# ECE 445 Final Paper

# Agricultural Drone Refilling System

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# 1 Introduction

## 1.1 Problem and Solution

In the past few years, there has been an increased use of agricultural drones to efficiently spray crops rather than human flown aircrafts. In many agricultural drones, the sprayer tank needs to be manually refilled instead of using an automated system. While this does not pose a problem with a small number of drones, as the fleet size increases, tank refilling will take up more time, questioning the efficiency of this current system. This will result in a decrease in productivity as more time will be spent refilling the tanks instead of operating the drones or taking care of other tasks, such as analyzing the data collected from the drones and performing maintenance on various equipment among other examples. An automated refilling system would relieve the issue detailed above by refilling the empty sprayer tanks without human intervention. This would free up the farmer and enable the drone fleet to operate more efficiently by reducing the downtime caused by waiting for an empty tank to be refilled. The mock refilling system would consist of a crane that contains motors, a string with a replica nozzle attached at the end (representing the nozzle and hose) and camera sensor needed to align the replica nozzle to the refilling port on the drone. Additionally, a computer and microprocessor would be needed to handle the image processing from the camera and control the crane motors. Visual markers can be used to determine the location of the fill port, as well as the distance to the fill port, using image processing. Overall, automating the entire process of the Agricultural Drone Refilling System would help increase farmer productivity and optimize any drone fleet's downtime in reality.

## 1.2 High Level Requirements

The high-level requirements involved in deeming this refilling system successful are centered around the three main objectives: alignment, dispensing, and reliability.

- Alignment: Being able to locate the fill port using computer vision and image processing is a major component of our refilling system.
- Dispensing*: After aligning to the correct location on the fill port, our dispensing system must be able to accurately place the replica nozzle inside the refilling port
- Reliability: The replica nozzle needs to repeatedly, and reliably, align on top of the refill port

*Due to advice from both the machine shop and professor, we have decided to downsize our project by eliminating the fluid aspect of our design. This reduces the complexity of our design and also drastically reduces the construction time of our project by eliminating the need to check for leakage, potential electrocution risk, as well as the complexity associated with pumping the water, preventing spills, and checking the fluid levels in the drone and station. Additionally, we also decided to downsize the number of axes that we would be representing as a part of this project. Due to time constraints, the Machine Shop suggested we also remove the z-axis of our project which drops down from the carriage as a weight and into the fill port of the agricultural drone. After further discussion within our group, we decided this was a good idea considering the fact that it would already be difficult to make sure two motors are working together in a controlled manner. Overall, the downsizing of our final project revolved around removing the fluid aspect and the third axis within our system.

# 2 Design and Verifications

## 2.1 Block Diagram

The block diagram below shows the original proposal with detailed components that were going to be for our project including the different power connections as specified in the legend.

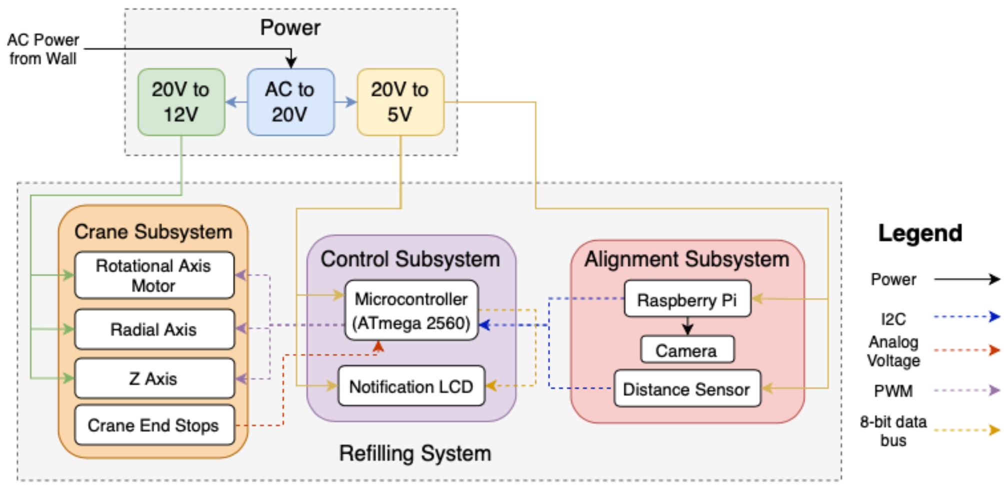


Figure 2.1: Original Block Diagram

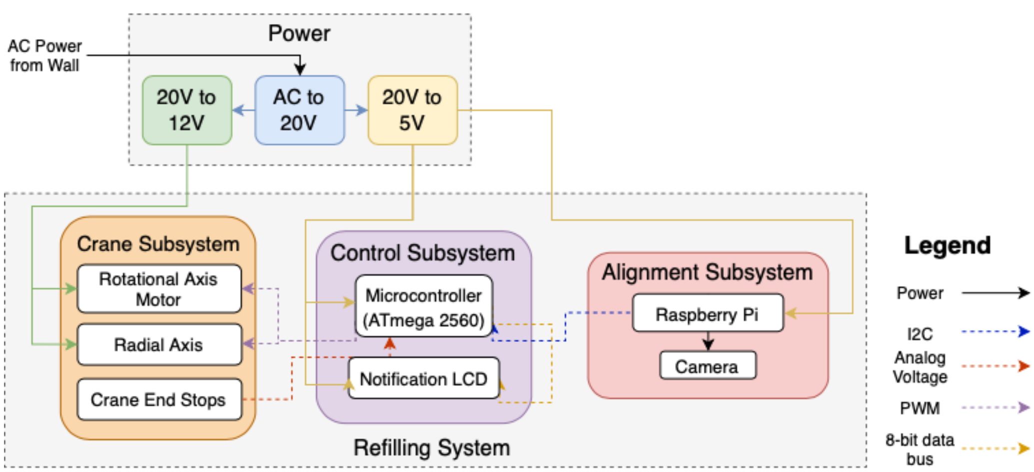


Figure 2.2: Final Block Diagram

After speaking with the Machine Shop and discussing the timeline amongst each other, we worked to figure out a finalized block diagram where we removed the z axis (as a part of the fluid aspect), with reasons mentioned above. We also removed the distance sensor as a result of removing the z axis because there was no weight that needed to be dropped after alignment. Because of this, having the distance sensor as a part of our system would become bulky and Overall, the difference between our original design and our final design is removing the z axis and distance sensor within our final project because it did not pertain to our revised requirements and timeline for the rest of the course.

## 2.2 Subsystem Overviews

### 2.2.1 Alignment Subsystem

This subsystem will use a Raspberry Pi for image processing and a camera for accurately aligning the dispensing subsystem with the drone's fill port. This subsystem also used OpenCV and software design structures to make sure programs represent a controlled way for the motors to move, detect the location of the fill port using particular visual markers that were set by the team and written specifically in the code, and properly align to the fill port using center of mass algorithms.

### 2.2.2 Crane Subsystem

This crane-style subsystem will use a stepper motor and high-torque servo motor to move the dispensing system in a controlled and precise manner. A part of this system is also making sure that there is proper communication between the two stepper motors being used for the two different axes in the system. This way, there is no wild or abrupt movement from either axis.

### 2.2.3 Control Subsystem

This subsystem will control crane movement and monitor the dispensing process to prevent the drone from overfilling. If time permits, we will have an LCD display that provides notifications. The notification panel (computer terminal) will display system notifications such as "searching for the refill port", "aligning to the refill port", and "successfully connected to the refill port".

### 2.2.4 Power Subsystem

The AC to DC power supply will be the ToolkitRC ADP180 180W power supply. This power supply was chosen because it was already on hand and a new power supply would not need to be purchased. The ADP180 outputs 19.5V which will be converted to the 5V and 12V supply voltages with high amperage voltage regulators, thus making sure the power is properly maintained throughout the system.

### 2.2.5 Drone Replica

The Drone Replica represents a replica of the important parts of the drone including the wing/fuselage area around the fill port, the fill port, and visual markers. The wing/fuselage mockup will be used to model the actual geometry of the drone in order to provide a realistic testing scenario. The fill port will be on the top surface of the replica such that it will be easily reached by the refilling system. The visual markers will be made of retroreflective material for easy identification by the alignment system in order to properly locate and align the replica nozzle with the fill port. The only requirement for this subsystem is to represent an accurate mock-up of the important parts of the drone near the fill port.

# 3 Verification

The Requirements and Verifications for each subsystem is located in the appendix, however, a brief overview of each subsystem verification is down below.

## 3.1 Alignment Subsystem

The Alignment Subsystem was able to locate and align the nozzle with the fill port location on the drone successfully, however, the system was susceptible to noise. We were able to verify that the alignment subsystem was able to locate the refilling port due to the notifications displayed while running. We were able to verify that the nozzle was aligned correctly with the positional data sent to the Control Subsystem. If the difference between the coordinates of the calculated center of the refilling port and the alignment point determined in software was greater than 10 for either X or Y, then the system did not align the nozzle correctly. In the 8 test runs we conducted, 6 of the runs were able to successfully align the nozzle to the refilling port. In the two failed runs, noise in the filtering caused the system to falsely stop the alignment process. The noise was mainly caused due to shadows or lighting and exposure around the refilling port area during testing but we were able to implement a filtering algorithm that worked to filter out the noise a little bit during the locating and alignment process.

## 3.2 Crane Subsystem

The Crane Subsystem was able to move the carriage and the crane arm in a repeatable and reliable manner. Although the dispensing subsystem was mainly cut from the project, the Crane Subsystem was able to support the weight of itself as well as the camera on the carriage without collapsing or getting stuck in any part of the operational area. Additionally, even when the arm would rapidly zip across from one side to another, the system would not collapse due to the weight being moved fast, which shows that there was a proper amount of weight and counterweight for the entire system.

## 3.3 Control Subsystem

The Control Subsystem was able to meet all the requirements originally set in our Design Document. It was able to display the correct system notification during each stage of the alignment process, it did not overshoot any of the endstops for the two axes, and it was able to communicate with the Alignment Subsystem. All of this was made sure to be accurately met within the software design and the code for the rotating and horizontal movement within our entire system. The first requirement was verified by checking to see if the correct message was displayed during the appropriate stage of operation. In all three cases of operation, the appropriate notification was displayed onto the computer's terminal. In the initial searching phase, the running light was illuminated to notify the user that the arm was moving, in the alignment stage, the correct notification was displayed to the user that the searching phase had concluded and now alignment was in progress, and finally the correct notification was displayed once the refilling port was properly aligned above the refill port of the drone.

## 3.4 Power Subsystem

The Power Subsystem verification was straightforward in that the requirements were that it provide the necessary voltages, 5V and 12V, for the microcontroller and motors, respectively. Each rail of the Power Subsystem was measured with a multimeter and both were within the +/- 15% margin of error that was specified. The 5V rail was measured to be 5.02V and the 12V rail was measured to be 12.01V. The +/- 15% margin of error for the 5V rail was determined by the maximum operational voltage of the ATmega 2560 microprocessor used. Since the 12V rail only provides power to the motors, the same +/-15% specification was arbitrarily chosen for the 12V rail as well.

### 3.5 High Level System Verification

From a high level point of view, our system was able to accomplish the goal of finding the refilling port and aligning the nozzle to it, however, it was susceptible to shadows and other such sources of noise. While a more robust alignment system would have been more desirable for this proof of concept, a more robust system is needed for a system that might be developed at a later point in time.

## 4 Cost and Schedule

Labor cost estimates should use the following formula for each partner:

Labor Cost = Ideal Salary (Hourly Rate) x Actual Hours Spent x 2.5 = $45 x 3(150) x 2.5 = $50,625
Electronics Cost (Detailed Below) = $40.94
Machine Shop Labor Cost = $30 x 10 x 2.5 = $750

| Component | Part number | Price per unit | Number of units | Cost |
|---|---|---|---|---|
| ToolkitRC ADP180 180W AC to DC Power Supply | ADP180 | $39.99 | 1 | $0.00 (already owned) |
| ATmega 2560 | ATMEGA2560-16 AUR | $15.16 | 2 | $30.32 |
| High Torque Servo Motor | DS3235sg | $29.99 | 1 | $29.99 |
| Misc. PCB Components (capacitors, resistors, etc.) | N/A | $5.31 | 2 | $10.62 |
| ToolkitRC M6D Dual Charger | M6D | $59.99 | 1 | $0.00 (already owned) |
| Raspberry Pi 4B 4GB | PI4-4GB | $55.00 | 1 | $0.00 (already owned) |
| Sparkfun Big Easy Driver | ROB-12859 | $19.35 | 2 | $38.70 |
| Logitech c920 USB Webcam | 960-001384 | $69.99 | 1 | $0.00 (already owned) |
| Total Cost | | | | $109.63 |

Table 4.1: Bill of Materials

# 5 Conclusions

## 5.1 Successes

As we near the end of our project, we had successes within the Alignment Subsystem, Crane Subsystem, Control Subsystem and Power Subsystem aspects of our entire project.

Within the Alignment Subsystem, we were able to successfully implement image processing and get the program to locate the fill port using the camera sensor and stop when necessary. Our code successfully calculated the center of the refilling port and communicated that information to the microcontroller over a serial connection while being able to filter through some of the noise that was present during certain lighting and exposure environments in testing.

In terms of the Crane Subsystem, we were able to get a smooth travel and drive of the carriage along the rail as well as precise control of the crane arm throughout the alignment and locating process. We were able to deliver the full 180 degrees of rotation that was promised in our initial design. Additionally, the arm had a full travel distance of 270 degrees, allowing us to view areas slightly behind the refilling station, however, these areas are not practical to include in the system's working area, so we limited the working area to the promised 180 degrees. Smooth carriage travel was achieved through microstepping of the stepper motor. This allowed us to have a smooth travel because there was a smooth transition between the different phases of the stepper motor's coils energizing.

Most of our Control Subsystem was able to be implemented successfully, particularly in terms of serial communication between the Alignment Subsystem, controlling the motors reliably, and communication between the camera sensor and display. The Alignment Subsystem and Control Subsystem had a full duplex communication link between them allowing for positional data for alignment to transfer from the Alignment Subsystem to the Control Subsystem and system notifications to transfer to the Alignment Subsystem that was connected to a display and terminal. This helped make sure that the user knew exactly what position in the process our system was at in any case.

Lastly, all of our Power Subsystem was implemented successfully as we were able to maintain the proper amount of power for the entire system throughout the whole process. Sufficient power was supplied to the servo and stepper motors during search and alignment phases making sure that there were no spikes and abrupt stops or zips within the rotational or horizontal axis movements. In the final configuration, the microcontroller was isolated from any voltage spikes that might occur from the servo motor suddenly coming to a stop, ensuring a controlled manner and movement for our entire system.

## 5.2 Challenges

While we had many successes within each of the subsystems, there were particular setbacks throughout the project building and software design process that we had to overcome.

In the Alignment Subsystem, some of the problems we had were with filtering noise from the camera during the alignment process. We had limited control of camera settings which made it harder to work with the filtering and make sure our program reliably picked up on the correct visual markers for the fill port. Additionally, during the debugging process of our project, we realized that a part of the reason that the camera was not picking up on the LED visual markers was because the LEDs were too bright and we were not able to dim the brightness of the LEDs enough. Due to this, we had to resort to using a red box (with marked brightness and exposure values) illuminated with ambient light as a visual marker for our agricultural drone's fill port.

While beginning testing and debugging the motors in the Crane Subsystem, some of the challenges we encountered were in regard to our original DC motor and our later added servo horn. We worked with the Machine Shop in order to make sure the mechanical aspect of our system was properly built and are grateful for their help with building our crane-like system. The Machine Shop helped us to add a stepper motor and DC gear motor into our system for the horizontal and rotational axis, respectively. During the software development stage, we realized that there was little to no documentation on the rotary encoder on the gear motor in addition to insufficient torque at low speeds from DC gear motor so we asked the Machine Shop to switch our DC gear motor to another stepper motor for us to easily control the rotational axis.

After some back and forth with building from the Machine Shop, we got our final build of the mechanical system with the correct servo motor for the rotational axis back from the Machine Shop. We finally started testing and within a few days of testing and debugging, the rotational axis stopped working in a controlled manner due to the plastic servo horn stripping. Because the servo horn failed Friday evening, we had to go to the Siebel Center for Design to work on designing a new adapter plate that would work with a metal servo horn that we had. Designing and manufacturing took up a lot of time as training to use the water jet was a lengthy process and fixing manufacturing tolerance issues on the steel plate with a needle file consumed a lot of time. Additionally, assembly of the adapter plate into the system was an arduous task as the crane had not been designed with attaching the plate in mind.

In terms of our Control Subsystem, the challenge that we faced was making sure that there was consistent serial communication with our Raspberry Pi. This was because we were using the standard delay function in the Arduino IDE to prevent the rotational axis from zipping through the degree rotation. This was breaking serial communication and, as a result, we used a non-blocking wait statement so that the servo was moving at a proper speed rather than zipping from one side to the other.

Lastly, the final challenge that we had to overcome for the success of our project were the voltage spikes caused by the servo arm coming to a complete stop and trying to prevent the crane arm from overshooting the desired position. During testing, the servo arm would occasionally overshoot the desired position either due to a programming error or the microcontroller sending it nonsensical data while programming new firmware. As the crane arm has a non-negligible amount of momentum while moving quickly, the servo would produce large voltage spikes as it attempted to correct for the crane arm's overshoot during movement. Originally, the servo power was connected to the same 5V power rail as the microcontroller, which had power filtering designed to prevent power spikes. However, this was not enough as at one point during testing, the microcontroller was damaged and became non-functional. This issue was solved by connecting the servo to its own power rail, which therefore allowed it to operate without needing to worry about power spikes damaging other components.

## 5.3 Ethics and Safety

Our project complies with IEEE Code of Ethics I-4, I-6, and II-7 [3] as anyone in the agricultural farming industry will be able to have access to this technology. We will be completing this project in a lawful manner while advancing the technological capabilities of agricultural drones.

Some of the main safety considerations with this project are injuries caused by a propeller and a pinching/entanglement hazard from the mechanical aspect. The first safety issue is addressed by the use of a drone replica. For both a fixed-wing aircraft and multirotor aircraft, the replica will not have any of the hardware needed to fly, or even spin the propellers even though a propeller might be included. This design decision was made to prevent the possibility of an injury caused during propeller operation. Additionally, the pinching and entanglement hazard can be avoided by tying back long hair and clothing as well as keeping hands and fingers away from moving parts when the system is powered on.

One safety concern that arose during development was when the rotational axis drive was changed from an open loop motor controller to a closed loop motor controller. Since open loop motor controllers, like stepper motor drivers or DC motors with an attached encoder, do not have positional feedback, they can only control how many degrees or revolutions a motor moves, not what angle the motor should be at. When the DC gear motor was swapped to a high torque servo motor, the open loop control was replaced by the integrated closed loop controller inside the servo. This posed a new safety concern because while the microcontroller was being programmed or reset, erroneous positional commands were occasionally being sent to the servo, which caused the crane arm to sometimes swing wildly. This safety hazard was mitigated by unplugging the servo from power when resetting the system or uploading new firmware for the microcontroller.

Additionally, a push button switch and indicator light were added to ensure that the system would not start running unless the button was pressed and indicating to the user that the system was running.

## 5.4 Future Work

Based on our final design, some improvements that can be made is to have a continuous running mode which allows the system to return to the start state on its own. Currently, the user must manually turn the crane arm and carriage to the zero (start) position. A continuous running mode would further automate the system. Another improvement to the current system is to add automatic detection of a drone arriving or completing its fill process.

While we were able to create a functioning proof of concept for a drone refilling system, there are several advancements we would add to our project.  In the future, it would be optimal to include a third axis in the vertical z-direction. This would allow for three axes working in conjunction with each other allowing for alignment right up to the drone’s fill port.

To add onto the third axis, the system would also need to account for wind. As the nozzle is being lowered into the fill port, wind calculations should be taken into account for a more realistic prototype that would work outside on farms rather than only in a wind controlled environment.

Another advancement to the system would be to add solar panels to power the entire system. Not only would this eliminate the need to be restrained to a wall outlet, but it would be more practical as our system is designed to work in an environment where solar energy can be leveraged. This would also help with making sure that our system can be used in any given environment, making it more efficient and appealing as a product to customers.

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## Appendix

Table A.1: Alignment Subsystem

| **Requirements** | **Verification** | **Verified?** |
|---|---|---|
| Locate fill port of a drone located in the working area | The system notification should switch from displaying searching notification to the aligning notification | Yes |
| Align replica nozzle to the refill port on the drone | Before the replica nozzle is lowered, the replica nozzle should be above the refilling port | Yes |
| Do not crash the replica nozzle into the drone | The replica nozzle is properly lowered into the refilling port and not dropped anywhere else | N/A<br>(removed after speaking with Machine Shop) |

Table A.2: Crane Subsystem

| Requirements | Verification | Verified? |
|---|---|---|
| Move the dispensing system to the correct location reliably | The crane's movement axes should move in a smooth fashion without getting caught or snagged | 75% of the time |
| Support the weight of the dispensing subsystem | The crane does not break and remains structurally sound | Yes |

Table A.3: Control Subsystem

| **Requirements** | **Verification** | **Verified?** |
|---|---|---|
| Displays system notification on current action. | The appropriate system notification is displayed for the current operating mode | Yes |
| Operates the crane in a controlled manner without | 1. The carriage on the crane arm does not fall | Yes |

| | | |
|---|---|---|
| overshooting end stops | off the front or back ends.<br>2. The crane does not rotate beyond the designated 180 degree range of operation and cause cause carriage to itself | |
| Communicates with alignment subsystem to align replica nozzle to the refilling port | The crane's axes move appropriately based on the output from the alignment subsystem. | Yes |

Table A.4: Power Subsystem

| **Requirement** | **Verification** | **Verified?** |
|---|---|---|
| Power supply provides the necessary 5V and 12V with a ±15% margin of error | A digital multimeter will be used to measure the 5V and 12V lines to ensure that the appropriate voltages are being supplied | Yes |