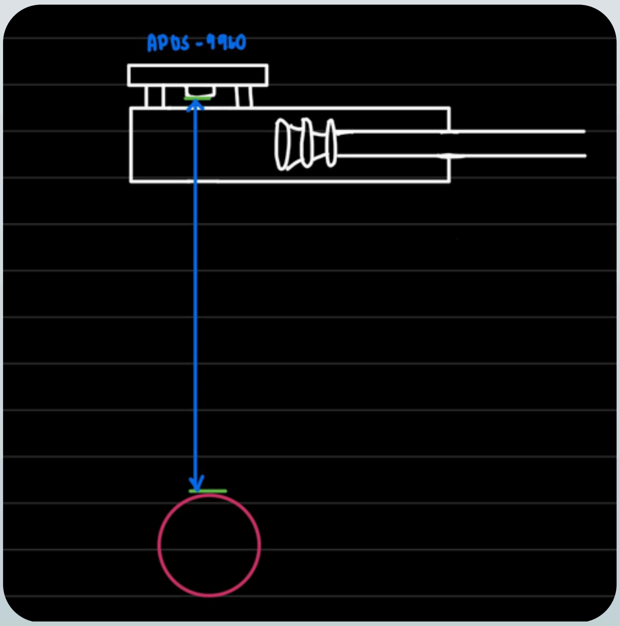
Ball pickup also depends upon the height at which each ball is present, based on which the depth of the pickup varies as well. The depth of the arm is controlled by servos 1, 3, and 4 while the simple front and back motion is controlled by servos 1 and 2.

IDEAL PICKUP:



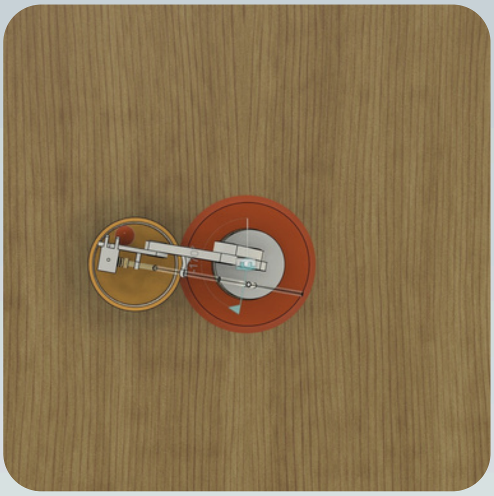
The optimum pickup distance is about 5 cm from the APDS-9960 sensor, this optimum value can be appropriately changed according to the build.

In the case of a distance more than the ideal distance like the one shown below, the arm then bends to bring down the suction gripper, or takes a deeper position inside the collection bin. The height difference between the APDS-9960 sensor and the ball height controls this depth.

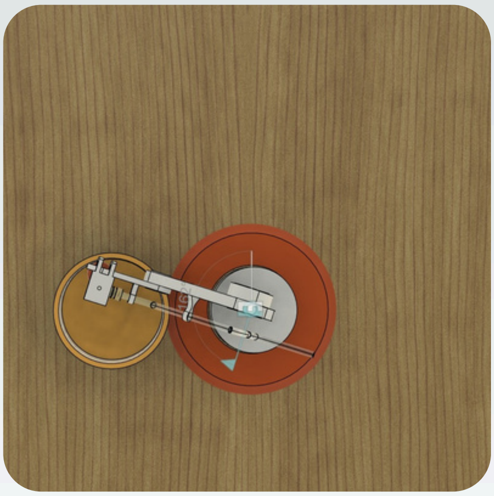


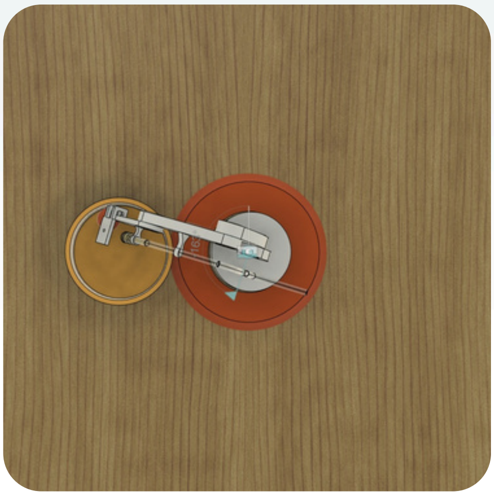
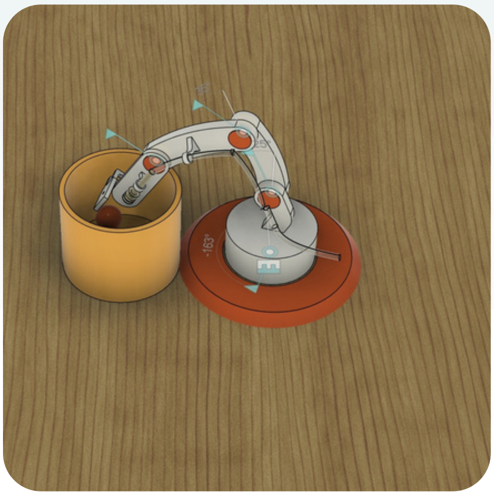
WORKING AROUND AN EDGE CASE:

1. Detection of the colored ball by the arm, to begin with

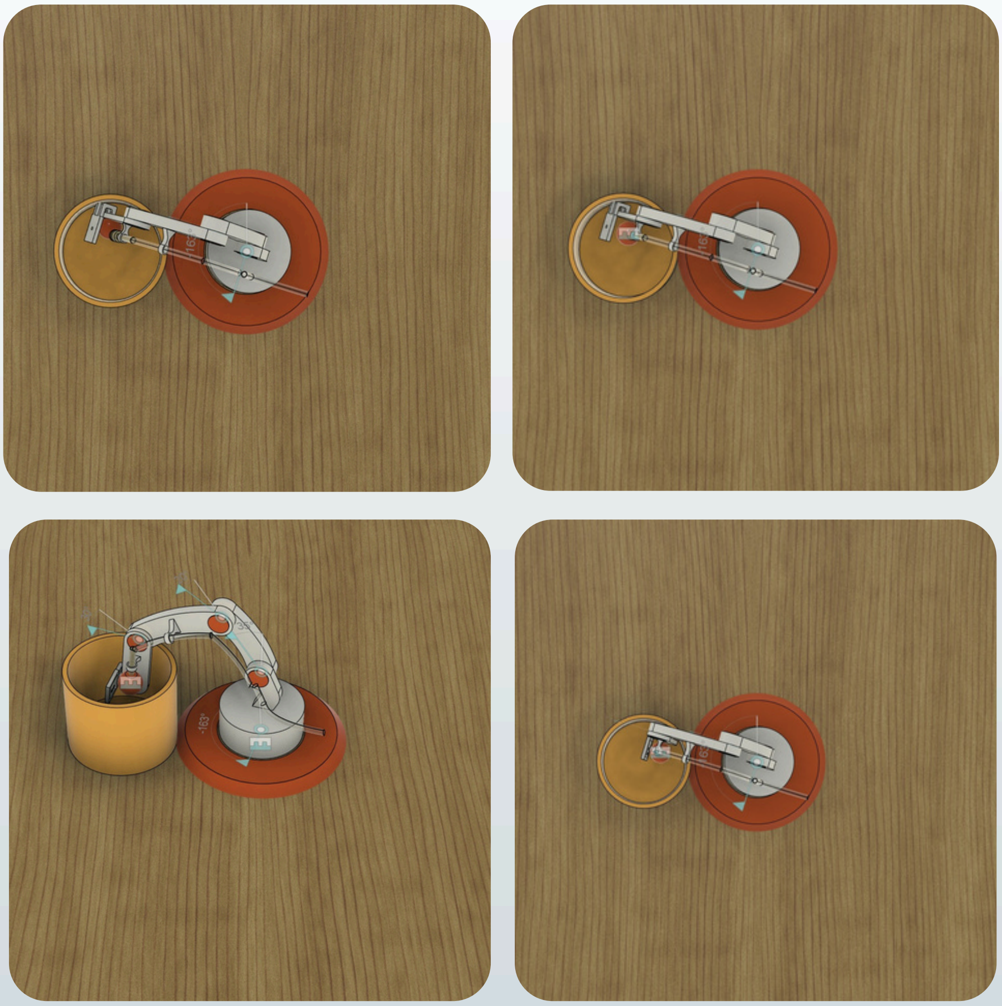



2. It detects the ball at the "Move back, left, and pickup" region based on the servo threshold. The arm then moves back and left simultaneously, taking a deeper plunge for the pickup.

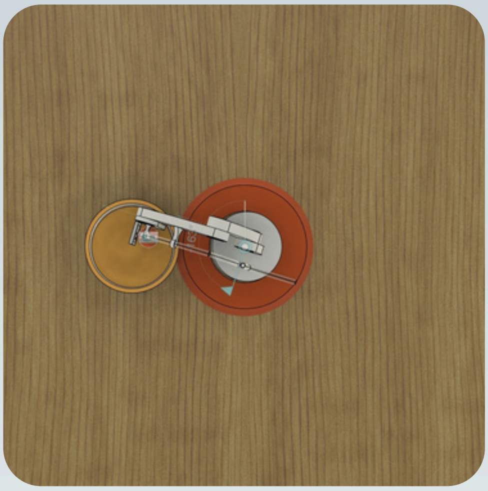


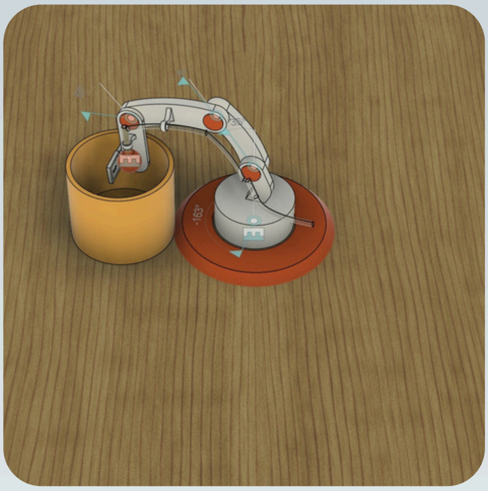



3. As the arm approaches closer to the ball, and the distance is less than the threshold (which will be determined experimentally after the mechanism is built), it'll activate the suction pump, which shall then create good enough suction to get the ball stuck to the enclosure.

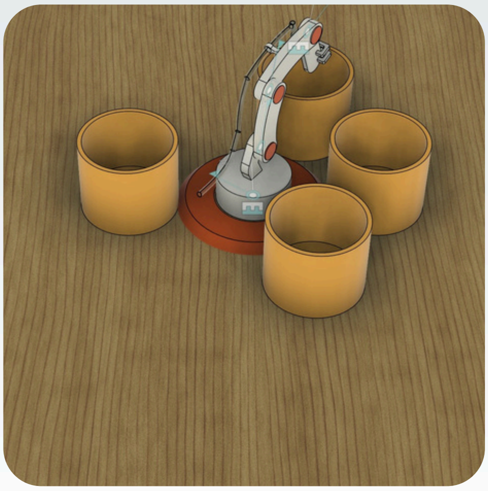


4. Once the ball sits right on the suction cup, the color sensor simultaneously detects the color based on the predetermined threshold. While this is happening, the arm will still be moving, in order to make the entire process of picking up and sorting the ball much quicker.

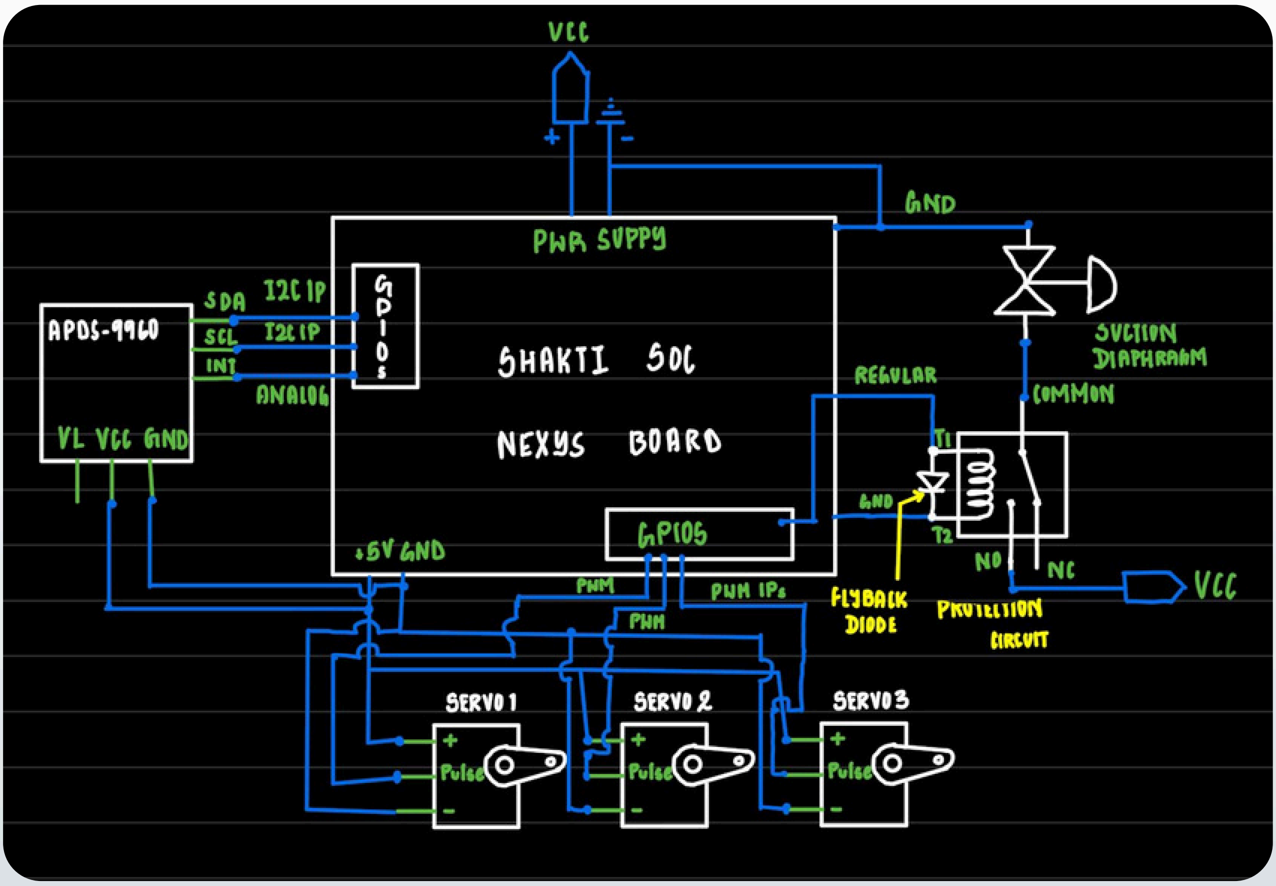




5. After it determines the color it appropriately turns toward the bin and drops it. It repeats till the ball bin becomes empty.



LAYOUT DIAGRAM



ALGORITHM

- **Step 1:** Start the “Area Sweep Maneuver” as soon the arm is powered “ON”.
- **Step 2:** The height threshold and color thresholds are already set.
- **Step 3:** When a height difference is detected by the APDS-9960, the arm pauses at that position.
- **Step 4:** First the arm based on the servo position decides the pickup logic.
- **Step 5:** Second based on height difference decides the depth of the pickup.
- **Step 6:** The arm then begins the pickup procedure, using the APDS-9960 to check for the close proximity of the ball.
- **Step 7:** As soon as it detects the presence by a combination of change in color and close proximity (which will be experimentally decided after build) it powers “ON” the suction and the ball sits on the suction cup.

- **Step 8:** It runs the color detection logic multiple times (will be manually set based on experimentation) before concluding a color.

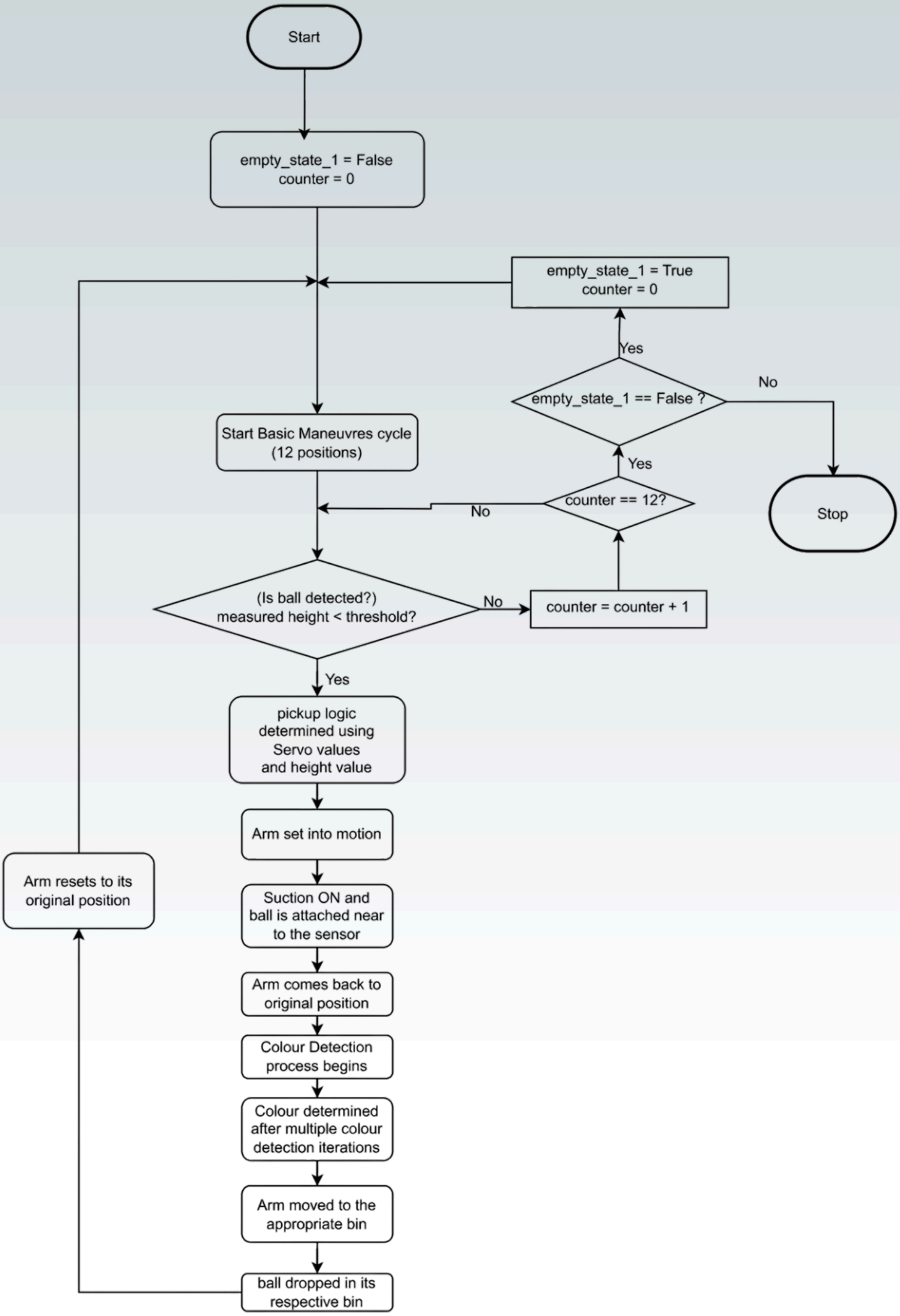
- **Step 9:** The base servo motor turns a specific angle to reach the color bin corresponding to the color.

- **Step 10:** The suction is then released and the ball is dropped.

- **Step 11:** The base servo motor rotates back to the ball bin and performs the maneuver.

- **Step 12:** If no height difference between the set threshold and the measured distance by APDS-9960 is detected from more than 2 maneuvers then come to a halt by concluding all the balls have been sorted.

FLOWCHART


Start
empty_state_1 = False
counter = 0
empty_state_1 = True
counter = 0
Yes
No
empty_state_1 == False ?
Start Basic Maneuvres cycle
(12 positions)
Yes
counter == 12?
No
Stop
(Is ball detected?)
measured height < threshold?
No
counter = counter + 1
Yes
pickup logic
determined using
Servo values
and height value
Arm set into motion
Arm resets to its
original position
Suction ON and
ball is attached near
to the sensor
Arm comes back to
original position
Colour Detection
process begins
Colour determined
after multiple colour
detection iterations
Arm moved to the
appropriate bin
ball dropped in its
respective bin

CONCLUSION

- This project is all about **making sorting simple, efficient, and reliable.** By using a **minimalist hardware approach with smart sensor integration**, we've created a design that gets the job done without unnecessary complexity.

- The **APDS-9960 sensor** lets us detect both color and proximity with a single module, reducing the number of components we need. The **vacuum suction gripper** makes picking up balls easy without requiring precise finger movements or extra actuators. And with the **SHAKTI SoC on an FPGA**, we have the processing power to make real-time decisions and handle future upgrades.

- In short, our proposed solution is **fast, lightweight, and effective.**