Fruit Picking Robot: Phase 1 Report

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MSE 4499: Mechatronics Capstone Design Project

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Executive Summary

The purpose of this report is to fully communicate the work done on an autonomous fruit picking mobile robot. The agricultural industry is currently experiencing a significant labour shortage that is only projected to grow with the coming years, resulting in an estimated monetary loss of $2.9 billion in 2017. The development of this device is to act as a pilot project regarding the automation of the harvesting of soft fruit as a means of offsetting this loss. The completion of a fruit picking robot is divided into several subtasks including a driving system, a fruit detachment system, a machine vision system, and a collection method, which combined will yield a functional device. Currently, several robots in development can complete this same task, however they are astronomically expensive, beyond the financial reach of most farm owner/operators. The concept of design a four-wheel driven robot, with an attached robotic manipulator, and a collection base is fully justified, along with the functional decomposition, morphological analysis, and decision matrix that led to its inception. The concept itself is detailed, and validation work is completed, with proof that the selected gearbox reduction will have an operating life exceeding 10,000 hours. A Solidworks model of the entire concept is produced, along with a simplified model better suited for analysis indicating the mass of the robotic manipulator will cause a deflection in the chassis top panel of less than 1mm. Fatigue analysis is completed on both the gears and shafts to be used in the driving system, finalizing a completed first iteration of this subsystem, and development of the machine vision system to be used is communicated and justified. Finally, an updated budget and schedule is proposed based the current work done, and the remaining work to be done is rescheduled to ensure the project is completed.

Introduction

Automation is one of the greatest technological advancements of the past 50 years. It revolutionized the manufacturing industry both in North America and abroad, resulting in greater productivity at lower costs for consumers. Naturally, seeking methods of automating other aspects of production will benefit both producers and consumers, while also addressing one of the largest labour shortages in world.

In 2014, approximately 25,000 agricultural positions were unfilled according to the Canadian Agricultural and Human Resources Council. By 2025 this shortage is projected to grow to 115,000 vacancies and is projected to grow larger with each year thereon [1]. As a direct result of this shortage, $2.9 billion of lost revenue was attributed in 2017. This loss is the result of production delays, lost sales, production losses, delayed capital investment, and overtime costs. While harvesters are only projected to make up 7% of the total shortage, it is a repetitive, unskilled job, which pays poorly, and is a critical stage in production. Filling these 7% of positions can safely be estimated to save at least $100 million across the Canadian agricultural industry. This product will be designed to fill this labour shortage, or act as a proof of concept at least.

The resulting device will autonomously pick cherry tomatoes grown in a greenhouse environment without causing any damage to them. In this environment, cherry tomatoes grow over vertical lattices in aisles. The tomatoes can be easily accessed from these aisles, and the environmental effects are minimized. Furthermore, picking fruit off vines rather than trees allow for a smaller robot to be constructed allowing for a much more feasible solution to be created on a limited budget of $300.

To accomplish this task, three subsystems will be created. A driving system, a fruit detachment system, and a fruit collection system. Each will be designed as independently as possible to maximize efficiency before integrating into a single cohesive device.

In this report the first complete iteration of the driving system is completed, based on which a better motor and gear train will be designed. The chassis for the resulting device is designed to completion. Development begins of the machine vision system, including the segmentation of the individual tomatoes from a background. The theory of colour blob image processing is examined, and the ramifications of which are considered, as well as the current state of the art regarding current advances in automated soft fruit harvesting. Finally, a detailed schedule of remaining work to be done is provided, and a comprehensive budget and census of the resources available and how they will be allocated to ensure this projected is completed.

Background Information

Current State of the Art

Automating the fruit picking process is not an entirely novel idea, several prototypes of functional devices have been designed in the past, however they have some critical errors that our team intends to address. The most notable example is a very recent development by a UK start-up enterprise called Fieldwork Robotics. Their device is capable of picking 1250 raspberries per hour compared to 1875 a human could pick in that same time period. Their robot uses template-based image processing, and a vaguely described four-armed flexible robotic manipulator. UK based media outlet Express covered the story, and in an interview with Fieldworks' robotics director Dr. Martin Stoelen, he stated "Different light conditions, branches, [and] pests … have been the biggest challenges" in reference to the sensitivity of the image processing methods to debris or partial occlusion of the raspberries. To date, £672,000 ($1,142,000 CAD) have been invested in the project [2]. This project is at the forefront of the current technological frontier regarding fruit-picking automation and highlights that image processing is the most challenging issue of this endeavor.

In a similar article published in the Washington Post, image processing concerns are echoed as the device described is unable to differentiate between ripe and over or underripe fruit. While outlining the technological concerns regarding the image processing issues, the article further references robot brutality towards produce. The focus of the article however is on the social implications of automating fruit harvesting. There is a clear stigma towards automation as it is seen as a replacement for human jobs (which to an extend is justified), however the benefits of new skilled positions are also discussed. Finally, the article discusses how this technology remain prohibitively expensive, with a specific model referenced at $300,000 USD ($400,000 CAD) [3].

Both articles refer to similar primary problems, and several secondary ones. The primary issues outlined are the image processing considerations, and the robot's ability to safely handle fruit without causing any damage. If a robot is unable to both identify and safely pick fruit, it is essentially useless in this application. As our team lacks an understanding of both the theory and application of advanced image processing techniques such as template matching, for the sake of feasibility our device will locate the centroid and outline of a color blob and cut a prescribed distance above the fruit. The second problem of the safe handling of the produce is a much more feasible task that will be addressed using a soft rubber transmission tube that will deposit the fruit into a collection bin. This is a simple concept, but we feel it will achieve the desired result, and are quite surprised that all the existing solutions rely solely on manipulators. The secondary problems include increasing the speed of the entire operation, ensuring the device can navigate difficult terrain, and finally can withstand the elements.

Color Blob Image Segmentation

To effectively pick tomatoes off a plant, the tomato must be identified and located using colour blob image processing techniques. This problem can be split into two distinct sub-problems. First, the tomato must be isolated from the background, second, the tomato must be assigned a position in three-dimensional space to allow the robotic manipulator to interact with it. Reviewing an IEEE published paper entitled "Color Blob Segmentation by MSER Analysis", color blob image segmentation requires four steps.

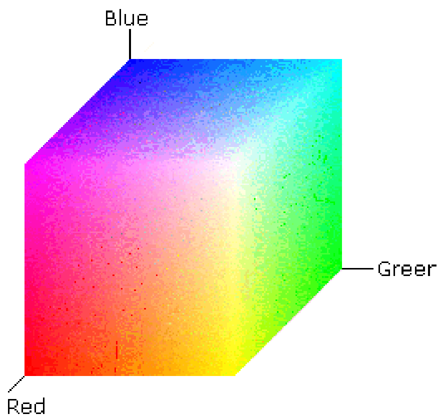


Figure 1: RGB Colour Space

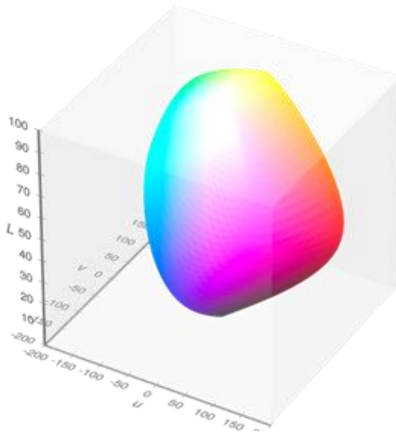


Figure 2: CIE Luv Colour Space

First, a set of colour values to be segmented must be defined. Next, the image is converted from RGB colour (red-green-blue) to the CIE Luv colour.

Next, the colour value of each pixel must be compared to those next to it. This is achieved by defining a vector to each pixel with values L, u, and v from the Luv colour space (μ), as well as a covariance matrix (Σ) based on Gaussian distributions to determine the colour similarities between pixels. Using these matrices, the Bhattacharyya distance (a quantitative value indicating the similarity of two pixels) can be determined using the following relationship.

Equation 1: Bhattacharyya Distance

$$\beta = \frac{1}{2}\ln\frac{\left|\frac{\vec{\Sigma}_1+\vec{\Sigma}_2}{2}\right|}{\sqrt{\left|\vec{\Sigma}_1\right|\left|\vec{\Sigma}_2\right|}} + \frac{1}{8}(\vec{\mu}_2-\vec{\mu}_1)^t\left[\frac{\vec{\Sigma}_1+\vec{\Sigma}_2}{2}\right]^{-1}(\vec{\mu}_2-\vec{\mu}_1),$$

Finally, a list of Bhattacharyya pixel distances is created, and those less than a set sensitivity threshold are grouped to form the selected suberegion of the image. This process is typically completed by software included in most image processing packages, and likely Matlab. However, it is important to understand the underlying priciples of image segmentation, to refine or develop an appropriate algorithym to isolate tomatoes from their background [4].

Scope, Objectives, and Constraints

Scope

In order to ensure the completion of a functional device, the scope of the project will be (in some ways) limited. This was primarily implemented during concept generation, with an obvious example being the elimination of any air-borne or UAV (unmanned aerial vehicle) based solutions. These solutions require very precise control, and very tight tolerances in manufacturing which are not feasible with the available budget and resources.

With these limitations, the objective of the project is to develop a fully functional device that can accurately and repeatedly pick fresh fruit without causing damage. The final device will be a mobile robot, designed for outdoor use, that can identify and autonomously pick fruit using machine vision.

Objectives

Fast Response Speed

The robot must be able to pick tomatoes as quickly as possible. The closest existing product to ours is a tomato picking robot developed by engineers at the Beijing University of Technology. This Chinese robot can pick individual tomatoes is under 8 seconds. The goal of our robot is to perform similarly if not better [5].

Multiple Degrees of Freedom Movement

A six degree of freedom robotic manipulator will be used to pick each tomato.

Modular Design

The robot should have a modular design for easy maintenance. As a potential future development, the robot should be designed such that changing the crop it is to pick can be achieved using software alone.

Accurate Fruit Detection

The implemented fruit detection method should be able to identify tomatoes from their surroundings and return 3D coordinates to the processor. The fruit detection method should work under various weather conditions, including under insufficient or strong light intensity (such as at noon), jittering objects (as on a windy day), or partially occluded fruits.

Easy and Intuitive to Operate

The machine should be simple to operate, requiring only minimal training.

Cost Efficient

The machine should be designed to cost as little as possible.

Durable and Maintainable

Sensitive electronic components must be protected and made replaceable, most mechanical components must be interchangeable and repairable. Many farms are in remote areas and they are not easily accessible by support technicians. Modern farming machines have become increasingly dependent on electronics (which are often difficult or impossible to repair without a qualified technician) resulting in delays.

Integrable to Larger System

The machine should be integrable into a complete fruit harvesting process that also includes fruit cleaning, grading, disinfection, artificial waxing etc.

Weather and Dust Proof

The machine is expected to work outdoors under various conditions including wind, rain, snow, heat, and be dust resistant.

Constraints

Safe to Operator

The machine should meet Occupational Health and Safety Act (OHSA) standards, other related regulations and local laws.

Safe to Fruits and Trees

The robotic end-effector must be designed to ensure that the tomatoes to be picked are not damaged. During testing, the end effector will be iteratively changed based on subsequent tests to minimize damage.

Concept Generation and Selection

During the concept selection and generation process, a series of design techniques was implemented, including functional decomposition, morphological analysis and decision matrix. In this section, all generated concepts will be detailly demonstrated, optimal solution will be discussed, and a complete engineering selection mechanism will be provided.

Functional decomposition

After analyzing the given constraints and objectives, to build a functional fruit-picking robot, the following functions must be accomplished:

- Driving mechanism: The robot must move freely
- Picking mechanism: The robot must pick fruits
- Detaching mechanism: The robot must detach fruit
- Collecting mechanism: The robot must store the collected fruit
- Machine vision: The robot must locate the fruit

Morphological Analysis

There are various ways to achieve above functions, after group brain storming and researching, multiple possible solutions for each mechanism was generated.

Moving mechanism

1. Four wheels

   This method is the simplest way to drive the robot, this method requires four wheels that have high coefficients of static friction to ensure the robot can travel over unpaved surfaces. The advantage for this concept is that four wheels also allow the robot to maneuver easily. The disadvantage is it requires a large portion of the budget and may not be able to operate on rough terrain.

2. Caterpillar bands

   Caterpillar tracks provide far more traction than wheels over unpaved surfaced. Two motors are used to drive the caterpillar tracks, with a large gear to provide torque, and a pinion to provide tension.

3. Multi-Legged

   A complex multi-legged walker can climb and travel over obstacles. Multiple stepper motors, and complex linkages will be used to implement this mechanism, which is extremely complex compared to other alternatives. The advantage is that it can travel easily on rough surfaces, the disadvantage is it is very complex and expensive.

4. Rail

   A railway system could be constructed on the ground so that the robot can move on it. This method is very simple but not cost-efficient. Although it is very easy to operate, a railway system would have to be built throughout the operating environment in order to make it work, which is very expensive. Additionally, the distance between robot and plant is not fixed, so the robot may be too far or too close to the plant to operate properly.

Picking mechanism

To pick up an object in three-dimensional space, a robotic arm is the optimal solution because it has six degrees of freedom. The following mechanisms will be implemented on a robotic manipulator.

1. Clamp

   A clamp is a simple way of picking up things. It is simplest possible solution, however, since the fruit is attached to its stem, the stem needs to be cut in order to detach the fruit from the plant. A scissor-like component would need to be implemented. A closed-loop control system is required in this mechanism, so the system will know if the force exerted on the fruit is appropriate. Insufficient force might result in an unstable grab, and too much force will result in damage.

2. Small basket

   This mechanism is a small basket with a pair of scissors on top of it. The robot detects the fruit, places the basket below that fruit, then the scissor cuts off the stem. This method is considered more convenient because it does not require a force control system.

3. Vacuum

   Using a vacuum to collect the desired fruit can easily damage the fruit and can be quite expensive and complicated to implement. This solution requires significant power, which would result in high operating costs.

4. Transmission tube

   This method of collecting the fruit is to cut the stem, then allow the fruit to fall down a flexible rubber or PVC tube. This method is the easiest, and most efficient way to transport fruit.

Compared to the other detaching mechanisms, scissors are the most efficient, least complex, most cost-efficient, easiest to implement, most durable, and safest technique. CAD modelling and finite element analysis will be used to test an initial design of the scissor mechanism. A prototype will be built and tested before integrating the mechanism into the robot.

Detaching mechanism

1. Scissor

A pair of scissors will be attached to the picking mechanism to cut the stem above the fruit.

2. Knife

A knife is connected to a stepper motor. After identifying the location of the stem, the knife will pass through that location to cut the stem. However, the blade may damage the plant.

3. Saw

A motor connected with a circular saw blade can be used. After identifying the location of the stem, the saw will pass through that location to cut the stem. This method has same disadvantage as the knife, as it may damage the fruit.

Collection Mechanism

1. Basket
2. Case
3. Net

The above three collection mechanisms are all considered as viable and effective solutions.

Decision matrix

To select the optimal solution from the above generated concepts a, decision matrix will be used. The decision matrix will be evaluated based on different criteria; corresponding weights will be assigned to each of the following:

- Complexity (Weight=3): Difficulty to implement, test or operate
- Cost (Weight=5): The value of money to produce
- Efficiency (Weight=5): The ability to quickly achieve the desired result
- Sustainability (Weight=3): The concept’s environmental impact
- Durability (Weight=4): The ability to remain functional without excessive maintenance or repair
- Safety (Weight=4): The level of inherent danger to operators
- Reliability (Weight=3): The capacity to perform as required over time

The following decision matrix correlated each criterion with each concept. A value between one and five is assigned to, with one being the worst and five being the best.

Table 1: Decision Matrix

		Complexity	*Cost*	*Efficiency*	*Sustainability*	*Durability*	*Safety*	*Reliability*	*Total*
	Weight (1-5)	3	5	5	3	4	4	3	*135*
Moving mechanism	Wheels	4	4	5	4	4	5	4	*117*
	Caterpillar	4	4	3	4	5	5	5	*114*
	Multi-Legged	1	1	3	3	2	2	3	*57*
	Rail	3	3	2	2	3	3	1	*67*
Picking Mechanism	Clamp	3	3	3	4	3	3	4	*87*
	Small Basket	4	5	3	4	4	4	5	*111*
	Vacuum	2	1	2	3	1	1	1	*41*
	Transmission Tube	4	4	5	4	4	4	5	*116*
Detaching Mechanism	Scissor	4	5	5	4	5	5	5	*129*
	Knife	3	4	4	3	4	4	1	*93*
	Saw	2	2	3	3	4	1	3	*69*
Collection Mechanism	Basket	4	4	4	3	3	3	4	*97*
	Case	4	3	5	3	5	5	5	*116*
	Net	5	5	3	2	3	3	3	*94*

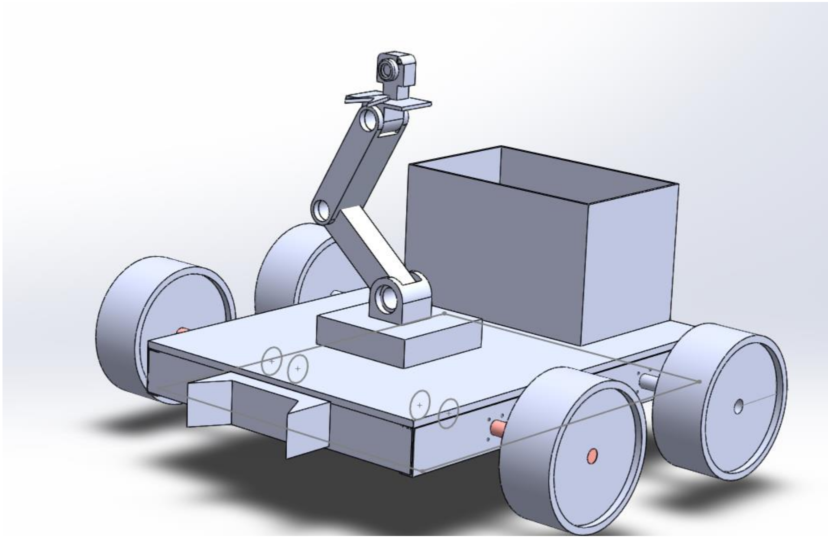


Figure 3: Graphical Concept Model

While validating the design, materials and dimensions were defined which resulted in the following second version, which, while appearing less mechanically complex was fit for finite element analysis to be performed in the following section.

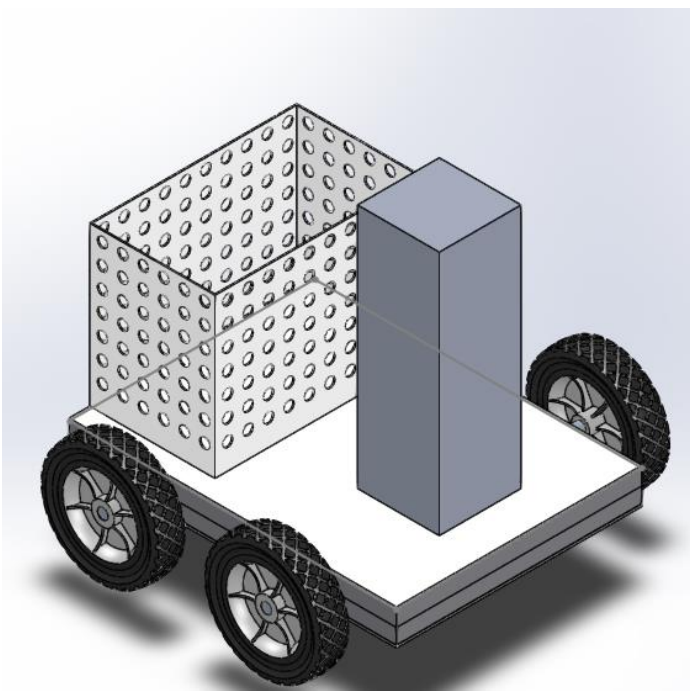


Figure 4: Simplified Finite Element Analysis Model

The arm was removed from the model and replaced with a block with assigned mass to simulate the arm in a vertical position during finite element analysis, and to observe the effect of the displacement of the top panel on the manipulator position. Furthermore, appendages such as mounted sensors were also removed as their mass was inconsequential to the rest of the device and only added computational difficulty to performing any simulations.

Based on the motor analysis done in the following section, the following gear train was developed after several iterations. This design is the result of several iterations of adjusting the ratios between gears, the sizes of the shafts, and the moduli of the gears and pinions. Based on the subsequent shaft analysis, the motor shaft was found to be predicted to only last 250 hours. The remaining shafts are both predicted to have service lives exceeding 10,000 hours. A new motor with a larger shaft will be selected, and new gears will be selected with a lower expected service life. This is to save money by using components with similar predicted service lives.

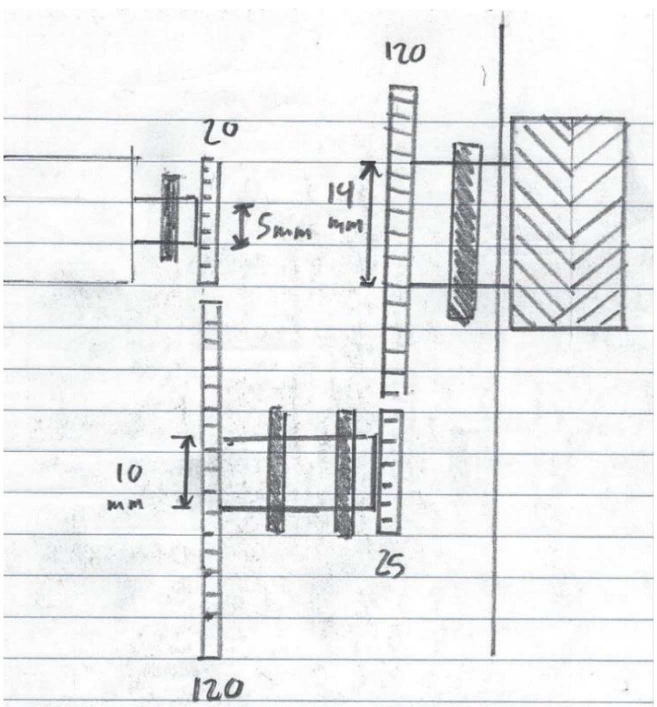


Figure 5: Gear Reduction Concept Sketch

Design Validation

Drive Motor Selection

After specifying the materials to be used for the robot, and creating a Solidworks model, the mass was determined to be approximately 5kg accounting for attached sensors and actuators. At each of the rear axles, at least 2.5Nm was calculated to drive the robot.

$$\tau = mg * d$$

$$\tau = (5kg)(9.81 \frac{m}{s^2})(0.1m)$$

$$\tau = 4.9\ Nm$$

Using two motors the drive the device, and rear differential steering, the required torque from each motor can be defined as half of the total torque requirement.

$$\tau = 2.45\ Nm$$

The robot was also defined as being able to travel at a linear speed of 1 m/s. The wheels specified in the solidworks model have a diameter of 15.24 cm (6 in.) and a circumference of 47.75 cm. To allow the device to travel at 1 m/s, the wheels must rotate at a rate of 2.13 Hz or 13.38 rad/s. Combining the torque and angular velocity requirements, an output power requirement of 32.78W was determined and rounded to 35W to allow for a factor of safety during calculations.

$$\omega = 2\pi f = 13.38\ rad/s$$

$$P = \tau\omega = (2.45Nm)(13.38 \frac{rad}{s}) = 32.78\ W \approx 35W$$

Using the above requirements, a 24VDC motor from NMB Technologies Corporation, model SE30R2NTCD was selected. That motor has the following profile.

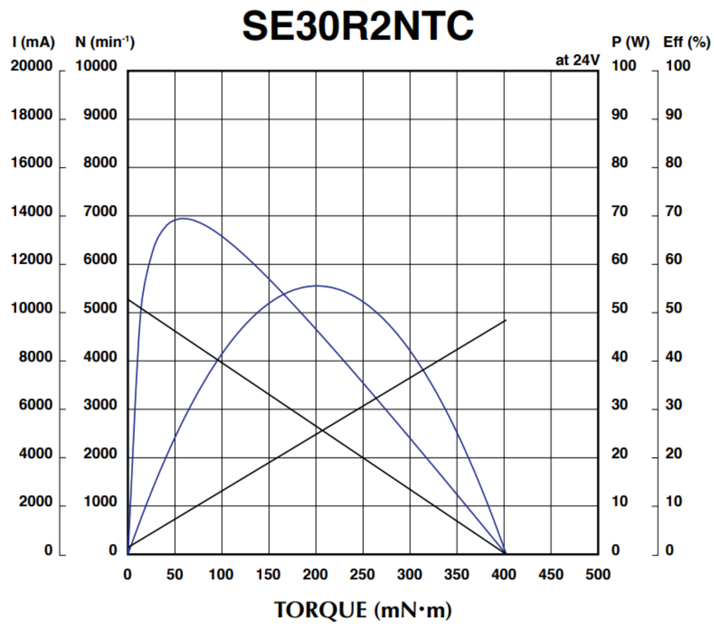


Figure 6: 24 VDC Torque/Speed Profile

Operating at the rated 24V and controlling the torque through the current as the plot suggests provides the following values.

$$K_t = \frac{i_{stall}}{\tau_{stall}} = 23.63\frac{A}{Nm}$$

$$\frac{\omega_{no\ load}}{\tau_{stall}} = \frac{5279\ rpm}{402\ mNm} = 13.13\frac{rpm}{mNm}$$

The following relationship between the speed and torque can then be calculated.

$$\omega = 5279\text{rpm} - 13.13\frac{rpm}{mNm} * \tau$$

Ordinarily the speed constant K_v would be used, however the motor data sheet provided only the above plot at 24V DC, and no data regarding the resistance of the motor making theoretical voltage control calculations impossible.

Using a 24 VDC – 6A power supply, the peak allowable current that can be provided to each motor can be specified as 2.5A to ensure current can be provided to other components (other motors excepted). Operating the motor at 2A in continuous operation, and 2.5 A in peak operation results in the following table of output conditions.

Table 2: Motor Operating Conditions Before Reduction

Motor current (mA)	*2000*	*2500*
Torque (mNm)	84.64	105.8
Angular speed (rpm)	4167.7	3889.9
Angular speed (rad/s)	436.4	407.4
Output power (w)	37.0	43.1

In both cases, the mechanical power output by the motor exceeds the required 35W to allow movement. To ensure the speed and torque targets of 13.38 rad/s and 2.45 Nm are met, a 32X gear reduction will be used to step down the speed of the motor shaft to match the desired output at the tire.

Table 3: Drive Wheel Speed and Torque

Motor current (mA)	*2000*	*2500*
Angular speed (rad/s)	14.48	12.73
Torque (mNm)	2708.5	3174.0

Provided the motor does not operate its arm while driving, the specified motor and power supply will allow the device to achieve a continuous speed of 1 m/s. However due to currently unknown variables such as traction and mechanical losses, it is not yet possible to accurately estimate the rate of acceleration.

Gear Train Design

The gears used to match the motor to the drive axle are outlined in the following table. AGMA bending and contact stress analyses were performed with the resulting factors of safety listed below. The relevant MATLAB code used to determine each factor of safety can be found in the appendix.

Table 4: Selected Gear Properties

Module	No. of Teeth	Pitch Diameter (mm)	Bore (mm)	Face Width (mm)	Bending Factor of Safety	Contact Factor of Safety
0.5	20	10	8	5	2.91	1.24
0.5	120	60	10	5	4.05	3.15
1	25	25	10	10	2.00	1.07
1	120	120	14	10	2.48	2.41

Chassis Design

To ensure the chassis can support the weight of both itself and the attached robotic manipulator, a detailed CAD model was created, the materials and dimensions used were specified, and a finite element analysis simulating gravity was performed. The following plot shows the resulting deformation of the chassis from a finite element analysis simulating gravity.

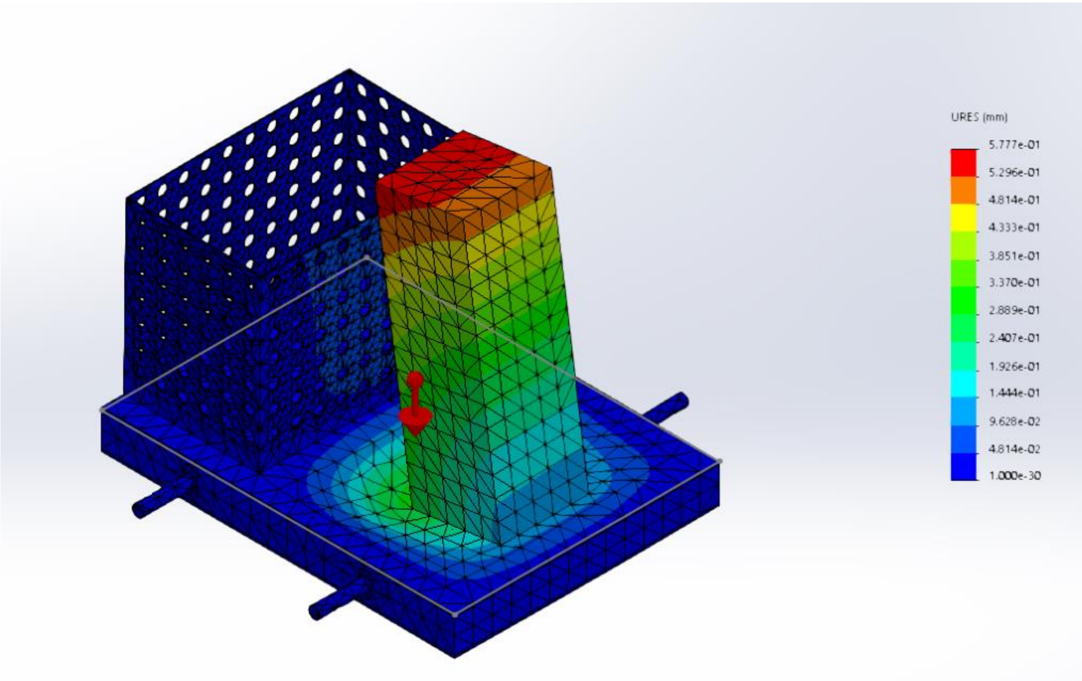


Figure 7:First chassis design - displacement analysis

In the above figure, the large block at the front of the robot was given a specified mass of 800g, slightly larger than that of the manipulator to be used. This allowed the simulation of the weight of the manipulator on the chassis without fully modelling the manipulator itself. As can be seen, the acrylic top panel is deflected by approximately 3mm, and the top of the manipulator is displaced by 6mm.

This modelled block has an equivalent height to the manipulator in a vertical, colinear configuration. This deflection is substantial and was rectified by adding a crossbeam support as seen in the following figure.

By adding two crossbeams parallel to the front axle, the deflection of the chassis top was reduced to less than 1mm, and the displacement of the top of the manipulator is less than 2mm. This simple change significantly improved the accuracy of the end effector by reducing the deflection of the top panel of the chassis to which it is attached. That plot is shown in the following figure.

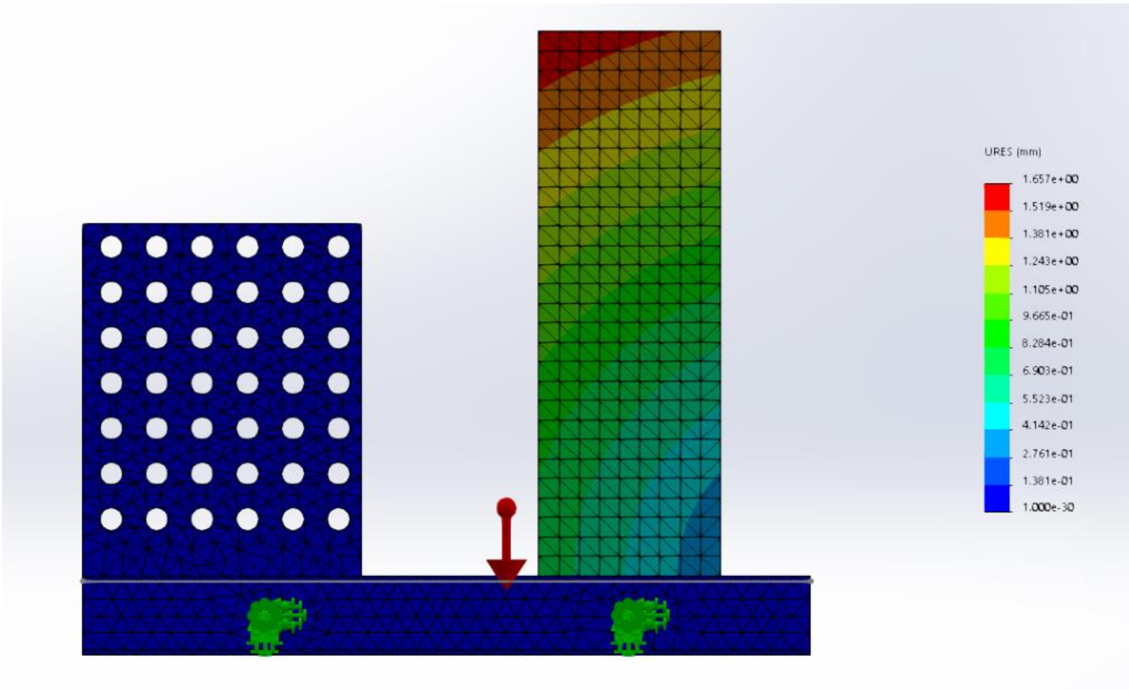


Figure 8: Chassis displacement - revised design with crossbeam

Shaft Analysis

Using MATLAB to determine the number of cycles to failure of each shaft, it was determined that the parallel reduction shaft and the output shaft will not fail within 10,000 hours of operation. However, a motor with a larger shaft will need to be selected and re-evaluated before completing this project. Failing this, a more complex gear train will need to be designed to increase the service life of the motor.

Shaft	Cycles to Failure	Time to Failure
Motor-Pinion Shaft	60,918,000	254h
Parallel Reduction Shaft	283,500	25515h
Output Shaft	162,250	11682h

Object Recognition and Image Processing

The workflow of the object recognition algorithm in this application is represented below:

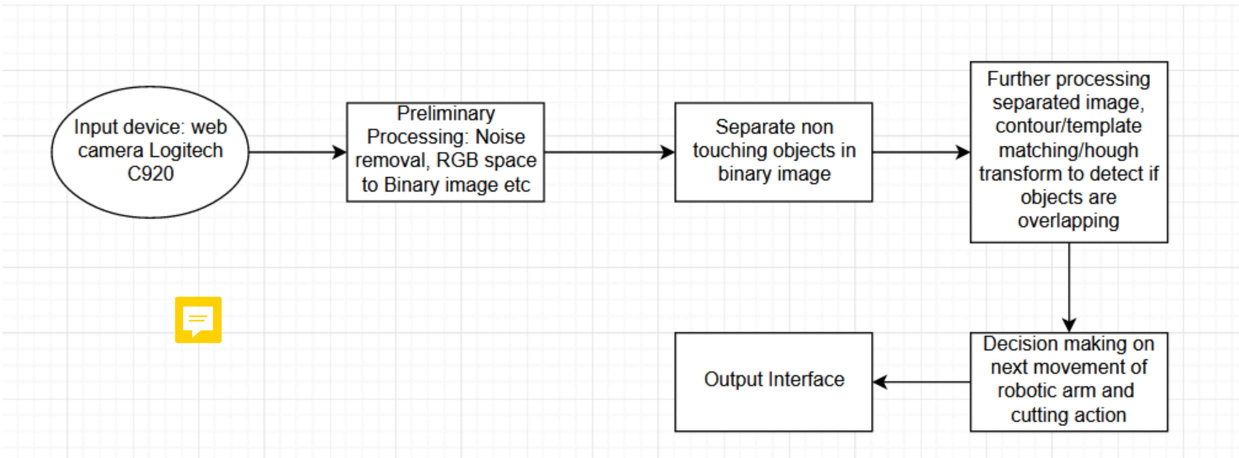


Figure 9: Image Processing High-Level Workflow

As the application is processing video data as provided by the attached camera, the processing time for the application must be less than the frame rate of the video being used. The decision-making process also needs to be aware of the response time of the robotic arm and cutting action. Currently code is being developed using Matlab for prototyping thanks to its advanced image processing toolbox and fast development nature. Later, the code may be written on OpenCV or integrate OpenCV also using MATLAB's OpenCV interface to increase the processing speed of the application. Currently the code written on MATLAB attempts to utilize vectorization, memory pre-allocation, and parallel processing to increase speed.

Current Progress

Input and Connections

Using MATLAB’s Image Acquisition toolbox and the standard ‘winvideo’ hardware adapter. The RGB colour space is used and the video resolution is set to 640x480 to reduce processing time. The capture framerate is currently set to 10 frames per second as it is frequent enough for this application.

The hardware setup is shown below:

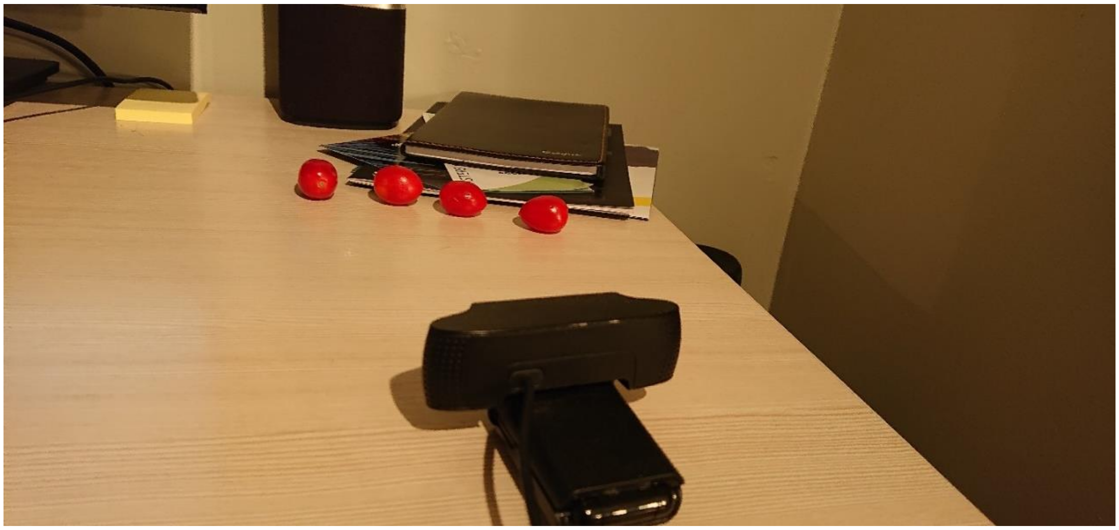


Figure 10: Image Processing Experimental Hardware Setup

Preliminary Processing:

First, the RGB channels are combined to a single grayscale channel. As the grape tomatoes are saturated red, with a mix of green, brown (red + green), and blue background, we decided to use a linear algorithm that promotes red and downvotes green and blue to create the grayscale image based on the following relationship. Grayscale=3*(red channel)-2*(blue channel+ green channel)

$$Grayscale = 3 * (red) - 2 * (blue + green)$$

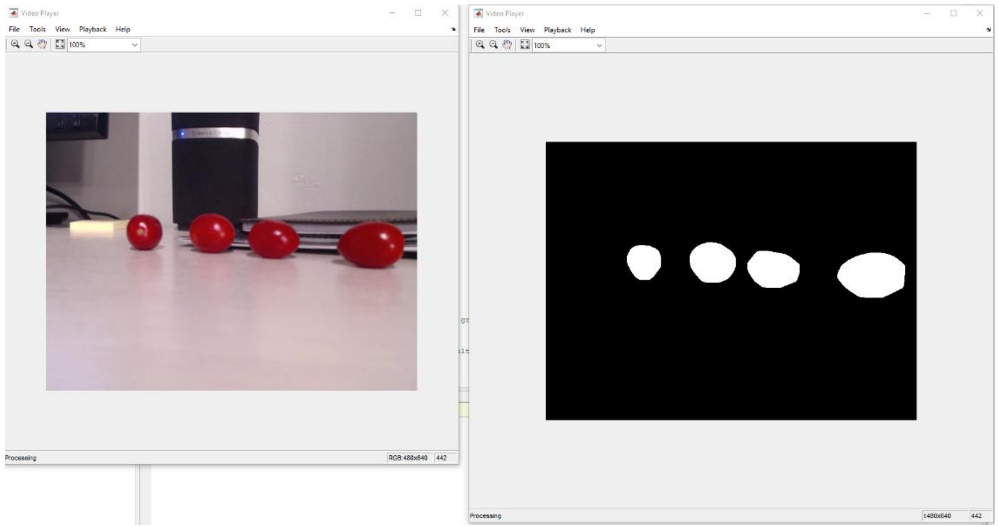


Figure 11: Initial Image Processing Results

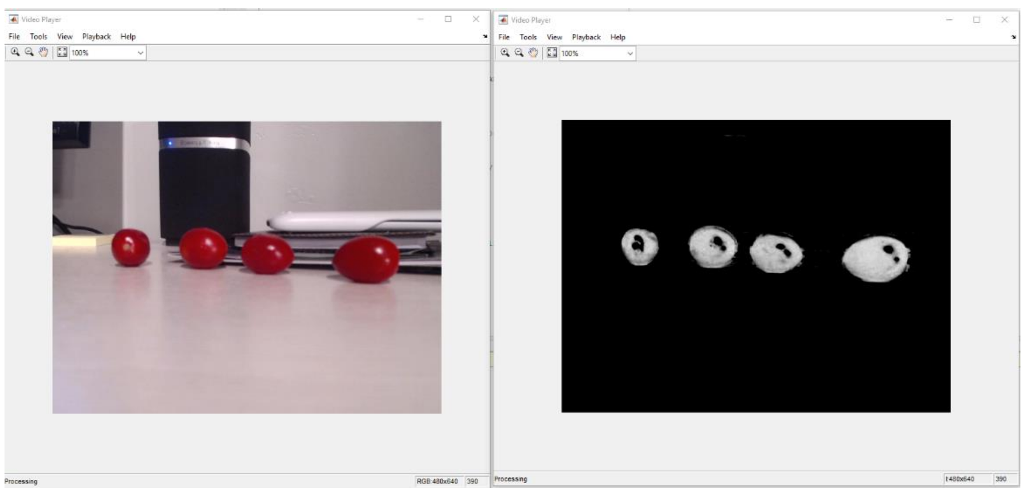


Figure 12: Overexposed Greyscale Rendering

Notice on the following image, the holes inside the tomatoes are the result of overexposed areas. To get a cleaner image and fill the holes, one method is to use morphological reconstruction on the image resulting in the following rendering. Future work includes research and testing various methods for segmenting overlapping objects. Furthermore, the centroid of each tomato will be transmitted to the robotic manipulator once a specific manipulator has been selected. Corresponding figures of each

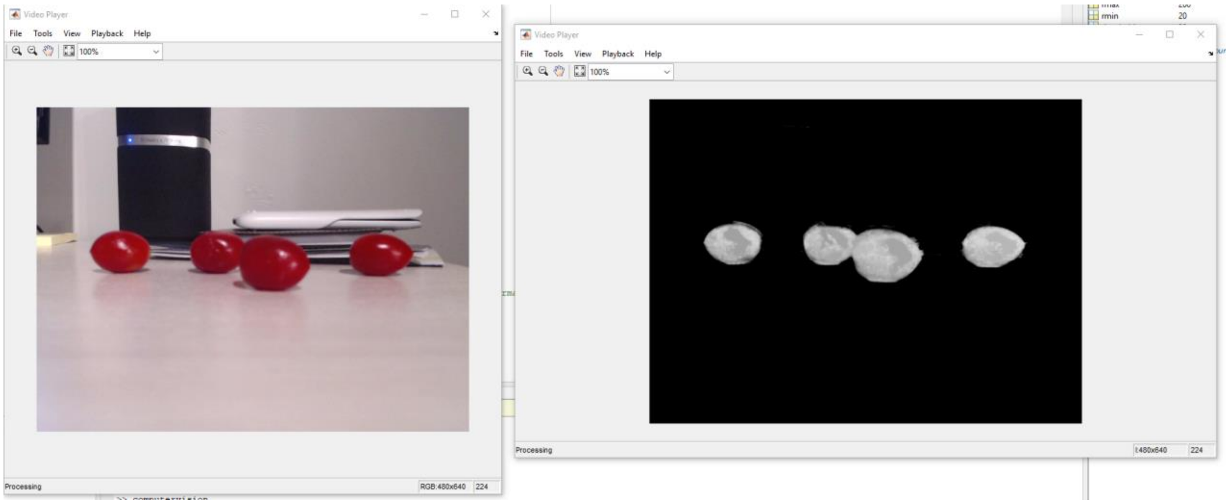


Figure 13: Greyscale Rending with Closed Contours

Progress, Schedule, and Planning

According to the project proposal, the project schedule was refreshed regularly. Initially, we planned that the entire group would work together for each task. However, we found the efficiency was too low to finish the project. Therefore, we decided to use parallel task management. Every member has assigned a different task to best utilize their abilities.

The driving machine and machine vision are completed at the same time. Alex and Qi will finish the design of the driving component within 17 days. At the same time, Mingyang and Ziqin will work on the machine vision within 30 days. After finishing the driving machine, Alex and Qi will start the design of the control system. After completing the machine vision component, Mingyang and Ziqin will design a picking mechanism based on their machine vision algorithm within 55 days. Then, they will join Alex and Qi to complete the control system by February 25th, 2020. After finalizing a complete framework of the control system, Qi and Alex will begin building the prototype for the showcase. The entire duration of the control system and prototype design phases are set to 86 days and 64 days respectively.

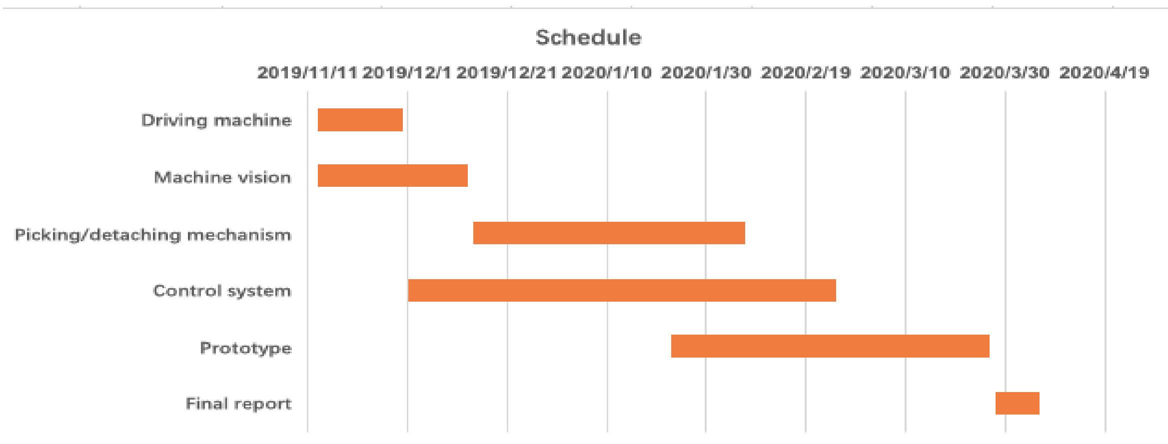
We plan that each person works 7 hours a week, with plans to increase the number of hours spent closer to any deadlines, as well as a contingency measure.

To ensure the schedule is followed, a group meeting will be held weekly. Each task should be finished with established period. Meaningful status reports from every member, whether formal or informal are required every week. Which is important for providing information to identify missed internal deadlines and potential project delays. When delays occur, each member should communicate effectively. Once consequences are fully analyzed, alternative remedies and specific contingencies must be considered.

Table 5: Task Schedule with Durations

Task	Starting Date	Duration(Days)	Ending Date
Driving machine	2019/11/13	17	2019/11/30
Machine vision	2019/11/13	30	2019/12/13
Picking/detaching mechanism	2019/12/14	55	2020/2/7
Control system	2019/12/1	86	2020/2/25
Prototype	2020/1/23	64	2020/3/27
Final report	2020/3/28	9	2020/4/6

Table 6: Gannt Chart Showing Parallel Task Completion



Resources and Budget

According to each member's qualifications, they are assigned different tasks. Alex will be managing mechanical design as he is certified to use the University Student Workshop. Qi and Ziqin have extensive knowledge and experience in programming and control systems. Mingyang has research advanced image processing techniques, so he will oversee any machine vision requirements.

To complete the project, different types of software and equipment will be used. MATLAB and Solidworks will be used for most simulation and computation required. Microcontrollers such as the Raspberry Pi will also be used in early prototyping and will be replaced in the final design.

All mechanical CAD drawings, 3D models, and finite element analysis simulations will be completed using Solidworks. EAGLE will also be used to design electrical circuits and printed circuit boards.

The mechatronic engineering laboratory (ACEB 3435) has most of the essential equipment that is required during prototype construction, such as a function generator, multi-meter, soldering station and oscilloscope. The University Student Workshop is another great resource in prototype construction, with access to equipment such as a drill press, band saw, mill, bench grinder etc.

Sensors and actuators will be purchased in the university electronics shop, Digi-key, and other vendors with the key component being the camera for machine vision system. An ultrasonic range sensor will also be used in a closed-loop feedback system as a crucial component of the drive subsystem. A robotic manipulator is required and will be the most expensive and important actuator.

3D printing materials and the laser-cut plastic materials will be used to build the prototype components as they are more cost-efficient. However, several high strength components will be manufactured from low carbon steel.

The average robotic engineer's salary in Ontario is approximately $27/hour [6]. Alex has access to a machine shop that would otherwise cost $50/hour. Based on this information, an estimated project budget is as follows with dramatic cuts being made to the showcase prototype to meet the specified $300 budget.

Table 7: Completed Project Budget Including Labour

	Project budget		**Prototype cost**				
	Engineering hours	*Salary*	*Machine shop time*	*Machine shop price*		*Materail&componets*	
Drving mechanism	17	CA$459	10	CA$	500	CA$	50
Machine Vision	30	CA$810	30	CA$	1,500	CA$	300
Picking/detaching mechanism	55	CA$1,485	10	CA$	500	CA$	300
Control system	86	CA$2,322	10	CA$	500	CA$	100
Total	188	**CA$5,076**	60	**CA$**	**3,000**	**CA$**	**750**

Discussion, Conclusions, and Recommendations

Since the last report, the project has made some progress. Through some calculations and simulations, we have almost completed the design of driving mechanism. The materials and components for each part have been selected. We have also completed the CAD model of the driving mechanism. Next, we will begin testing the drive system and connect the motors to the microcontroller. Based on the test results, we will further improve the driving mechanism.

The design of the machine vision has also passed the preliminary test. Identifying the overlap between two tomatoes was the most challenging part. We have now tested an algorithm and achieved that effect. Next, we will improve the algorithm to adapt to more complicated situations in real life.

According to the plan, we will start the design of the control system. This is the core of the design. After a discussion, the team members agreed that the choice of the robotic arm could be a problem. Therefore, the design of the picking mechanism will be discussed as soon as possible.

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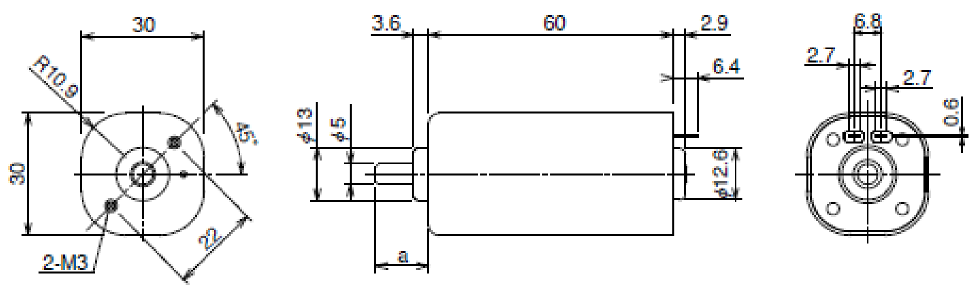
Appendix

Minebea

SE30R

■ モータ外観寸法 External Dimensions

Weight:210g



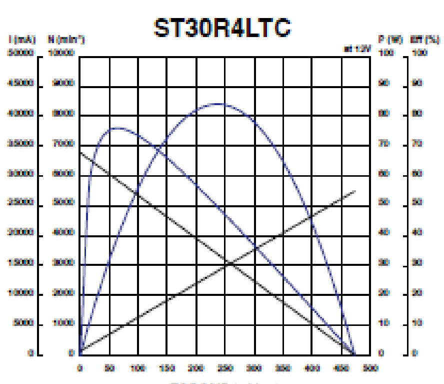
a=13.0mm

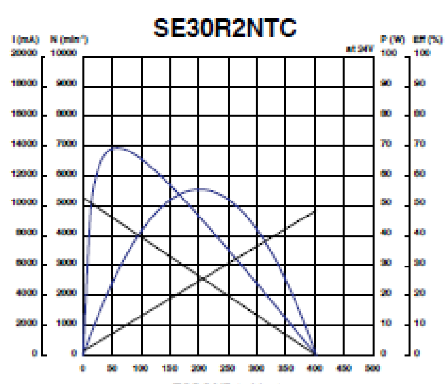
Unit：mm

■ 参考特性 Reference Characteristics

型式 Model	電圧 Voltage		無負荷 No Load		定格負荷 Rated Load		定格負荷 Rated Load		起動トルク Starting Torque		起動電流 Starting Current
	駆動電圧 Operating	定格電圧 Rated	回転数 Speed	電流 Current			回転数 Speed	電流 Current			
	(V)	(V)	(min⁻¹)	(mA)	(gf·cm)	(mN·m)	(min⁻¹)	(mA)	(gf·cm)	(mN·m)	(mA)
ST30R4LTC	8 to 13.5	12.0	6790	683	510.2	50.0	6073	3516	4826.5	473	27507
SE30R2NTC	21.6 to 26.4	24.0	5279	286	714.3	70.0	4360	1926	4102.0	402	9709

■ トルク特性 Torque Characteristics





MATLAB Scripts

Gear Analysis

```
%AGMA Gear mesh analysis
clc
clear

Np = 25;        %Number of teeth on pinion
Pd = 1;         %Module of pinion (teeth/mm)
Yp = 0.34;      %table 14-2 in textbook
Fp = 10;
Jp = 0.37;      %Figure 14-6

Ng = 120;       %Number of teeth on gear
Pg = 1;         %module of gear(teeth/mm)
Yg = 0.45;
Fg = 10;
Jg = 0.45;
%************************************************

n = 4200;       %Pinion speed (rpm)
H = 45;         %output power


dP = Np/Pd;     %diametral pitch of pinion
dG = Ng/Pg;     %diametral pitch of gear
V = pi*dP*n/60; %linear speed in m/s
Wt = 33000*H/V; %tangential load in N

%Marin Factors
%overload factor
Ko = 1;         %assume uniform loading
Qv = 7;         %assume commercial quality

%dynamic factor
B = 0.25*(12-Qv)^0.667;
A = 50 + 50*(1-B);
Kv = ((A + sqrt(V/1000))/A)^B;

%shape factor
Ksp = 1.192*(Fp*sqrt(Yp)/Pd)^0.0535;
Ksg = 1.192*(Fg*sqrt(Yg)/Pg)^0.0535;

%load distrobution factor
Cmc = 1;
Cpf = Fp/(10*dP)-0.025;
Cpm = 1;

Cma = 0.125;
Ce = 1;
Km = 1+Cmc*(Cpf*Cpm+Cma*Ce);
```

```
Kb = 1;
mG = Ng/Np;
N_pinion = 10^8;
N_gear = 10^8/mG;

Ynp = 1.3558*N_pinion^-0.0178;
Yng = 1.3558*N_gear^-0.0178;

Kr = 0.85;
Kt = 1;
Cf = 1;

I = (((cos(deg2rad(20)))*sin(deg2rad(20)))/2)*(mG/(mG+1));
Cp = 191; %assuming steel gears being used
Hb = 200;

st = 0.533*Hb+88.3;      %allowable bending stress
sc= 2.22*Hb+200;      %allowable contact stress

Znp = 1.4488*N_pinion^-0.023;
Zng = 1.4488*N_gear^-0.023;

Ch = 1;

%tooth bending stress
sigma_pB = Wt*Ko*Kv*Ksp*Pd*Km*Kb/Fp/Jp;
sigma_gB = Wt*Ko*Kv*Ksg*Pg*Km*Kb/Fg/Jg;

%tooth wear stress
sigma_pC = Cp*sqrt(Wt*Ko*Kv*Ksp*Km*Cf/(dP*Fp*I));
sigma_gC = Cp*sqrt(Wt*Ko*Kv*Ksg*Km*Cf/(dG*Fg*I));

PinionBendingFOS = (st*Ynp)/(Kt*Kr)/sigma_pB
GearBendingFOS = (st*Yng)/(Kt*Kr)/sigma_gB

PinionWearFOS = sc*Znp/(Kt*Kr)/sigma_pC
GearWearFOS = sc*Zng/(Kt*Kr)/sigma_gC
```

Shaft Analysis

```
clc
clear
%Shaft Analysis
Sut = 620;%     1060 steel
SePrime = 0.5*Sut;
d = 8;  % shaft diameter
r =d/2; %shaft radius
L = .05;    %shaft Length
M = 0.129;  %Peak bending Moment

volume = pi*r^2/10^6*L;
density = 7850;         %kg / m3

mass = volume*density;
y = r;
I = 0.5*mass*r;
sigma = M*y/I;



a = 1.58;
b = -0.085;

ka = a*Sut^b;   %ground finish
kb = (d/7.62)^-0.107;
kc = 1;         %bending loading
kd = 1;         %room temperature
ke = .897;     %95% reliable
kf = 1;

Se = ka*kb*kc*kd*ke*kf*SePrime

f = 0.86;
a = (f*Sut)^2/Se;
b = -(log(f*Sut/Se))/3;

N = (sigma/a)^(1/b) %Cycles to Failure
```