ROBOTIC SORTING SYSTEM

Pace Dominy

Joseph Miller

Lam Tran

**Concept of Operations**

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for

Robotic Sorting System

Team 2

Approved by:

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Project Leader Date

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Prof. Kalafatis Date

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# Executive Summary

The American agricultural industry is massive, with over 2 million small-scale farms in the U.S. contributing to almost $140 billion in agricultural exports alone. However, farmers and ranchers only receive 8 cents of every dollar spent on food. Much of the additional money goes to overhead costs such as labor and processing [1]. One particularly difficult - and expensive - problem in agriculture is fruit sorting. Fruit that is clearly defective or does not meet a customer’s standards may not be sold and wasted, reducing farmers’ income and contributing to the 40% of food made in America that is never eaten [1]. Our solution to this problem is the Robotic Sorting System, a small, portable, inexpensive fruit sorting system based on robotics and imaging technology.

To use the Robotic Sorting System, the fruit will be placed on a conveyor belt, where it will move to a sensing area. The system will then use a camera to determine the approximate size and color of the fruit. Based on this information, the fruit will then go through a robotic sorting system that will sort the fruit into different “bins” configured by the user. The automation of this process will improve productivity in fruit sorting while reducing or even eliminating the need for human fruit sorting.

Each member of the team will design a certain set of subsystems. Under the proposed schedule, each subsystem will be fully designed by the end of the Fall 2022 semester. In the Spring 2023 semester, each subsystem will be integrated into the overall system, then physically constructed using the team’s $300 budget, the Fischer Engineering Design Center, and outside printed circuit board (PCB) manufacturers. Finally, at the end of the Spring 2023 semester, the group will present a completed, functional prototype of the Robotic Sorting System.

# Introduction

The Robotic Sorting System is a system capable of taking produce that is on its conveyor belt and sorting the fruit by type as well as quality. Quality will be determined by a large presence of scarring or bruising on the fruit as well as whether or not the fruit is overripe. Sorting will be done primarily through the qualitative analysis of the size and color of the fruit. At the end of the sorting process, the weight of the produce that will be sold and the weight of the unwanted fruit will be analyzed separately to get a rough estimate of how much fruit is being discarded and how much possible “shrink” is being prevented. Shrink is the difference between what the store has recorded for inventory and the actual amount of what is in stock. If a product, such as fruit, goes bad and has to be thrown out, that would mean that the store would have shrink from having less fruit in stock then they have recorded for their inventory.

## *Background*

In order for fruit to be transported to the store to be sold to the consumer, it has to be transported from the field to processing areas, then shipped. While in transport, some of the fruit will end up scarred, bruised or overripe and will be sold by the store where the customer will not buy any fruit that they deem overly scarred, bruised or overripe. This unsold fruit results in shrink for the store.

Our solution to this problem of unsold fruit is the Robotic Sorting System. This system will have a conveyor belt on which fruit will be sorted by type as well as quality. The fruit that does not meet the correct quality standards will be sorted into a receptacle where it will be disposed of later. Sorting out all the low quality fruit after it has been transported will save the store and the farmer from losing money while also not requiring much human interaction with the system.

## *Overview*



*Figure 1: Diagram of Robotic Sorting System*

Once the fruit is on the Robotic Sorting System’s conveyor belt, a camera will capture a picture of the fruit and determine its type and quality. The conveyor belt will then sort the fruit onto a specific length of the conveyor belt with the robotic levers, where the fruit that meets the user’s standards will go on to be sold by the store.

## *Referenced Documents and Standards*

American Farm Bureau Corporation, “Fast Facts About Agriculture and Food,” *American Farm Bureau Corporation*, 2021. [Online]. Available: <https://www.fb.org/newsroom/fast-facts>. [Accessed: Sep. 15, 2022]

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# Operating Concept

## *Scope*

The overall goal of the Robotic Sorting System is to reduce food waste and to improve customer satisfaction for both intermediate customers, such as supermarkets, and end customers. To do so, the Robotic Sorting System will use a camera-based system to accurately sort fruits by color and size. This will ensure that customers receive, as closely as possible, the exact quality of fruit ordered. The camera system will also be able to detect some basic fruit defects based on the user’s configuration. After sorting, the weight sensor will provide information on the weight of each sorted “bin” of fruit, which will allow fruit producers to easily see how much fruit is in each sorted category.

The project will be broken down into five fundamental subsystems. The first is power delivery, which will safely deliver the required power to all electrical and electronic components of the sorting system. The second subsystem is the conveyor belt, which will physically move fruit to the sensors, then to the robotic sorting levers and finally to the bin. The third subsystem is the robotic levers that will physically sort the fruit based on the information from the sensors. The fourth subsystem, the sensors, will gather the color, size, and weight information then give that data to the robotic control logic. The final subsystem is a mobile application for Android-based devices that will allow the user to easily configure and run the machine.

The actual design and fabrication of the Robotic Sorting System is broken down into the following design goals.

* The only external electrical connection required will be a connection to the standard American power grid (with a voltage of 120 V and a frequency of 60 Hz).
* The data that the sensors collect must be transmissible to the robotic lever subsystem’s control logic.
* The conveyor belt must be durable enough to hold fruit without damaging the machine and able to stop and start based on commands from the sensor (so that the sensor data is accurate).
* The robotic arms must use data from the sensors to physically guide the fruit to the correct bin.
* The Android application must be able to control the sorting configuration and the physical operation of the machine via Bluetooth. It should also provide documentation and provide contact information to get help with problems that the user cannot solve by themselves.
* Each system must be integrated into the overall sorting machine.
* Finally, the Robotic Sorting Machine will be physically fabricated.

The resources available for development are the personal time of each member, the shared lab time on Monday afternoons, the $100 given to each member of the team (for a total of $300), and the design and fabrication resources at the Fischer Engineering Design Center.

The design process will take place over the course of two semesters over the following timeline.

* The first revision of the Concept of Operations will be finalized by September 15th, 2022.
* The first revision of the Functional Systems Requirements document, the Interface Control Document, and the Execution Validation Plan will be finalized by October 3rd, 2022.
* The final report for the first semester of work will be finalized by December 4th, 2022.
* The design of each subsystem will be finalized by the end of the Fall 2022 semester.
* The integration of the subsystems and physical fabrication of the machine will be complete by the end of the Spring 2023 semester.

## *Operational Description and Constraints*

The Robotic Sorting System is intended to be used by workers to automate sorting fruits. Several robotic levers and conveyor belts will be installed inside a warehouse that stores fruits. Sensors are used to determine the quality of the fruits. These sensors will include cameras and scales. The cameras will examine each fruit and the microcontroller unit will process the image to check the fruit’s size, shape and color. The microcontroller will verify that the fruit meets the standards set by the user. The robotic levers will move the fruit onto a scale to measure its weight. The measured weight value is used to calculate the total weight of fruits that met the standards and the total weight of the fruit that failed. The robotic levers will move the fruit onto a specific section of the conveyor belt based on its quality. The conveyor belt will then move the fruit into a receptacle. Once the receptacle is full, it is placed onto a scale to measure the total weight of fruits that met the standards and the total weight of the fruit that failed. Farmers and sorting workers can configure the details of each of these processes via the mobile application connected to the machine via Bluetooth.

The following constraints apply to the design:

* The cameras must capture the entire surface of the fruit.
* The budget is $300, which limits the materials and parts that can be used.
* The robotic lever must be able to move the fruit without damaging it.
* The application must work on a commercially available smartphone.

## *System Description*

Robotic Levers: The robotic lever subsystem is a group of levers attached to the conveyor belt that move the fruit on the conveyor belt to the required area. The dimensions of this “required area” will be determined from the data collected from the sensors. Based on the sorting logic, the levers will move the fruit on the belt to the required section of the belt for the fruit to end up in the correct ending state (inside the correct receptacle).

Power: The power subsystem will deliver power to each electrical component of the system at the required voltage. The main power source will have a voltage of 120 V, but it will be necessary to design and implement power converters to avoid damaging components.

Conveyor belt: The conveyor belt will physically move fruit to the area where the sensors will identify each fruit’s color and size. When the robotic control logic has decided where to send each fruit, the conveyor belt will also move the fruit to a sorting bin. The conveyor belt must be able to start and stop on commands from the other subsystems to ensure proper integration. It must also be able to physically support the weight of the fruit.

Sensors: The cameras will capture an image of the fruit at the required area. The microcontroller will process that image to measure the size and color of the fruit with a PI camera algorithm. Then it will determine whether the fruit met a standard for the market or not. The microcontroller will tell the robotic levers to move the fruit from the scale to a certain conveyor belt based on the quality of the fruit. The conveyor belt will move the fruit to a conveyor belt. Once the receptacle gets full of fruits, it gets weighed the scale.This data is used to calculate the total weight of fruits that are for the market, or the total weight of “shrink”.

Mobile application: The mobile application is a freely available Android application that serves as the primary interface for the user to configure, run, and troubleshoot the machine. The application will be used to determine the criteria for sorting the fruit and pushing it to the sorting equipment via a Bluetooth connection. The application will also allow the user to start and stop the machine remotely. In the event of a problem with the machine, the application will provide easy access to the user manual and contact information for the manufacturer, allowing users to resolve problems as easily as possible.

## *Modes of Operation*

The Robotic Sorting System will only have one autonomous mode of operation (except for a human worker turning the system on or off and supervising operation via the app). Once the system is started it will work without any necessary human interaction outside of oversight and configuration.

## *Users*

The target customer for the Robotic Sorting System is relatively small-scale farming operations that may not be able to afford existing large-scale sorting machines, but would still benefit from the improved speed and accuracy that automated sorting offers. Towards this end, the machine will be designed so that it does not require an elaborately prepared space or a highly specialized electrical connection. However, another key beneficiary of the Robotic Sorting System would be workers that sort fruit by hand. With a Robotic Sorting System, the sorting worker can simply oversee the machine, reducing labor while increasing productivity. In some cases, the machine may be able to handle all sorting, freeing up labor for other tasks.

The installation of the Robotic Sorting System will simply require the user to ensure that the machine is assembled correctly, find a space for the machine, and plug the machine into the standard wall outlet. Training to use the machine will also be straightforward, requiring little to no human interaction outside of starting/stopping the sorting process via the application, giving the machine fruit to sort and removing the sorted fruit, and fixing any issues that may arise. The mobile application used to control the machine will be simple and descriptive with the underlying logic handling the more complex parts of the system’s operation. Any error in the system will immediately stop operation and give a clear, descriptive error message to allow troubleshooting.

## *Support*

The Robotic Sorting System will have support in the form of a User Manual detailing the operation of the system as well as detailing maintenance procedures. The emails of the designers will also be provided in the user manual as a contact if anything needs to be troubleshooted or repaired that falls outside the scope of the provided maintenance procedures. All of this information will be provided in the mobile application for easy reference.

# Scenarios

## *Cocktail Tree Sorting*

The cocktail tree is a unique variety of tree capable of growing both Meyer lemons and Key limes in the same plant [7]. Naturally, if these trees were used on a large scale, it would be desirable to have a way to automatically sort out the lemons and the limes. Based on the characteristics of lemons versus limes, the user could configure the Robotic Sorting Machine to identify the fruits based on differences in their size and color. Doing so would reduce labor requirements as it would be unnecessary for a worker to manually sort lemons and limes.

## *Sorting for Combined Farming*

In many cases, a farmer may own enough land to grow multiple different varieties of fruit – for example, they may grow lemons, limes, and grapefruit simultaneously. Much like the cocktail tree scenario described in Section 4.1, the farmer could configure the Robotic Sorting Machine to automatically sort the different kinds of fruits, allowing the farmer to sell only one kind of fruit at a time with little to no additional human labor.

## *Citrus Black Spot*

As an example of the Robotic Sorting System’s ability to detect visual defects in fruit, the system could be used to detect citrus black spot. Citrus black spot is a disease that affects citrus plants in subtropical climates. In addition to reducing the quantity of fruit produced from the tree, affected citrus fruits have black or brown spots on the rind of the fruit that reduces the quality of the fruit and makes it less desirable to customers [5].



*Figure 2: An image showing citrus black spot on the peel of an orange [6].*

Using the visual sorting capabilities of the Robotic Sorting Machine, a fruit producer could automatically sort out fruits showing symptoms of citrus black spot, ensuring that they are not shipped to customers (who would almost certainly reject the damaged oranges).

1. **Analysis**

## *Summary of Proposed Improvements*

The Robotic Sorting Machine brings multiple improvements to the fruit sorting process. One improvement is having the system able to be installed easily. The worker will then be able to install the system with minimal effort. Another improvement is the light weight and high mobility of the system. The worker can move the system from one place to another with ease. Another improvement is having the system to be energy efficient. Having the system to be energy efficient will bring the cost of electricity to a minimum without reducing the effectiveness of the system. Another proposed improvement is having the system to be easily maintained, repaired, and modified. The longevity of the system could be sufficient, as long as the farmer regularly keeps up with maintenance. The farmer can modify the system to suit their needs. Like adding solar panels to power the system off grid or installing custom software.

## *Disadvantages and Limitations*

In addition to the benefits of the Robotic Sorting System, there are also disadvantages and limitations to the system. The system could be a safety hazard to uncareful workers. For example, a worker could get loose clothing tangled from the motor of the conveyor belt. Due to our budget, the robotic arm/lever may not be able to carry a heavy load. So watermelon, eggplant, pumpkin, or any large fruit may not be applicable to the system.

## *Alternatives*

There are alternatives to the system. One alternative is the traditional, all human and no machine system.The farmer can hire and train workers to check the color, size, weight of the fruits and sort them into receptacles. Another alternative would be to have some machine involvement. The farmer can hire and train workers to check the color, size, weight of the fruits and use the conveyor belts system. Alternatively, the farmer can hire and train workers to use the sensors to check the quality and weight of the fruits and use the conveyor belts system.

## *Impact*

The system will have many impacts to the market, companies, and fruit “shrink”. Companies will save money with the system, since the training and salaries of workers can have a significant cost. The system will be better at detecting flaws on fruits than workers. This system will lead to the market receiving fruits that are higher in quality, which will in turn lead to better options of fruits for consumers at the store, due to the fruits being more consistent. Fruit “shrink” will decrease and food waste will be reduced from this.