ELEX 7790: Capstone Project Initiation

Proposal

Vine 'Em And Dine 'Em: VineBot

December 7th, 2018

Abstract

The Canadian agriculture industry has seen sustained growth in the wine industry with global exports totaling $145 million dollars in 2017. The industry has seen labour shortages and many vineyards are turning to automation to fill the need. Current solutions are expensive and imprecise. The harvesting of wine grapes at small to medium sized vineyards requires precision and care to avoid loss of product. These factors support an automated solution that allows for precision picking of grapes. This report outlines our proposed timeline for development of an autonomous robotic picking vehicle aided by computer vision and a suite of sensors for navigation.

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Executive Summary

This report describes the business case and implementation plan for an autonomous vineyard crop harvesting robot, VineBot.

Background

Our team is a composed of senior electrical engineering students studying at the British Columbia Institute of Technology. Our combined past experiences include working with industrial robots, machine vision, mechanical design and fabrication, and rapid prototyping.

This document is mainly intended for our stakeholders including our capstone mentor Craig Hennessey, our capstone coordinator Jeff Bloemink, BCITs School of Energy research committee, and external industry partners who would be our effective end-users.

There are several key driving forces for this project including: lack of available agricultural labour and demand for automation, the growing Canadian wine market and potential growth of the agriculture sector, and the absence of precision grape picking systems on the market.

Canada is home to 720 wineries and vineyards [1]. A total of $7.2 billion worth of wine was sold in Canada in 2012, with a gain of 3.1% from the previous year. Canadian winery global exports totaled $145 million dollars in 2017 The forecasted market value for 2018 is projected to be $10.28 billion.

"In 1921, agriculture was the single most common occupation," and throughout the years "farms have become more specialized and the average farm size has increased [2]." However, with the projected market growth in agriculture, labour shortages have become of great concern. According to the California Farm Bureau Federation survey, "55 percent of responding farmers had experienced employee shortages." [3] That study also outlined that "[problems] have been more acute among farmers whose crops require the most intensive hand labour, such as tree fruits and grapes." When asked what actions they have taken in response to employee shortages, one- third of respondents said they used mechanization if available; another 29 percent attempted or investigated mechanization.

According to Agriculture and Agri-Food Canada, most studies of the impact of climate change suggest that most regions of Canada are projected to warm during the next 60 years. Despite the known challenges that come with climate change such as drought and storm intensity, there are opportunities for the Canadian agriculture industry. Canada is a high latitude country, which brings more pronounced warming than the global average. This could lead to expansion of the growing season to go along with milder and shorter winters like those seen in Arizona and California [4]. Without the available labour pool, this potential for climate-change induced growth in Canadian agriculture could be squandered.

Project Objectives

Working in consultation with local wine producers (Okanagan Valley, Lower Mainland) is an objective of this project. Their engagement with our engineering team and feedback on the minimum viable product would be very valuable.

In terms of more technical requirements, the main objective for our group is to design and implement a proof of concept autonomous vehicle capable of navigating a vineyard to pick grapes while also avoiding obstacles.

Another objective is to become proficient in use of machine learning for image processing, 3D cameras, GPU processing, LiDAR processing, and robot motion and path planning.

We would like to have the following deliverables by the end of the project:

1. A proof of concept autonomous grape picking vehicle
2. A final report documenting our project by the end of the project term
3. An organized git repository with extended project documentation
4. A live demonstration of the project for the technology expo including signage and literature

Planning

For planning purposes, the project is set to commence on January 1st, 2019. Additional work will occur over the winter break as well. The final task in the project is to present a working prototype at the BCIT Project Expo around the 15th of May 2019. Significant work has been done on the project already and many of the following tasks build upon existing progress.

The Project Start stage of development deals with many of the technical aspects of the project. The subtasks include: pose estimation and mapping, Computer Vision, Motion Control, Human Machine Interface (HMI), Mechanical Design and Miscellaneous Software Development.

Once the Project Start stage of development is complete; systems integration can begin. This involves setting a standard for Inter-Process Communication (IPC) so that the different modules can pass information efficiently and effectively. Once this is complete, the modules must be interfaced together under a master control module.

The Project Wrap-up stage will involve documentation and demonstration. The final report will be written, the source code repository will be cleaned up and documentation expanded. We will then demonstrate the project to the public, students, faculty, and any other industry attendees at the capstone exposition. We would like to have an extendable banner with our "product" and "brand" on it as well as some information on how the system works. We would also like to have an artificial vineyard set up in a way that we can demonstrate the system.

The project will be divided up into 5 milestones:

Milestone 1 (January 19th) – Visual Camera, Machine Learning Test, and LiDAR Processing Complete

Milestone 2 (March 3rd) – 3D Camera, SLAM, and Path Planning Complete

Milestone 3 (March 29th) – NVIDIA Board Integration and Path Following Complete

Milestone 4 (April 19th) – Integration and Verification Complete

Milestone 5 (May 14th) – Documentation and Tech Expo Preparations Complete

Management

To streamline tasks and make sure that no conflicts arise when completing the project, free online project management software will be utilized. The software, Trello, is based on the Agile methods for project management, specifically the Kanban project management method.

Most of the main materials required for this project such as robot platform and robot arm have already been ordered as part of a previous project's budget (SoE VineBot). New Parts that must be ordered include 3D printing filament and various hardware fastener kits.

Risks associated with the proposed VineBot are limited, due to the scope of work we plan on achieving this year, as well as the relative affordability of the components we plan on using. There are still some potential risks that we've compiled into a risk probability matrix in the report. Most of the risks involve various technologies being ineffective and how we plan to substitute them and keep progressing.

1 Introduction

This report describes the design and potential market for an autonomous wine crop harvesting robot, VineBot. It is addressed towards the staff of the BCIT Electrical Engineering faculty, the BCIT School of Energy and our project mentor, Craig Hennessey.

Wine grape harvesting can be a rigorous, time-consuming, and labour intensive task which has already begun to be automated. There is also a social push towards organic and sustainably-produced products and produce, which could be an agricultural automation opportunity. Our senior engineering capstone group aims to improve on current systems by developing a robotic vehicle that can monitor and harvest grape crops autonomously and selectively. Ideally, this robotic vehicle should be able to navigate a vineyard without the need for human intervention, work during all times of the day, and successfully detect and harvest wine grape crops. This is going to be accomplished by using cutting-edge vision technologies, robotics, and various engineering methods we've picked up at BCIT.

This proposal will outline what we hope to accomplish with our project, and how we plan on carrying out what is being proposed. We will not however go too-far in depth into technical aspects of the project.

In the following sections of this report, topics such as the motivation for our project will be introduced, including end-users and stakeholders, and the application and need for our project. Some background information based on the agricultural industry will then be discussed, and the state of the art with respect to wine grape harvesting. This will be followed by key literature items which we feel provide an important insight into the project. External consultations we've undertaken, and previous work completed on the project will also be introduced and explored in more detail. The scope of our work for this project including objectives, deliverables, and key design activities are next up. The, in the final sections of our report, we will include some product specifics which encompass requirements, a high-level overview of the project, a defined work plan for the project, and some resource information. A summary will then conclude the report.

2 Background and Motivation

Briefly put, the main objective of our project is to develop an autonomous vehicle capable of navigating a vineyard and picking grapes. This is a worthwhile objective because grape picking is labour-intensive, time consuming, costly, and we have identified a good business case. To start, we will identify end-users and stakeholders in the project. The application and need for VineBot are also addressed, including information regarding the wine industry in Canada, crop migration, and agricultural labour.

2.1 End-Users and Stakeholders

The end users and stakeholders of this project can be divided into two categories: internal and external. The internal stakeholders are comprised of ourselves and various BCIT faculty. Our external stakeholders are the end users and industry contacts who have been consulted for this project.

2.1.1 Internal Stakeholders

This capstone project is a continuation of a BCIT School of Energy (SoE) seed-funded project intended to investigate robotic agriculture management. Our previous achievements and the success of the capstone project will benefit the SoE in several ways. The more we achieve with this project, the more value we bring to the SoE investment. Due to its physically tangible nature, our project can be easily used for marketing purposes and promotion of the technical activities engaged in at BCIT.

We consider our mentor Craig Hennessey to be one of our key internal stakeholders. Craig has been instrumental in the proposal of the original SoE project and has agreed to be our mentor under the condition that we do our best to successfully achieve our design objectives. Craig has also been a proponent for a robotics-based design elective for the B.Eng. Electrical program. It is hopeful that the technology we explore may be helpful in implementing the course.

Our capstone coordinator, Jeff Bloemink is another internal stakeholder. His goal is to provide us with the knowledge and tools to execute a successful capstone project.

Finally, the three members of the capstone team are significant stakeholders in this project. We are poised to gain tremendous amounts of technical knowledge and design practice. Our project and team work can be leveraged in the future when seeking employment. Note, more information about our capstone team can be found in the Personnel section of this report.

2.1.2 External Stakeholders

Our first intended end users are employees of small and medium sized vineyards. Larger vineyards can absorb the cost of product lost due to the violent and indiscriminate techniques of current mechanized grape picking. We are hoping to create a proof of concept for what can be an accurate and efficient method of picking for smaller enterprises.

We have several industry contacts we will be consult. The first is Graeme Duncan of Naramata BC. Graeme owns and produces around 6 acres of Chardonnay grapes on his family owned property in the Okanagan.

The second is Kim Hoath, also of Naramata. Kim is a member of the International Sommeliers Guild (ISG), and an employee of BC VQA in Penticton, BC. The International Sommelier Guild is the world's leading licensed provider of Sommelier education. Established in 1982, the ISG has grown from its North American roots to become a truly global provider of Sommelier education and certification. BC VQA stands for "British Columbia Vintners Quality Alliance". The BC VQA program is an "appellation of origin" system, like the AOC and DOC systems utilized in France and Italy respectively. The BC VQA system guarantees origin and ensures that qualifying wines meet certain minimum quality requirements.

2.2 Application and Need

Agriculture is a large part of the Canadian and American Economy. With the increasing opportunities in Canada for agriculture due to pending climate change induced crop migration in the near future, new methods for harvesting and monitoring crops will need to be developed [5].

2.2.1 Wine Industry

Canada is home to 720 wineries and vineyards [1]. The wine industry in Canada occupies a large share of in the agricultural market and continues to grow. A total of $7.2 billion worth of wine was sold in Canada in 2012, with a gain of 3.1% from the previous year and almost all provinces reporting gains [6]. $992 million of this was Canadian domestic shipments, and $61.8 million was exports [7]. This reflects well on the demand for Canadian wine. As for the current market, Figure 1 shows the projected growth of wine industry [8].

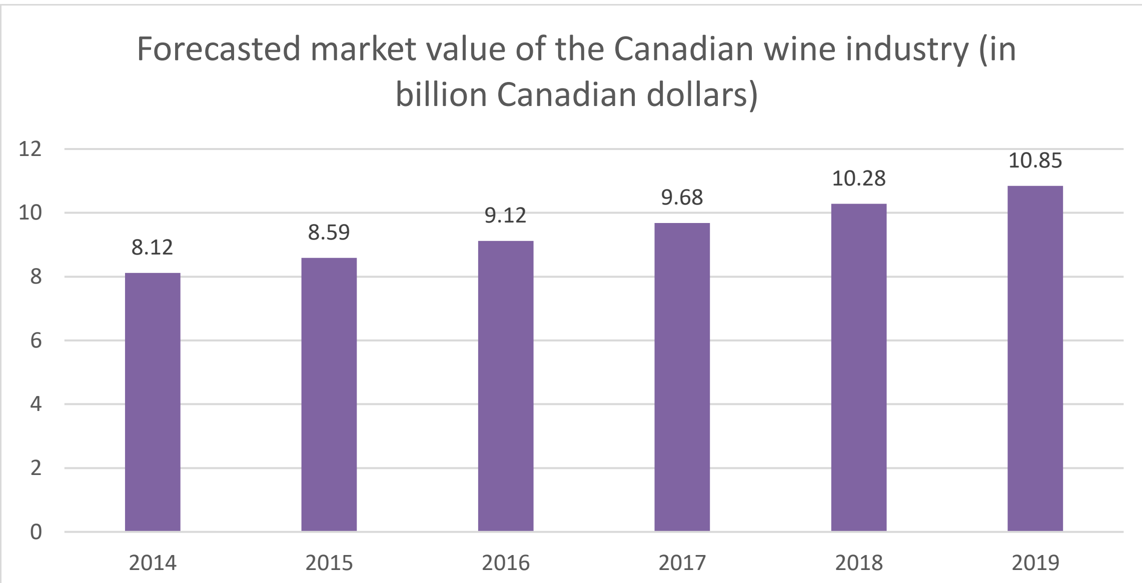


Figure 1 - Projected Market Value of Canadian Wine Industry (Courtesy of Statista)

Canadian winery global exports totaled $145 million dollars in 2017, with growth in the years leading up [9]. Wine exports are currently less than wine imports, but this could one day due to crop migration, and increased growth in the local wine industry.

As British Columbians, we have a vested interest in our provincial successes. Research of the industry from 2012 indicates that most wine-making establishments operate in British Columbia and Ontario. At the time, the industry employed over 3,700 people [10]. As the wine industry continues to grow, it is expected that employment will also increase. Automated solutions could be the answer to filling these new roles.

2.2.2 Labour

"In 1921, agriculture was the single most common occupation," and throughout the years "farms have become more specialized and the average farm size has increased [2]." However, with the projected market growth in agriculture, labour shortages have become of great concern. "In 2014, 26,400 jobs went unfilled in Canada's agriculture sector [11]." The sector lost $1.5 billion in revenue which continues to impact the sector today [11]. Future growth of the industry is stunted, and expansion plans have been delayed due to growing concerns that labour will not be available as readily. These shortages exist even with the Canadian government's Temporary Foreign Worker (TFW) program that brings workers from Mexico for periods of 8 months [12]. Many wineries take advantage of this program but are required to pay for round-trip travel and provide accommodation for the workers. These are costs that could be reduced with automated picking robots.

The labour shortage isn't a problem only in Canada. According to the California Farm Bureau Federation survey, "55 percent of responding farmers had experienced employee shortages [3]." That study also outlined that "[problems] have been more acute among farmers whose crops require the most intensive hand labour, such as tree fruits and grapes." When asked what actions they have taken in response to employee shortages, one- third of respondents said they used mechanization if available; another 29 percent attempted or investigated mechanization. This provides ample opportunity for automation to fill the need in other sectors of agriculture, not just wine.

2.2.3 Crop Migration

Crop migration refers to the drift in growing location of crops due to either an increase or decrease in suitability of growing in that region. The US has already seen northern migration of some crops such as soy beans and corn. This brings the question of whether agricultural regions could move North into Canada. According to Agriculture and Agri-Food Canada, most studies of the impact of climate change suggest that most regions of Canada are projected to warm during the next 60 years.

Despite the known challenges that come with climate change such as drought and storm intensity, there are opportunities for the Canadian agriculture industry. Canada is a high latitude country, which brings more pronounced warming than the global average. This could lead to expansion of the growing season to go along with milder and shorter winters like those seen in Arizona and California [4]. Many areas of the country that are typically thought of as frigid and inhospitable for growing could soon turn into usable agricultural land [13]. Climate change may also improve soil quality by enhancing carbon sequestration.

Without the available labour pool, this potential for climate-change induced growth in Canadian agriculture could be squandered. This is another opportunity for agricultural automation to thrive.

2.3 State of the Art

We were not able to find any current methods of precision picking of grape clusters. A patent was filed in 2004 for a "Robot Mechanical Picker System [14]," but despite its merits, it would not be suitable for grapes. We found many examples of robotic picking solutions for other types of fruit. The primary non-precision method of grape picking is outlined in the next section.

2.3.1 Current Grape Picking Systems

For some vineyards, hand picking of grapes is still preferred over mechanized systems due to the higher picking quality. Some larger vineyards have been experiencing labour shortages and have moved to

Figure 2 - Pellenc Group Optimum Harvester (400,000 USD)

mechanized systems. One example is a Washington vineyard's [15] use of the Optimum system (Figure 2). The machine is built by the Pellenc Group, a company that has been manufacturing agricultural tools since 1973.

This 400,000 USD harvesting system indiscriminately scrapes a series of arms across the plants and knocks the berries into a sorting system that also filters out stems and other materials other than grapes (MOG). As seen in the above picture, there is plenty of potential for damage to the grapes and they must be used quickly. The yield is high, but the quality is low.

2.3.2 Precision Fruit Picking Systems

Some of the common precision picked fruits include bell peppers, strawberries, and apples. A commonality can be seen here in that these are all general brightly colored fruits that are distinct from the canopy and leaves around them making them easier to detect than green grapes on a green canopy, for example.

One solution that stood out in our research, is the Sweeper robot (Figure 3). This is a multi-institute project funded by the EU Horizon 2020 research and innovation program [16].

Figure 3 - EU Funded SWEEPER Bell Pepper Picking Robot (4,000,000 EUR)

The project is the result of 4 million EUR being allocated to various universities and businesses for development of a picking solution tailored for use specifically in greenhouses. It uses depth cameras and detection models trained specifically for the pepper plants to identify ripe peppers. The robot is confined to tracks that run between rows of plants.

Strawberry harvesting can currently be completed by the AGROBOT, a 100,000 USD robot that requires uniform row spacing to conduct picking operations (Figure 4). The vehicle may be equipped with up to 24 small robot arms that pick individual berries.

Figure 4 - AGROBOT Strawberry Picker

Google Ventures has taken the lead in investing in Silicon Valley based startup, Abundant Robotics, to the tune of 10,000,000 USD [17]. This budding company is demonstrating their suction-based apple picking system. The system (Figure 5), which is essentially a horizontal mounted delta robot, can pick apples from the trees with minimal bruising or other damage.

Figure 5 - Abundant Robotics Apple Harvesting System

2.4 Key Literature Identified

In this section we will highlight some of our most relevant and useful literature sources.

2.4.1 Reports

Our report from Agriculture and Agri-food Canada [4] outlines the possible changes Canada could see in the future with regard to climate change induced increase in farmable land. This report describes the increase in farmable Canadian land that could accompany global warming due to shorter winter seasons. It also details the drought conditions and high storm intensity that we could face if warming increases even further.

Statistics Canada has a great report [18] which provides insight into the Canadian wine industry, which includes information regarding exports and local sales. Similarly, an excerpt from a Statistics Canada report yields the sales of alcohol in different categories (Wine, Beer, Spritzers) [6]. Wine makes up 32% of the alcohol market in Canada and grew 3.2% from 2017.

One of our top papers comes from a project sponsored by the EU's Horizon 2020 initiative. The project, a four million Euro conglomeration of various universities and industry partners carries the objective of picking greenhouse bell peppers autonomously [16]. The Horizon 2020 website contains a repository of all the papers submitted by each agency, and our selected paper outlines development and testing conditions used for their proof of concept. This paper gave us the idea of training a machine learning model to detect the grape clusters.

2.4.2 Patents

A 2005 patent awarded to Vision Robotics outlines a Robot Mechanical Picker System and Method [14]. The patent describes an autonomous robot that makes its way through crops, maps fruit locations, and plans a picking strategy for its harvesting counterpart. The patent outlines the fact that harvesting with the same vehicle that does the mapping may be too computationally intensive. In the 13 years since the patent has been filed, technology has increased to the point where it is now feasible for this to be done.

2.4.3 Relevant Codes and Standards

A relevant standard that may apply to our project is CAN/CSA-Z434-14 Industrial robots and robot systems. While we do not currently have access to this standard, it covers safety requirements for automated robot systems in a variety of industries. This may include autonomous agriculture, but the industry is still too new to have completely developed safety standards.

2.4.4 Technical Resources

A repository of robotics algorithms for autonomous navigation posted by Atsushi Sakai, an autonomous navigation system engineer from Japan. He was nice enough to include documentation, which clearly communicates the basic idea of each algorithm and provides visualizations to demonstrate their use [19].

2.5 External Review and Consultation

2.5.1 BBA

We gave students from the Bachelor of Business Administration (BBA) program a short abstract of our project, as well as a short summary of our objectives related to this project. In return, they gave us a business analysis of our project. We found it useful to note that trying to become a price leader during commercialization would result in the start and increase of demand for VineBot. The BBA students pointed out how our lack of internal marketing and advertising specialists, could potentially lead to problems since advertising is an important aspect of any business.

The BBA students informed us of opportunities including the continuously growing industry and the relatively low competition regarding small-to-medium-sized customers. This confirmed our intuition and was useful as verification.

2.5.2 MAKE+

The consultation at the BCIT MAKE+ center allowed us to form some new relationships between visiting researchers, which can be used further in the project. General take-aways from the consultation included networking with a manufacturing expert who suggested we use vacuum molding to build an attractive outer shell for the VineBot before the capstone exposition. We also gained the contact info of an SFU mechatronics graduate student, Garrett Kryt, who could serve as a helpful resource for any of our complicated robotics questions.

2.6 Previous Work on SoE VineBot

Since this project was proposed originally from the School of Energy (SoE), work has already been accomplished. A main objective of the SoE project was to streamline data collection from the field, including the use of remote imaging. This imaging could be used to estimate crop yields and assess plant health without human intervention to increase the operational efficiency of a vineyard.

A vehicle was intended to be constructed for the purpose. The vehicle would need to be able to navigate a vineyard autonomously, would have to be rugged enough to withstand the terrain of a vineyard, and would need to be able to collect data.

2.6.1 Navigation

Navigation of the vineyard involves driving down rows of grape plants and knowing where trellis posts and other objects are so that VineBot can avoid obstacles and mitigate the risk of collision. To aid in navigation, a rotary LiDAR sensor was used along with an inertial measurement unit (IMU).

LiDAR

A two-dimensional rotary Light Detection and Ranging (LiDAR) unit is used to survey the immediate area around the vehicle for obstacles. This produces a point-cloud map (Figure 6) with the origin defined as the location of the sensor. The point-cloud by its self is simply a series of data-points in a cartesian coordinate system.

To retrieve meaningful information from this data, associative clustering algorithms are applied to divide the dataset into groups that follow the natural structure of the data [20]. Through this process, the data-points for each observed physical object such as surrounding structures, vine trunks, and trellis posts, are divided into individual clusters. By applying a series of statistical analysis algorithms to each cluster, clusters can be classified as erroneous data-points, surrounding structures, and vineyard structures. Objects other than the grape vines and related trellis posts can be removed from the data-set to simplify further processing [21].

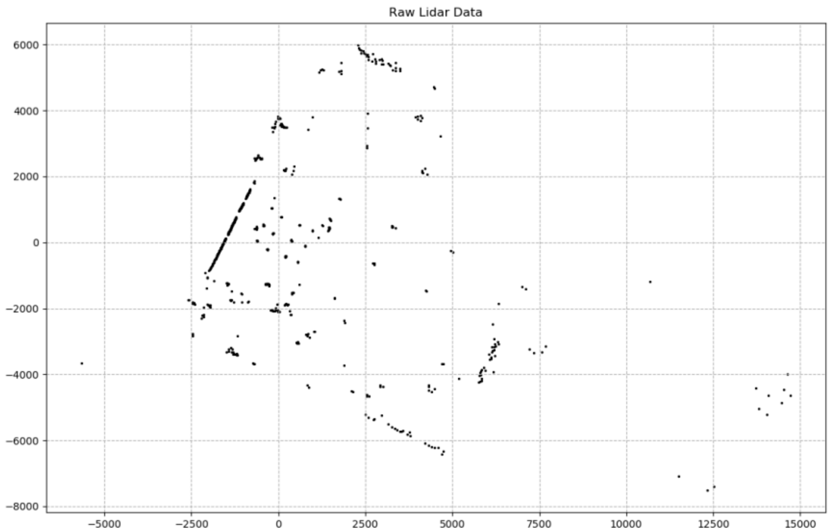


Figure 6 - Raw Lidar Data

A reasonable estimate of the location and orientation of the vine rows around the vehicle can be produced through further statistical analysis of the clusters. By analyzing the distances and angles between each cluster representing a grape vine or trellis post and applying a series of probability distribution functions (Figure 7) to these metrics, an educated guess can be made as to the position of the vine rows. In addition, a probability of accuracy can be associated with each resulting vine row, as seen in Figure 8.

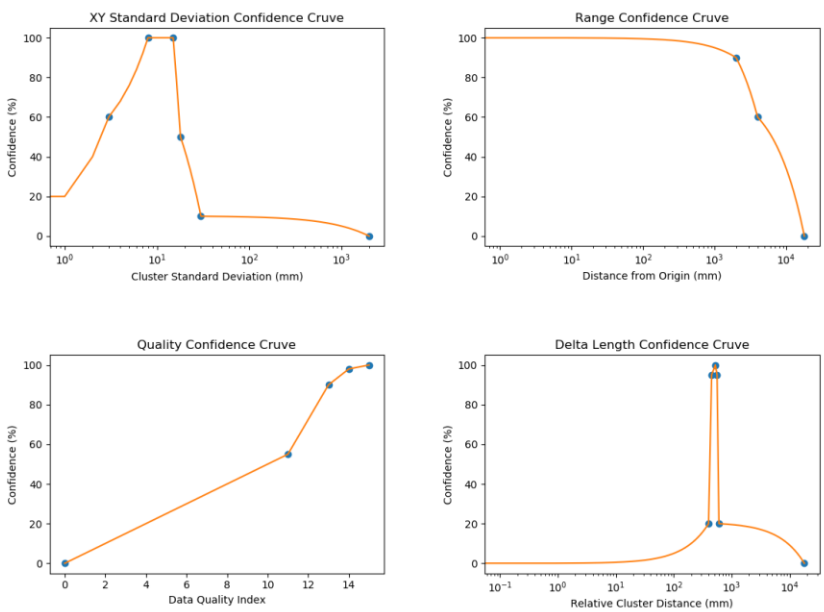


Figure 7 - Confidence Curves for Statistical Analysis

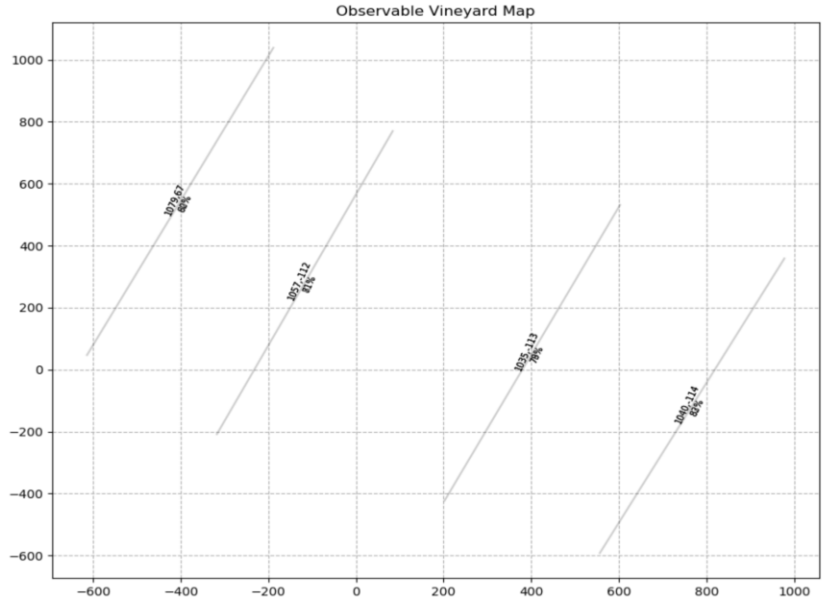


Figure 8 - Computed Vineyard Rows

From the Figure 8, it appears that no meaningful patterns can be extracted. To give meaning to data points, clustering techniques found from a third-party source were used with modification for our purposes [20]. In terms of statistical quantification, confidence intervals show in Figure 7 provide insight into how linear rows were filtered from the data set [20].

Inertial Measurement Unit

The vehicle contains an Inertial Measurement Unit (IMU), comprised of a gyroscope, accelerometer, and magnetometer. In order to leave the navigation system with the possibility of GPS use in the future, we have developed an IMU server on the device that can be accessed by any software being developed. This server allows access to the vehicle's compass bearing after adjustment for local variation (declination), as well as access to the acceleration forces being felt by the vehicle with respect to North as seen on a GPS. The server also provides information as to how far the vehicle is tilted in any direction and could be used to avoid situations where the vehicle could overturn.

2.6.2 Mechanical Design

Due to the software-rooted nature of the original SoE project, a kit-built vehicle platform was utilized to minimize time spent on mechanical design. The Actobotics Nomad platform (Figure 9) was chosen for its cost effective yet rugged nature. The vehicle dimensions are 15 in long, 9 in high, with a wheel base of 13 in.

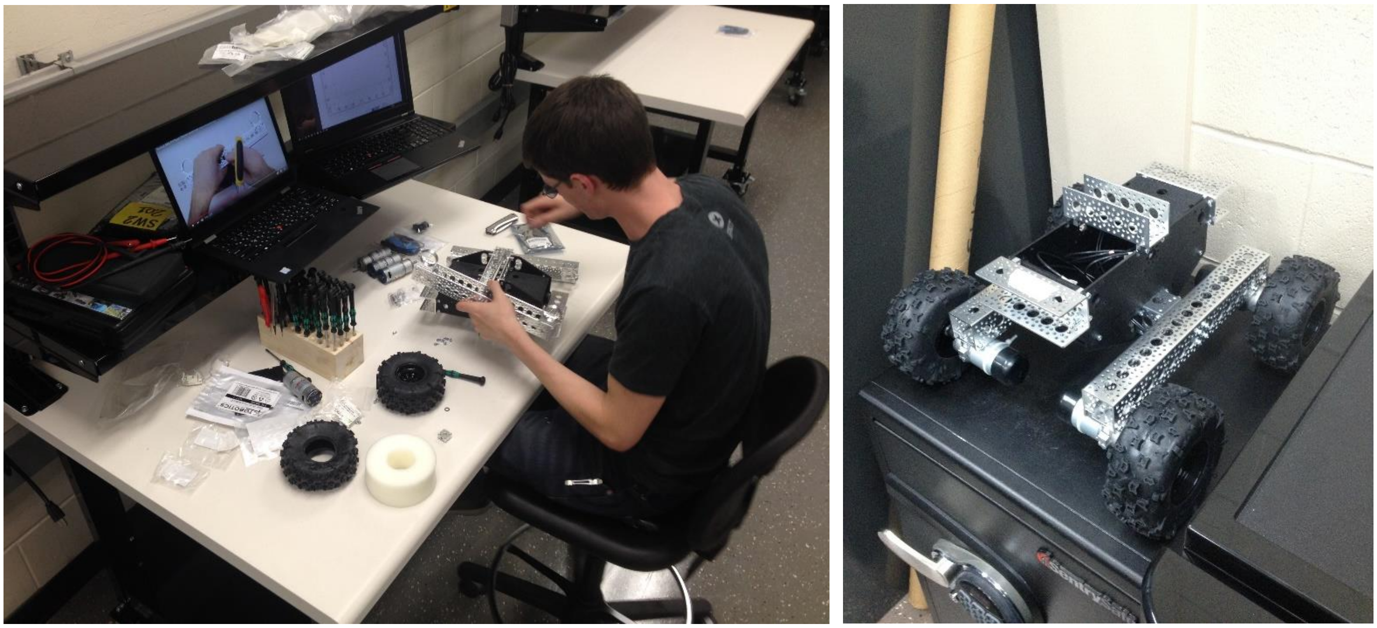


Figure 9 - Nomad Kit-Based Robotics Platform

The vehicle structure is constructed from a rigid aluminum channels, planetary gear hand drill motors, a chassis with cut-outs for various accessories, and an internal cavity for circuitry. The vehicle is equipped with rubber tires intended for outdoor all-terrain use. Electrical component placement in the current VineBot prototype, shown in Figure 10, has been chosen arbitrarily to leave the final positioning flexible.

Figure 10 - Current VineBot Vehicle Prototype

3 Scope of Work

To better understand how we plan on providing value to vineyard owners, the scope of our work needs to be defined. Some objectives and goals associated with this project will be introduced, including a more general strategic plan which will help outline steer our group in the right direction, and an operational plan which will cover the implementation of our goals. The plan can be broken up into key design activities.

3.1 Recommended Long Term Objectives

Based on feedback and objectives outlined by the SoE, and through discussions with industry partnerships, some recommended objectives have been drawn up. These objectives include both general goals for the project, but also delve into more technical ambitions.

3.1.1 General Goals

A basic goal of this project is to support Canadian agriculture. The Canadian agricultural industry can benefit greatly from the innovative works of engineering students, by ways of a creative-destruction culture. This also ties in another goal, which is to facilitate competition with California, Europe and Japan agriculturally, since British Columbia is an agricultural competitor of these regions.

Lastly, having this project help facilitate in creating a robotics design elective for B.Eng. students at BCIT is also an outcome we hope to achieve. It is hopeful that the technology we explore may be helpful in implementing the course.

3.1.2 Technical Objectives

Various vision and lighting methods with the help of image processing should make the vehicle adequate for operation at night. Another technical objective for the vehicle is to be able to make use of a mechanical end effector for selectively picking entire grape clusters, without the need for human intervention.

3.1.3 Future Vision

For the VineBot project, we hope to expand on previous work to develop a minimum viable product (MVP) VineBot all the way up until the end of our project term in May. If we finish the MVP VineBot early, there are some optional objectives which we plan on accomplishing.

If time permits, and a product created by our team is deemed to be adequate, The DARPA Grand Challenge Winter may be a competition that our project could be entered in. Another optional objective would be to experiment with lighting. Since a large chunk of our project involves image recognition, further research into lighting for computer vision, and image processing techniques that can be used to help reduce the effects of bad lighting could also be explored. Due to the modular design of the project, we may also want to investigate selectively harvesting other types of produce which are hard to mechanically pick, including blueberries and cannabis. The modular design philosophy may require partial redesign of some components but would bring added value.

3.2 Capstone Project Objectives

Working in consultation with local wine producers (Okanagan Valley, Lower Mainland) is an objective of this project. Their engagement with our engineering team and feedback on the MVP would be very valuable.

In terms of more technical requirements, the main objective for our group is to design and implement a proof of concept autonomous vehicle capable of navigating a vineyard to pick grapes while also avoiding obstacles.

Another objective is to become proficient in use of machine learning for image processing, 3D cameras, GPU processing, LiDAR processing, and robot motion and path planning.

A final objective is to have a professional demonstration of our project ready for the year end project exposition, with the goal of showcasing our project to students, public, faculty, and prospective employers.

3.3 Deliverables

We would like to have the following deliverables by the end of the project:

5. A proof of concept autonomous grape picking vehicle
6. A final report documenting our project by the end of the project term
7. An organized git repository with extended project documentation
8. A live demonstration of the project for the technology expo including signage and literature

3.4 Key Design Activities

To facilitate the flow of the project from design to implementation, we have drawn up some key design activities. These activities help segment parts of VineBot so that group members can work on VineBot while avoiding redundancy. As such, design activities have been created so that they are, to an extent, mutually exclusive of each other.

The vision design activity requires handling all the vision requirements for the project, including coming up with the algorithms and methods for locating grapes on a grape vine, providing coordinates for the VineBot robotics system, handling lighting requirements, and creating images ready for transmission. The vision requirements also involve choosing vision hardware for things like machine vision, and multispectral imaging.

Robotic motion control of VineBot is included in the motion control design activity. This activity involves choosing relevant robotics equipment so that VineBot can efficiently reach for and pick grapes. Picking grapes based on given location is also part of this design activity, by means of precision coordination of a robotic arm, as well as a distance detection.

Moving VineBot up and down a vineyard falls under the navigation design activity. This activity involves having VineBot navigate a vineyard and be able to move based on various inputs. Calibration of motors and selection of motor control algorithms are done at this stage of the design. Navigation based on sensors is also part of this design activity. Sensors and technologies to help with obstacle avoidance and path planning such as LiDAR and GPS are selected and interfaced.

After all the other critical design activities have been carried out and appropriate testing has been done, integration of each system must take place. Integration involves choosing a central processing unit and interfacing the unit with each individual system. After the system has been tested, adding the system to the VineBot chassis should take place. The chassis should be modified to hold all components. Also, creating software which can be used to control and monitor the vehicle should be carried out in this design activity.

Finally, if time permits, a new chassis can be constructed in the chassis revision design activity. This activity requires mechanical design of a rugged chassis, which should be able to enclose all but necessary components to inside of VineBot. Optional design choices such as waterproofing and using flexible conduit can be considered at this stage of the project. Also, aesthetic design can be carried out.

4 Product Specifics

4.1 End-User and Stakeholder Requirements

Requirements have been developed in conjunction with project objectives described earlier. Most of them derive from the necessities to create the MVP, while some have been inherited from the original SoE project. In general, the project requirements can be broken up into five major sections.

- Vision Requirements
- Robotic Requirements
- Motion Requirements
- Processing Requirements
- Power Requirements

A full set of technical requirements can be obtained from the project requirements spreadsheet [22].

4.1.1 Vision Requirements

For the vision requirements of the project, our solution would need to have one or more cameras which can stream video via a USB interface. This simple requirement supports object recognition, navigation of the vehicle, and even control over where the robotic end-effector should move.

Lighting can also be an issue when it comes to machine vision systems. In a factory setting lighting can be somewhat controlled, however out in a vineyard, controlled lighting can pose a challenge. Adequate lighting needs to be provided to the vision system such that the outside lighting conditions won't affect the performance of our device. This can be implemented by having physical lights on the device, or by image processing techniques. Some other associated vision requirements include the ability to identify grape clusters, identify grapes of three different colors, and identify points in space using the camera(s). Preference should be given to detection algorithms that don't rely on color but can rely on the physical shape of the grape clusters.

4.1.2 Robotic Actuator Requirements

The robotic actuator requirements of the project are in place so that picking the wine grape plants can be done effectively without being exceedingly expensive. This will limit us to use of the uArm Swift Pro robot arm. The most basic, and possibly most important requirement for the robotic picking is that the process doesn't damage the grapes or grape vines.

When it comes to picking the grapes, the robotic system needs to be able to move to a specified location (point in space). This location will likely come from the vision system and may have some error associated with it. To account for this error, a tolerance of half of the grasping width of the end effector opened, half of the length of the end-effector, and 3/8 of an inch up and down can considered a valid target for starting picking with the stock end effector on the Swift robot. These tolerances may be different when we implement a cutting mechanism.

The weight of the end effector, camera and a lighting apparatus chosen for the vision requirements, as well as the picked grapes should fall within the usable payload of the robot arm.

A minor requirement for on the robotic side of things is that there is minimal to no oscillation. The feedback control for arm position should reach its target without overshooting.

4.1.3 Vehicle Motion Requirements

The motion requirements of the project are important because they define how our vehicle should navigate a vineyard. Goals of the project first introduced by the SoE included the use of GPS and LiDAR for navigation, but we will be limiting our scope to LiDAR navigation for the capstone project.

The first requirement is that the vehicle should be able to navigate a vineyard comprising of grape vine trellises. In combination with the vision system, the vehicle shouldn't need a pre-programed route through the vineyard. Another requirement stated is that the vehicle should be able to move along the rows, avoiding obstacles in its path. If the vehicle were to veer off towards a trellis post, the vehicle's navigation system should be able to recognize this and change the heading appropriately. Lastly, the motor requirement is such that the vehicle should move the weight of itself and all the equipment during operation.

4.1.4 Processing Requirements

Coordination of the robot systems will be done on one or more single-board computers. Requirements for this system include the ability to run C, C++, and Python languages, since these are common programming languages for robotic development. Data should also be able to be accessed remotely, so that debugging and updating can be done in the field.

The system can be comprised of a network of hardware devices working together but should use the least amount of power possible. Due to these requirements, the chosen system should use the least number of devices possible and should have as many built-in peripherals as possible. The system is also required to have GPIO pins which can be used for attaching sensors and other external peripherals.

Other hardware requirements include the need for USB ports, a multi-core processor, and support for common device communication technologies such as UART, SPI and I2C.

4.1.5 Power Requirements

Due to the previous SoE work, the power requirements have already been determined. The current power system allows about an hour of testing, and the addition of a robot arm will most likely shorten this duration. The power system should be able to handle the load of all the motors spinning with the vehicle fully equipped, with the processing system running. The power system should provide a single, or multiple regulated output supplies of standard low voltages (e.g. 3.3V, 5V, 12V). The sources should also be rechargeable and swappable, so that the device can be easily operated by the end-user.

4.1.6 Documentation Requirements

The final report will be completed using the LaTeX document publishing language. Source code will be commented, and any frequently used custom APIs will be documented in Markdown on the git repository. Any required dependencies will be documented. The source code should be laid out in such a way that it can be downloaded and run easily in an identical vehicle.

4.2 Design

This section contains technical information describing the implementation of the various systems required to meet the project objectives.

4.2.1 High-level Overview of Project

To best describe how VineBot can be implemented, the systems which control the robot and the flow of information between those systems are shown in Figure 11 below.

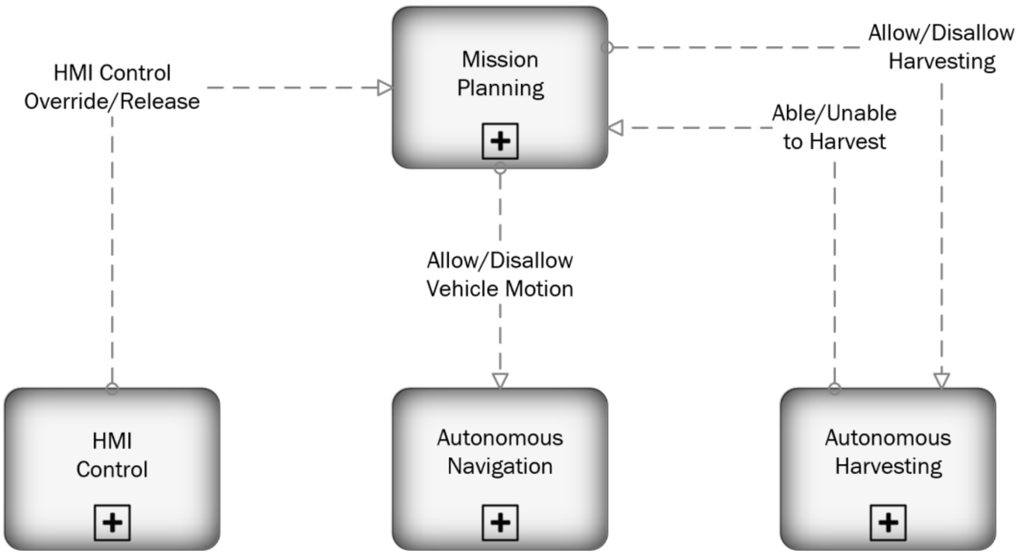


Figure 11 - Integrated Systems Block Diagram

This simple program structure facilitates independent development and validation of the navigation, harvesting, and Human-Machine Interface (HMI) systems prior to complete integration. Development and implementation of the Minimum Viable Product (MVP) can be carried out in steps with each system. For complex systems, further segmentation can take place at a sub-system level.

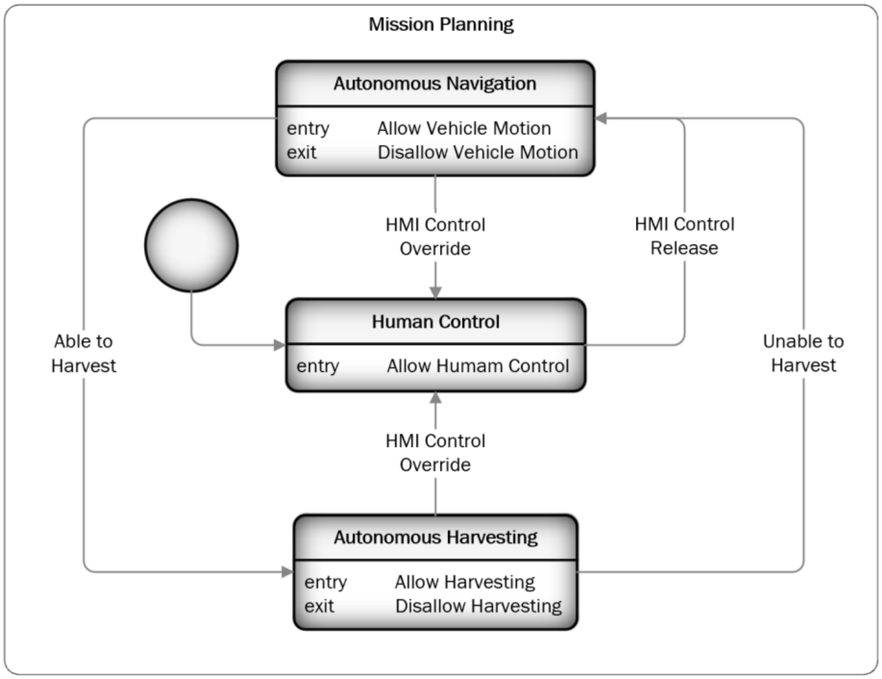


Figure 12 - Mission Planning System State Diagram

The mission planning system will be a state machine that coordinates write permissions of each system to peripherals such as the drive wheels and picking arm, as shown in Figure 12 above.

At startup, the VineBot will be put into the *Human Control* state. To begin autonomous operation, the HMI control system will notify the mission planning system of *HMI Control Release*, triggering the entry of the *Autonomous Navigation* state.

The *Autonomous Navigation* state will allow the VineBot to autonomously drive up and down the rows of a vineyard while the harvesting system is searching for grape clusters that can be reached by the picking arm. Once a grape cluster is found to be within picking range, the harvesting system will notify the mission planning system that it is *Able to Harvest*, triggering the entry of the *Autonomous Harvesting* state.

The *Autonomous Harvesting* state will ensure that the vehicle comes to a complete stop before allowing the harvesting arm to commence picking. The harvesting system will then pick the cluster(s) located within range of the picking arm, and once complete, notify the mission planning system that it is *Unable to Harvest*, triggering the entry of the *Autonomous Navigation* state.

The HMI control system will be able to interrupt an active *Autonomous Navigation* or *Autonomous Harvesting* state by notifying the mission planning system of *HMI Control Override*, triggering the entry of the *Human Control* state. This will interrupt the either the navigation or harvesting systems by bringing the VineBot to a complete stop and returning the harvesting arm to the stored position. An immediate response is necessary as this will be the method of performing a remotely activated emergency stop of all systems in the case where damage to the vehicle or people is imminent. The HMI control system can relinquish control back to the autonomous systems by notifying the mission planning system of *HMI Control Release*, triggering the reentry of the *Autonomous Navigation* state.

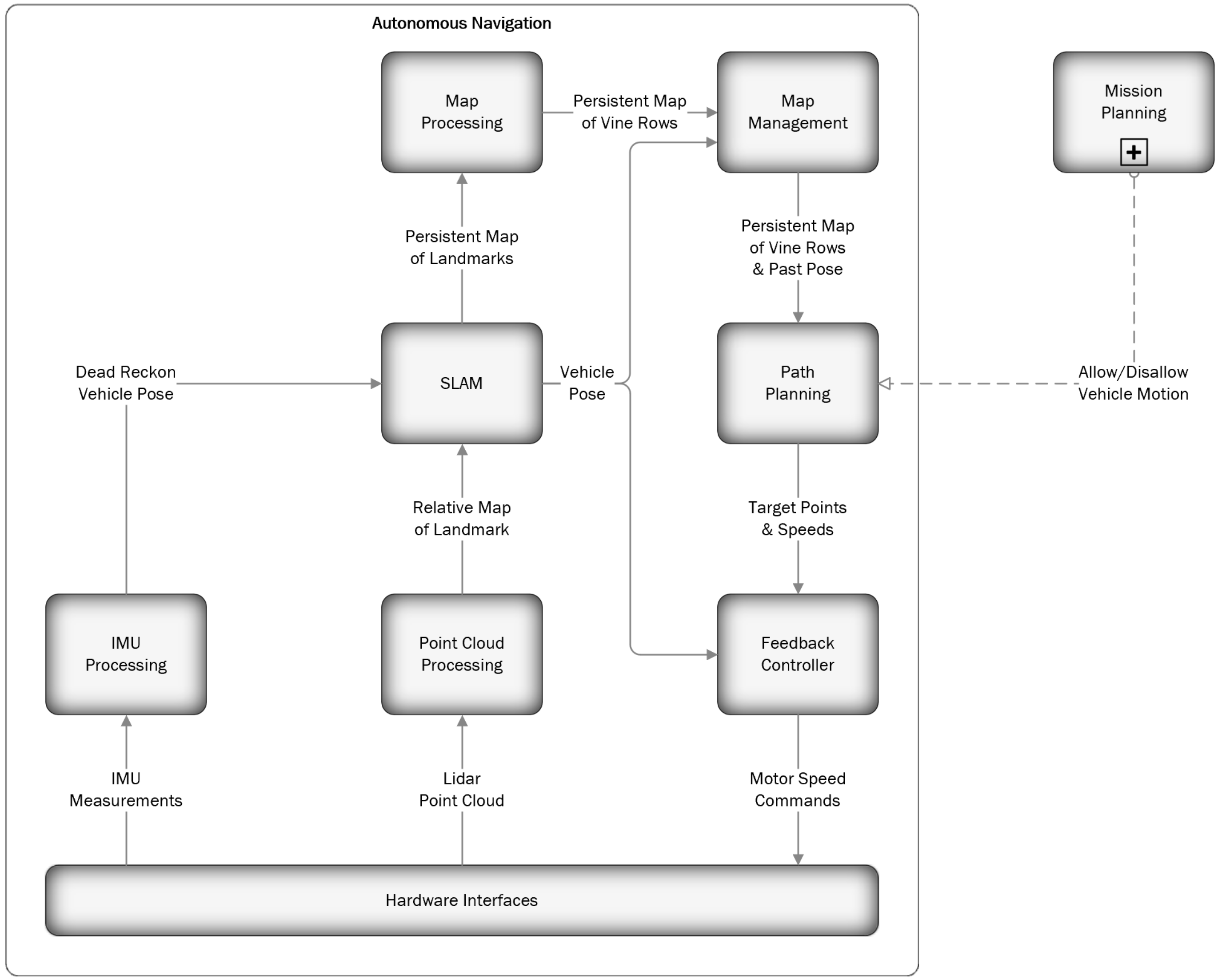


Figure 13 - Autonomous Navigation System Block Diagram

The autonomous navigation system will maneuver the VineBot along the rows of a vineyard without human aid to facilitate the search of harvestable grape clusters. Due to the limited rotational motion of the harvesting arm, harvesting will only be able to occur on one side of the vehicle. The VineBot will must keep the grape vines on the harvesting side of the vehicle within reach of the harvesting arm while navigating down a vineyard row. To accomplish this, the navigation system will consist of three major systems: SLAM, Path Planning, and a Feedback Controller. The layout of the autonomous navigation system can be seen in Figure 13 above.

A SLAM (Simultaneous Localization and Mapping) algorithm will be used to determine the current location of the VineBot with respect to the vineyard and construct a persistent map of the vineyard. This algorithm requires low-latency LiDAR scan data that has been processed to extract relevant landmark locations, consisting of vine trunks and trellis supports. The accuracy of the SLAM algorithm can be greatly improved by applying dead reckoning vehicle pose with an Extended Kalman Filter (EKF). The dead reckoning will be performed by the IMU processing system which will integrate vehicle acceleration measurements from the IMU to get position. The output of the SLAM algorithm will be a persistent map of landmarks and the vehicle's current position with respect to that map. The map processing system will be used to determine where the vineyard rows are based on the locations of vine trunks and trellis supports. The map management system will be used to add persistence to the vehicle pose from SLAM, facilitating the implementation of an efficient path planning algorithm.

The path planning system will be responsible for generating a path that will facilitate the efficient picking of all grapes within a vineyard. This includes decisions as to the direction the vehicle must travel to pick a specific grape vine based on the set harvesting side, whether both sides of a given grape vine should be picked, and at what speed the vehicle should travel for performing different tasks. The output of the path planning system will be a series of coordinate points with associated speeds forming a continuous path with respect to the persistent vineyard map. When vehicle motion is disabled by the mission planning system, the output path will be overwritten with a single target point for the vehicle to drive to and come to a complete stop.

The feedback controller system will consist of two feedback loops: vehicle speed and vehicle heading. This will keep the vehicle on the path generated by the path planning system. The output of the feedback controller system will be motor speed commands that will control the left and right drive wheels.

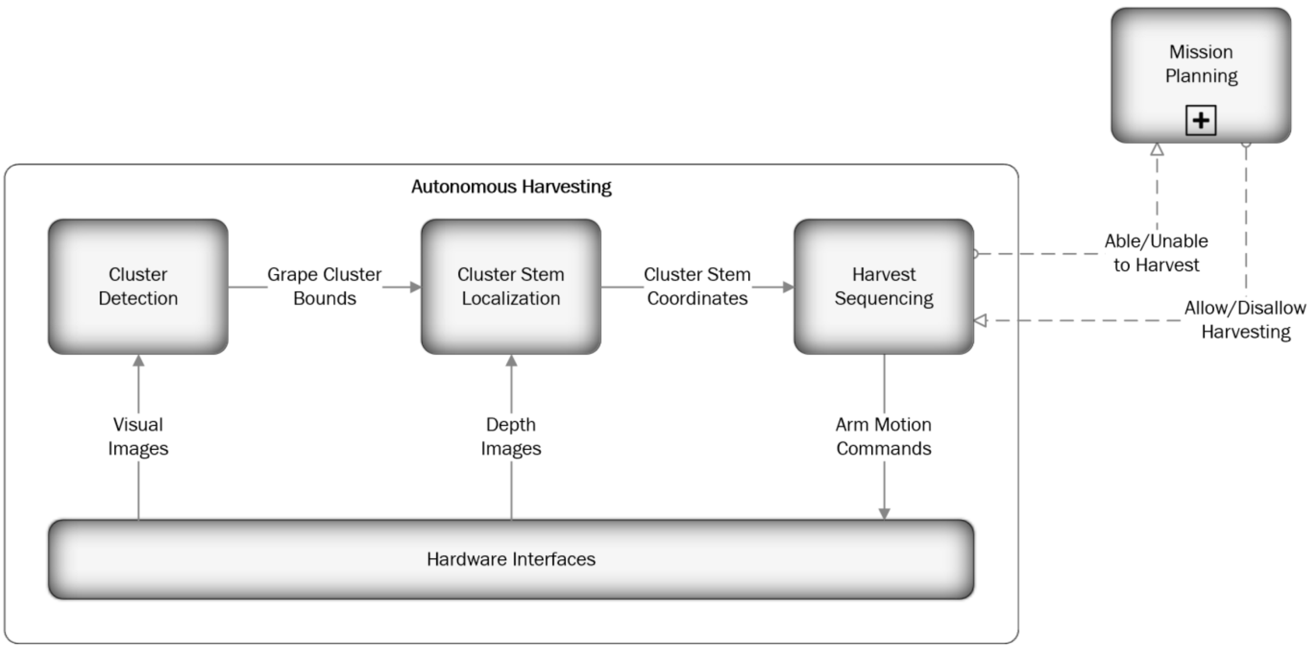


Figure 14 - Autonomous Harvesting System Block Diagram

The Autonomous Harvesting system will handle the identification of and subsequent harvesting of grape clusters within reach of the harvesting arm. To accomplish this, the harvesting system will consist of two main sections: machine vision and harvest sequencing. The layout of the autonomous harvesting system can be seen in Figure 14 above.

The machine vision systems will detect the presence of a grape cluster with the Cluster Detection system and then resolve the stem location using three-dimensional depth images. The Cluster Detection system will utilize a machine learning algorithm trained on a database of grape cluster images to determine the presence of and bounds of grape clusters within the visual image. The Cluster Stem Localization system will compare the bounds from the visual image with the content of the depth image to produce an estimate of the cluster stem location in three-dimensional space.

The harvest sequencing system will handle the coordination of the harvesting process with the mission planning system and will control the motion of the harvesting arm. When cluster stem coordinates are within the reach of the harvesting arm, the sequencing system will notify mission planning that it is able to harvest. Once harvesting is allowed by mission planning, the sequencing system will move the harvesting arm out of the store position and begin picking the clusters from the vine. When no harvestable clusters are available, the sequencing system will notify mission planning that it is unable to harvest, and it will return the harvesting arm to the store position.

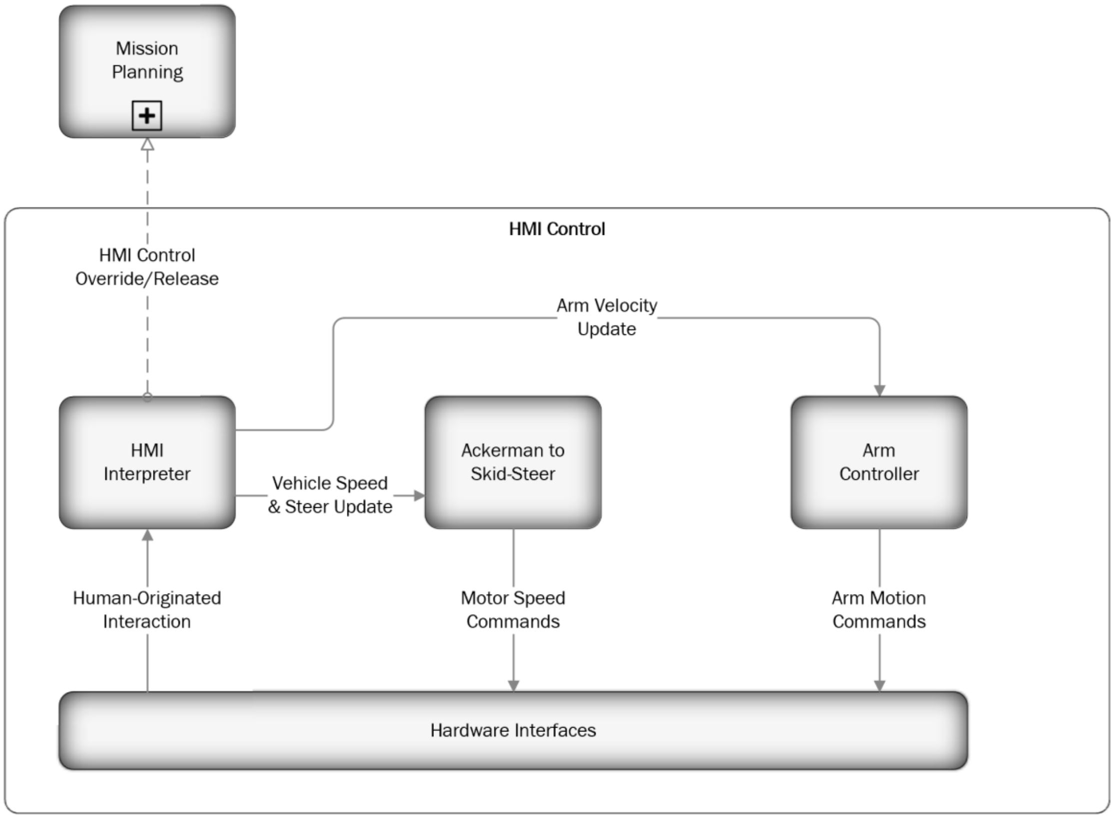


Figure 15 - HMI Control System Block Diagram

The HMI control system facilitates interaction between the VineBot and the human operator. The layout of the HMI control system can be seen in Figure 15 above.

Direct interaction via GPIO mapped hardware and remote interaction via TCP/IP socket will be handled by the HMI interpreter system. The interpreter system will map HMI events to actions to be performed and it will handle the *HMI Control Override/Release* coordination with the mission planning system.

4.3 Work Plan

For planning purposes, the project is set to commence on January 1st, 2019. Additional work will occur over the winter break as well. The final task in the project is to present a working prototype at the BCIT Project Expo around the 15th of May 2019. Significant work has been done on the project already and many of the following tasks build upon existing progress. A digital version of the work plan [23] goes into more detail of what exactly is going to be accomplished, and what resources are required.

4.3.1 Detailed Work Breakdown and Gantt Chart

The project will be broken down into three levels. The first level involves starting and working on the project, integrating the systems, and wrapping up the project with documentation and the project expo. The second level involves breaking each of the previous sections up into modules. The third level breaks up each module into specific subtasks.

Project Start (Level 1)

This first level of this section deals with many of the technical aspects of the project. The Level 2 tasks include: pose estimation and mapping, Computer Vision, Motion Control, Human Machine Interface (HMI), Mechanical Design and Miscellaneous Software Development.

Post Estimation and Mapping – Level 2 (56 Days)

This module involves the following Level 3 subtasks: creating LIDAR Point Processing Algorithms, System Localization and Mapping (SLAM) Implementation, and Path Planning.

Vision – Level 2 (73 Days)

This large module involves creating camera based grape detection systems and involves the following Level 3 subtasks.

Machine Learning (8 Days)

Navraj will be using a Google Open Image library of grapes to build a ML detection model on a GPU equipped computer. If this proves to be too slow, he will attempt to do the processing on the West Grid supercomputer cluster in order to decrease model update

Logitech Webcam Processing (29 Days)

Terry will be improving on an existing grape detection model implemented in the Open Computer Vision (OpenCV) library. Upon the success of this method, Navraj's ML model will be incorporated. Development of a lighting system to aid with grape detection will occur after these tasks.

PMD Pico Flexx (28 Days)

Terry and Navraj will be replacing the previous Logitech webcam with the PMD Pico Flexx time-of-flight 3D depth camera. This infrared camera is practically impervious to changing light conditions and allows us to measure distance from the grape clusters as well. Upon successful OpenCV grape detection, they will attempt to train and implement a ML model based on the depth images.

NVIDIA Jetson TX2 (16 Days)

The previously explored vision developments are PC based. To go one-step further, we plan on using the Nvidia Jetson TX2, an incredibly powerful single-board computer that is used for many autonomous vehicle projects due its graphics processing prowess. This Linux OS board will allow us to run computationally intense ML models on the actual vehicle, while consuming relatively little power. This subtask involves setup of the board and testing the previous programs on it.

Motion Control – Level 2 (14 Days)

This module involves completion of the uArm Swift robot arm motion system as well as a vehicle path following implementation. It is dependent on the previous vision work as well as the pose estimation and mapping module.

uArm Swift Pro (8 Days)

The current status of the robot arm allows it to be fed coordinates of an object relative to its field of view and slowly keep it centered. The control system needs to be modified to provide a faster response. After this is completed, the ability to maintain a certain distance away from the tracked object using the PMD Pico Flexx will be given. This will be managed by Terry.

Path Following (14 Days)

Brayden will be using his previous work on pose estimation to give the vehicle the ability to use its location information to plan and execute trips through the vineyard to look for grapes.

HMI – Level 2 (3 days)

This module involves giving the vehicle remote-control ability in order to conduct LIDAR mapping testing remotely and human-obstacle free. This will occur concurrently with the pose estimation tasks.

Mechanical Design – Level 2 (10 days)

This task involves any miscellaneous mounts or fixtures required for the robot. Up until this point, the cameras will have been temporarily attached to the robot arm.

Integration (Level 1)

Once the Project Start is complete, systems integration can begin. This involves setting a standard for Inter-Process Communication (IPC) so that the different modules can pass information efficiently and effectively. Once this is complete, the modules must be interfaced together under a master control module.

Inter-Process Communication Standard – Level 2 (7 days)

All three group members have developed methods of passing information between various systems using TCP sockets. A standard will have to be developed based on the requirements of each module. Some modules such as the OpenCV object detection modules required high speed transmission of camera data. Other systems require infrequent updates which don't have the same speed requirements.

Main Control Module – Level 2 (7 days)

The main control module involves the integration of each separate module of code. This will provide a single point of entry to the robot control code.

Verification – Level 2 (7 days)

This will involve running the system through a repetitive series of missions using the fake vineyard in preparation for the exposition. All team members will help with this testing.

Project End (Level 1)

This is the project wrap up stage.

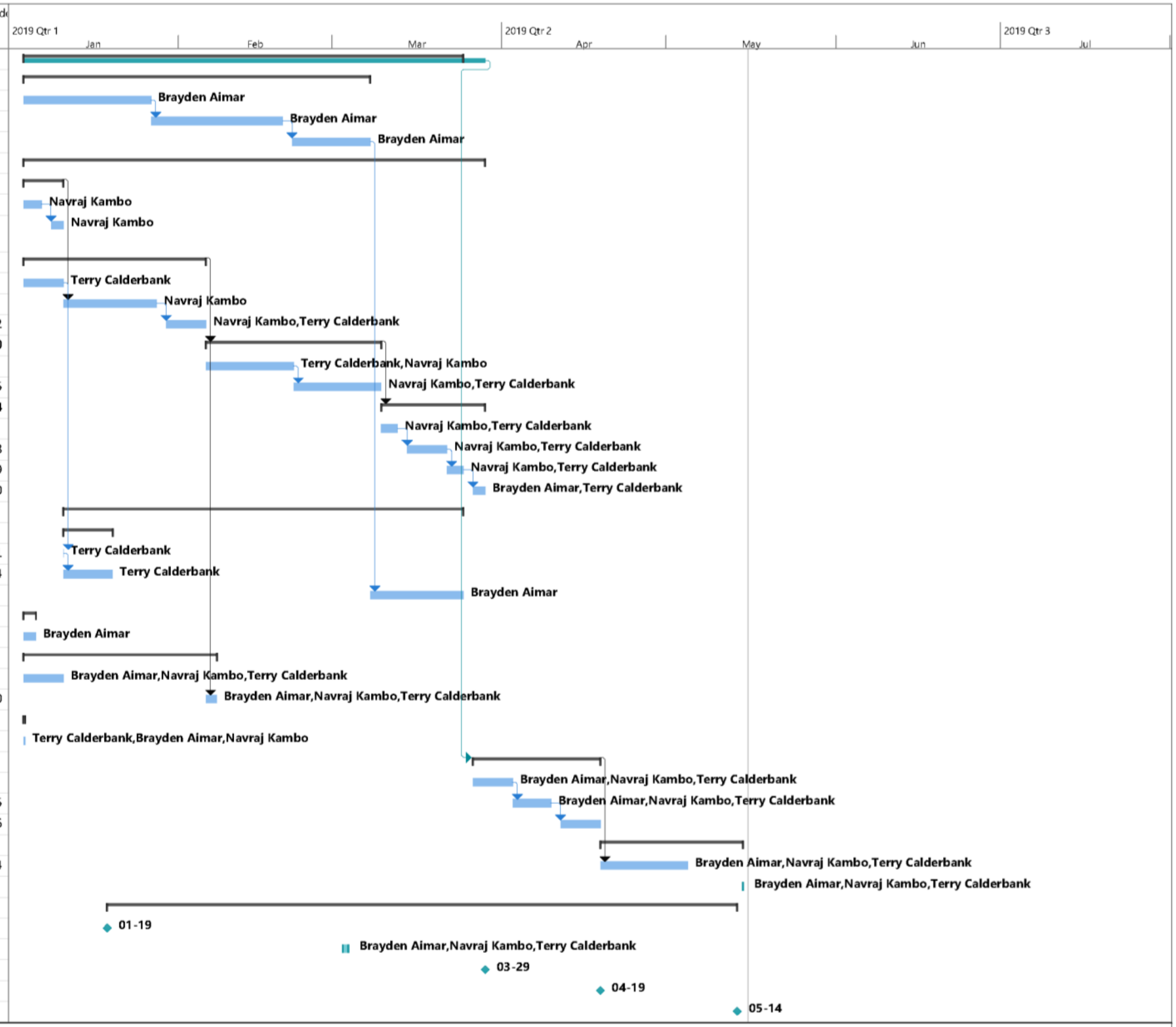
Final Documentation – Level 2 (7 days)

The final report will be written in LaTeX, the source code repository will be cleaned up and documentation expanded. All team members will contribute to this item.

Project Exposition – Level 2 (1 day)

This will involve demonstrating the project to the public, students, faculty, and any other industry attendees. We would like to have an extendable banner with our “product” and “brand” on it as well as some information on how the system works. We would also like to have all 16’ of artificial vineyard set up in a way that we can demonstrate the system during the expo.

ID	Task Name	Duration	Start	Finish	Predc
1	Project Start	70 days	Thu 19-01-03	Mon 19-03-25	
2	Pose Estimation and Mapping	56 days	Thu 19-01-03	Fri 19-03-08	
3	LIDAR Point Processing	21 days	Thu 19-01-03	Sun 19-01-27	
4	SLAM	21 days	Sun 19-01-27	Wed 19-02-20	3
5	Path Planning	14 days	Thu 19-02-21	Fri 19-03-08	4
6	Vision	73 days	Thu 19-01-03	Fri 19-03-29	
7	Machine Learning	8 days	Thu 19-01-03	Fri 19-01-11	
8	Build Model on GPU Machin	4 days	Thu 19-01-03	Mon 19-01-07	
9	Build Model on Westgrid Supercluster	4 days	Tue 19-01-08	Fri 19-01-11	8
10	Logitech Webcam	29 days	Thu 19-01-03	Wed 19-02-06	
11	Optimize OpenCV Only	7 days	Thu 19-01-03	Fri 19-01-11	
12	Webcam OpenCV with YOLC	14 days	Fri 19-01-11	Mon 19-01-28	7
13	Lighting	7 days	Tue 19-01-29	Wed 19-02-06	12
14	PMD Pico Flexx	28 days	Wed 19-02-0	Sun 19-03-10	10
15	Pico Flexx OpenCV Only	14 days	Wed 19-02-0	Fri 19-02-22	
16	PicoFlex OpenCV with YOLO	14 days	Fri 19-02-22	Sun 19-03-10	15
17	NVIDIA Jetson TX2	16 days	Sun 19-03-10	Fri 19-03-29	14
18	Setup	3 days	Sun 19-03-10	Wed 19-03-13	
19	Install Dependencies	7 days	Thu 19-03-14	Fri 19-03-22	18
20	Test Imaging	3 days	Fri 19-03-22	Mon 19-03-25	19
21	Inter-Device Communicatior	3 days	Tue 19-03-26	Fri 19-03-29	20
22	Motion Control	63 days	Fri 19-01-11	Mon 19-03-25	
23	uArm Swift Pro	8 days	Fri 19-01-11	Sun 19-01-20	
24	Integral Control	1 day	Fri 19-01-11	Fri 19-01-11	11
25	Distance / Gripping	7 days	Fri 19-01-11	Sun 19-01-20	24
26	Path Following	14 days	Fri 19-03-08	Mon 19-03-25	5
27	HMI	3 days	Thu 19-01-03	Sun 19-01-06	
28	Remote Control	3 days	Thu 19-01-03	Sun 19-01-06	
29	Mechanical Design	32 days	Thu 19-01-03	Fri 19-02-08	
30	Misc	7 days	Thu 19-01-03	Fri 19-01-11	
31	Camera Mounts	3 days	Wed 19-02-0	Fri 19-02-08	10
32	Software	1 day	Thu 19-01-03	Fri 19-01-04	
33	Misc	1 day	Thu 19-01-03	Fri 19-01-04	
34	Integration	21 days	Tue 19-03-26	Fri 19-04-19	1
35	IPC Standard	7 days	Tue 19-03-26	Wed 19-04-03	
36	Main Control Module	7 days	Wed 19-04-0	Wed 19-04-10	35
37	Verification	7 days	Thu 19-04-11	Fri 19-04-19	36
38	Project End	22.2 days	Fri 19-04-19	Wed 19-05-15	
39	Final Documentation	14 days	Fri 19-04-19	Sun 19-05-05	34
40	Project Expo	1 day	Wed 19-05-1	Wed 19-05-15	
41	Milestones	97.2 days	Sat 19-01-19	Tue 19-05-14	
42	Milestone 1	0 days	Sat 19-01-19	Sat 19-01-19	
43	Milestone 2 + Report	1 day	Sun 19-03-03	Sun 19-03-03	
44	Milestone 3	0 days	Fri 19-03-29	Fri 19-03-29	
45	Milestone 4	0 days	Fri 19-04-19	Fri 19-04-19	
46	Milestone 5	0 days	Tue 19-05-14	Tue 19-05-14	



Project: Capstone_Project.mpp
Date: Sat 18-12-08

Task	Project Summary	Manual Task	Start-only	Deadline	
Split	Inactive Task	Duration-only	Finish-only	Progress	
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress	
Summary	Inactive Summary	Manual Summary	External Milestone		

Figure 16 - Gantt Chart

4.3.2 Milestones

Milestone 1 (January 19th) – Visual Camera, Machine Learning Test, and LiDAR Processing Complete

At this point in time we would like to have moved past basic OpenCV processing and have a trained machine learning model doing the cluster detection. At this point the robot should be able to sample its surroundings with the LiDAR and know its position relative to the rows.

Milestone 2 (March 3rd) – 3D Camera, SLAM, and Path Planning Complete

We will be preparing a report for this milestone as it is our closest to the one third mark and we will have more to write about than after the first one. We should be done learning how to use the 3D camera and be well on our way to training a machine learning model with it. The robot should be able to continuously update a map of its surroundings and plan waypoints through the rows.

Milestone 3 (March 29th) – NVIDIA Board Integration and Path Following Complete

Testing of the NVIDIA Jetson TX2 should be completed and prepared to take on the image processing tasks of the system. The board should act as a peripheral that can be communicated with through serial communication or ethernet. The robot should be able to follow the paths that it plans.

Milestone 4 (April 19th) – Integration and Verification Complete

By this point we should have successfully implemented an inter-process communication standard to pass information between the robot's modules. The standard should consider the amount of information that needs to be communicated. Verification testing should be complete, and the robot should be able to successfully execute a mission.

Milestone 5 (May 14th) – Documentation and Tech Expo Preparations Complete

The final report should be completed, the source code should be documented, and a presentation/demonstration should be prepared for the capstone expo. We should have a banner stand with project information on it prepared as well as visual media like video or pictures displayed on laptops.

4.3.3 Project Management

To streamline tasks and make sure that no conflicts arise when completing the project, free online project management software will be utilized. The software, Trello, is based on the Agile methods for project management, specifically the Kanban project management method.

Using the Kanban method, main project tasks must meet the minimum viable product level designated by all project members before being advanced or replaced by alternate technology. Subtasks will be managed using the Kanban board on Trello, with project members attached to tasks which fall under their respective project areas.

Weekly progression will be tracked, and include a verbal report with our mentor Craig Hennessey, summaries and meeting minutes if they are deemed to be important with respect to the topics being discussed, and regular email communication between the project mentor and each project member.

Group communication will be done through a Facebook messenger group, while stakeholder and mentor communication will be done by email with all group members being cc'd on ingoing and outgoing emails.

If conflicts are to arise or project tasks including documentation are completed to a substandard level, it is the right and responsibility of any group member to bring it to the attention of the person producing the work and provide constructive criticism. Should there be disagreements on standards of work quality, the issue may be escalated to include the third group member. If disagreement remains, the issue may be escalated to the capstone mentor Craig Hennessey.

4.4 Budget and Resources

Direct costs associated with our project in terms of human resources and materials are stated below. These individual costs do include indirect or overhead expenses.

4.4.1 Materials and Equipment

Project Materials

Most of the main materials required for this project have already been ordered as part of the SoE VineBot budget. The critical hardware components of the project that we already have are shown in Table 1.

Category	Function	Item	Cost (CAD)
Structure	Chassis/Motors/Wheels	Servo City Nomad Robot Platform	300
Power	Battery	14.8V LiPo battery + Charger	100
	Speed Control	2 x Cytron 10A 5-30V Dual Channel DC Motor Driver	100
Processing	Command	Raspberry Pi 3 B+ Single Board Computer	50
	Image Processing	NVIDA Jetson TX2 Development Board	400
Sensing	Mapping	SlamTek 18m Rotary LiDAR	800
	Grape detection	Logitech WebCam C270 Camera	30
	Grape detection	PMD Pico Flexx TOF 3D Camera	450
Manipulation	Grape Picking	uArm Swift Pro	1100
		Total	3330

Table 1 - Previously Purchased Critical Materials

New Parts Needed

Parts that must be ordered can be found in Appendix A: Bill of Materials. These prototyping parts include 3D printing filament and various hardware fastener kits.

Long-lead Time Parts

With respect to the ordering of parts, components should be purchased through suppliers like sparkfun.com, or directly from manufacturers. Ordering from regions far away such as China should be avoided, however this can be evaluated on a case by case basis. For example, circuit boards ordered through ALLPCB.com are dispatched from China, however, take about a week to arrive due to express shipping.

Testing Resources

Other high-cost items which are not components used in this project but may be required to complete this project include oscilloscopes, function generators, lab computers, bench top power supplies, 3D printers, and soldering irons. These items have not been included in the bill-of-materials due to pre-existing access, they are however worthy to note. Also, a simulated vineyard used for testing in the lab requires at least a seven-foot-long stretch of floor space, which is also worth to consider.

If we were to quantify these resources, Table 2 shows what the breakdown would look like.

Item	Cost (CAD)
Testing Space / Work Benches	400 / Month x 5 months = 2000
MP Maker Ultimate 3D Printer	800
Rigol DS1054 Oscilloscope	500
GW GPC-3030D Bench Power Supply	650
Total	3950

Table 2 - Quantification of Provided Testing Resources

High-cost Items

A possible high-cost item that may need to be reconsidered is the NVIDIA Jetson TX2 developer kit (Figure 17). The NVIDIA Jetson TX2 is used by many hobbyists for machine vision and machine learning projects due to its GPU support. This processing unit is a 350 USD expense, which is a large portion of the allotted budget of our capstone project. It's useful to note that this is the student price and that there may be a limit to how many units one can order per year.

Figure 17 - NVIDIA Jetson TX2 Developer Kit

Other Facilities and Resources

Facilities or resources which could be used/needed in the future could include the BCIT MAKE+ center for manufacturing/assistance with further mechanical design for VineBot. Since the current chassis can be improved and expanded to accommodate newer components, a new chassis will most-likely be sought after. Brayden, our team mechanical design specialist, will most-likely take part in the design due to his experiences with industrial mechanical design, however machining will probably need to be outsourced to a third party. BCIT MAKE+ could be utilized for this task.

On the software side of things, machine learning training data will need to be compiled with the goal of training a more advanced object recognition model. The compilation process has been known to take time and would benefit from computing resources at or near BCIT. To be more specific, a computer or system of computers with GPUs can be utilized to compile training data for use with our chosen processing unit, to save time. Through Takashi Nakamura of the math department, we have already acquired access to the WestGrid supercluster for high capacity computing.

4.4.2 Personnel

Our group consists of three senior electrical engineering students: Terry Calderbank, Navraj Kambo, and Brayden Aimar. To summarize why each group member is competent to be on this team, a short description of their skillsets and justification of suitability for this project is provided.

Navraj Kambo is a 4th year engineering student who is interested in computer vision systems, and feedback control systems. Experiences with technical documentation, software version control, and signal processing make him a good fit for the various tasks involved in this project, including but not limited to documenting technical work carried out, aiding and resolving bugs in code, and implementing algorithms for mobile and specialized hardware. Also, his creativity in terms of 3D printing prototypes to work with existing hardware make him an asset.

Terry Calderbank is also a 4th year engineering student whose interests include computer vision systems, robotics and mechatronics related systems, and general automation. Work experiences with applied industrial robotics, and his ingenuity in terms of problem solving make him an invaluable team member. He is experienced in 3D design and printing, and has experience maintaining 3D printers used at BCIT. Previous work on the VineBot also speak well to his commitment and interest in the project.

Brayden Aimar is a 4th year electrical engineering student whose interest include electromechanical system design, and high-voltage electronics. He has several years of Vex Robotics competitions under his belt and his experience working in mechanical engineering make him extremely beneficial to the group due to his ability to fabricate metal parts and assemblies for the project if needed.

In addition to the information provided above, Appendix C: Resumes contains up-to-date single-page resumes for each of the group members.

4.4.3 Utilization

Below, human resourced based on the presented work plan are shown.

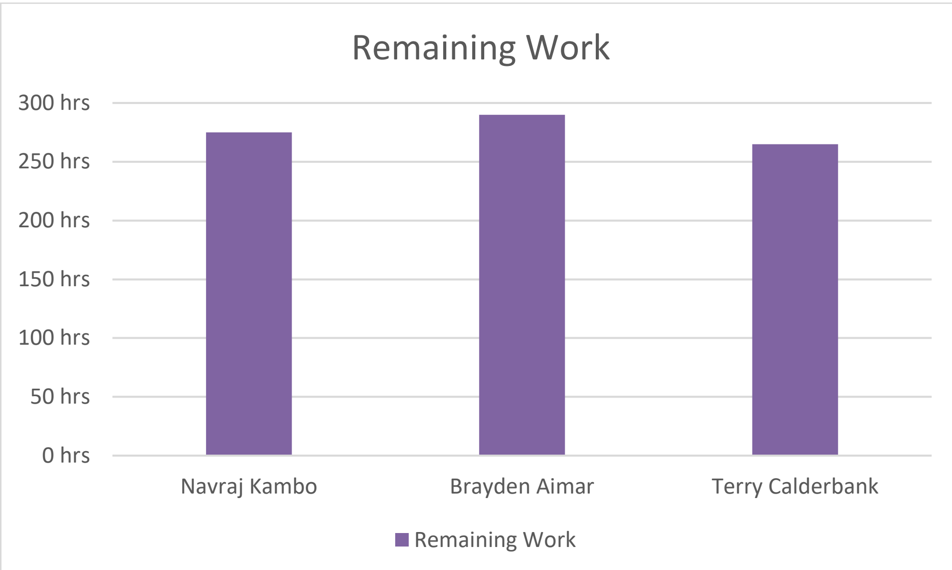


Figure 18 - Utilization of Group Members (Hours)

Figure 18, generated from MS Project, shows an estimated amount of time that will be spent on the project. It is useful to note that the time spent for each group member is very close to balanced and is based on an estimation. During the project, more time will likely be allocated to the project on a per-member basis.

4.5 External Review and Consultation – Design

One of the things we were unsure about before the MAKE+ meeting was how to improve the mechanical design and overall visual appeal of the current VineBot, while trying to maintain the current form factor. Ken Zupan, a Professor of SFU's School of Interactive Arts and Technology was able to provide us with the idea or vacuum forming, and how it may be a good way to cover the electronics of our project, without the need to heavily modify current designs. He also sold us on the notion that it would make our project more aesthetically pleasing, which isn't a design requirement per-say, but would be a nice addition to the project.

Vacuum forming is "the heating of a plastic sheet which is then draped over a mold whilst a vacuum is applied. The molding is then allowed to cool before it is ejected from the mold using a reverse pressure facility [16]." A simple buck could be constructed from wood, which would be used during the vacuum forming process to mold over, accurately depicting the space required for components. With the possibility of vacuum forming at BCIT, it could be a relatively painless procedure in terms of scheduling. In terms of the aesthetics, Ken was able to recommend that a translucent vacuum formed shell could be created in multiple colors and would be easy to decorate by common methods such as painting and decaling.

The other good thing that came out of the consultation was access to future consultations for robotics related questions through Garrett Kryt, a graduate student in the Mechatronics program at SFU. The student was able to provide us with an email address, should questions arise.

4.6 Risk Analysis

Risks associated with the proposed VineBot are limited, due to the scope of work we plan on achieving this year, as well as the relative affordability of the components we plan on using. However, there are still some items which may need to be addressed, so that potential risks involved can be mitigated.

To sum up some possible risks, we've compiled a risk probability matrix, shown below in Table 3. Important risks which should be considered above all others are also mentioned below, to explain how they may be avoided or dealt with if need be.

		Impact				
		Trivial	Minor	Moderate	Major	Extreme
Probability	Rare			Inability to Access WestGrid supercomputer cluster		
	Unlikely			Long Lead Time of Pico Flexx	uArm Swift Robot Failure	Unreliability of SLAM Navigation
	Moderate			Ineffective Machine Learning Model		
	Likely					
	Very Likely					

Table 3 - Risk Probability Matrix

Risk 1: Inability to Access WestGrid Supercomputer Cluster

If our machine learning models take too long to compile on a personal computer, we will need to build them on a more powerful system. The impact of this is moderate and the likelihood is Rare. Our mitigation strategy is to attempt to do the building onboard the Jetson TX2 board. This would involve learning some advanced GPU processing techniques that we have not researched. Worst case scenario, we can switch to a different machine learning framework and spend the extra time choosing one.

Risk 2: Long Lead Time on Pico Flexx 3D Camera

We plan to replace the visual camera with the 3D infrared camera in order to get better spatial information about the grapes. It is unlikely that this camera will fail to arrive before the 3rd week of January 2019. If not, we will have to stick with the results of the visual camera.

Risk 3: uArm Swift Robot Failure

This is a consumer grade desktop robot arm and it may not stand up to the rigorous use we will be putting it through while testing. If it fails, we can resort to using the non-Pro version of it belonging to Craig

Hennessey in the mean time while we wait for a replacement. We should have enough budget to replace the arm if necessary. There are several other arms on the market that may cost less in the future as well.

Risk 4: Ineffective Machine Learning Model

While we have assembled over 500 bounding box annotated images of grape clusters on which to train an object recognition model, we are complete beginners in this field. There is moderate risk that our models will not work effectively. In this case, we can gather more images and hand-annotate them, switch frameworks, or abandon the idea entirely and put more time into an OpenCV only detection system.

Risk 5: Unreliability of SLAM Based Navigation

The movement of our vehicle through the vineyard depends on navigation plans determined by the LiDAR and SLAM processing. If this strategy proves to be unreliable, it will cripple our ability to create an autonomous vehicle. It is unlikely to happen, but if it does, we will have to put more time into developing the existing navigation system. The absolute worst-case scenario is that we keep the harvesting process automated, and manually driver the vehicle using camera feedback like a field operator.

5 Conclusions

We hope that the previous sections have been indicative of a definite need for a precision picking system for grapes with the goal of combating labour shortages in a growing industry that has the potential to continue growing due to external factors like climate change induced crop migration.

We have outlined enough detail to show that this project can be feasibly completed by the middle of May with the following deliverables:

1. A proof of concept autonomous grape picking vehicle
2. A final report documenting our project
3. An organized git repository with extended project documentation
4. A live demonstration of the project for the capstone expo including signage and literature

We have the right personnel and skills to take on this project and the time resources to learn how to accomplish anything that is outside our current skill set. We have assessed the feasibility and created a realistic timeline for development. We have set frequent and measurable milestones with which to track our progress and planned to mitigate any serious identified risks such as equipment failure of ineffectiveness of planned concepts such as SLAM navigation and machine learning object detection.

We have the support of various mentors and prototyping experts, and the ability to consult with potential end-users to ensure that our strategies are effective.

We already have almost everything we need to proceed with the project, and we recommend that the rest of the materials be ordered in time for development starting in January.

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7 Appendices

7.1 Appendix A: Bill of Materials

In this appendix, we have provided our proposed bill of materials for things during the completion of our project. The bill of materials attached below outlines items that we will need to continue development of the project.

Item	Supplier	Website	Quantity	Price (CAD)
Black AMZ3D ABS Filament	Amazon Canada	http://a.co/d/3rja9TK	1	25.88
Green HATCHBOX ABS Filament	Amazon Canada	http://a.co/d/geGLT5h	1	26.29
M3 M4 M5 Socket Cap Screw / Nut Kit	Amazon Canada	http://a.co/d/c3nAXqv	1	29.99
Metric Set Screw Kit	Amazon Canada	http://a.co/d/4ovst1y	1	15.88
Standard Set Screw Kit	Amazon Canada	http://a.co/d/7LgnoD2	1	21.00
			Total	119.04

7.2 Appendix B: SWOT Analysis

To briefly summarize important details from the internal and external analysis of the VineBot project, a compilation of strengths, weaknesses, opportunities and threats are gathered below in Table 4. This SWOT analysis includes information discussed previously in the proposal.

Strengths	Weaknesses
• Accumulated Team Experience • Previous Progress • Testing Flexibility • Minimized Losses with Precision Grape Picking	• Limited Business Experience • Divided Priorities (School)
Opportunities	Threats
• Growing Agricultural Automation Demand • Growing Agriculture/Wine Markets • Lack of Precision Picking Solutions	• Speed of Non-Precision Solutions • Drought

Table 4 - SWOT Analysis

7.2.1 Strengths

Our strengths include accumulated team experience, the previous VineBot work completed for the SoE, and the inherent flexibility and adaptability of the product.

Besides his experience in the telecommunications field, and skill as a computer vision programmer, Navraj is a forward-thinking competent documenter who ensures that notes are taken throughout the design process. These notes are invaluable when it comes to troubleshooting and evaluating alternatives. Navraj has a knack for creative research and consistently finds resources that enable progress. Brayden brings to the table four years of professional mechanical design and automation experience. His work with CNC machines has provided us expert insight into motion control which is a large component of past, present, and future work. Brayden's experiences in the industrial workplace have given him a practical and pragmatic viewpoint into design. Terry has experience in the industrial robotics and automation industry. He also introduces creativity to any project taken on and is a dependable group member. Projects overseen by Terry are seen through to completion. He is also from BC's main wine growing region and has experience harvesting wine grapes.

The SoE project has provided us with a functioning prototype vehicle, and most of the financial resources required for the capstone project. We have already ordered many of the parts required for our project and as a result have more time to work towards the capstone. Most of the research we have done for the previous project is applicable to this one as well.

Early design decisions have given us flexibility in testing motion and vision. We have built sixteen feet of scale vineyard model to test our work with. The realism of our model allows us to conduct indoor and outdoor testing at our leisure for the duration of the project. Many of our design decisions are not specific to picking grapes. The robotic picking abilities may apply to other crops as well such as tree fruits or cannabis.

7.2.2 Weaknesses

Our weaknesses result from lack of business experience and having to share our time with schoolwork.

Besides working in businesses and taking management, marketing, and finance classes, we bring no real entrepreneurial experience to our project. It can be easy to assume that because a project is feasible or interesting, that there is demand for it. Until we have feedback from our stakeholders in the wine industry, we cannot determine value or demand. We will need to provide a minimum viable product to garner this feedback. Also, due to our lack of internal marketing and advertising specialists, it would be difficult to promote this idea and gain attention in our targeted industry, without external help.

Besides managing the capstone project, our time must be shared with our school work. The best we can do to mitigate this, is incorporating as much capstone research and work as we can into other class projects.

7.2.3 Opportunities

Some of our opportunities include growing markets, growing demand, and lack of precision solutions.

Possible market opportunities include Canada's growing agricultural industry, and wine industry. As demand for local labour continues to grow, solutions will be sought out for making the task of farming as efficient as possible. VineBot can be easily adapted to work in different agricultural fields, which allows further expansion after a working proof of concept. Projected labour shortages also provide a possible opportunity for VineBot to be adopted. Since agriculture will continue to grow, and the agricultural labour force may not be able to meet demands, automating farming tasks may help lighten the load, so to speak.

In terms of staying competitive, technological advances in agriculture may not be extremely valuable now, however, it is a possibility soon. Being a pioneer in an agricultural shift towards autonomous technology driven farming could give British Columbia, and even Canada, a competitive edge over regions known for agricultural production, like California, Europe and Japan.

There are currently no precision grape picking solutions on the market. Current work is done by imprecise and violent mass-harvesting machines that are too expensive for small to medium sized enterprises.

7.2.4 Threats

Our main threats include the speed at which current solutions can harvest grapes, and the possibility of drought in the future.

Despite the damage to the grapes involved in current mechanized picking solutions, they are extremely fast and have begun to receive some approval from even the harshest vineyard purists when necessitated.

Some analysts worry that the increase in farmable land brought by climate change in Canada, could be offset by water shortages induced by drought.

7.3 Appendix C: Resumes

Provided below is a compilation of our team's experiences and relevant work. This section may bring insight into our capabilities as a collective group and is added as supporting evidence to show that we are competent in providing the proposed solution (VineBot).