# Technical Training for Industry 4.0 Technologies: Low-Cost Gantry Candy Sorting System for Education and Outreach

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## Abstract

Technology is changing at a much faster rate than ever. We call this the fourth industrial revolution (Industry 4.0). In the authors' community college and workforce development programs, instructors focus on hands-on learning for high-level courses, including computer vision (CV) and capstone courses. Often the learning experience is hindered by lack of resources. To introduce Industry 4.0 concepts to students, a low-cost automated system for sorting candy that uses a portable gantry robotic system with computer vision was developed.

Existing work on candy sorting machines can be broadly divided into two categories: optical sorting and mechanical sorting. Optical sorting machines use camera and computer vision algorithms to identify flavor through color. A CV algorithm uses inputs such as objects and images/videos from a sensing device such as a camera. It analyzes the image and automatically recognizes color, shape, and size as a human would, but faster. Mechanical sorting machines use a physical mechanism and gates with color sensors to do the sorting; these are typically slower rate and less accurate.

The objectives of the work described in this paper are to 1) develop a low-cost portable gantry robotic system with computer vision for sorting jellybeans by flavor; 2) design lesson plans and activities for advanced programing and machine learning subjects and outreach to high schools; and 3) evaluate the impact of the system and lesson plans and make suggestions for future improvements. Python libraries were used for real-time data retrieval, processing flavor identification through color and coordinates.

Initial evaluation results suggest that the system and lesson plans have a positive impact on student learning in advanced manufacturing and machine learning. Future work includes (1) evaluating the lesson plans with college and high school students; (2) utilizing the system in a dual-credit course with a local high school; and (3) integrating the existing system with IoT, cloud-based manufacturing, and industrial Internet. Faculty can investigate which subjects the system can be used to teach and use the system to help introduce project-based learning in dual credit courses by conducting workshops with high schools and college instructors.


## Motivation

A McKinsey report states that Industry 4.0—also called the Fourth Industrial Revolution or 4IR—is the next phase in the digitization of the manufacturing sector, driven by disruptive trends including the rise of data and connectivity, analytics, human-machine interaction, and improvements in robotics [1]. McKinsey Global Institute also estimates that Industry 4.0 could potentially increase global GDP by $5.7 trillion by 2030 [2]. At the same time, the McKinsey report also foresees a global shortage of skill workers as a result of implementation of Industry 4.0 technologies such as data analytics and collaborative robotics [3]. Potential solutions such as exploring the magnitude of the skills gap and proposing solutions, including on-the-job training, micro-credentials, and apprenticeships were proposed. In the U.S., Hsieh [4] conducted a workshop and industry survey to understand the challenges and needs from industry in the implementation of Industry 4.0 technologies. The most used technology was analytics and more than half of respondents reported using machine-to-machine communication, technologies for identification and traceability of final products, cloud computing, vertical integration, industrial robots, and automatic identification of nonconformities in production. Also, 71% of respondents noted that the need for workers to use computers more has changed the nature of work at their company and 57% noted a need for training to be more individualized/ personalized. The top two worker skills selected by respondents were technical skills and process skills, where technical skill refers to programming and adapting to new technologies and process skills refers to critical thinking and deductive reasoning. Industry 4.0 is driving manufacturers to build smart factories, which are integrated with smart sensors and Internet of Things (IoT). Integrating software with hardware and analyzing the data yields better outcomes and increases productivity.

Successful implementation of Industry 4.0 begins in the classroom. There are not enough courses designed to teach machine learning at vocational colleges. At universities, machine learning (ML) is taught to computer science and data analytics majors; ML instruction is not typically available for high school students or workforce development programs. To bridge this gap and flourish Industry 4.0, there is a need to revise curricula at lower levels of the educational system. Moreover, an Industry 4.0 system for education can be expensive.

Candy sorting based on color is an interesting topic to students. Krishnakumar [5] described a system for high-speed sorting of candy into desired locations. A color sensor (TCS230) detects three colors: red, green, blue, and black (no color). When a piece of candy passes by the sensor, the sensor output frequency is captured by a microcontroller and used to sort the candy based on color.

In this paper, our focus is on designing and building a low-cost candy sorting machine using a camera that provides not only color information but also the shape of the candy. This allows students to understand and provides them hands-on experience in machine vison and machine learning as applied in an automated system. The system can be incorporated into lesson plans for students in different disciplines of engineering (such as computer science, manufacturing, mechanical and electrical engineering technologies) and at both the college and high school levels.

## Design of Candy Sorting Machine

The overall structure of the candy-sorting machine includes (1) Cartesian robot platform design and (2) computer vision application development. Figure 1 shows an isometric view of the candy-sorting machine which includes the Cartesian robotic platform and robotic gripper and camera system. Figure 2 shows the overall system architecture.

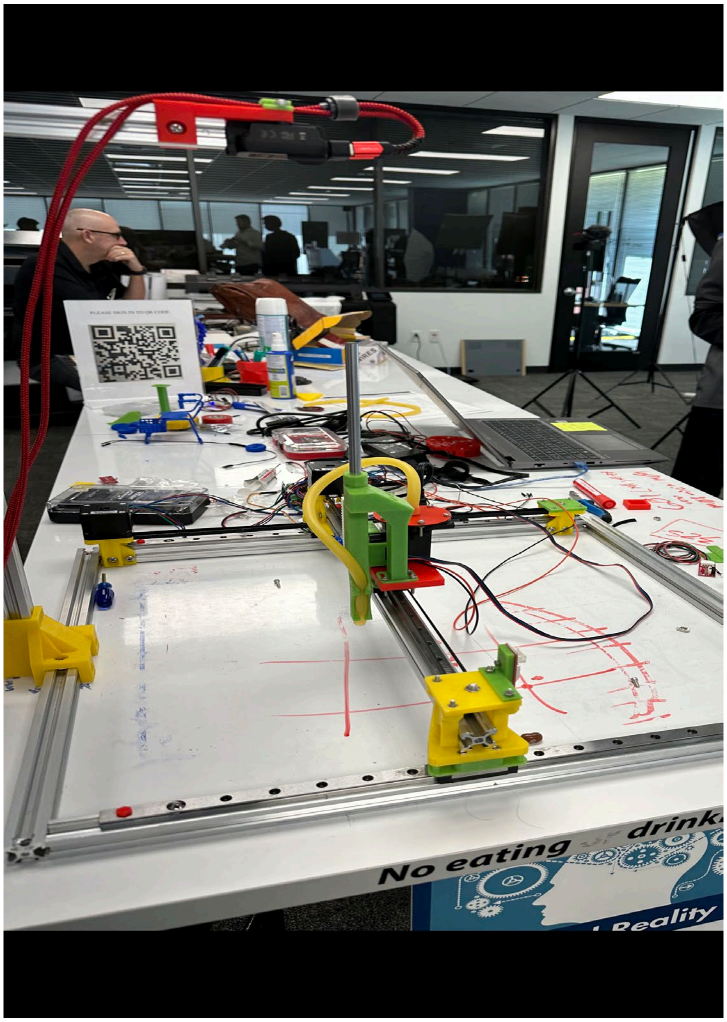


*Figure 1. Isometric View of Cartesian Robot Platform.*

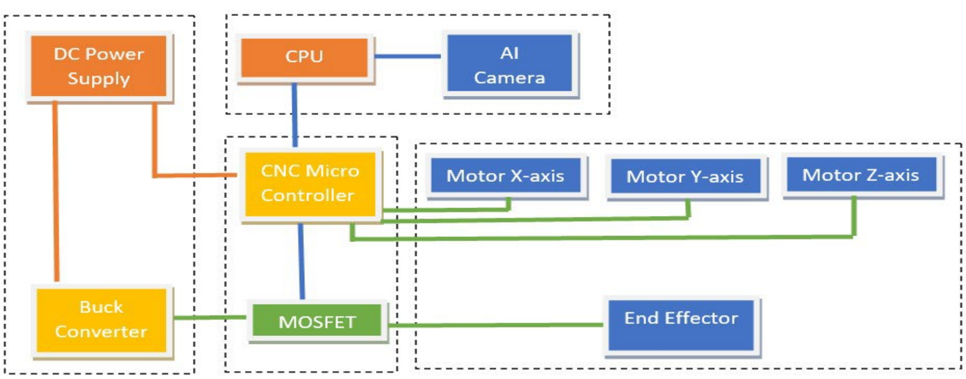


*Figure 2. Overall System Architecture.*

### Cartesian Robotic Platform Design

Primary components include the Cartesian robotic platform and gripper and the camera system. The robotic platform is a low-cost suction gripper and camera system. The gripper is built based on pneumatic power; students can learn about the application of fluid power in candy sorting machines. Also, stepper motors are included, which can be used to teach motor control concepts in an integrated systems such as Industry 4.0 candy sorting machine. Figure 3 shows the platform from various angles. Figure 4 shows a flowchart of one sub-process (moving the robot arm gripper); flowcharts like these were used to help students who did not have a programming background to visualize processes.

Figure 5 shows the components involved in the candy sorting system. The plastic parts for the system were made using 3D printers in the Innovation lab. Other materials such as Arduino, camera, DC motors and the gantry crane parts were purchased online. Table 1 lists the major purchases; Appendix A lists the 3D models and electronics components. The total cost of development was about $1200.

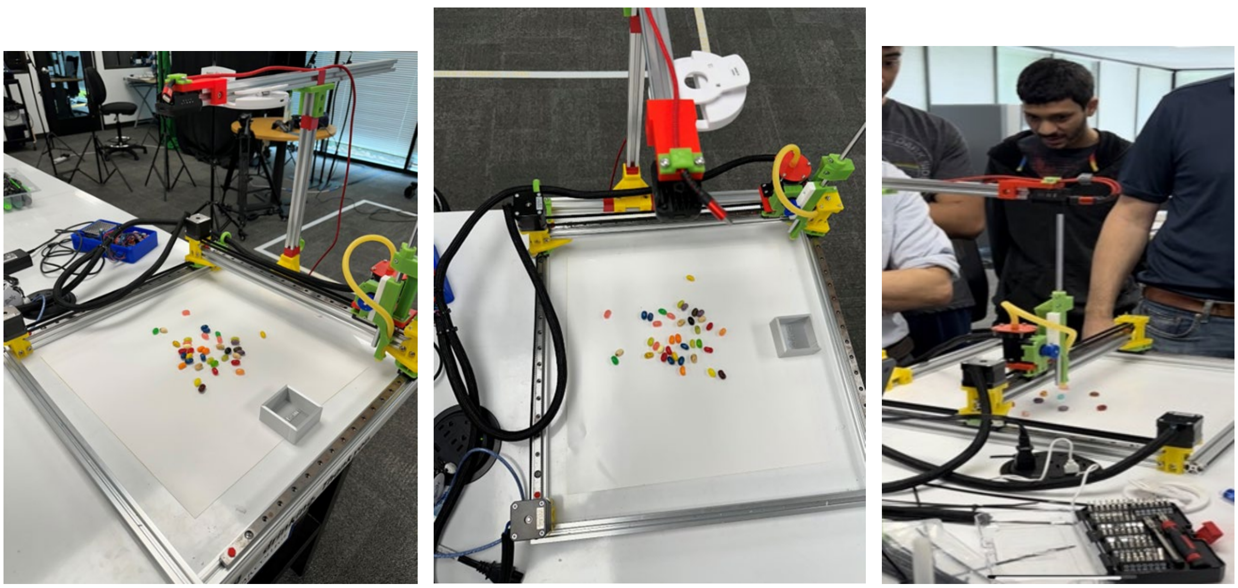

*Figure 3. Views of Robotic Platform from Various Angles.*

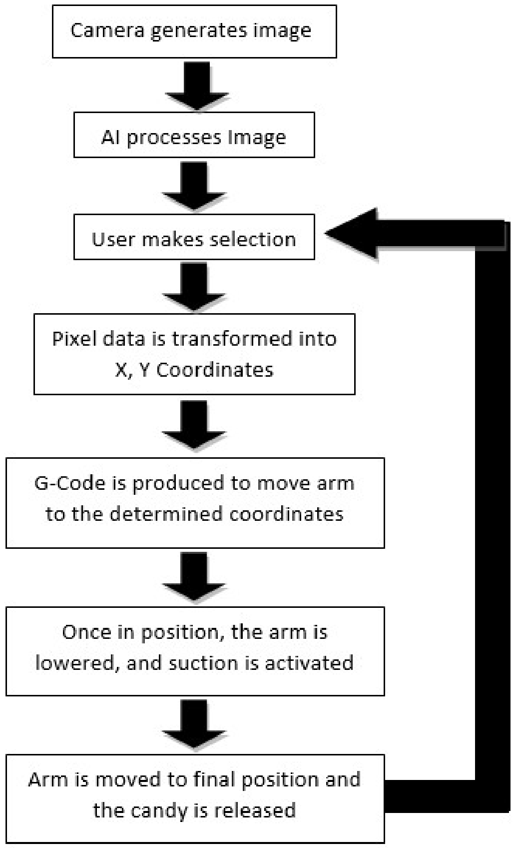


*Figure 4. Flowchart of robot arm gripper movement.*

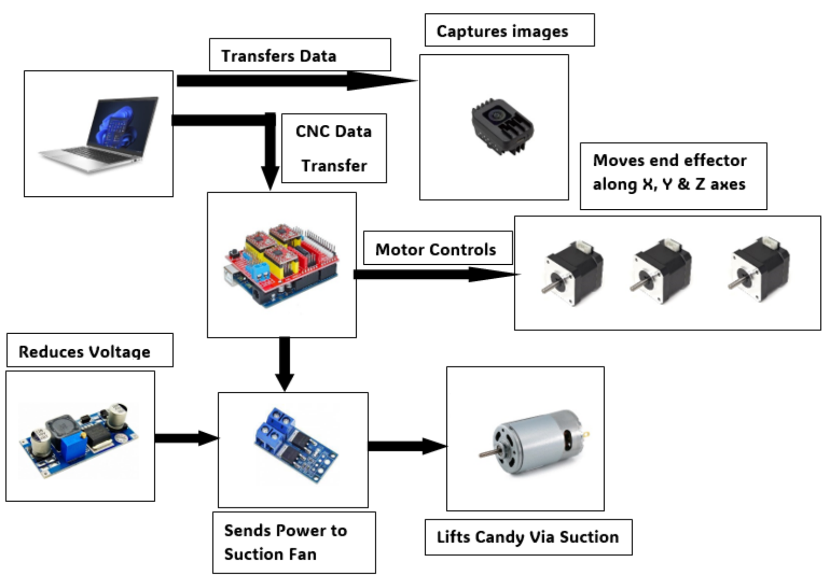


*Figure 5. System Components Involved in the Candy Sorting machine.*

| Item Name | Qty | Cost |
|---|---|---|
| Oak-1 Lite Robotics Camera - Auto Focus<br>Luxonis OAK-1 Lite (no depth, auto focus) | 1 | $99.00 |
| Oak Y-Adapter (USB adapter) | 1 | $19.00 |
| Powered USB Hub<br>Powered USB Hub, RSHTECH 4 Port USB 3.0 Hub Splitter Portable Aluminum USB Data Hub Expander with Individual On/Off Switch and Universal 5V AC Adapter, 3.3ft USB 3.0 Cable (RSH-516) | 1 | $19.99 |
| Hosyond 7-inch display panel<br><br>Hosyond 7 Inch IPS LCD Touch Screen Display Panel 1024×600 Capacitive Screen HDMI Monitor for Raspberry Pi, BB Black, Windows 10 8 7 | 1 | $45.99 |
| Cable<br>USB-C to USB A Cable 3.1A Fast Charging [2-Pack 6.6ft], JSAUX USB Type C Charger Cord | 1 | $8.99 |
| Screen case holder<br>Longruner 7-inch Raspberry Pi Touch Screen Case Holder for Raspberry Pi 3 2 Model B and RPi 1 B+ A BB Black PC Various Systems LSC7B-1 | 1 | $13.99 |

**Computer Vision Application Design**

Roboflow, a tool for building computer vision applications that utilizes open-source computer vision models, was used to recognize the color of candy [6]. The Python-developed Jelly Belly Flavor Picker application integrates with a JellyBelly5 model hosted on Roboflow.com (https://universe.roboflow.com/alan-gandy-llah9/jellybelly5) [7]. The application utilizes Python libraries for real-time data retrieval, processing flavor identification and coordinates. The GUI features a live video feed, snapshot functionality, and a confidence-sorted flavor table. User-selected flavors are converted into g-code commands for a robotic arm, akin to a 3D printer mechanism, enabling candy picking and placement. This integration of computer vision (CV), user interface, and robotics demonstrates a technologically innovative approach to automated candy selection.

**Machine Learning Model Development**

The development of the Jelly Belly Flavor Picker application was a methodical process that began with the creation of the JellyBelly5 computer vision model. This endeavor involves a sequence of steps:

1. Data Collection and Preparation: A diverse set of 50 Jelly Belly flavors were collected and photographed from various angles using an iPhone 12 and a USB webcam to ensure a comprehensive dataset.
2. Dataset Annotation and Augmentation: The initial set of 539 images was annotated and then augmented to a total of 1,291 images using Roboflow.com, enhancing the dataset's diversity and the model's ability to generalize.
3. Model Training and Evaluation: JellyBelly5 was trained using Roboflow 3.0 Object Detection (Fast), balancing the needs for speed and accuracy. The model demonstrated high accuracy, with a mean Average Precision (mAP) of 93.7%, precision of 78.0%, and recall of 87.1%.
4. Model Deployment and Integration: Post-training, the model was integrated into the application, analyzing camera feed images to identify and display each candy's flavor.

This process highlights the detailed approach in model development, essential for the application's effectiveness in identifying a wide range of candy flavors based on color.

**Lesson Plans**

The lesson plans are divided into software and hardware systems (see sample in Appendix B). The first level is a high-level overview. Introduce the concept and demonstrate a working version of the system that students can use with their phones. Then students can be broken up into teams (one software and other hardware). The second lesson reconstructs the components into smaller parts (using prebuilt software and hardware). Future student lessons can be developed to have the students build their own dataset (of smaller size objects) through model training, development, and application development.

The hardware team can have lesson plans for Mechanical drives (pulleys, conveyors, gear systems, including fabrication of the 3D printer parts).

**Student Evaluation**

The machine and lesson plans were pilot tested by five senior students. Some students had a strong mechanical background and less programming skills. Different tasks were assigned to different groups of students. The students showed immense growth in their knowledge of motor controls, artificial intelligence, programming in both Python and machine code, structural analysis, engineering design, 3D CAD software, and 3D printing.

With regard to machine learning, students learned about supervised learning, in which labeled data sets are used. They also learned about the link between machine learning and camera vision by utilizing Roboflo.com cloud-based tools, and became familiar with data collection and preparation and model deployment.

Additionally, and most importantly, the students developed interest in, and self-motivation to learn, all different aspects of the project. Students learned software programming and CAD modeling voluntarily and on their own. They were further motivated to create their own projects after completing development of the candy sorter. Furthermore, they were no longer afraid of the unknown and recognized the value of the trial and error/iterative design process.

**Student Comments**

Student comments were overwhelmingly positive. The number one comment was enjoyment of seeing a project develop from conceptual, through iterative design, to completion. Further, the students enjoyed the fact that so many disciplines were integrated into one project, and that they could tangibly see how they all worked together. Students also stated that they felt empowered by the fact that the project was completely designed by them and not just purchased; they designed and 3D printed many of the parts. They also appreciated working alongside professors who also did not "know the answer." They enjoyed participating in the creative design process where the solution was unknown and therefore there was no correct answer, but instead the one they created. Students stated that the project initially seemed insurmountable due to its complexity and their limited knowledge. But witnessing the messy process of development and being part of all the success and failures gave them confidence to try their own difficult projects. Figure 5 shows the opinion survey results. The numbers on the vertical axis correspond to the questions listed below about the project and the numbers on the horizontal axis are the average levels of agreement.

1. The candy sorting machine system helps me to understand ML concepts.
2. Integrating stepper motors in the system helps me learn motor controllers.
3. Low-cost system concepts developed in the lab gives me full engagement to develop and implement learning.
4. It is a good exercise to implement computer science, motor control for integrated systems, and pneumatic power in courses and develop student lessons.
5. It helped critical thinking, designed the system and integration with self-discovery of important concepts in AI.

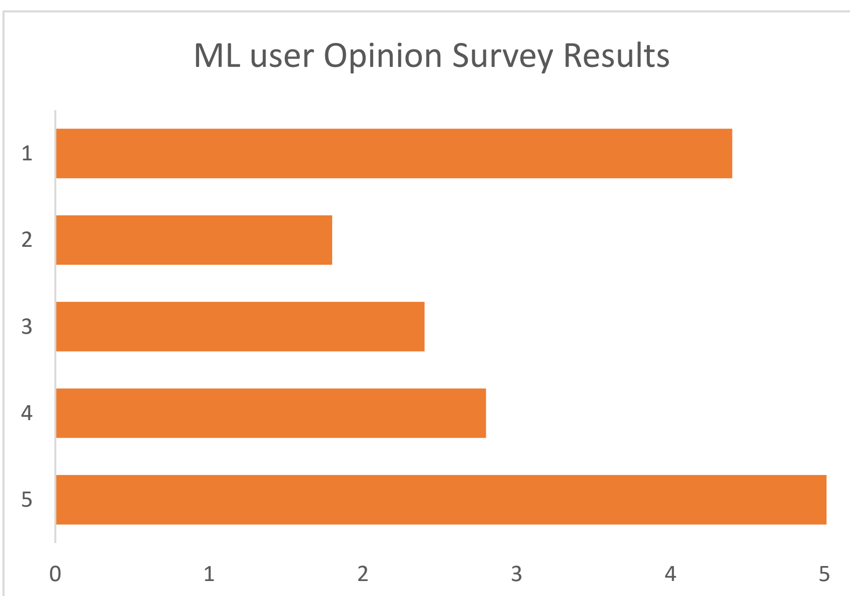


*Figure 5. Machine learning user opinion survey results.*

Item 2 ("Integrating stepper motors in the system helps me learn motor controllers") was relatively low. This may have been because students were already familiar with motor controllers in previous coursework.

## Lesson Learned

Although the sample size was small, it appears that the students benefited greatly from working alongside professors and participating in the design process where they could witness professors making errors too. The project team also realized the modularity of this project and how it can be integrated with other Industry 4.0 projects such as conveyor and assembly systems. This project can further be adapted to various levels of difficulty for students, allowing the range of education level to vary greatly. A kit can be developed for elementary students with most parts pre-designed, and fewer components defined can apply to higher levels of education, up through high school and college.

## Conclusions

The Jelly Belly Flavor Picker project demonstrates the effective use of Roboflow.com cloud-based tools in developing a computer vision-based application. The seamless integration of these tools facilitated the efficient annotation, augmentation, and training of the JellyBelly5 model. The project illustrates the potential of combining advanced computer vision technology with practical applications, showcasing the synergy between cloud-based development platforms and Python programming.

## Future Directions

The success of this project opens avenues for educational initiatives. Plans include expanding the current system to include packaging and shipping processes and replicating this development process in community college courses focused on programming and computer vision. This approach will help students learn about computer vision and programming but also demonstrate the practical application of these skills in real-world scenarios. Adapting the methodology used in the Jelly Belly Flavor Picker project to similar objects will allow students to gain hands-on experience in developing computer vision-based applications, leveraging cloud-based tools like Roboflow.com for streamlined development.


## Acknowledgement

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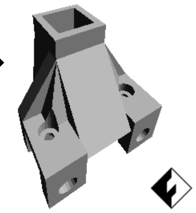
[7] https://universe.roboflow.com/alan-gandy-llah9/jellybelly5

## Appendix A

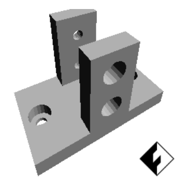
# 3D Models:

- **Camera Base Mount** – A press fit, mounting component for connecting vertical and horizontal aluminum bars for the camera, allowing for vertical adjustments.



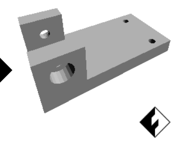
Camera base mount

- **Camera Mount T** – Links 2 aluminum bars for the camera suspension that allows for horizontal camera adjustments.



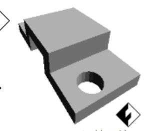
camera mount T

- **Camera Mount Main** – Attaches the camera to the suspended aluminum bars.



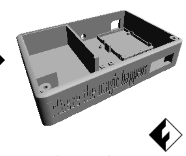
camera mount main

- **Camera Mount Cable Guide** – A small piece to help guide and manage the cables that connect to the camera.



camera mount cable guide

- **Electronics Housing** – Houses and mounts many electrical components including the Arduino, MOSFET, buck converter and cable splitter.

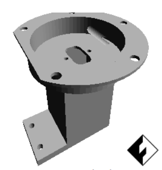


Electronics housing

- **Fan Cable Holder** – Directs the power lines from the DC fan motor to avoid cables being bound

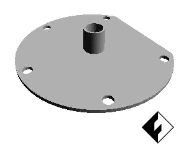
Fan Cable Holder

- **Fan Main body –** Houses the DC motor and fan blade and connects to various other components.



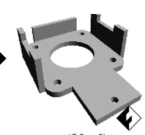
Fan Main body

- **Fan Top cap –** Covers the top of the main fan body and has an inlet port that connects to the tubing which is used to lift items via suction.



Fan Top cap

- **Nema 17 Face Plate –** Mounts the stepper motor used to raise and lower the suction arm to the sliding mechanism the fan is mounted to.

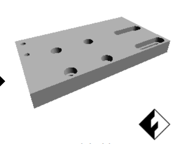


nema 17 Face Plate

- **Pulley Mount Cap –** Connects the T-slot legs together for stability and allows for belts to be connected.

Pulley Mount Cap

- **Rack Holder –** Used to connect the fan parts, a stepper motor, rack and pinion and other components to a slide belt connect.



rack holder

- **Slider Belt Connect –** Connects multiple components to the sliding bars on the aluminum rails and is used to hold and tension belts used for movement.

Slider Belt Connect

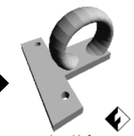
- **T-Slot Legs –** Mounts the Nema 17 motors to the aluminum rails.

T-Slot Legs

- **Wire Guide 1 –** Helps guide the cables from various components to avoid cables getting snagged.

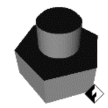
wire guide 1

- **Wire Guide 2 -** Helps guide the cables from various components to avoid cables getting snagged.

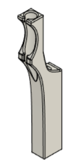


wire guide 2

- **Bar Plug –** Used as a stopping point for the sliders that are attached to the aluminum rails

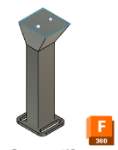


- **Tube Holder –** Holds the suction tube above the work area and is moved up and down to apply suction.



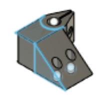
Holder

- **Tube Holder Support –** A mounting mechanism to increase the vertical mobility and stabilize the Tube Holder



Component15

- **Pin Clamp –** Acts as a limiter for the upward movement of the tube holder

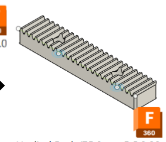


Clamp

- **Helical Gear –** Attached to a nema 17 motor and used in conjunction with the rack to facilitate vertical movement for the tube holder

Healical Gear (16R@0.00 m=1.0

- **Helical Rack** – Controlled by the Helical gear and attached to the tube holder. This piece interacts with the gear and allows for vertical movement.



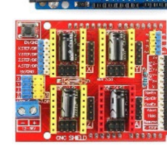
Healical Rack (75.0mm R@0.00 m=1.0)

## Electronics:

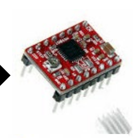
- **DC power supply –** Supplies power to the Arduino and buck converter

- **Arduino Uno –** Used in conjunction with the CNC components to send G-code to the various stepper motors and fan control.

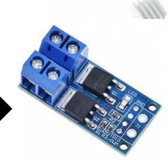
- **CNC Shield -** Used in conjunction with the Arduino and CNC drivers to send G-code to the various stepper motors and fan control.



- **CNC A4988 Driver modules -** Used in conjunction with the Arduino and CNC shield to send G-code to the various stepper motors.



- **MOSFET digital trigger –** Allows for power from the buck converter to be sent power to the fan motor when a DC or PWM signal is applied.



- **Buck converter –** Adjusts the voltage from the power supply so it can be applied to the fan motor

- **DC fan motor –** DC motor used to spin a blade to create air flow

- **Nema 17 motors –** Allows for precise rotational movement; used to control the X, Y and Z axes of the machine.

**Appendix B – Sample Lesson Plan**

Jelly Belly Project: In-Depth Computer Vision Exploration

**Lesson Plan Overview**

**Duration**: 2-3 Hours

**Objective**: To provide students with an engaging and accurate introduction to the principles of Computer Vision (CV) and Artificial Intelligence (AI), using a practical jelly bean flavor identification activity as a basis.

**Materials Needed**

- Trial size bags of Jelly Belly jelly beans for each student. Mobile phones with internet access.
- QR Code for the Jelly Belly model (ensure access to Roboflow Demo).
- Whiteboard or flip chart.
- Markers or pens.

**Part 1: Jelly Bean Flavor Identification Using CV**

1. Introduction to Computer Vision (CV) and Artificial Intelligence (AI) (20 mins):

Define AI and CV, emphasizing their role in data interpretation and decision-making processes. Outline the project's goal: identifying Jelly Belly flavors using a CV model.

2. Activity Setup (15 mins):

Distribute jelly bean bags and assist students with scanning the QR code. Provide a demonstration of the Jelly Belly model on a mobile device.

3. Hands-On Experimentation (45 mins):

Students use their mobile devices to identify a flavor of jellybean. The Jelly Belly model selects the requested flavor.

Encourage testing under various conditions (lighting, angles, grouping, distance).

4. Critical Analysis and Discussion (40 mins):

Facilitate a discussion on the model's accuracy and potential discrepancies. Encourage students to hypothesize the impact of different factors on CV accuracy.

Discuss potential improvements for model accuracy.

5. Exploring Practical Applications (30 mins):

Guide students to brainstorm real-world applications of CV and AI.

Encourage identifying synergies between different CV-driven technologies.

6. Summary and Q&A Session (20 mins):

Recap the day's key takeaways. Address any questions or curiosities.

**Instructor Notes**

Definitions

- Computer Vision (CV): A field of AI enabling computers to interpret and understand the visual world using digital images, videos, and deep learning.
- Artificial Intelligence (AI): The simulation of human intelligence processes by machines, particularly computer systems.

Object Detection and Challenges:

- Light: Variability in lighting can affect color recognition and shadow interpretation. Angle: Different angles can obscure or alter the perceived shape of objects.
- Distance: Greater distances can reduce detail and clarity, impacting identification. Grouping: Overlapping or clustered objects may be misidentified or missed.

Mitigation Strategies:

- Utilize consistent, adequate lighting.
- Standardize angles and distances for object capture. Separate objects to avoid clustering.

Real-World Applications: Highlight examples like automated quality control in manufacturing, facial recognition technology, or navigation systems in autonomous vehicles.

Extensions (Optional)

- Assign research on recent advancements in AI and CV.
- Organize a project where students create basic CV models using educational platforms.