Vineyard Automated Pest Deterrence System

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Abstract

The purpose of this project was to create a prototype of an automated pest deterrence system for Wachusett Vineyards. The following report details how birds can greatly affect a vineyard's crop yields, how robots are used to solve agricultural problems, and how we planned and designed a cyber-physical system to deter birds from the grape crops. We used a Raspberry Pi and camera to run motion detection software and automatically scare away these birds via predatory audio. We also created a desktop application to monitor the live stream footage, manually activate the sound deterrence, and view information about previously captured motion detections.

Acknowledgments

The Vineyard Robotics MQP would like to thank several individuals that contributed to our project. We would like to thank our advisor, Professor Michael Gennert for guiding our project and keeping us on schedule throughout the year. We would also like to thank Brion and Pamela Keagle, WPI class of ‘94 alum and owners of Wachusett Vineyards, who suggested this project to Professor Gennert. They allowed us to test our system on their vineyard as well as provide insight to their vineyard and common pests while providing support for our project. We greatly appreciate the contributions of these individuals and our project would not be possible without their help and support.

Executive Summary

Vineyards across the world face the seasonal challenge of keeping their crops safe from a variety of pests. Birds, deer, and insects cause significant damage to vineyards and it can be both time consuming and expensive to prevent this damage. While some vineyards implement netting or coverings over their crops, these can be expensive and require labor to install and take down at the end of the season.

Birds have the ability to reduce crop yields by up to 45% by puncturing and eating grapes in uncovered vineyards. Vineyards such as Wachusett Vineyards in Hubbardston, MA are looking for a more efficient and affordable method of deterring pests. They are greatly affected by birds due to the number of trees surrounding their field, which place them at a higher risk for bird damage.

Some methods of deterrents include kites, lasers, and cannons. These methods provide short term relief for vineyard owners but have not been proven to sustain efficiency over a long period of time. The constant repetition of these methods allows the birds to grow accustomed to the sounds and visuals, thus reducing their efficacy. While some vineyards are testing drones to scare birds, this potentially successful option for vineyards can be challenging in the United States due to UAV and bird regulations in place to protect wildlife.

After researching and comparing pest deterrent methods, we chose to implement an audio response system using hawk recordings to scare away birds. These audios are cycled to maintain a variety of sounds. Users also have the ability to alter the pitch and speed of these recordings to reduce repetition. These audio clips are triggered by a motion detection system. This system consists of a Raspberry Pi and camera that can be monitored and controlled by a custom computer application.

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1 Introduction

Although caring for vineyards and creating wine are processes that have been perfected over hundreds of years, one problem that continues to plague the wine community is the labour surrounding protecting crops from pests. Animals such as birds and deer have the potential to significantly reduce crop yields and revenue. Birds are known to eat entire clusters of grapes and puncture many others in order to eat seeds. Deer can defoliate vineyards, killing plants. These animals continue to pester vineyards even with attempted methods of protection.

Wachusett Vineyards is an up-and-coming local wine vineyard that has had success in their wine-making. Despite their success, they are currently facing the pest problem mentioned above: birds are eating and destroying their grapes while deer are eating their vine leaves. Wachusett Vineyards is looking to implement a pest-deterring solution that allows them to continue growing their wine-making business.

Some current methods that are used to protect crops in vineyards include visual, auditory, or automated deterrents. Other deterrents include hawk kites and signs that can scare birds from fields as well as reflective devices that can cause birds to rethink their flight patterns. However, birds are known to overcome these simple devices and render them useless. The same pattern occurs with using sounds to scare birds. Using the sound of hawks or birds in distress may initially work, but neither method will work for an extended period of time. New methods using technology such as UAVs have been considered to move bird activity away from vineyards.

In some vineyards, UAVs have proved to be effective at deterring birds. While effective, this solution requires manual control of the UAV, which decreases the overall productivity of the vineyard management. Our project aims to implement a system consisting of sensors, cameras, and an autonomous UAV to deter pests without the need for human interaction. The following proposal contains background research conducted to aid us in understanding the problem and the methods we plan on using to solve it.

1.1 Objectives

- Create an autonomous system to deter vineyard pests.
- Analyze real time sensor data to determine if pests have entered the vineyard.
- Establish an intuitive user interface to monitor the system.
- Implement speaker systems as a primary method of defense.
- Integrate UAV usage as a secondary method of defense.

1.2 Project Motivation

This project idea was brought to Professor Gennert by local vineyard owners Brion and Pamela Keagle who own Wachusett Vineyards located in Hubbardston, MA. After working on their vineyard for a few years, they had discovered one of their main challenges was pest management. Pests such as birds and deer eat the grapes and grape leaves off of the vines or puncture and ruin others. This results in massive losses and the harm that these animals are doing is detrimental to a new business such as their own.

Originally, the idea of using unmanned aerial vehicles was proposed to focus on scaring birds away from the crops. With consideration of this new project, a more defined system that focuses on bird detection was established. While UAV implementation could be a successful method to reduce bird activity in the vineyard, there would first need to be a thorough detection system to alert the vehicle of activity in the area. This is essential for any method of defense against the birds that may become accustomed to deterrents if they are used constantly even if no activity is detected.

In order to successfully scare away birds from the vineyard a detection system using a Raspberry Pi and camera will be established in the field. This will trigger a series of predatory audio clips that will scare away birds in the area.

2 Background

The background research for this project was conducted in order to help the team have context to the problem and be better suited to create an innovative solution. Background research included the damages caused to vineyards by pests and what vineyard owners are doing to combat it. Other topics researched include the use of robotics in agriculture, a high-level overview of UAVs, and the laws in place to regulate them.

2.1 Vineyards

2.1.1 Hybrid Vineyards

Hybrid grapes are a new and popular solution for many vineyards outside of Europe. Due to the more temperate climates in regions of France and Italy, European *Vitis vinifera* vines are a native choice of grape that has grown successfully for years [1]. However, when phylloxera was introduced to european vineyards from America in the 1800s, this small pest destroyed many vineyards. This destruction led to new experimentation with American grapes that could withstand this pest [2]. These new grapes are formed by cross-breeding European *Vitis vinifera* vines and American *Vitis labrusca* [3]. This experimentation process began in Europe, but was not well received by farmers and consumers who preferred their traditional flavors. These varieties were adopted in North America after discovering that these plants could sustain the harsher climates that the original European strain could not while providing fruitful flavors.

Figure 1: Phylloxera on a grape leaf [4]

2.1.1.1 New England Vineyards

New England has faced challenges in establishing vineyards since the 1600s. The cold winters and humid summers created a difficult environment to host traditional european vines in. With the advances made in creating hybrid vines, there has been more opportunity to start vineyards in areas of the Northeast that were previously unsuccessful. In the early 2000s, the University of Minnesota began experimenting with vineyards and nearly twenty years later they have produced over 12,000 experimental vines [5].With thorough testing and experimenting, the University of Minnesota has been able to provide advice to growers on new hybrid vines that are suitable for various climates, resistant against regional pests, and provide unique flavors never been farmed before. These new advancements in hybrid experimenting have made it possible for vineyards to become successful in New England, a region that was once considered an unsuitable place for vineyards.

Variety	Year	Type
Frontenac aka Frontenac noir	1996	Red and rosé, port
Frontenac blanc	2012	White wine
Frontenac gris	2003	White wine
Itasca	2017	White wine
La Crescent	2002	White wine
Marquette	2004	Red wine
Edelweiss*	1977	Table, wine

Table 1: New Hybrid Grapes Created by the University of Minnesota [5]

2.1.2 Pests in Vineyards

Some of the main challenges vineyard owners face is how to protect their crops from local pests. Animals such as birds and deer can significantly reduce the crop yield by eating or contaminating grapes and grape leaves [6]. Sorting through contaminated vines is a painstaking process, and completely contaminated plants must be thrown out entirely. There are various methods of deterring pests from a vineyard but none have been proven to completely deter animals from destroying crops.

2.1.2.1 Birds

Birds pose a threat to vineyards by puncturing or consuming bundles of grapes. This decreases the number of suitable grapes for wine making by reducing the physical number of grapes to be picked and contaminating or rotting others [7]. Birds are attracted to the natural sugar in fruits and will wait until they have ripened to eat them. Color is an indicator to tell birds when fruit is most nutritious [8]. Birds tend to fly down from trees and quickly damage vineyards; this causes the outermost edges of a vineyard to be the most susceptible to bird damage. Due to this fact, smaller vineyards with large portions of their fields surrounded by trees are more likely to see higher percentages of crop loss due to birds [8]. Birds can also be drawn to vineyards to feed on insects. Rainfall has been shown to increase the number of insects in vineyards, thus attracting more birds. The damage caused by birds can be devastating to a vineyard. On average, uncovered vineyards lose 45% of total crops to birds [8].

2.1.2.2 Deer

Deer can damage vineyards in addition to birds. Although they do not eat the fruit like other pests, they can reduce the crop yield by damaging the vines themselves. Deer defoliate vines by eating the grape leaves [9]. Repetitive damage to vineyards can result in the stunting of the vines' growth or can even kill the plant. Fences and netting can help to keep these pests out of a vineyard as well as sounds to disturb the deer.

2.1.3 Current Methods

There exist several methods that successfully deter and keep out birds. Some examples of these are using sounds of predators or birds in distress. Other methods include using kites or hawk shaped objects to scare the birds [10]. While effective, neither of these are permanent solutions. Birds can become accustomed to these methods once they realize that there is no physical threat corresponding to these sounds or visuals [10]. Netting is a more successful option of deterring pests. The downside to this method is that it is more expensive and can cost upwards of $500 per hectare [8]. This investment could be beneficial especially for landowners who are losing 50% of their crops. Investing in netting in this scenario could result in a return on investment in 10 years [10].

Figure 2: An example of netting installation [10]

Automated approaches have also been considered. One study was conducted in 2019 using Unmanned Aerial Vehicles (UAVs). In this example a UAV was used to physically fly over a vineyard and scare birds in addition to using visual deterrents such as reflectors, and netting. This UAV was flown manually for five minutes every hour. Three locations were monitored over a seven day period; the results showed that the land with the UAV had the least amount of damage followed by the netting and the reflectors respectively [10].

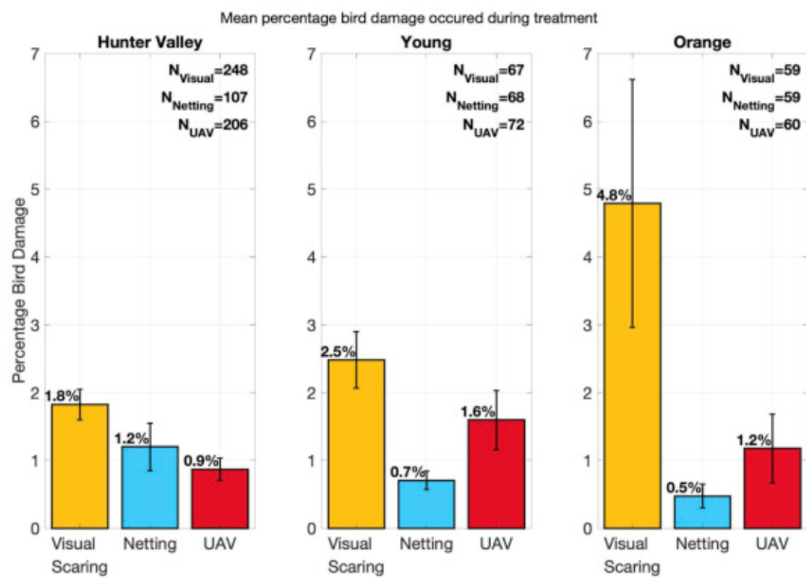

Figure 3: The damage in each location is shown corresponding with the type of deterrent [10]

2.2 Agricultural Applications of Technology

2.2.1 Robots in Agriculture

2.2.1.1 Harvest Automation HV-100 [11]

Harvest Automation is a small company based in Billerica, MA that specializes in creating agricultural robots to increase efficiency and optimize workflow in an agricultural work environment. Their flagship robot, the HV-100, is an autonomous robot that is designed to work in a greenhouse without human interaction. This robot's technical specifications state that it is designed to carry out various tasks concerning potted plants, such as spacing, relocation, and collection. In support of its tasks, this robot is said to be able to bear a payload up to 22 lbs. In a case study done by Metrolina Greenhouses in Huntersville, NC, 4 of Harvest Automation's HV-100 robots were able to relocate and properly space out over 40,000 poinsettia plants in four days. Their easy-to-swap batteries made it possible for these robots to work for 20 hours a day. The appeal of these robots is not only their ability to work autonomously without human interaction, but their ability to greatly outperform human workers, thus increasing efficiency.

Figure 4: The HV-100 robots working at Metrolina Greenhouses [11]

2.2.1.2 Tertill [12]

Franklin Robotics is another small robotics company located in MA. Based in North Billerica, Franklin Robotics was co-founded by Joe Jones, who is known as the inventor of the Roomba. This company created and sells the Tertill: a small, automated robot similar to the Roomba that specializes in weed destruction in the garden. Equipped with camber wheels for damaging emerging weeds, a nylon whacking string for cutting, and a solar panel for green charging, the Tertill can navigate gardens and destroy weeds with ease. It uses sensors to detect the height of a potential weed; if the plant is tall enough to touch its underbody (about an inch), it deems the plant as a crop that should be left alone. Otherwise, it destroys the plant. Similar to the

HV-100, this robot's autonomous capabilities make it an excellent assistant in the garden for cumbersome tasks that are inefficient when done manually.

Figure 5: The Tertill Robot as it works in the garden. [12]

2.2.1.3 Semi-Autonomous Vineyard Sprayer [13]

A group of robotics researchers from Greece and Cyprus created two versions of a semi-autonomous vineyard sprayer: the AgriRobot and the SAVSAR. For the purpose of this analysis, a cross of the two's best features will be discussed. Between these two robots, this team was able to support all terrain capability, GPS, and sonar, laser, and lidar sensors. The GPS and laser units are used for navigation around the vineyard in conjunction with the sonar units to detect obstacles. The lidar is used for environment modeling as the robot moves through the field. A user interface was also created for human overriding capabilities as a way to keep humans on the loop. The SAVSAR robot's user interface has on-screen controls for the robot, as well as for its camera. This robot offers the benefits of autonomy while still having controls over the robot if the need arises.

Figure 6: The AgriRobot and the SAVSAR [13]

2.2.2 UAVs in Agriculture

2.2.2.1 UAV Use in Monitoring Crops [14]

UAVs allow for many different kinds of sensors to collect data that might be difficult or impossible for a person to collect. This modularity is an advantage when using UAVs for monitoring crops. For example, UAVs equipped with infrared cameras can be used to detect early signs of disease inside of a plant that would otherwise be impossible to find. This early detection could potentially save a lot of crops from what would have been inevitable loss, thus avoiding wasting money and resources. Additionally, UAVs equipped with multispectral cameras are able to detect the water levels underground that supply the crops. This can be used to tell farmers whether or not plants are getting enough water. UAVs that have different sensor attachments enable them to collect remarkably useful data.

2.2.2.3 UAV Use in Monitoring Livestock [15]

Another area of agriculture UAVs can aid in is livestock monitoring. In Qatar, a group of researchers used a UAV to track and document the movement patterns and herd numbers of sheep.

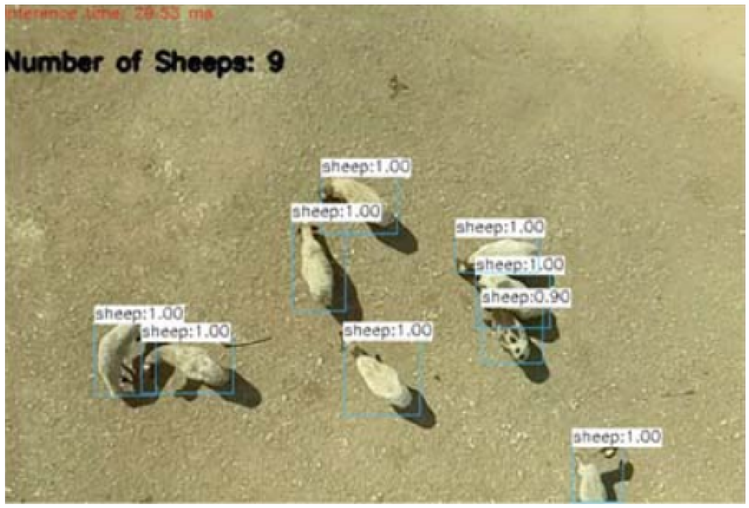

Figure 7: A UAV-taken image of a moving herd of sheep [15]

This research shows that UAVs can be used to track groups of animals and document them. Free-range animals like sheep can be timely for a person to track, so developing a UAV to perform this task can help farmers to account for all of their livestock. Future developments of this research could result in being able to identify behavioral abnormalities in these animals and notify the farmer.

2.2.2.2 UAV Use in Pest Control [16]

UAVs can also be effectively used in pest control. In Australia, a group of researchers and professors created a UAV intended to keep birds away from a wine vineyard. The UAV was affixed with a taxidermy crow to mimic captured prey.

Figure 8: A bird-repelling UAV carrying a taxidermy crow [16]

This UAV was able to perform missions due to its semi-autonomous stack: a GPS antenna, Pixhawk and PX4 autopilot hardware and firmware, and QGroundControl software as ground control. The UAV would carry out missions by following GPS coordinates like waypoints, but it could be overridden with a remote control transmitter if needed. Although this UAV was successful in deterring birds, they suggest that a fully autonomous UAV, from powering on to returning to base and landing, would be a great improvement. A system of sensors to detect birds and alert the UAV is also crucial to this proposed fully-autonomous system. A system similar to this will be the ultimate goal of this project.

2.2.3 Sensors

2.2.3.1 Motion Sensors

Motion sensors are often used to detect pests that cause damage to crops. A commonly used subset of motion sensors are Passive Infrared (PIR) sensors. PIR sensors detect infrared radiation emitting off of an object that has passed into its field of view. They are called passive because they rely solely on receiving radiation; they do not emit radiation themselves [17]. The sensitivity of these sensors can be adjusted to better target a variety of animal sizes: a more sensitive tuning will be better at detecting smaller targets while a less sensitive tuning will better suit larger targets. Additionally, microwave sensors are also used in motion detection systems. These sensors actively send out microwaves that reflect off of surrounding surfaces. If there is no motion, the microwaves will continue to return in the same way. They are activated when a disturbance in the usual pattern is caused. Like PIR sensors, microwave sensors can be tuned to be more or less sensitive [18]. This tuning can be helpful when trying to reduce the likelihood of false positive detections from environmental factors such as slight planet movement.

2.2.3.2 Lidar

Light Detection and Ranging (lidar) is a sensing technology that uses light pulses to accurately create a 3D map of an environment [19]. When mapping, these sensors emit light waves that reflect off of nearby surfaces. The distance the waves travel before returning can be used to determine how far away these surfaces are. In agriculture, lidar sensors are commonly used in autonomous robots. One application of this is in plant detection. A team of researchers from Robert Bosch GmbH in Germany created a robot that used lidar to map a field for precision navigation. This robot was designed to perform specialized tasks to care for individual plants. For agricultural devices, precision pathfinding is essential to not damage any plants while navigating a field to a specific plant [20].

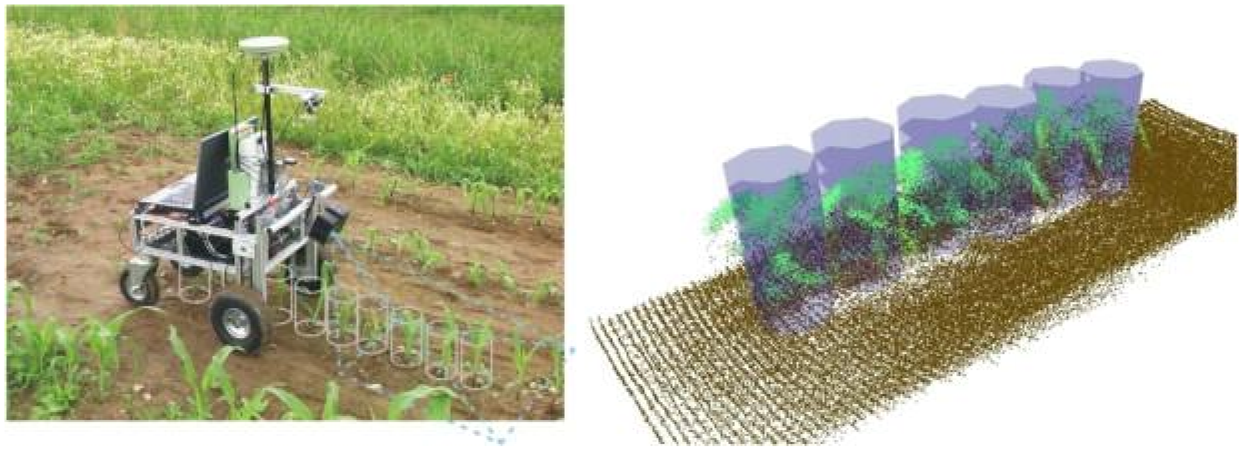

Figure 9: Field Robot using Lidar to Detect Plants [20]

2.2.3.3 Sound Sensors

Sound sensing modules can be used for a variety of applications, such as locating a person in need by their voice or summoning a robot by calling its name. A technique called sound localization is used to locate a source of sound. It involves using an array of microphones that all work to estimate the direction and distance of a sound [21]. By the repeated processing of an ongoing sound, a microphone array on a robot can figure out which microphone is receiving the strongest audio levels; this is an indicator of which direction the sound is coming from. Additionally, how long it takes the sound to reach the microphones can tell the robot how far away the sound is coming from. In agriculture, this can be used to automatically deploy a robot to go check on a group of livestock.

2.2.3.4 Cameras

Cameras are a useful tool in agriculture for pest surveillance and crop monitoring. When cameras are put in the field to monitor crops, this can save a lot of time by eliminating the need to go manually check up on every single crop. A group of researchers from the University of

Nebraska created a system called the crop phenology recording system (CPRS) to autonomously collect data on crops. This system used cameras to photograph crops every hour continuously to observe crop growth changes over different seasons [22]. Cameras allow for an increased level of documentation and data collection that can help farmers increase their awareness of the condition of their crops.

As opposed to using displaying camera images directly, image processing can be used to recognize pests and diseases that are plaguing crops. One common approach to this recognition are neural networks that can be trained to recognize specific aspects in images using Google's TensorFlow library. Using this software, a neural network can be given robust datasets of pests or diseases plants to process; the neural network will then learn to recognize these things and ideally begin to recognize them in the targeted crops [23].

2.3 UAVs

2.3.1 Overview

Unmanned aerial vehicles are aircraft that can be flown without a human pilot onboard. They can be used in a variety of different ways including recreationally, commercially, and militarily. UAVs can be categorized based on their design [24]. The design of a UAV can greatly affect its ability to perform certain tasks. The following sections will outline the various types of drones and what they are best suited for.

2.3.2 Fixed Wing UAVs

Fixed wing UAVs, as their name states, have wings to help them stay in the air. This design can also be commonly seen in airplanes. These UAVs typically use less energy (fuel, battery power, etc) on average in order to stay in the air [24] . This conservation of energy allows these vehicles to fly for substantially longer periods of time than any other type of UAV, making them perfect for jobs that require long flight times [24]. Their need for a basic runway makes them impractical for shorter jobs; fields like agriculture would have no use for these types of vehicles.

Similarly, these drones tend to carry a large price tag, which also contributes to their impracticality. The military, however, uses these drones for longer missions like surveillance and reconnaissance.

2.3.3 Multi Rotor UAVs

Multi rotor UAVs are the most common type of UAV found in the recreational category. These vehicles typically have either 4, 6, or 8 rotors [24]. Unlike fixed wing UAVs, these multi rotor systems need to constantly work in order to keep the UAV afloat. This results in a significantly shorter flight time due to the increased expenditure of resources [24]. The advantage of this type is its lack of need for a runway. These drones are useful for short jobs and can be launched from virtually anywhere, which makes them well-suited for agricultural jobs.

2.4 Regulations

2.4.1 UAV Regulations

When preparing to fly a personal or commercial UAV, there are rules and regulations established on both state and federal levels. These regulations generally restrict where a UAV can be flown as well as when it can be flown.

2.4.1.1 State UAV Regulations [27]

In addition to adhering to federal UAV laws established by the Federal Aviation Association (FAA), drone users must also follow guidelines set by the state. In Massachusetts it is prohibited to operate a UAV in any land owned by the Department of Conservation and Recreation (DCR). This includes land or waterways; it specifically states that UAVs cannot take off, fly, or land in these areas. Several regions in Massachusetts have created additional regulations. For example, Boston, Belchertown, Chicopee, and Holyoke have separate restrictions. These cities restrict where drones can be flown except in Boston: they permit the use of UAVs in public parks as long as the FAA regulations are followed.

2.4.1.2 Federal UAV Regulations

The FAA has established regulations regarding UAVs in the United States. The FAA requires users to register their drone. This registration is valid for 3 years. In 2019, the 1.3 million UAV users registered with the FAA, however it is predicted that nearly 40% of additional drones remain unregistered [30]. Drones must be flown outside of controlled air spaces which are typically restricted due to nearby airports, but permissions can be obtained to fly within these areas. The FAA has created an app called B4UFLY that takes the user's location to determine and notify the flyer if they are safe to fly [28].

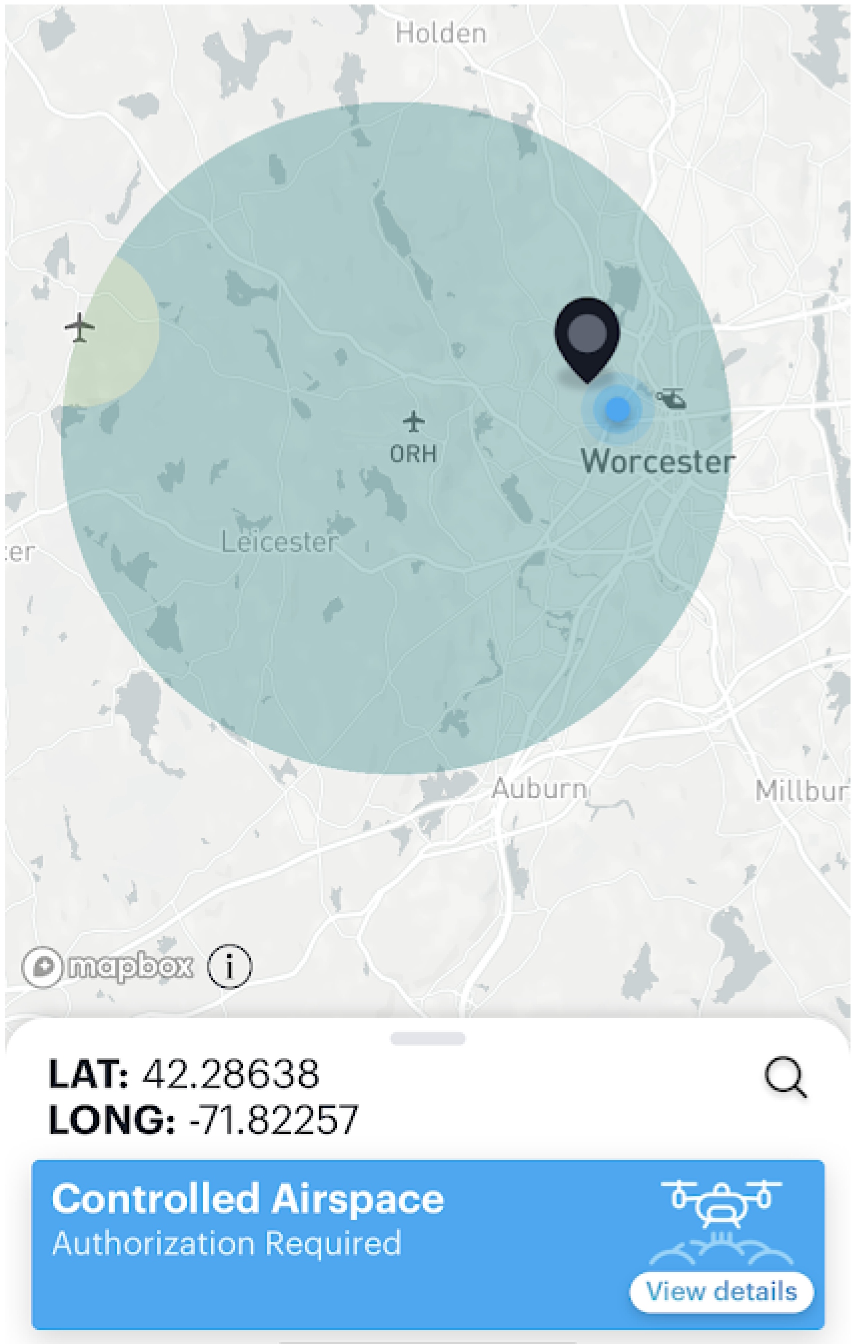

Figure 10: Example of the B4UFLY app [30]

FAA Part 107 refers specifically to commercial drones. This includes UAVs that are used in business to make money. These vehicles must weigh under 55 lbs and must be flown in the pilot's field of vision at all times. The UAV should only be flown during the day and should not be flown directly over individuals. A remote pilot must always be where the UAV is flying and they cannot operate more than one vehicle at a time. This pilot must receive a remote pilot certificate by passing an aeronautical knowledge test or have a Part 61 Pilot Certification [27].

The several types of UAV users include recreational flyers, certified commercial operators, public safety and government users, or educational users [29]. While educational users do not fall under the all rules established in Part 107, some do still apply. For instance, UAVs must be under 55lbs.

2.4.2 General Safety

When operating a UAV, many precautions must be taken before and during flying. Drones can become dangerous if caution and preparation is not exercised. For example, flying conditions can create unsafe environments for the vehicle as well as the operator. Ensuring that the temperature is above freezing, winds are moderate, and there is no precipitation is essential. When operating a UAV, the operator must be familiar with controlling the vehicle and be able to conduct an emergency landing or take over if the vehicle is autonomous [27]. Having an additional observer to look out for obstacles or humans nearby is strongly suggested. Finding a safe area to fly the vehicle is also important; UAVs must not be flown within 5 miles of an airport or over people, including the operator and visual observer.

Before taking off, it is essential to follow a UAV preflight checklist. This additional step is so users can check the vehicle for physical damage prior to takeoff as well as checking that batteries are well charged and connected. From a software perspective, it is important to have enough storage if a camera is being used onboard as well as checking for any firmware updates [27].

2.4.3 Wildlife

When working with wildlife such as birds and deer, it is important to acknowledge and address any ethical concerns or additional precautions that must be followed. To protect wildlife, UAVs are not allowed to be flown over land that have Temporary Flight Restrictions in place. The FAA keeps an up to date list of these locations with various explanations for restrictions ranging from hazards to space operations [25].

Additional wildlife restrictions include not interfering with young animals or a species that is nesting or breeding. In addition to these restrictions, UAVs must take off from at least 100 meters away from an animal and cannot approach birds vertically. This is how a predator would approach a bird and can be dangerous to the species. Also, Bald and Golden Eagles must never be disturbed or attacked and all protected migratory birds must not be killed or trapped [31]. Finally, it is important not to injure birds with UAVs and remain a safe distance away during flying.

3 Design

3.1 Requirements

The proposed system must meet several requirements. These requirements include functional requirements, non-functional requirements, and software requirements. The following section will define the requirements needed for every aspect of the intended system.

3.1.1 Functional Requirements

Title	Description
Human Interaction	Users should be able to manually control the system to activate animal-warding mechanisms if needed
Autonomy	The system should be able to detect and ward off unwanted animals without human interference
System Monitoring	Users should be able to monitor the vineyard using live data feed from the system.
Safety	The system must be safe for vineyard employees to work on the land and must not physically harm the pests.

Table 2: Functional Requirements

3.1.2 Non-Functional Requirements

Title	Description
System Lifecycle	The system should be able to run nonstop for 24/7 monitoring
Response Time	The system should be able to respond to animal activity immediately

Table 3: Non-Functional Requirements

3.1.3 Software Requirements

Title	Description
Documentation	The software for this system should be well-documented for future iterations of this project
Software Design	The software for this system must make proper use of software design patterns to increase understandability, modifiability, and modularity

Table 4: Software Requirements

3.1.4 Measures of Performance

The measures of performance defined in this section are the minimum quantitative results we wish to achieve in order for the system to be satisfactory. These measures are divided into functional, non-functional, and software based on the requirements section above.

3.1.4.1 Functional Measures

These measures of performance are concerned with how fast the system should be able to perform when carrying out its core functional requirements.

Category	Design Aspect	Requirement
Functional	Human Interaction	System must respond to interface interaction within 3 seconds.
	Autonomy	System must react to pests in the environment within 3 seconds.
	System Monitoring	Interface should update with sensor data within 3 seconds.

Table 5: Functional Measures

3.1.4.2 Non-Functional Measures

Non-functional measures are quantitative measurements that are not concerned with the system's basic functionality, but are necessary in making the system effective.

Category	Design Aspect	Requirement
Non-Functional	System Lifecycle	System should be able to stay powered in the field for 24 hours.
	Response Time	System must detect pests and respond with a deterrent in under 1 second.

Table 6: Non-Functional Measures

3.1.4.3 Software Measures

Software measures of performance determine how the application is specifically designed to maximize performance and what precautions are taken to ensure that the system is still working as expected.

Category	Design Aspect	Requirement
Software	Documentation	The system should be well-documented for ease of understanding (i.e. proper documentation on all classes and functions)
	Software Design	Software should use the Model-View-Controller (MVC) Design Pattern.

	Application performance	The UI should never lock for more than 0.5 seconds.

Table 7: Software Measures

4 Methodology

4.1 Planned System Design

Detection is the first step in approaching the challenge of deterring pests from the vineyard. In order to best deter these pests, the system must first be able to correctly identify animals such as birds and deer. These pests can have a large impact on crops because they target the leaves and grapes. These pests, especially the birds, can do considerable damage quickly in vineyards when they fly by and puncture the grapes. To address these pests, a sensor system will be implemented to detect movement in the field. After filtering the data inputted, most likely from a camera, the system will be expected to respond. The first method of deterring pests will be to use pre recorded audios to scare them away. A possible second method of defense would be to implement a UAV. This method will not be relied on as it will take much longer to respond. For user convenience and control, an interface will be created.

4.1.1 System Parts

4.1.1.1 Sensing

Having a system that works constantly throughout the day without a detection mechanism may initially work, but this could lead to the system being completely ineffective. Birds can quickly adapt to sounds and visuals. Due to their intelligence it is important that the system only be used when birds are detected and that the system provides variation in sound. By only using sounds when birds are detected, this will make these sounds more effective at scaring the birds by reducing the amount of times they hear them.

The system must be able to filter out the raw data that is inputted, either by a camera or other sensor, and determine if it is a pest. The ability to quickly detect a pest will be instrumental in deterring them.

4.1.1.2 Activating

After detecting a pest, the system will activate two subsystems to scare it off: audio and drone. The audio subsystem will have various sounds such as the sounds of predators or the sounds of birds in distress. By providing variation within the audio responses, this will also improve the effectiveness of the system.

The system will respond to the sensor input by audio. Various sounds will be used such as the sounds of predators or sounds of birds in distress. By providing variation within the audio responses, this will also improve the effectiveness of the system.

The system will autonomously respond to the pests by using outdoor speakers placed around the vineyard. To further deter the pests, the effectiveness of the speakers will be tested to decide if all speakers should be used at once or if the sounds should appear to be coming from different parts of the vineyard.

The drone subsystem will respond to pest detection by flying a UAV over the vineyard to physically scare away pests. This is a good way to address larger pests and pests that may become accustomed to the system. The interface will also be designed to observe and oversee the maintenance and effectiveness of this system.

4.1.1.3 Observing

A convenient user interface will be designed for the user's benefit. This interface will provide a way for the user to monitor the autonomous system by providing a live stream of data from the sensors as well as a notification if a pest is detected. If the user is watching the stream and notices that a pest goes undetected, there will be an option to force the system to respond. This will allow the choice to deter pests if there are any problems with sensors.

4.1.2 Software

A desktop application will be built for Wachusett Vineyards to be able to constantly monitor their vineyard. This software will give them control over all aspects of the pest deterrence system. The app will be built using the Qt application framework. When creating this application, the Model-View-Controller design pattern will be used. This design pattern will make the system easily modifiable by enforcing the Single Responsibility Principle: each part of the code (class, function, module) will only be responsible for fulfilling one task. Another advantage of the MVC design pattern is its natural enforcing of high cohesion and low coupling. This means that all likewise functionality will be within the same classes to enforce singular responsibility, while unrelated functionalities' will not rely on each other. This clear distinction between different features on the app will allow for features to be added, removed, and modified easily without causing any dependency issues. Using design patterns will help the code be more clear for future modification by possible later iterations of the project.

In order to show the video live stream on the application, the stream will need to be accessed over a network. Camera footage can be accessed by the application from an IP address associated with the camera. This can be done with either an IP camera or a Raspberry Pi with a camera module. IP addresses usually change after a certain amount of time, so the camera system will have to create a static IP address that does not change or use a Dynamic Domain Name System (DDNS) to ensure that the system's footage will always be reachable.

4.2 Planned Process

4.2.1 System Design and Parts Gathering

During this stage of the project, the team will begin by conducting research to analyze the advantages and disadvantages of various products for each component of the system. For example, this analysis will assess using cameras versus other more traditional sensors like microwave sensors for detecting the pests, or using Raspberry Pis versus arduinos as the main processing units of the system. Additionally, while it would be most beneficial to monitor the entire vineyard, this project's limitations (budget, team size, etc) will only allow for a section. It will be important to test the effectiveness of the system on a smaller scale before taking on the entire land. Once the system is planned, the team will begin to buy parts. These parts will be determined by their compatibility in the overall system.

4.2.2 Building and Initial Testing

Each sensor that is bought will be extensively tested. To start, the sensors will accept all input without filtering out environmental movements. This will help to figure out how much of an issue these environmental factors are, which will aid in knowing how to adjust sensor sensitivity to exclude these factors. When testing the cameras, computer vision libraries will be used to detect motion within the camera's line of sight. Similar to the sensors, analysis will be done on the video feed to test how well the cameras are able to detect motion. Robust tests will be done on both sensors and cameras to test detection range, detection time, motion sensitivity, and ability to discern between living and non-living motion. These tests aim to find an effective combination of sensors and cameras that balance out each component's strengths and weaknesses.

4.2.3 Designing and Building the User Interface

While the sensors and cameras are being tested, a user interface will also be designed and built. This interface will need to follow software engineering best practices such as proper code documentation and code organization with software design patterns. This application will need to get live data from the cameras and sensors. This will also help to test the network connection between the system and any remote computer that is actively running the application. Finally, testing will also include sending a response back to the system from the application to test the response time of a manual override.

4.2.4 Finish Building and Test Outdoors

To finish building the system, speakers will be added as a follow-up mechanism to a proper detection. The response time of the system with the speakers in place will be thoroughly tested to ensure that the system can respond in a timely manner. The interface will be able to signal the system to play sounds if need be. Once the system components and interface have been tested thoroughly indoors, it can be brought outdoors for another series of testing. These outdoor tests will assess the system’s network connectivity without an active internet connection as well as test the system’s overall weather resistance. The remaining challenge will be to ensure that the system is successful in the field and can detect birds and other pests that may pose as threats to the vineyard. The areas of the vineyard with the most pest-related damage will be a large factor in the consideration of where to place the system.

Throughout this process, the stakeholders' feedback and input will be valued and they will have the opportunity to provide any questions or concerns they may have.

4.3 Timeline

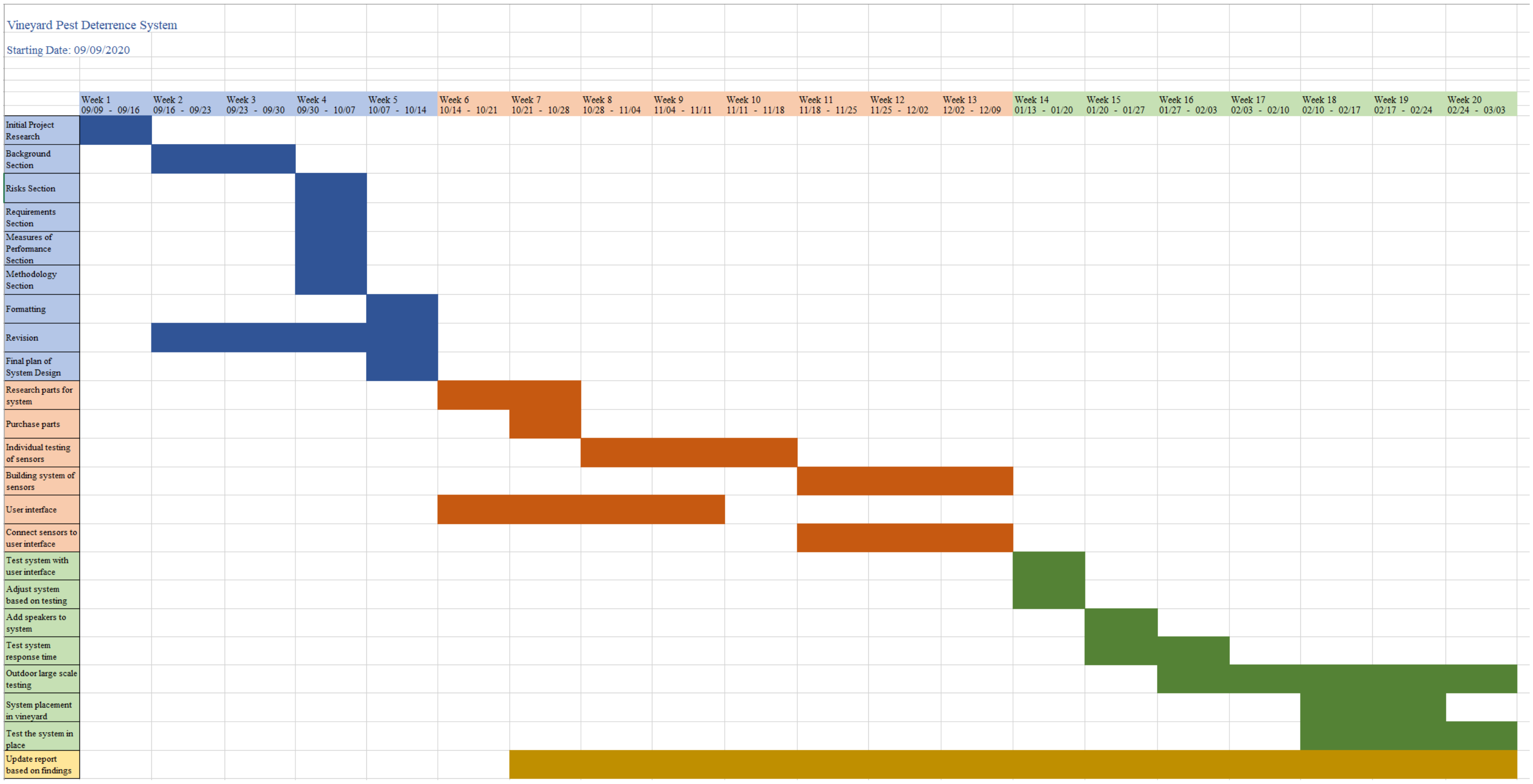

Figure 11: Gantt chart for the whole project

5 Implementation

5.1 User Interface

The user interface of this system was created as a way to monitor the pest deterrence system and manually override the system if necessary. The frontend of this app was created with QtDesigner to allow for efficient development, and the backend was created with Qt's python binding (PyQt5). The app was created using the MVC design pattern. The interface features a home page, an event log page, and an audio settings page. In figure 12, a full class diagram of the user interface is shown.

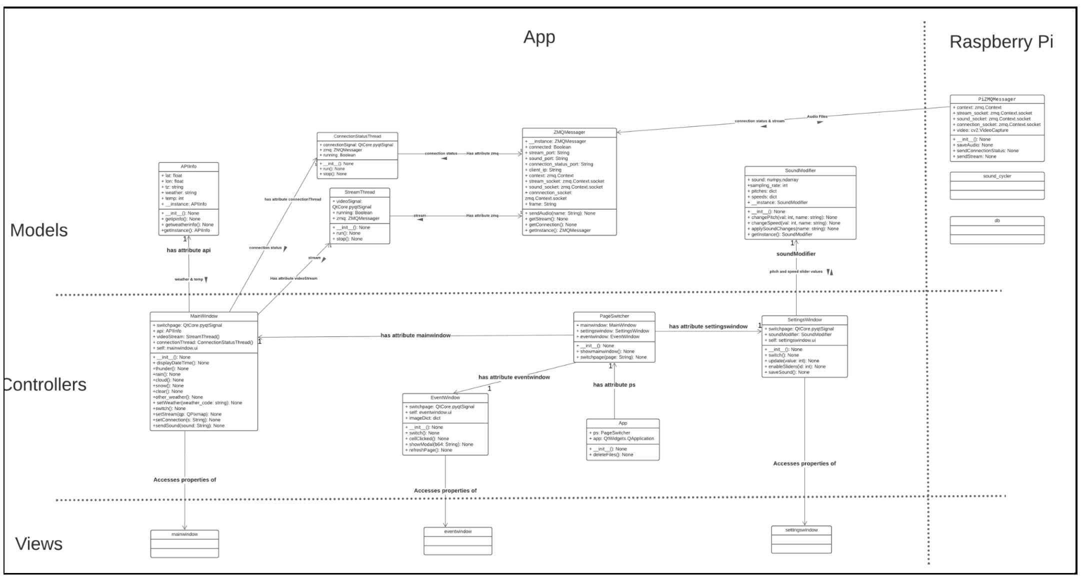

Figure 12: UML class diagram of the system

5.1.1 Home Page

The home page is designed to be simple and user-friendly. As seen in figure 13, the top of the page features the current date, temperature, and time. The page also displays a live stream from the deterrence system as well as the connection status to the system. When the app is not connected to the system, it displays an image from the vineyard in place of the stream. Figures 13 and 14 show the difference below. Additionally, this page has sound alert buttons that allow the user to manually signal the system to play off-putting sounds. This page also serves as a landing page to navigate to the other pages of the application.

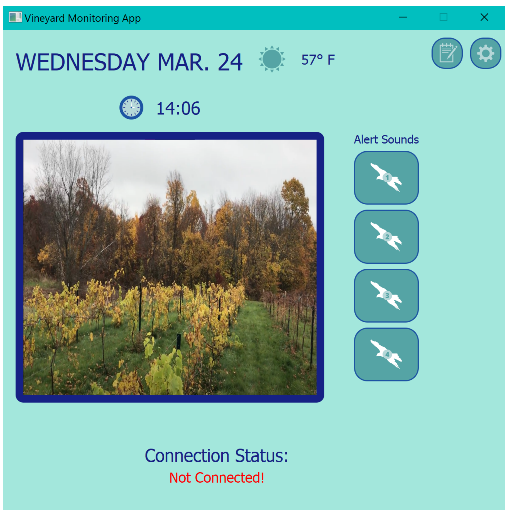

Figure 13: App when not connected

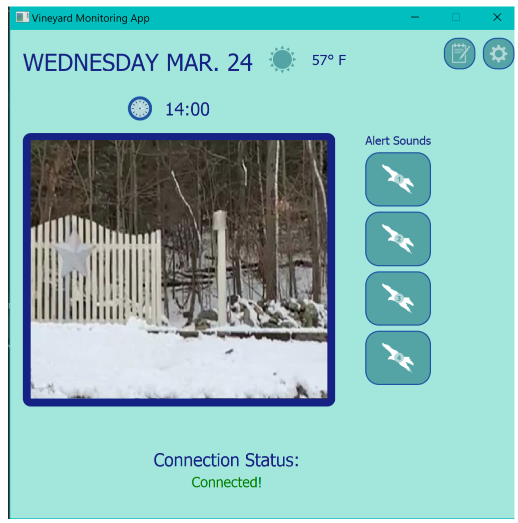

Figure 14: App when connected

5.1.2 Event Log Page

The event log page serves as a record for successful motion detections in the vineyard. The date of the motion detection and the time are displayed in a table.

When the system detects a motion, it saves a picture of the frame that caused the system to activate. Upon saving, another script is run that sends the date, time, and picture to an online database (MongoDB). When navigating to the event log page, this database is accessed and all of it's entries populate the event log table. When a row is selected, a modal displaying the image is shown. As seen in Figure 16, a small red box was drawn over a detected bird.

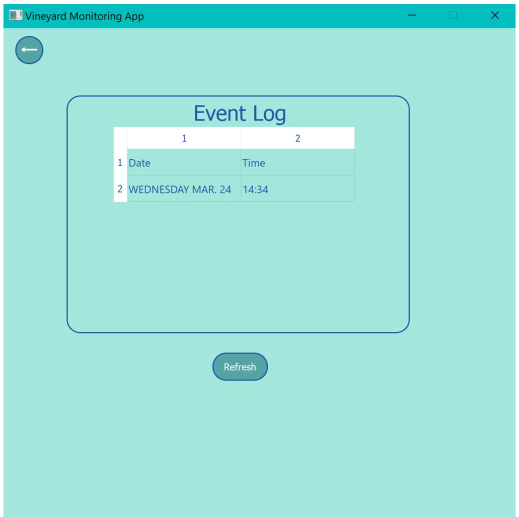

Figure 15: Event Log

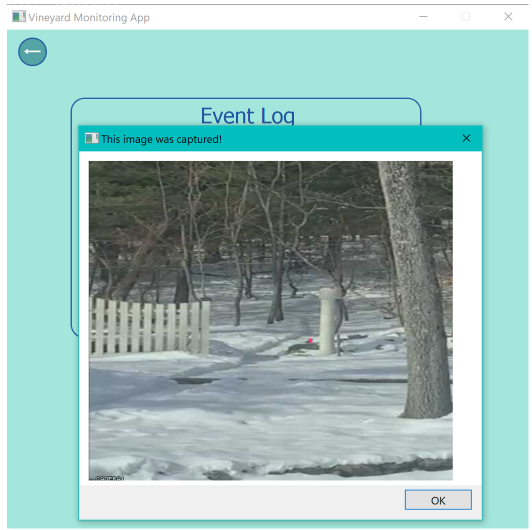

Figure 16: Detected movement modal

5.1.3 Sound Settings Page

The sound settings page is where the user can alter the sounds that the birds hear. The editable attributes of the sounds are pitch and speed. Altering these sounds is important as past research has shown that birds can become accustomed to hearing the same sounds. This was done with librosa, a music and audio analysis python library that enables the modification of sound files. When the user chooses to modify a sound, it creates a copy of the sound to perform the modifications on; the original sound file is kept as a starting point.

When modifying the pitch of a sound, the frequency is altered. Librosa labels this metric as “half-steps”. In the app, the pitch slider ranges from -10 to 10 half-steps. When the number of steps to modify is less than 0, the frequency is decreased. On the other hand, when the number of steps to modify is greater than 0, the frequency is increased.

When changing the speed of a sound, the rate at which the sound plays is altered. The speed slider on the app ranges from 0.25 to 2. When the chosen rate of play is less than 1, the sound is slowed down. Conversely, when the rate is greater than 1, the sound is sped up.

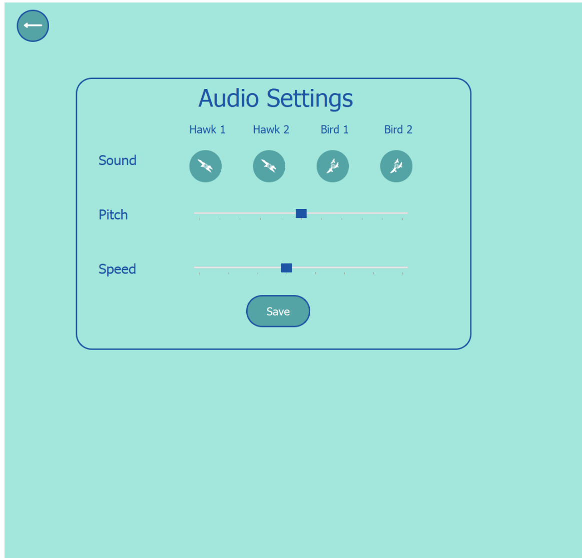

Figure 17: Sound settings page

5.1.4 Communication between interface and system

In order for the app and the deterrence system to communicate with each other, ZeroMQ is used. This is a messaging library that allows the app and system to send data to each other using the TCP networking protocol. Three separate sockets are used within the system architecture: one for sending modified sounds from the app to the system, one to send the connection status from the system to the app, and one to send the live stream frame-by-frame from the system to the app.

The modified sound files are sent to the system when the user presses one of the alert sound buttons, while the connection status and the live stream are being sent to the app every second indefinitely. Usually, these indefinite loops result in UI lock-up due to the main process of the app being occupied. In this app, these two indefinite processes occur on their own threads to prevent this issue.

A helpful technique we use to easily send information between the Raspberry Pi and the app is encoding information as a Base64 string. When sending a sound file to the Raspberry Pi, the file is encoded as a Base64 string, sent via ZeroMQ, and decoded back into a sound file. This technique is also used when sending information to the online database. The captured detection images are encoded as Base64 strings for storage in the database and decoded back into pictures in the app.

5.2 Detection

The detection aspect of the system involves a Raspberry Pi 4 and a Raspberry Pi High Quality Camera with an additional wide angle lens. This system is designed to remain in the vineyard as long as necessary in order to monitor and detect pest activity. The system uses a detection software named the "Motion Project" that has the ability to be altered to the requirements of the system via parameters.

5.2.1 Motion Software

The Motion software utilized in the system is a detection library that allows for adjustment. This software can be altered by adjusting the threshold of the number of pixels that are used to determine if motion is detected between frames. This amount varies based on the size of the objects that need to be detected. For our project, this involved testing with our camera and videos of birds in areas with brush and trees. A lower threshold is used to pick up bird movement in the distance while also trying to reduce the amount of false positives detected from leaves and branch movement. Other factors that are important include the option to save images when motion is detected.

5.2.2 Raspberry Pi High Quality Camera

The Raspberry Pi High Quality Camera is a small camera that can be easily connected to the Raspberry Pi. This camera is paired with a compatible 6mm wide angle lens. This lens is a necessary component to the camera and allows for a clearer view with a 63 degree field angle. This field angle is sufficient for the vineyard field as it is angled toward the trees above the vineyard. This camera lens can be easily adjusted by twisting the camera to change the amount of light allowed in the lens as well as adjusting the focus.

5.2.3 Audio Response

The audio response to motion detected was also created through this program. The software includes the option to run a custom script when an event is first detected. In order to avoid overlapping events which would interrupt the audio files, we set each event to last at least five seconds. This allows the audio file to play in full before another bird could trigger the system. This script file plays one of our four audio files of hawks and predatory birds to scare away the birds in the vineyard. These files are cycled through to avoid repetition rather than playing the same audio repeatedly. Additionally, there is another python script that automatically sends the saved detection photos to an online database that can be accessed by the desktop application.

5.2.4 Physical Model

The Raspberry Pi and camera required a structure to connect and secure the items to. This structure is also the method of attaching the camera to one of the posts in the vineyard. This system would secure the physical components and keep them level and steady while the camera was running.

The first design idea involved a 3D printed model that would sit on top of the post as a cap. This model was later discarded due to the angle at which the posts in the field are set; this is shown in Figure 18. These posts are at an angle in the ground and the cap would tilt the camera towards the sky rather than straight over the field at the trees. This design is shown below in Figure 19.

Figure 18: Angled post

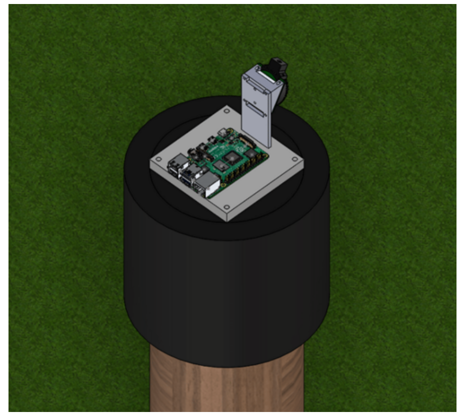

Figure 19: Cap design

The model was reconsidered and altered to be an "L" shaped wooden structure that would further elevate the camera while allowing the connecting ribbon to comfortably reach the pi. This model would be screwed into the top of the post at the end of the plank and secured by three screws. This was the final model tested in the field as shown below in Figure 20.

Figure 20: Final design

6 Results & Evaluation

6.1 Software Results

The software for this project includes the desktop application created for monitoring the system and the python scripts on the Raspberry Pi to perform tasks while the system is running. These tasks include cycling between the various predatory bird sounds, sending saved detection photos to an online database, and maintaining a TCP connection between the Pi and application for data transfer. Section 3 of the report defines our initial design requirements and measures of performance for the software. The desired design requirements are proper documentation and use of software design patterns. Both of these requirements were fulfilled over the course of the project. Next, the measures of performance include the app being able to accurately communicate with the system with a delay no greater than 3 seconds. The app updates it's live stream feed and connection status indefinitely, and it also is able to send a modified sound to the play for deterrence within a second. The initial measures of performance were all met in the completed version of this project.

6.2 System Results

The system created for this project involves a Raspberry Pi and Raspberry Pi High Quality camera with a 6mm wide angle lens attached. The system is attached to a wooden frame that can be secured on to a fence post. This system uses the "Motion Project" to identify bird activity in the field. In order to properly identify birds and reduce false bird detection the threshold was adjusted and tested to determine a successful range. As previously stated in Section 3 of the report, prior to building and testing this system there were several requirements established for the project. The system achieves the functional requirements such as safety, autonomy, system monitoring, and human interaction. The non functional requirements are also met. The response time of the system complies with these requirements as audio responses to motion detected are able to respond in under 3 seconds and the system can run for an unlimited time. One of the requirements not met by the system is that the system is unable to run in the field at this time as there is no reliable power source or internet access. While short term solutions were found for testing purposes, the system was not left alone in the field for an extended period of time. The functional requirements of the system were met in this project, however there are further steps that must be taken before the system is complete.

7 Conclusion

While this project was the first MQP to establish pest control within vineyards, significant progress was made. This project created a system involving a Raspberry Pi 4, a Raspberry Pi high quality camera, and a compatible 6mm wide angle lens. This system implements the "Motion Project" to detect birds in an outdoor environment and respond with one of four predatory sounds of hawks. This system is compact and can be placed on top of vineyard posts easily to monitor a field. In addition to this system there is a computer application that serves as a user interface to monitor the live stream of the camera, maintain an accurate event log of motion activity, and modify the pitch and speed of the sounds to vary based on user input. Overall this system establishes important groundwork to further adapt and improve by future teams.

7.1 Future Work

While working on this project we established achievable goals for our team to complete over three terms. We had a few restrictions based on the time to complete this project and the number of team members we had working on it. There were several aspects that we considered while planning and believe that this project has the potential for future teams to continue and focus on. These future ideas include drone implementations, advanced cameras and sensors, data collection, and software development.

7.1.1 Drone Implementation

One of the original suggestions made by our sponsor was to implement UAVs in the vineyard to scare away pests. This first involved establishing a system to detect pests which would then trigger the vehicle. While we chose to focus on building a reliable detection system, the idea of drone implementation could be a great focus for a future MQP project.

This task would involve building or purchasing a UAV and creating a method of housing and charging the vehicle in the field. It would be crucial to the system that the vehicle is able to launch autonomously at the request of the detection system from a nearby location.

7.1.2 Additional Cameras & Sensors

We chose to first establish a system with one camera that is placed along the edge of the vineyard to monitor bird activity. With more time and resources another camera could have been implemented into our system to provide a larger field of view in the vineyard. In the future, another team could build off of the detection system by connecting more cameras or even a range of sensors such as lidar to work with the camera to further improve the accuracy of detection.

Additional cameras could also be marketed to larger vineyards or landowners who have multiple properties. While using our interface these camera views could be easily accessible and provide thorough monitoring for pests and security to these businesses.

7.1.3 Analysing Data Collection

Another future consideration would be to use this system to study pest response and pest activity. Although there are several methods for pest deterrents involving physical movement, audio, laser beams, and other tests, it is unclear that the long term response to these deterrents is as successful as short term. To study and analyse the camera video collected as well as monitoring responses could prove to be beneficial in further understanding pest activity and therefore management in agriculture.

7.1.4 Further Software Development

When researching ideas for our interface there were many security applications that we observed including systems such as Ring and ADT. We considered the future of our application if another team were to install additional features such as more cameras, sensors, or even a UAV.

Our interface has the potential to grow with the system and provide users with a way to manage their property with features such as maps to pinpoint system locations (implying that there are multiple systems on their property) as well as the ability to view their land from a live stream. If multiple vineyards or farms implement this technology there is the potential to share information across users to better inform businesses of pests in the area.

Appendix A

Stakeholder & Needs Analysis

A.1 System Needs

In order for our proposed system to be successful, it needs to accomplish a sequence of tasks. This sequence consists of:

1. Bird and deer detection: This system should be able to successfully detect unwanted animal presence in the vineyard.
2. Warding away animals: The system should then be able to immediately respond to ward away the detected animals from the grape vines.
3. Deploying a UAV: The system should be able to deploy an autonomous UAV to patrol the area of the vineyard with reported animal activity.

A.2 Stakeholder Identification

Stakeholder	Involvement/ Type	Met By...	Rationale
Sponsor (SH01)	Wachusett Vineyards Owners (Brion & Pamela Keagle)	Meeting with them, regular updates, and questions	Brion and Pamela Keagle reached out to us with their problem and we are working to directly solve their pest control issue
Student(SH02)	Working on project	Conducting research and working on MQP over three terms	Students achieved a successful system for fulfillment of degree requirements
Advisor(SH03)	Advising & Guiding Project	Having weekly meetings with the students	Advisor provides feedback and grades the project
WPI(SH04)	Organized Project	Funding a portion of	MQP project is

		the project and providing an Advisor	required to fulfill degree requirements

Table 12: Stakeholder Identification

A.4 Needs Elicitation

Stakeholder	**Needs**	**Stakeholder Considerations**

Sponsor	• System must deter pests such as birds and deer
	• Using automated methods
	    ○ Sensors
	    ○ UAVs
	• System must be intuitive and easy to use
	• System must be able to be deployed in a vineyard
	•
		• System must reduce the need for other forms of pest control
		• System must increase productivity

Students	• System should be with the team's financial means • System must incorporate Robotics and Computer Science aspects to fulfill degree requirement	• Must budget the system and possibly apply for further support • Implement sensors and UAV to reduce crop loss

Table 13: Needs Elicitation

A.5 Stakeholder & Needs Analysis

Need	**Statement**	**Validation**	**Priority**
Autonomous (N01)	System must respond autonomously to natural events	SH01, SH02	2
Primary Pest Deterrent	System must implement a primary method of removing pest from the vineyard (intimidating sounds)	SH01, SH02	3
Secondary Pest	System must implement a	SH01, SH02	4

Deterrent	secondary method of removing pests from vineyard (UAV)		
Safety	System must protect the vineyard from pests. It must not physically endanger the pests or their natural environment	SH01, SH02, SH03, SH04	1

Table 14: Stakeholder & Needs Analysis

Appendix B

Budget

B.1 Preliminary Budget Brainstorm

Item Name	Type	Range/ Ability	Price	Link
Raspberry Pi Camera Module v2	Camera Sensor	Capture video at 1080p30, 720p60 and 640x480p90 resolutions	~$25	https://www.raspberrypi.org/products/camera-module-v2/
Raspberry Pi High Quality Camera	Camera Sensor	12.3 megapixel sensor	~$50	https://www.raspberrypi.org/products/raspberry-pi-high-quality-camera/
Arducam Mini Module Camera Shield with OV2640 2 Megapixels Lens	Camera Sensor	2 megapixels image sensor OV2640	~$25	https://www.amazon.com/Arducam-Module-Megapixels-Arduino-Mega2560/dp/B012UXNDOY
Ultrasonic Distance Sensor - HC-SR04	Ultrasonic Sensor	provides 2cm to 400cm of non-contact measurement functionality with a ranging accuracy that can reach up to 3mm	~$3	https://www.sparkfun.com/products/15569
Leonlite Microwave sensor	Microwave Sensor	360° sensing, 52.5ft range, ip65 water resistant	~$34	https://www.amazon.com/LEONLITE-Microwave-Attachment-Adjustable-Commercial/dp/B07BT

				Y7ZQF/ref=sr_1_5?dchild=1&keywords=microwave+motion+sensor&qid=1601950871&sr=8-5
QCRobot motion sensor	Microwave sensor	For arduino & Raspberry Pi, 2-16 meter detection range	~$20	https://www.amazon.com/CQRobot-10-525GHz-Microwave-Compatible-Measurement/dp/B089NKGWQQ/ref=sr_1_4?crid=37KHHFV7LDX02&dchild=1&keywords=arduino+microwave+motion+sensor&qid=1601994537&sprefix=arduino+micro%2Caps%2C146&sr=8-4
Gravity digital microwave sensor	Microwave sensor	For arduino, detection range is 2-16 meters	~$9	https://www.dfrobot.com/product-1403.html?tracking=5b603d54411d5
Arduino Uno REV3	Arduino		~$25	https://store.arduino.cc/usa/arduino-uno-rev3
Junction box	Housing	Waterproof electrical box for raspberry pi/arduino	~$8	https://www.amazon.com/Zulkit-Dustproof-Waterproof-Universal-Electrical/dp/B07PXZHPKJ/ref=sr_1_5?dchild=1&keywords=waterproof+electrical+box+clear&qid

				=1601954325&s=hi&sr=1-5
400 point solderless breadboard	Breadboard	Could be used for prototyping	~$10	https://www.amazon.com/Breadboards-Solderless-Breadboard-Distribution-Connecting/dp/B07DL13RZH/ref=sr_1_3?dchild=1&keywords=Breadboard&linkCode=ll2&linkId=82fcb14576272d1280c9e37c9f77e6f8&qid=1601954660&s=industrial&sr=1-3&tag=pimylifeup-20
Raspberry Pi 4 Model B - 2 GB RAM	Raspberry Pi		~$35	https://www.adafruit.com/product/4292
CQRobot Speakers	Speaker	Would work for raspberry pi	~$8	https://www.amazon.com/CQRobot-JST-PH2-0-Interface-Electronic-Projects/dp/B0738NLFTG/ref=sr_1_5?dchild=1&keywords=raspberry%2Bpi%2Bspeaker&qid=1601956792&sr=8-5&th=1
MakerHawk Speakers	Speaker	Works with raspberry pi	~$10	https://www.amazon.com/MakerHawk-Full-Range-Advertising-Separating-JST-PH2-0mm-2/dp/B07FTB281F/ref=sr_1_10?dchild=1

				&keywords=speaker+bonnet&qid=1601956988&sr=8-10

Table 15: Preliminary Budget Brainstorm

Appendix C

Risks

C.1 Identifying Risks

- Supply chain issues: if delivery for parts is too long, or if they are the wrong part/ don't fit
- System won't work in the intended environment, or environmental factors were insufficiently or incorrectly considered, especially weather in the winter months
- System won't work reliably or repeatedly, or works only in special situations; system not is fast enough, the sensors are not working properly/ not collecting enough data
- System won't meet specifications, if the sensors do not detect pests/ response time is too slow
- Team members are insufficiently experienced or knowledgeable to carry out the project to a successful conclusion/ limitations due to size of the team
- Limited budget- if sensors/ drone are outside budget

C.2 Expressing Risks

- IF the parts are delivered after the expected date, THEN the system construction may fall behind the anticipated timeline deadlines.
- IF the system cannot withstand cold temperatures in New England, THEN the system may become a seasonal tool to be used only during harvesting months.
- IF our sensors do not collect enough data to draw conclusions of pest activity, THEN we may need to consider sensor fusion of various sensors or purchasing higher quality technology.

- IF our interface does not read our sensor input in real time, THEN we must redesign and test the connection between the raw data and the interface.
- IF the sensors detect too much movement, THEN we must filter the data to detect specific pests such as birds and dear.
- IF our alert system is responding to pests after they have left the vineyard, THEN we must consider moving our sensors to detect pests prior from entering.
- IF our team faces challenges regarding inexpertise, THEN we must consult our advisor and continue our research.
- IF the costs for our planned system are above our budget, THEN we must adjust the scale of our system or inquire about alternative funding.
- IF the system designed becomes too large of a challenge for two students, THEN we must reconsider the scope of the project and make realistic changes.

C.3 Assessing Risks

C.3.1 Enhanced Risk Assessment Matrix

Risk	**Consequence**	**Trigger**	**Owner**	**R(P) - response plan prior to event**	**R(A) - response plan after event (contingency)**
Parts do not arrive on time	Loss of time	Construction of system	Team who ordered parts	Account for buffer days when ordering	Finding alternative parts
Parts are do not work in climate	Loss of Sensors	Temperature / water testing	Team	Testing individual sensors	Determine a covering for the system
System is too large to be completed	Loss of system components	Scheduling	Team	Realistically establishing objectives	Reassessing the scope of the project
Parts are out of Budget	Loss of quality	Budget	Team	Planning a budget prior to beginning	Finding affordable solutions/ alternatives

Table 8: Enhanced Risk Assessment Matrix for Parts

C.3.2 Management Plan

Risk	**Likelihood**	**Consequence**
Parts do not arrive on time	50%	The system design and components must be adjusted or the timeline of the system will be delayed
Parts are do not work in climate	75%	Additional testing or construction of a protective covering must be considered
System is too large to be completed	30%	Redefining a realistic scope for the project
Parts are out of Budget	50%	Budget must be adjusted by finding alternative funding or parts must be modified

Table 9: Management Plan for Parts

C.3.3 Enhanced Risk Assessment Matrix

Risk	**Consequence**	**Trigger**	**Owner**	**R(P) - response plan prior to event**	**R(A) - response plan after event (contingency)**
System is not thoroughly tested	Loss of time and Productivity	Running the code	team	Establish clear tests for small fragments of the code	Create tests for fragments of code to determine errors
System cannot filter sensor data	Loss of input	Testing for sensor recogniti on	team	Use computer vision resources to filter by colors and shapes	Establish through tests for sensors and filters
System Response is inaccurate	Loss of reliability to detect pests	Testing detection	team	Place sensors at optimum viewing position and test filters	Redefine the filters of the data or move placement of sensors

Table 10: Enhanced Risk Assessment Matrix for Software

C.3.4 Software Management Plan

Risk	**Likelihood**	**Consequence**
System is not thoroughly tested	25%	The production of the interface will be delayed and all code must be reevaluated through testing.
System cannot filter sensor data	30%	The sensor filters must be adjusted and the system production timeline will be delayed.
System Response is inaccurate	50%	Filters must be adjusted as well as the position of the sensors, sensors may need to be reconsidered.

Table 11: Software Management Plan

Appendix D

Expected Results

D.1 System Results

At the end of this project,we expect to have a system to detect pests in a vineyard. For the scope of this project, we do not expect for our system to detect all pests. We are expecting that the system will be able to detect birds that enter the vineyard. The cameras in the field will be angled upwards and rotate to constantly search for birds. Within three seconds of a bird entering the camera's view, the system should recognize that a bird has entered the field. Within another three seconds, the primary deterrent should be triggered. This deterrent will be various sounds to scare the birds. These sounds should not repeat twice in a row and must be the sounds of birds in distress or predators. The system must be designed to implement a UAV as a secondary method of deterring pests.

We expect that the birds will not grow accustomed to these sounds due to the variety in the audios. Within the time allotted, the system will detect and scare away pests in under 6 seconds.

We also expect the system to run autonomously throughout harvest season. It must be able to scan the vineyard throughout the day and night to deter pests.

D.2 Software Results

The system must be able to properly detect pests from other objects. The raw data must be analyzed and filtered to properly detect these pests. It is expected that the system will be able to correctly identify birds and respond to their presence in the field.

The system must also have a user interface to interact with the sensors. This interface is expected to have a live feed of the field sensors and provide the raw data for the users. It also must have the capability to trigger the audio on command if a pest goes undetected by the sensors. The user interface will provide an additional level of security for the crops and surveillance of the system itself.

Appendix E

Software

E.1 Motion

The motion detection library used can be found here:

https://github.com/Motion-Project/motion

E.2 Github Repositories

There are two repositories for this project; one is for the desktop application, and one is for the python scripts on the Raspberry Pi. They can be forked here:

1. App: https://github.com/Vineyard-MQP-2021/VineyardApp
2. Raspberry Pi: https://github.com/Vineyard-MQP-2021/Raspberry-Pi-Code

References

[1] “French-American and Other Interspecific Varieties,” *Cornell School of Integrative Plant Science, Horticulture Section*. [Online]. Available: http://www.hort.cornell.edu/reisch/grapegenetics/bulletin/wine/winetext4.html. [Accessed: 20-Sep-2020].

[2] “Grapes,” *University of Massachusetts Amherst, The Center for Food, Agriculture, and the Environment*. [Online]. Available: https://ag.umass.edu/fruit/ne-small-fruit-management-guide/grapes. [Accessed: 20-Sep-2020].

[3] “A Beginners Guide to Hybrid Grapes,” *WineEnthusiast*. [Online]. Available: https://www.winemag.com/2020/05/21/hybrid-wine-grapes-guide/. [Accessed: 20-Sep-2020].

[4] “Meet Wines Worst Enemy, Phylloxera” *WineEnthusiast*. [Online]. Available: https://www.winemag.com/2019/05/02/wines-worst-enemy-phylloxera/. [Accessed: 20-Sep-2020].

[5] “The Grape Breeding Process,” *University of Minnesota*. [Online]. Available: https://mnhardy.umn.edu/varieties/fruit/grapes. [Accessed: 20-Sep-2020].

[6] A. Anderson, C.A. Lindell, K.M. Moxcey, W.F. Siemer, G.M. Linz, P.D. Cu, “Bird damage to select fruit crops: The cost of damage and the benefits of control in five states,” *Crop Protection*, vol. 52, pp. 103-109, 2013.

[7] C.M. Somers and R.D. Morris, “Birds and Wine Grapes: Foraging Activity Causes Small Scale Damage Patterns in Single Vineyards,” *Journal of Applied Ecology*, vol. 39, pp. 511-523, 2002.

[8] J.P. Tracey and G. Saunders, “Damage to the Wine and Grape Industry,” *Report to the Bureau of Rural Sciences, Department of Agriculture, Fisheries, and Forestry*, 2003.

[9] “How to Manage Pests, UC Pest Management Guidelines” *University of California Agriculture and Natural Resources*. [Online]. Available: http://ipm.ucanr.edu/PMG/r302600311.html. [Accessed: 20-Sep-2020].

[10] Z. Wang, D. Fahey, A. Lucas, A.S. Griffin, G. Chamitoff, and K.C.Wonga, “Bird damage management in vineyards: Comparing efficacy of a bird psychology-incorporated unmanned aerial vehicle system with netting and visual scaring,” *Crop Protection*, vol. 137, 2020.

[11] “Harvest Automation: Mobile Autonomous Robots for Agriculture.” [Online]. Available: https://www.public.harvestai.com/. [Accessed: 17-Sep-2020].

[12] “Tertill the solar powered weeding robot for home gardens,” *Franklin Robotics*. [Online]. Available: https://tertill.com/. [Accessed: 17-Sep-2020].

[13] G. Adamides, C. Katsanos, I. Constantinou, G. Christou, M. Xenos, T. Hadzilacos, and Y. Edan, “Design and development of a semi-autonomous agricultural vineyard sprayer: Human-robot interaction aspects,” *Journal of Field Robotics*, vol. 34, no. 8, pp. 1407–1426, 2017.

[14] M. Reinecke and T. Prinsloo, “The influence of drone monitoring on crop health and harvest size,” *2017 1st International Conference on Next Generation Computing Applications (NextComp)*, 2017.

[15] N. Al-Thani, A. Albuainain, F. Alnaimi, and N. Zorba, “Drones for Sheep Livestock Monitoring,” *2020 IEEE 20th Mediterranean Electrotechnical Conference (MELECON)*, 2017.

[16] Z. Wang, A. S. Griffin, A. Lucas, and K. Wong, “Psychological warfare in vineyard: Using drones and bird psychology to control bird damage to wine grapes,” *Crop Protection*, vol. 120, pp. 163–170, 2019.

[17] I. Li, “What is PIR Sensor, How PIR Sensor works, Difference between PIR Sensor and Motion Sensor,” 03-Aug-2019. [Online]. Available: https://www.seeedstudio.com/blog/2019/08/03/pir-sensor-introduction-and-how-pir-motion-sensor-works-with-arduino-and-raspberry-pi/. [Accessed: 22-Sep-2020].

[18] “Microwave vs. Passive Infrared Motion Detectors,” *Alarm Grid*. [Online]. Available: https://www.alarmgrid.com/faq/microwave-vs-passive-infrared-motion-detectors. [Accessed: 22-Sep-2020].

[19] National Oceanic and Atmospheric Administration, “What is LIDAR,” 01-Oct-2012. [Online]. Available: https://oceanservice.noaa.gov/facts/lidar.html. [Accessed: 25-Sep-2020].

[20] U. Weiss and P. Biber, “Plant detection and mapping for agricultural robots using a 3D LIDAR sensor,” *Robotics and Autonomous Systems*, vol. 59, no. 5, pp. 265–273, 2011.

[21] C. Rascon and I. Meza, “Localization of sound sources in robotics: A review,” *Robotics and Autonomous Systems*, vol. 96, pp. 184–210, 2017.

[22] T. Sakamoto, A. A. Gitelson, A. L. Nguy-Robertson, T. J. Arkebauer, B. D. Wardlow, A. E. Suyker, S. B. Verma, and M. Shibayama, “An alternative method using digital cameras for continuous monitoring of crop status,” *Agricultural and Forest Meteorology*, vol. 154-155, pp. 113–126, 2012.

[23] A. Albanese, D. D’Acunto, and D. Brunelli, “Pest Detection for Precision Agriculture Based on IoT Machine Learning,” *Lecture Notes in Electrical Engineering Applications in Electronics Pervading Industry, Environment and Society*, pp. 65–72, 2020.

[24] E. Smith, “Types of Drones - Explore the Different Types of UAV's,” *Electronic Circuits and Diagrams-Electronic Projects and Design*, 03-Feb-2017. [Online]. Available: https://www.circuitstoday.com/types-of-drones. [Accessed: 27-Sep-2020].

[25]*Federal Aviation Administration - Graphic TFR's*. [Online]. Available: https://tfr.faa.gov/tfr2/list.html. [Accessed: 28-Sep-2020].

[26] “Top 3 Drone Preflight Checklists [FREE DOWNLOAD],” *SafetyCulture*. [Online]. Available: https://safetyculture.com/checklists/drone-preflight/. [Accessed: 28-Sep-2020].

[27]“What is the FAA Part 107? The Drone License Requirement Explained,” *UAV Coach*, 12-Dec-2019. [Online]. Available: https://uavcoach.com/what-is-faa-part-107/#1FAA107. [Accessed: 28-Sep-2020].

[28] *Unmanned Aircraft Systems (UAS)*, 26-Aug-2020. [Online]. Available: https://www.faa.gov/uas/. [Accessed: 28-Sep-2020].

[29]*Educational Users*, 21-Apr-2020. [Online]. Available: https://www.faa.gov/uas/educational_users/. [Accessed: 28-Sep-2020].

[30] “LAANC: How to Get Your Drone Flights Approved,” *Drone Pilot Ground School*, 26-Jul-2019. [Online]. Available: https://www.dronepilotgroundschool.com/faa-laanc-authorization/. [Accessed: 28-Sep-2020].

[31] US Department of Agriculture Forest Service, n.d. *Drone (Unmanned Aircraft Systems) Use On National Forest Lands & The Protection Of Wildlife*. US Forest Service.