ME 481 Design Report
Autonomous Tennis Ball Collector

December 4, 2009

Prepared for:

Professor Jan Huissoon

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Dr. Jan Huissoon
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Dec 4, 2009

Dear Dr. Huissoon,

Please accept the accompanying report, entitled "Autonomous Tennis Ball Collector" as our final design report for ME 481. Our project is an autonomous robot that collects tennis balls from a tennis court. The robot is designed to reduce the down time a player faces when having to collect balls after practicing with a ball lobber.

The report outlines the design and decision procedures carried out by Group 27 throughout the Fall 2009 Term. It discusses possible means of meeting the need of extending solo tennis training time. It then presents the optimal solution with supporting reasons for its selection. The remainder of the report explains the in detail the components of the solution including the systems utilized for positioning, ball-pickup and vision.

The report commences with a summary of the project thus far and a series of appendices that include CAD drawings, images, sketches and calculations that help to give more insight into the physical manifestation of the solution.

Sincerely,

Ryan Collier
Mohammed Adham
Perry Haldenby
Kevin Smith

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1 Executive Summary

The purpose of this report is to give insight into the decisions made and procedures carried out by Group 27 in the ME481 Design Project course. The report explains the need that must be met, the potential means of meeting that need, the solution selection including justification and a detailed explanation of the components that make up this solution.

Ball sport training generally requires a partner of the same skill level. Automatic ball launching machines have been designed to allow for solo practice, but these systems do not emulate the endurance aspect of training against a partner, specifically in the case of tennis. Section 2 outlines the introduction to the problem. It is determined that 35% of all time spent with an automatic tennis ball launcher will be downtime caused by having to re-collect balls and refill the launching machine. Sections 3 to 5 outline the problem, and define criteria, constraints and goals for any solution. It is determined that a solution needs to be effective, portable, fast, scalable, durable and cheap. Section 5.4 investigates solutions that have been derived in the past, and determined that all patents relating to this problem are expired, and that none fulfill the constraints, as they are not portable.

Section 6 outlines the decision process in deciding on an optimal solution. Four different possibilities are considered, and after weighted analysis, it is decided that an autonomous ball-seeking robot would be the optimal solution to the problem. Section 4 outlines the chassis selection and design. After considering a number of platforms, the KODIAK platform designed by the UW Robotics team is selected. Section 5 outlines the specifics of the components of this platform.

Section 6 outlines the general collection strategy of the robot, and the overall flow chart for decision making. This will be composed of five processes: analysis, ball drop off, ball finding, ball selection and ball pick-up. Section 9 outlines the method that will be used to position the robot in its environment. This will be composed of a mix of wheel encoders and LIDAR/SONAR based on testing. Section 10 details the mechanism that will be used to pick up the tennis balls. This will be a rotating wheel with bristles, which pushes the balls into on-board storage. This system will also be used to eject the balls when the storage bin is inclined by a pulley mechanism. Section 11 outlines how the vision system will work, and its components. The two main components are the blob detection tool, and the color segmentation tool.

Finally, Section 12 outlines a brief schedule of the project, which leads into Section 13, the budget. Conclusions and Recommendations are presented in Section 14 and 15, where it is determined that the autonomous mobile robot will fulfill all constraints and requirements, and meet the needs assessment. It is recommended that the project go forward. It is also recommended that further testing be performed on the positioning system to determine the optimal solution for this application.

2 Introduction

Professional tennis matches can last upwards of 3 hours, often with little more than 10 minutes of rest in-between sets. The need to train for such endurance matches becomes difficult without a partner of adequate skill. For decades, tennis players have been using automatic tennis ball launching machines to train without the need of a partner.

Testing has concluded that in general, an automatic ball machine that holds 100 tennis balls will launch at an average rate of 10 balls every 29 seconds. Therefore, the total amount of time an average tennis ball machine can last without needing to be refilled is as shown in (1).

$$\frac{29s}{10Balls} \times 100balls = 290\ s \quad (1)$$

Therefore, the maximum time that a tennis player can play with an automatic ball machine is in the area of 4 minutes and 50 seconds. After which, the player must stop all play and collect all the balls around the tennis court using a bottom-loading basket, as is standard procedure in tennis. This is a physically straining procedure, which is generally despised by avid tennis players. From additional experimentation it would take in the area of 2:15 to manually pick up 85 balls. From (2), it can be determined that it will take the player two minutes to pick up all the balls after using the capacity of the tennis ball machine.

$$\frac{135s}{85Balls} \times 100balls = 158\ s \approx 2{:}38min \quad (2)$$

Therefore, it is determined that using current technology, a player will spend ~35% of the total time collecting tennis balls, and not training. This is a large proportion of the time, and needs to be reduced to truly emulate a tennis match.

There are certain methods of automatically collecting tennis balls, as will be investigated in section 3 - Proposed Solutions, but these are not portable, and require extensive modifications to the tennis court.

3 Needs Assessment

There is a need to improve upon the experience of the solo practice sessions of ball sport athletes by extending the duration of consecutive shots, kicks, or swings of the soloist through the conception of a ball-gathering system that operates while the solo athlete is in practice. Current practice session durations are limited by the number of balls initially loaded into the automatic ball launchers. At the end of practice sessions, or during intermissions, the balls must be manually picked up. Existing automatic ball return systems are not portable and cannot be used in conventional courts.

4 Goal Statement

The solution shall serve as a tool to improve the solo practice experience by gathering stray balls in conventional practice environments and returning them to the user, or a more desirable location. The system shall also be relatively portable, and address the need of requiring manual collection of stray balls following each practice session.

5 Problem Formulation

5.1 Objectives

The following objectives are adapted from the project goal statement. These objectives represent the goals that the final design will ideally achieve:

- Decrease training downtime by 75%
- The solution will be adequately portable
- 1 hour without requiring external power
- 80% ball retrieval rate
- Durability – Can be struck by a tennis ball

5.2 Constraints

The following constraints demonstrate strict requirements that any potential solution must achieve:

- The solution must reduce downtime in solo tennis training
- The solution must be able to run on internal power (on-board battery)
- The solution must be able to return stationary tennis balls to the launching device
- The solution must not be destroyed when struck by returned tennis balls

5.3 Criteria

The following criteria were used to judge potential solutions:

- Duration of continuous operation (Duration)
  - Weighting of 6
- Rate of ball collection and transport (Speed)
  - Weighting of 7
- Collection success rate (Reliability)
  - Weighting of 4
- System portability (Portability)
  - Weighting of 5
- Compatibility with conventional court environments (Court Compatibility)
  - Weighting of 5
- Compatibility with conventional ball launching machines (Launcher Compatibility)
  - Weighting of 5
- *Development cost (Cost)
  - Weighting of 4

*A higher cost results in a lower score for these criteria

A description of five potential solutions, along with how those solutions scored with respect to the above criteria can be found in the Proposed Solutions section of the report.

5.4 Patents

Numerous patents where found that relate to tennis ball collection mechanisms. Due to the fact that tennis as a sport has been around for a while, many patents relating to collection mechanisms have since expired. Patents found could be grouped into 2 categories: those that utilized an augmented tennis court and those that required human locomotion to move a device around the tennis court that would then simplify ball collection. The basic idea behind the augmented tennis court is that the court would be slanted either towards a centre point or away to the walls for the balls to roll to a desired area. While effective, this approach requires a special tennis court that is expensive to create and would prevent actual play on the court which would waste space. There existed many cleaver manual ball collection mechanisms, but all required human intervention to provide the device with locomotion around the tennis court. A few patents of interest can be seen in Table 1: Tennis Ball Collection Patents.

US Patent Number	Title
4046131	Tennis ball collection, pick-up and propelling system
5125654	Tennis ball retrieving system
5407242	Tennis ball retriever
6079930	Apparatus for tennis ball retrieval
4116192	Tennis ball retriever
4606543	Practice tennis court
4456252	Tennis service practice court with recovering collecting means

Table 1: Tennis Ball Collection Patents

6 Proposed Solutions

6.1 Abstraction

Five potential solutions were examined in order to determine the best means of meeting the Needs Assessment:

1. Human Controlled Manual Pickup
2. Augmented Tennis Court
3. Vacuum and Conveyor
4. Path-Driven Autonomous Robot
5. Autonomous Ball-Seeking Robot

6.2 Human Controlled Manual Pickup

Human controlled manual pickup involves the use of a tool such as those seen in *Figure 1: Manual Tennis Ball Collection Mechanism*. This type of solution requires the user to stop his/her training session in order to both collect the ball and load them back into the launching device. This solution will score well in the areas of cost and portability, but will obviously rank very low in terms of speed.

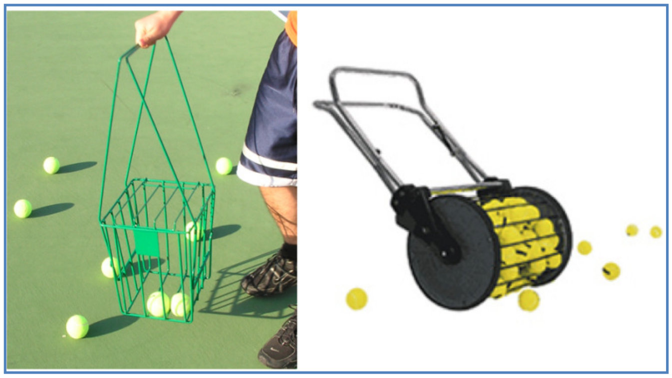


Figure 1: Manual Tennis Ball Collection Mechanism

6.3 Augmented Tennis Court

The augmented tennis court works by adjusting the elevations of the court such that the balls pool to a single common point. This can be seen in figure 2. From the collection point, balls are automatically transported back to the launching device, typically by means of a conveyor system. This solution will score well in terms of speed as the balls are steadily brought back to the launcher. It will do poorly in areas portability and court compatibility as it must be built into the court and is obviously not immediately transferable to other courts.

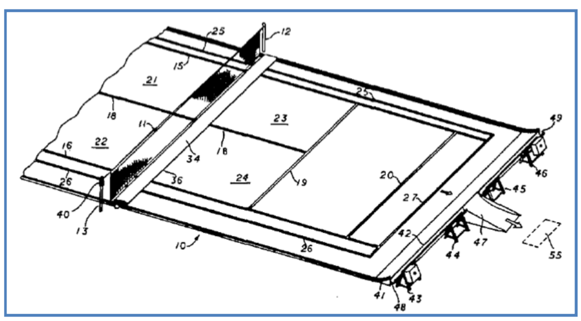


Figure 2: Augmented Tennis Court

6.4 Vacuum and Conveyor

The vacuum and conveyor system can be thought of as a more portable version of the augmented court. A fan is used to blow all balls on the court to a single corner. Once in the corner they roll onto a short conveyor that transports them back into the hopper of the launching device.

6.5 Path Driven Autonomous Robot

The path driven autonomous robot is a hard-coded machine that sweeps the court in a preset pattern. At the end of the sweep cycle, the robot dumps the balls into the launcher's hopper and repeats the sweep. This solution would score well in terms of portability and court compatibility.

6.6 Autonomous Ball-Seeking Robot

The autonomous ball seeking robot is very similar to the path driven robot outlined above. This robot however is able to seek out the balls in order to pick up more balls in less time. It ranks highly in the areas of speed and portability, but is undoubtedly one of the most expensive potential solutions

6.7 Final Selection

Table 2: Method Decision Matrix shows a decision matrix that rates each solution in its ability to adhere to the seven criteria. Each criterion is weighted as outlined in the Criteria section. The sum of the products of each weight multiplied by the potential solution's ability to meet the given criteria represents the potential solutions overall score.

	Human Controlled Manual Pickup	**Augmented Tennis Court**	**Vacuum and Conveyor**	**Path-Driven Autonomous Robot**	**Autonomous Ball-Seeking Robot**
Duration (6)	8	8	8	5	5
Speed (7)	1	9	8	5	7
Reliability (4)	8	8	5	6	6
Portability (5)	8	1	4	7	7
Court Compatibility (5)	9	1	4	8	8
Launcher Compatibility (5)	3	7	6	6	6
Cost (4)	7	2	4	5	3
Total	**215**	**196**	**210**	**214**	**220**

Table 2: Method Decision Matrix

The optimal solution, as determined by the decision making matrix is the Autonomous Ball-Seeking Robot. This solution is the most likely to adhere to the meet the criteria and achieve the objectives defined above.

The Autonomous Ball Seeking Robot utilizes a ball pickup mechanism to bring the balls form the tennis court floor into its onboard storage area. A decision matrix comparing the possible mechanisms for picking up the balls is located in the appendices of the report. A description of the selected mechanism is located in section 10.

The robot is location aware. It utilizes a positioning system in order to determine its location relative to objects on the court. These objecting include walls, balls, the net and the ball dumping station. The means by which the balls are transported from the dumping station to the hopper of the ball launcher are not within the scope of this report. The robot has a dumping mechanism that allows it to unload its stored balls into the dumping station.

The robot will utilize an onboard camera to actively seek balls on the court. A description of the implementation of the camera and vision system is located in section 11 of the report.

7 Design

To reduce cost and development time, numerous platforms were explored for the locomotion of the robot. RC cars and simple robot kits found online offered stable platforms for locomotion starting at $120. RC cars, at the lower end of the price spectrum, are the least practical due to their Ackerman steering. While manageable, Ackerman steering severely limits a robot's maneuverability in tight corners. Also, RC cars do not come with motor encoders for feedback, which would add cost to an RC car platform. Robot platforms that did include encoders were exceedingly more expensive. For prototyping purposes, a sturdy base utilizing a stripped down version of an existing robot form the UW robotics club at no cost was selected. The robot, named 'Kodiak', was originally designed for landmine detection in rough terrain. It provides a large frame to build off of for the collection and storage of balls. The drive train also offers ample torque. To prepare the robot for use, group 27 stripped down the robot to its bare frame and repaired the drive train. For future work, a similar robot base can be designed with lower torque requirements.

7.1 Chassis

The chassis consist of an aluminum frame held together by 2 sheets of thick aluminum, that run along the side of the robot, welded to 2 pieces of square tubing at the front and back of the robot. All components of the robot are mounted to the 2 thick sheets of side aluminum. A sheet of aluminum is attached to the bottom of the frame for rigidity and additional mounting if needed. A CAD model of the chassis can be seen in Figure 3: Exploded Chassis View.

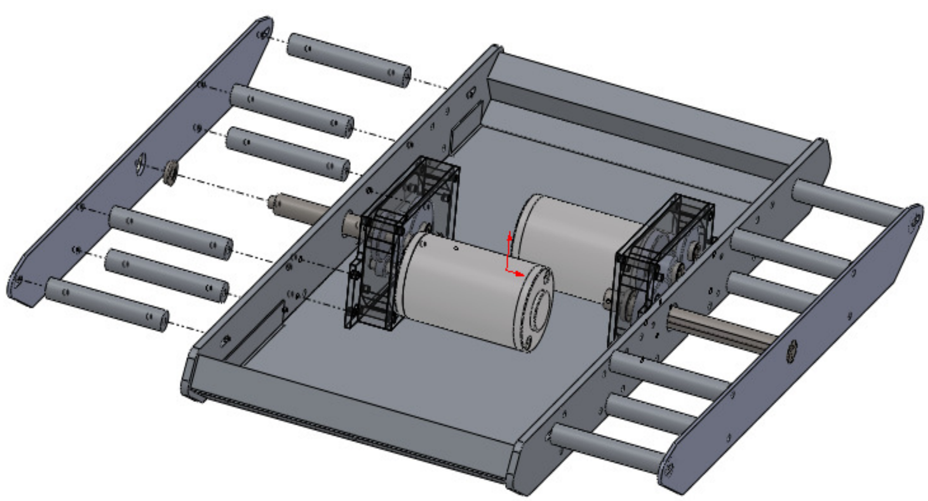


Figure 3: Exploded Chassis View

7.2 Drivetrain

The drivetrain consists of six 8.5” in diameter foam wheels meant for lift trucks. They are chain driven and receive power from a custom gear box and CIM motors, the same motors used by FIRST robotics. The centre wheel is mounted slightly lower than the outer wheels for easy maneuverability of the robot. This reduces friction for pin-point turning that would normally occur if all 6 wheels lied on the same plane. The center wheels contain keyed hubs and are driven by the motors directly from the gear box. The outer wheels contain bearings in their hub and are attached to a fixed axle. They are driven via chain and sprocket from the centre wheels. The motors have a stall torque of 19.65 in-lb at a stall current of 107 amps with a maximum power output of 321 watts. The custom gear box is geared for torque, which produces more than enough torque for the required application at a reasonable speed. Figure 4: Drivetrain shows a picture of the assembled chain and sprocket drive train.

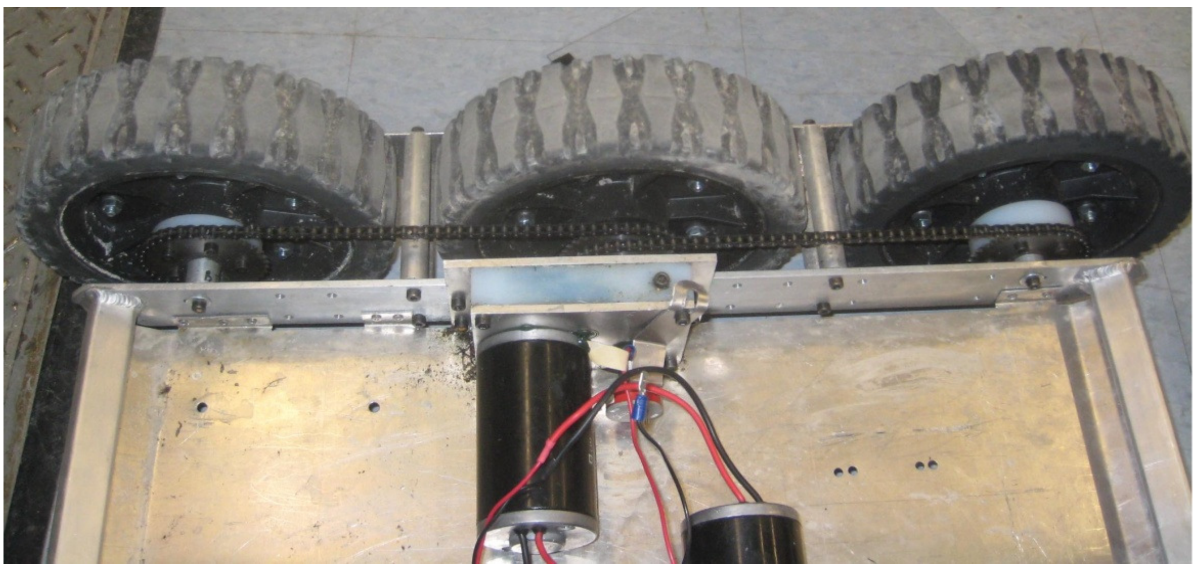


Figure 4: Drivetrain

7.3 Battery Power

The drivetrain is powered by a custom lithium ion battery pack constructed from lexan and copper plate. The battery pack consists of 3x3.6V lithium ion cells in serial for a nominal voltage of 10.3V. It then packs 10 of these sub-units in parallel, each having 2.4A max discharge, for a total max discharge (~30 seconds operation) of 24A. This generates a maximum output of 247.2 watts, providing a generous supply for the motor’s maximum power rating of 321 watts. Each lithium ion cell contains its own over-voltage, under-voltage and temperature protection circuitry for safety. The battery pack contains a solid state switch for powering the supply on and off. It also contains an RF receiver and relay for remote enabling and disabling of the power supply.

7.4 Motor Control

The motors are independently controlled by their own Parallax motor controllers. They operate at 25A continuous (greater than the 24A peak discharge from the battery pack) and operate between 6 and 16 VDC. They are controlled by a PWM signal. 1.0ms full reverse, 1.5ms neutral and 2.0ms full forward. The motors are each coupled to an optical quadrature encoder via the custom gear box. The encoders are managed by an Olimex MCU header board that runs FreeRTOS on a 32-bit ARM7TDMI RISC core. Motor speeds are set via a serial interface to the MCU, which then uses PID control to drive the PWM signal to the motor controllers. The quadrature encoder gives feedback to the PID controller. The Mars Rover project on the UW robotics team is currently fabricating a PCB break-out board for the MCU header board that will allow us to easily connect power, encoders and a serial port to the MCU.

Communication with the MCU will take place via serial UART data transfer. In order to facilitate communication between the tablet PC and the Serial (RS 232) interface of the MCU, a serial to USB adapter will be adapter will be used. Adapters cost approximates $12 and include a driver. Once installed, the driver allows communication to the serial output via the Windows COM ports. In order to write communication algorithms that will be correctly interpreted by and received form the MCU, a few basic parameters of the MCU are required. These include (but are not limited to) baud rate and parity.

Pseudo code for the MotorControlUnit class and a listing of basic motor control functions is located below:

```
MCU = new MotorControllerUnit(parameters inherited from serial class - include Baud rate,
Parity settings, etc. as well as callback pointer/delegate (for c#));

MCU.MoveForward(duration/distance);
MCU.MoveBackward(duration/distance);
MCU.TurnLeft(degree);
MCU.TurnRight(degree);
```

NOTE: It will likely be decided that the above functions should not accept parameters and that these variables will simply be controlled by programming on the laptop (in C#). For example, MCU.MoveForward() causes the robot to move forward a very small distance, but in the main program will exist as a command within a loop.

7.5 Sensors

Motor speed is managed with quadrature optical encoders by the MCU. A serial interface is present to send and receive motion commands to the MCU. This serial interface will be connected to a serial-USB dongle. All sensor I/O will run on a Universal Serial Bus to a tablet PC computer. The only sensor that is real time sensitive is the quadrature optical encoder which is handled on the MCU. All other sensors do not require strict real time performance and can be handled on a PC. A Hokuyo LIDAR sensor will be used for obstacle detection, mapping and localization. Blobs will be detected via a webcam with signal processing on the PC.

7.6 Software

Microsoft Robotics Studio (MSRS) on Windows XP will be used for the software development environment on a tablet PC. C# will be used for its extensive library support and high level capabilities. MSRS offers a robust framework for development by offering simulation, remote control and a graphical programming environment. Individual windows services manage all peripheral communication that is then managed by a master controller. Each service will be responsible for 1 USB peripheral. One service will manage imaging, one service will manage LIDAR, one service will manage the motor control and one optional service will manage voice communication. The master controller passes messages to all the services and orchestrates the entire control of the robot. Each service will log vital information (such as raw sensor data) to a SQL database for offline analysis. The services work by addressing their respective USB peripheral by its unique device address. In the case of the serial-USB dongle used for controlling the motor via serial commands, the USB dongle driver will make a windows COM port available for programming against the serial port.

8 Collection Strategy

The overall goal of the collection system is to be somewhat intelligent about where to pick up tennis balls. The goal is not to simply seek blobs in a loop, but to scan the environment and make decisions based on the characteristics.

8.1 Environment and Ball distribution

The environment for this system is narrowed to ensure ease of preliminary design. Through a partnership with the Northfield tennis club, a fixed environment of operation is chosen to be an indoor tennis court with artificial lighting. The lighting in the court is uniform. The tennis court also includes an automatic tennis ball machine. The exact model is a “silent partner”, as shown in *Figure 5: Silent Partner.*

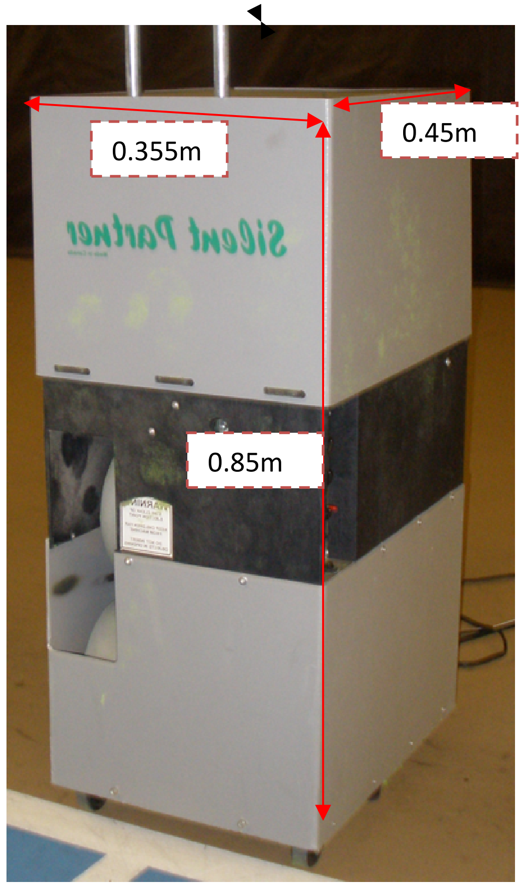


Figure 5: Silent Partner

Tests are carried out using the silent partner and an average skilled player. After a number of tests, a general distribution of the location of the balls is calculated. It is determined that roughly 85% of the tennis balls will be found behind the tennis court's base line, with the remaining tennis balls in front of the tennis net. The distribution is generally proportional against the back wall, as shown in *Figure 6: On Court Ball Distribution.*

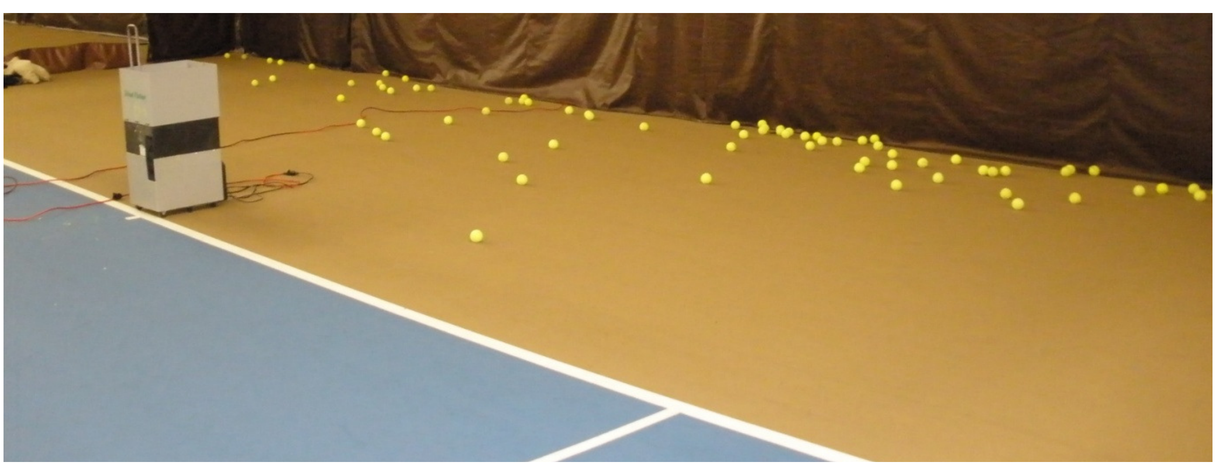


Figure 6: On Court Ball Distribution

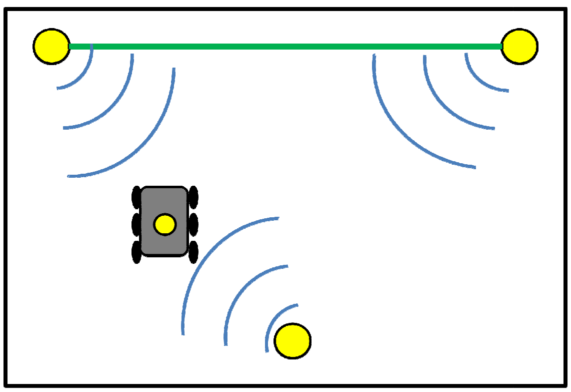
After this analysis, the area of operation of the robot is defined. Appendix 16.2 indicates the area of operation in which the robot will generally operate, an area of around 2 meters squared.

8.2 Collection Strategy Flow Chart

Appendix 16.3 shows a flow chart of the overall strategy of the robot. It consists of five main processes: analysis, ball drop-off, ball seeking, ball selection and ball pick-up. The basic decision process of each of these sections is laid out in the overall flow chart. Each section of these processes will be detailed further as the report proceeds. It should be noted that while in this flow chart, the robot is to always be analyzing its surroundings to avoid key problems. It will always use sensory output to detect if a collision is imminent, as well as if it is leaving its area of operation.

9 Positioning

When developing the location system for the robot, the initial intention was to implement a triangulation positioning system. The system relied on three sonar beacons that would be mounted according to the diagram below.



The Sonar beacons would emit a constant signal/pattern that would be received by the robot. Each beacon would emit a signal of different frequency. When the signals were received by the robot, it would determine how long each signal took to reach its receiver and, multiplying by the approximate speed of the signal (near the speed of sound,) the distance form each beacon could be determined. Knowing the three distances, the robot's relative position could easily be determined.

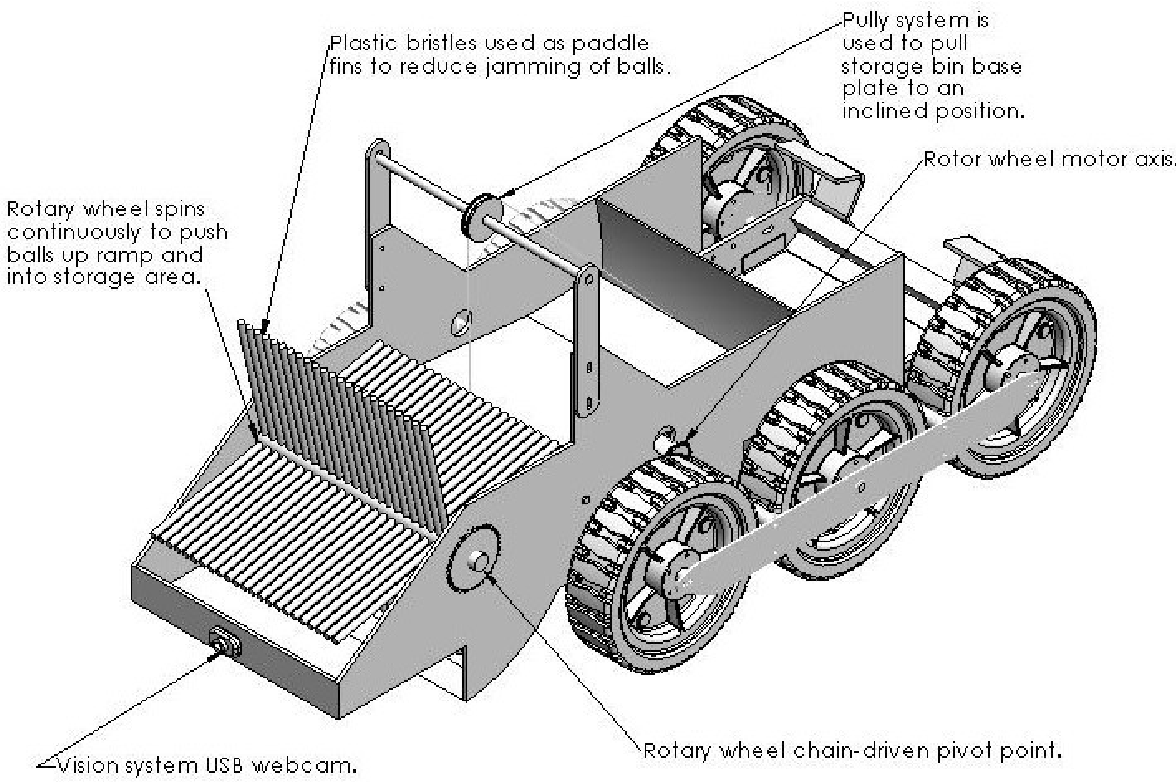
With further research into commonly used forms of robot positioning, it was determined that the difficulty involved with fully implementing a position triangulation system would not be worth the benefit of the marginally increased position accuracy.

The final positioning system relies heavily on wheel encoders to keep track of the robot's position. The dropped axel of the robot chassis/drivetrain helps to eliminate the wheel slip that would traditionally distort the encoder data of a wheeled robot. The working environment of the robot (one half of a tennis court) will be sectioned into an x,y coordinate plane. The robot will keep track of its position in the form of x,y coordinates. So long as the robot has not run into an obstacle, high resolution of position is not a strict requirement. The working environment will be a grid of one foot squares and the centre of the robot will be tracked with respect to which square it is currently above. It is expected that experimentation will show that higher resolution is possible, and if necessary, will likely be implemented.

Starting from a known position, the encoders initially highly provide accurate location data. As the robot travels further away from the starting point, however, distortions in the encoder data cause the robot's knowledge of its position to become increasingly inaccurate. In order to overcome this, the robot will rely on either sonar or LIDAR to perform object detection. (Whether sonar or LIDAR is implemented will depend on group 27's access to the UW Robotics Team's LIDAR module as well as the accuracy of each system with respect to detecting mesh object such as a tennis net.) Obstacle detection allows for the accurate "re-sync" of the robot's x,y position. For example, when the LIDAR or sonar sensor detects an object in front of it, the robot can use its semi-accurate position information to determine what the object is (i.e. It is in the bottom left region of the court, traveling left, it sees an object 4 feet away, the object is likely the left wall.) Once the robot has determined what the object is and how far away it is, it can update the information about its position (i.e. the left wall is 3 feet away, therefore the x position gets set to 3 – the y position remains unchanged.) Additionally, a tennis court is painted with a set of lines of known position. If necessary, a form of line detection will be used to further increase the accuracy of position data. Line detection is possible with the webcam (currently being used for ball detection,) but may be done with an independent light/colour sensor to improve accuracy and avoid potential complications.

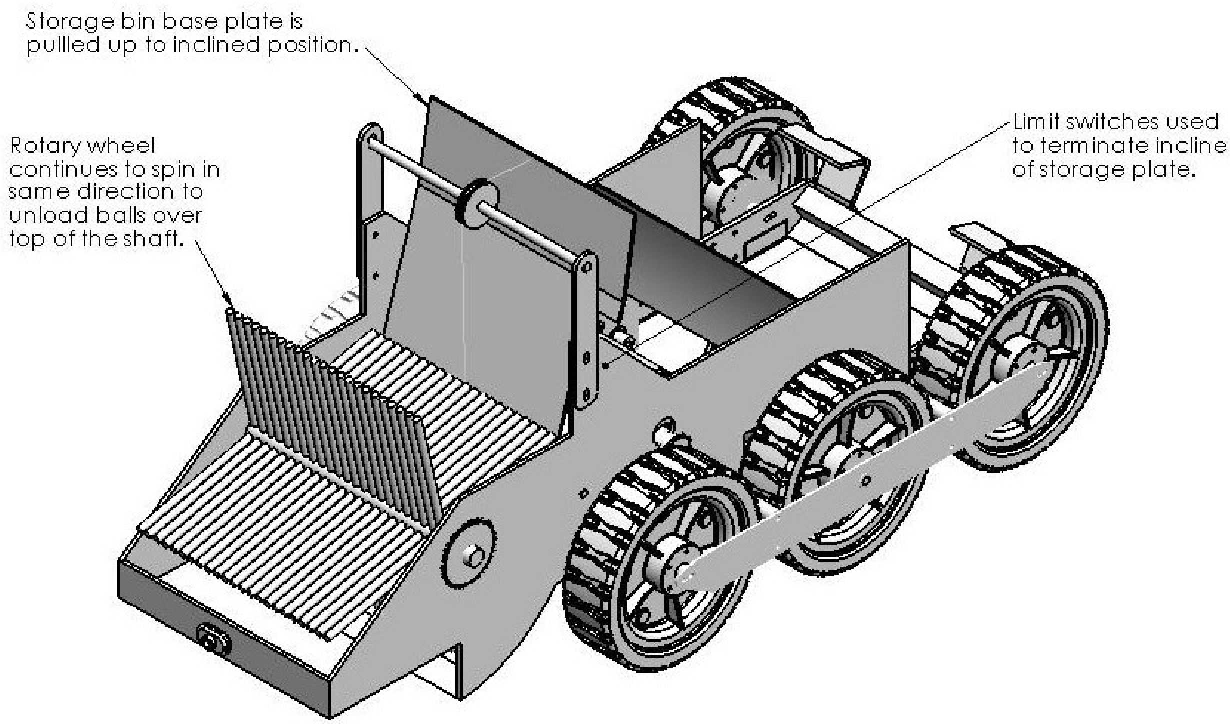
10 Pick-Up Mechanism

The system to be used in picking the balls up off the court consists of a single rotating shaft mounted on the front of the robot with 4 or 5 rows of stiff, plastic bristles that shall push balls up a curved ramp and into an onboard storage bin area in the chassis. The storage area is designed such that the bottom plate of the bin can be raised by use of a motorized pulley system to unload balls over top of the bristle wheel. The bristle wheel is in constant rotation when the solution is in operation. The figure below describes various details of the system in collection mode.

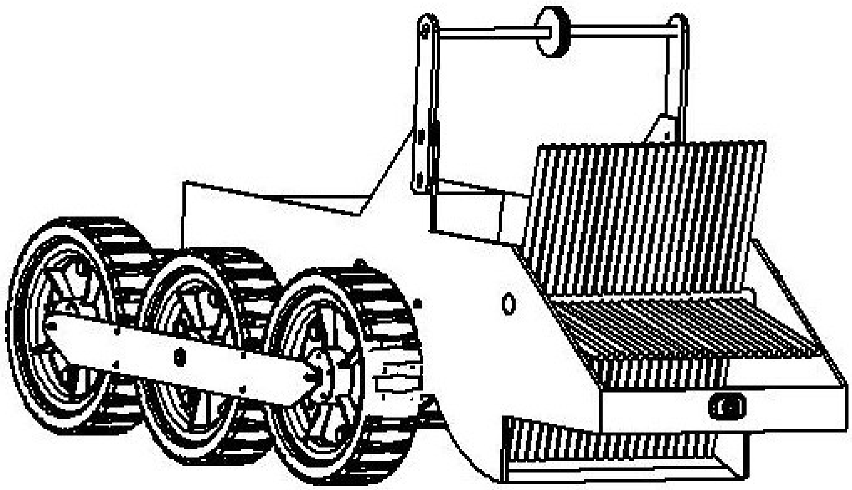


The build consists of aluminum frame that shall be tack welded and riveted to the existing Kodiak chassis. The side panels consists of the support framework for the system components, and make use of the existing mounting holes in the Kodiak chassis body.

The rotary wheel is to be chain driven from a spur gear that is pre-mounted on the Kodiak chassis. All measurements for the existing Kodiak structure are available in the Kodiak database provided by the UW Robotics Team. Further torque analysis shall be done to determine the minimum required torque to rotate the bristle wheel and lift the maximum amount possible load (geometrics allows for a maximum of 4 balls to be lifted in any given 90 degree rotation of the bristle wheel).



A force analysis will be required to determine the optimal height of the pulley rod, and the motor torque required to lift the bin platform from a horizontal position to nearly vertical position, while considering the weight of the platform and ball load. The motor for the pulley system is to be mounted underneath the storage bin platform in front of the drive wheel motors (not viewable in the diagrams). The pulley support links are to made adjustable to accommodate some adjustability. The system gives unloaded balls a potential energy of 0.109 N at a height of 18.5 cm from ground level. This should allow enough feasible potential energy to displace the balls to a desired orientation in the drop-off bay to reload into the ball machine.



11 Vision System

A major aspect of the control of the robot is the vision system. Major strategic decisions will be made based on the feedback from the vision system. The system will be composed of an off-the-shelf web-camera, in tandem with the image processing capabilities of the Microsoft Robotics Studio software. The system will be composed of three main parts, blob detection, color segmentation, and overall analysis.

11.1 Blob Detection

The first job of the vision system is blob detection. From the flow chart in Appendix 16.3, blob detection will be the main sensory input for the "Look for Balls" process. Blob detection inside of Microsoft robots studios is quite advanced, and does not require extensive image processing knowledge to be used. The first step in blob detection is calibration.

Calibration of the blob detection system is key to overall performance, and is done very well by Microsoft robotics studio. In Microsoft robotics studio, there is a built in tool named "Blob Tracker Calibration", which allows the user to select the color of the blob from a live video feed. This effectively makes the color selection field programmable, and will allow for calibration on-site, to avoid issues with lighting and other chaotic environmental conditions. The goal is to have the user program the blob detection color when the robot is initialized, as to always ensure optimal tracking conditions. This, along with the fact that the testing environment has uniform lighting conditions indoors, ensures stability in blob detection. Testing is carried out on site using the built in blob detection and is proven to be very accurate.

The blob detection algorithm is based speed. The system uses a live feed from a webcam to perform image analysis. The speed of image analysis is based on the speed of the system running the software. Testing proves an approximate rate of 20fps using the hardware selected for this project. The algorithm focuses on analyzing the colors in the image, and creating a convex hull around the colors that are to be tracked. Figure 7 shows an example of the system tracking tennis ball color.

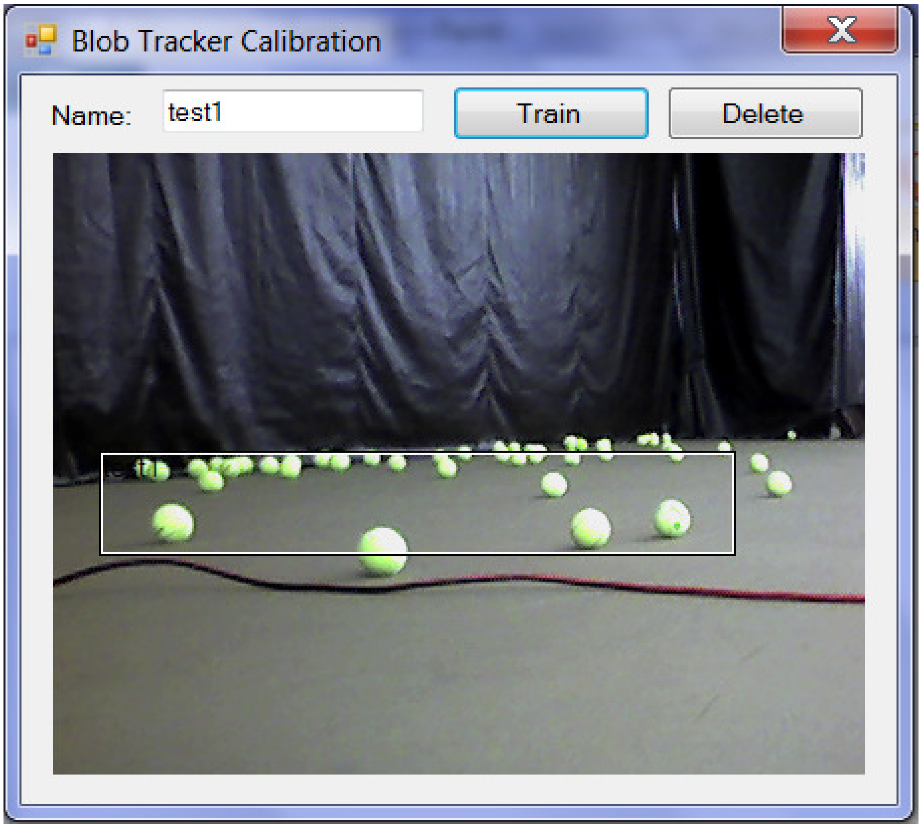


Figure 7: Blob Tracker Example

It is important to note from this image that single balls are not selected, but the group is selected. This is important for the overall control of the robot. This process will be used to detect whether there are any balls in front of the robot. Once a blob of balls is detected, the system returns an X and Y coordinate of the centroid of the blob. This the robot will then centre x position of the blob in the vision of the robot, and move onto color segmentation.

Blob detection will also be used to detect the drop off station for the balls.

11.2 Color Segmentation

The final stage of the vision system is to decide which blob or single ball to pick up. This is the "Blob selection" stage of Appendix 16.3. Color segmentation is the process of segmenting an image into different clusters of the same color. This is important to the vision system, as it allows the robot to get a general idea of where the balls are distributed, and decide how to proceed based on analysis of this information.

Color segmentation will be done through Microsoft Robotics Studio's built in functions. Much like blob tracking, Microsoft Robotics Studio provides a calibration tool for color segmentation, that is also field programmable. The actual color segmentation tool in Microsoft Robotics studio then runs on the live webcam feed. It should be noted that color segmentation is far more computationally intensive that blob tracking, will therefore only be run once a blob of balls is found. This will prevent unnecessary stress on the system.

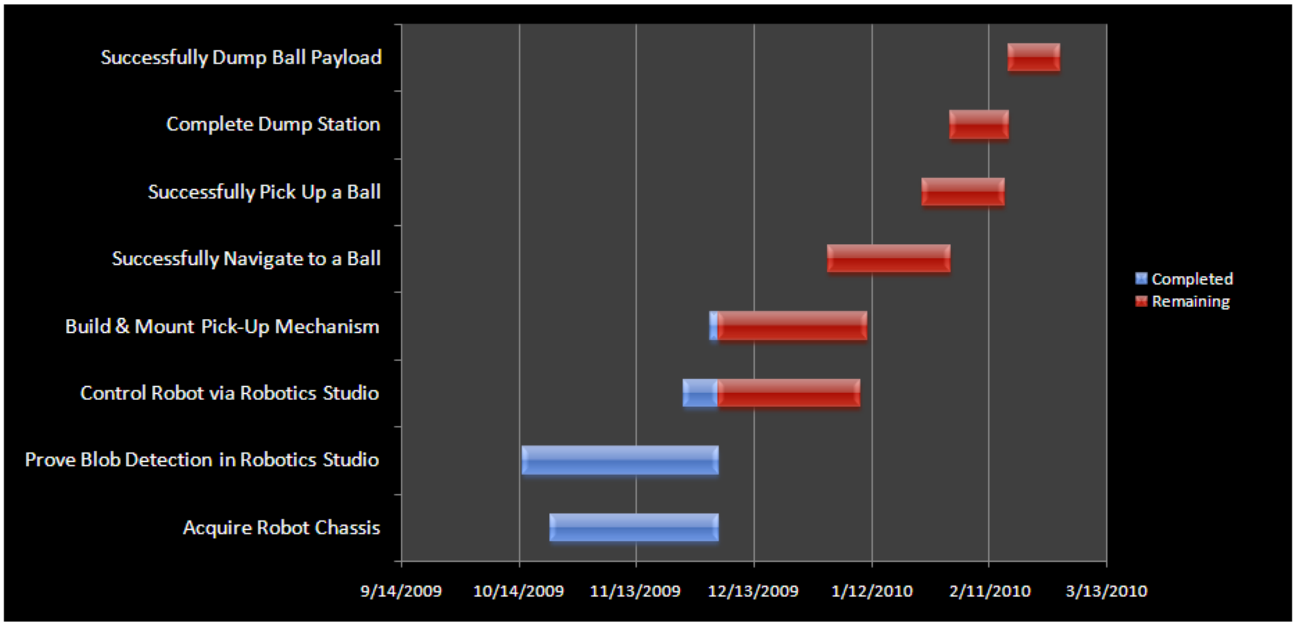
The color segmentation tool returns an array of segments in the screen. This array contains the x and y coordinates of the centroid of each segment found. Based on this array, analysis can be performed to determine the best plan of attack to pick up the largest amount of balls. The first process in this decision is distance. Appendix 16.4 outlines the basic geometry of the vision system. Based on the two fixed variables y (distance from the ground to the camera) and Φ (angle of camera from ground), analysis can be done on the Y position on the image to determine the distance from the ball. Initial calibration will be needed to determine the exact distance of the ball based on the placement of the ball in the camera view. It should be noted that due to the nature of an angled camera, the higher the value of h1 (from diagram), the farther the ball from the robot. This increases on an exponential scale, as the camera can see far into the horizon.

Once the distance to each ball segment is determined, the algorithm will then analyze the optimal decision on where to proceed. While distance is important, the distance of one ball to the next ball is also important, and will be weighed into the algorithm. Testing will be carried out to determine which weighting of distance to ball versus distance to next ball is optimal.

Finally, the segmentation algorithm will also be used to determine the approximate number of balls stored on the robot. Based on the fact that the robot will be aware when it is approaching and picking up a ball, a count will be maintained to allow the robot do determine when the maximum 15 balls are reached and that it should proceed to ball drop off.

12 Schedule

The following Gantt chart displays the schedule of group 27. It begins form the start of classes on September 14th and extends to the approximate date of project completion in mid March.



13 Budget

The initial budget for the project is defined by the department of Mechanical and Mechatronics Engineering. It is set to a total of $350 for the duration of the project. The majority of the costs is $0 due to donations by team members, as well as sponsorships from the Northfield Tennis Club and the University of Waterloo Robotics Club. These are budgeted costs, and have not all been sourced at this point.

Item	Quantity	Cost
Kodiak Platform	1	$0 (donated)
Tablet PC	1	$0 (donated)
Court Time at Indoor Club (1 hour)	20	$0 (donated)
Webcam	1	$10.00 (purchased)
Aluminum 6063 (5mm)	$2m^2$	$80.00 (scrap cost estimate)
Motor for pulley system	1	$0 (dontated)
Steel Cable (1m)	1	$5.00
Tennis Balls	100	$0 (donated)
Plastic Bristles	4 x 15	$30.00
Chain, Gears, Bearings	1	$70.00
Limit Switches	2	$20.00
LIDAR	1	$0 (donated)
TOTAL (approximated):		$215.00
Excess for Incidentals		$135.00

14 Conclusions

Based on thorough analysis, a number of conclusions can be made. There is a need for a portable system that can automatically collect and deliver tennis balls to automatic ball launcher. The optimal method to perform this task has been determined to be an autonomous mobile robot that actively seeks tennis balls on the court. The optimal chassis for this application is a KODIAK platform provided by the University of Waterloo Robotics team.

The proposed solution meets all defined constraints and requirements. Based on experimental analysis, it will be able to collect 85% of the balls inside its area of operation. The system is portable, and can be brought to any tennis court and calibrated to the given environment on the fly. The solution is able to function off of battery power for a significant duration of time, and is durable enough to withstand the impact of a tennis ball.

The project's scope can be completed within the allotted time, and has a loose schedule. The budget is generally within the scope of the project, but cost over-runs are expected.

15 Recommendations

The autonomous ball seeking robot project should proceed onto the build and test phase as soon as possible

After thorough analysis, a final design has been proposed to achieve all constraints and objectives. It is recommended that this design be implemented and taken forward as soon as possible to meet the prospective schedule timeline.

Further testing should be carried out on the color segmentation algorithm to determine optimal decision weightings

The design of the exact decision algorithm for determining which cluster of balls to approach and pick up first can only be done through testing and optimization. It is recommended that the decision algorithm be optimized after chassis construction and control mechanisms are completed.

Testing should be carried to determine the feasibility of LIDAR versus SONAR for positioning control

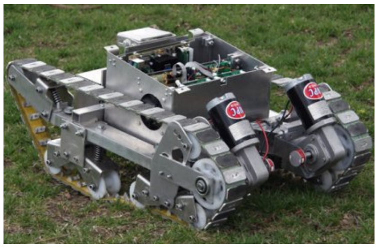
While both systems are useful for positioning control, only one is necessary, and testing of the optimal solution can only be completed once the chassis and control mechanisms are completed. It is recommended that these two systems be implemented after this stage and the optimal one selected.

16 Appendices

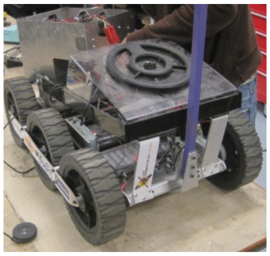
16.1 Potential Platforms

The Traxter 2 robot platform is a study, stainless-steel, tank-driven robot base. It's retail price is $200 including two 7.2V DC motors and it's are 9 inches by 8 inches.

The Stinger robot platform is a highly maneuverable two-wheeled (plus third ball-type support). Its retail price is $135 (Including motors) and it measures 11.6 inches by 10.3 inches.

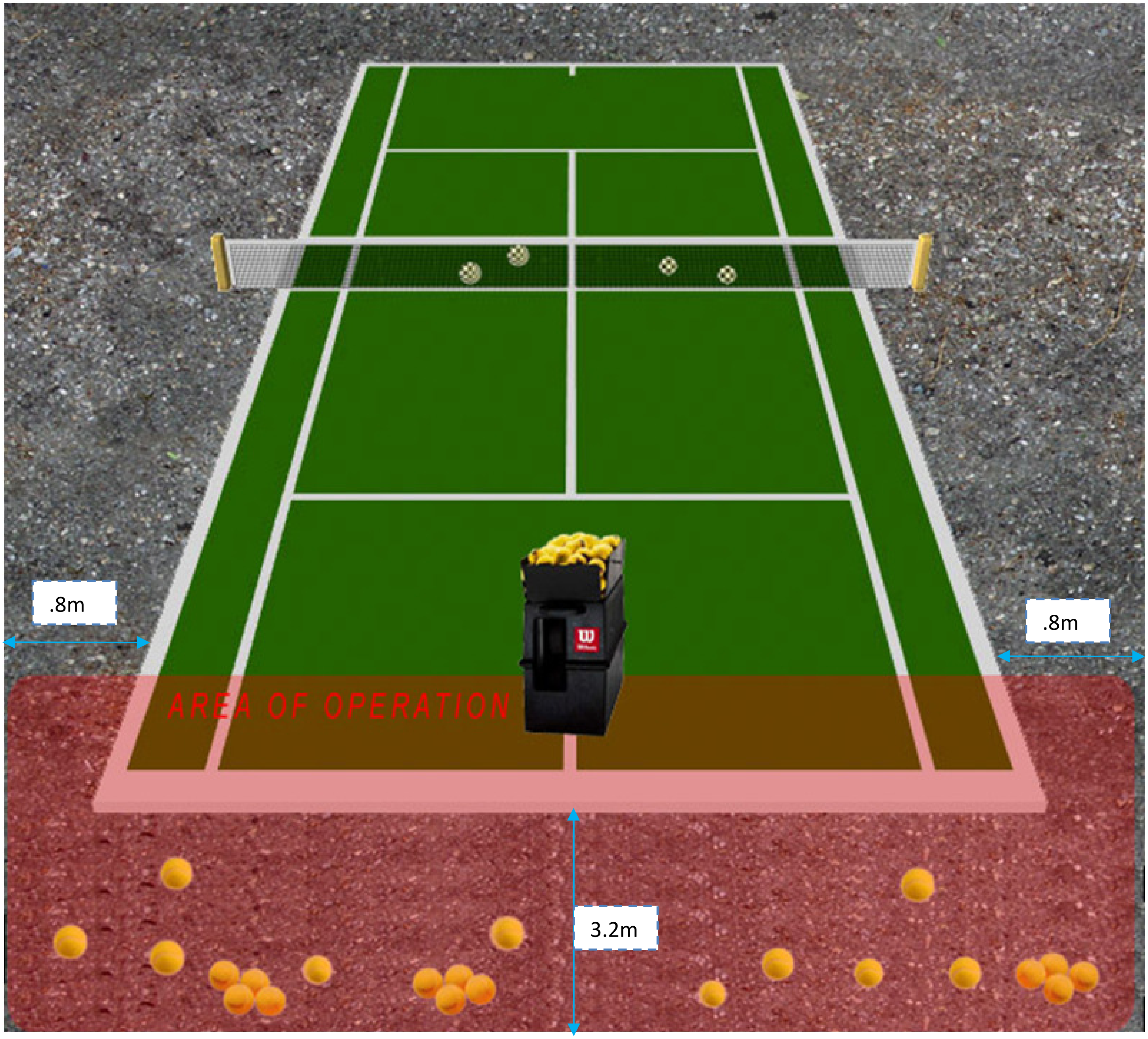


The Marauder was created by the UW Robotics Team and therefore has a cost of $0. Its dimensions are 18 inches by 36 inches. Its treads provide good maneuverability. It requires substantial maintenance to return to working condition.

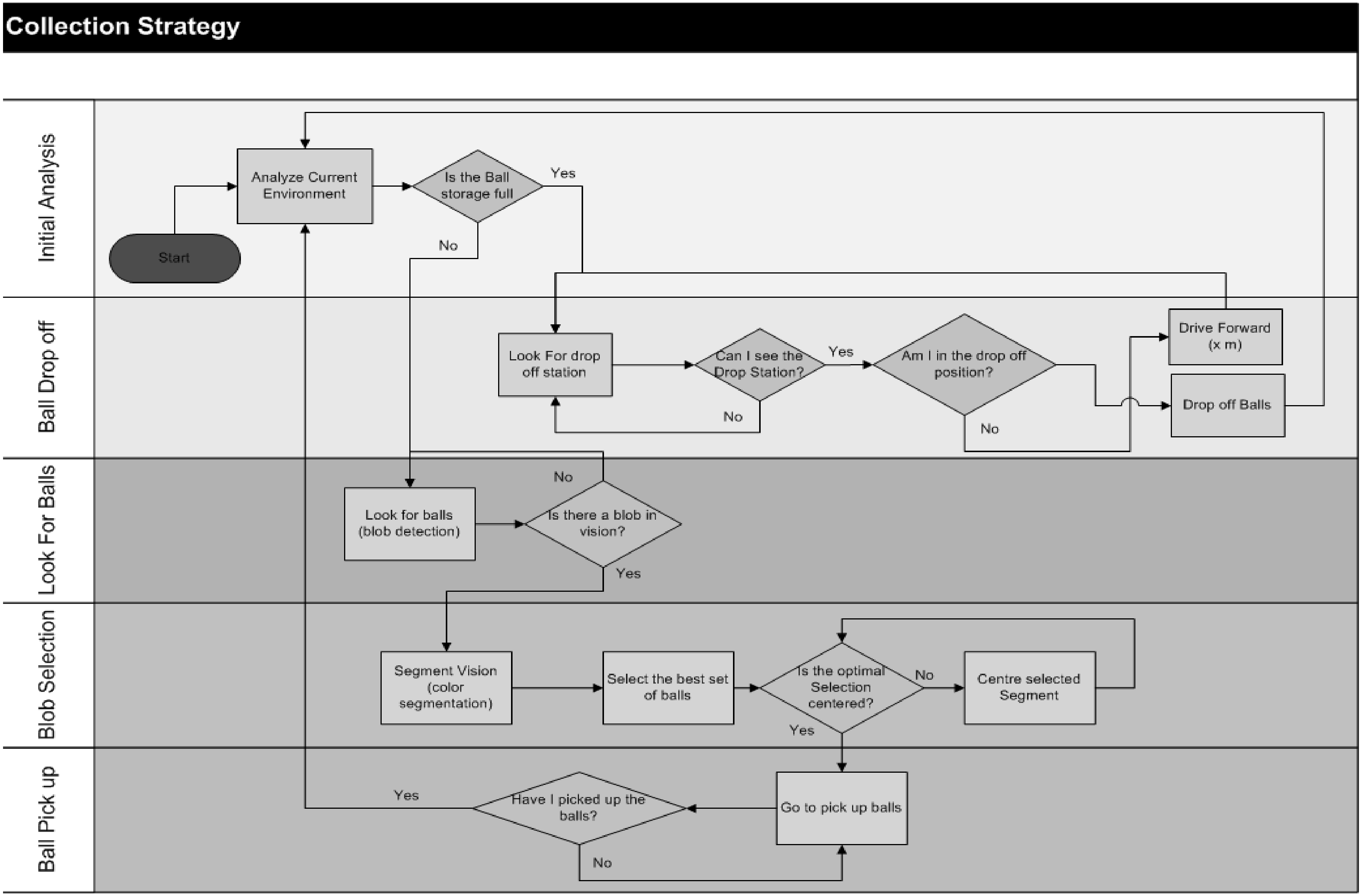


The Kodiak was created by the UW Robotics Team – its cost is $0. Each set of three wheels turn independently from the opposite side allowing for excellent maneuverability. It is constructed of aluminum and is 18 inches by 36 inches.

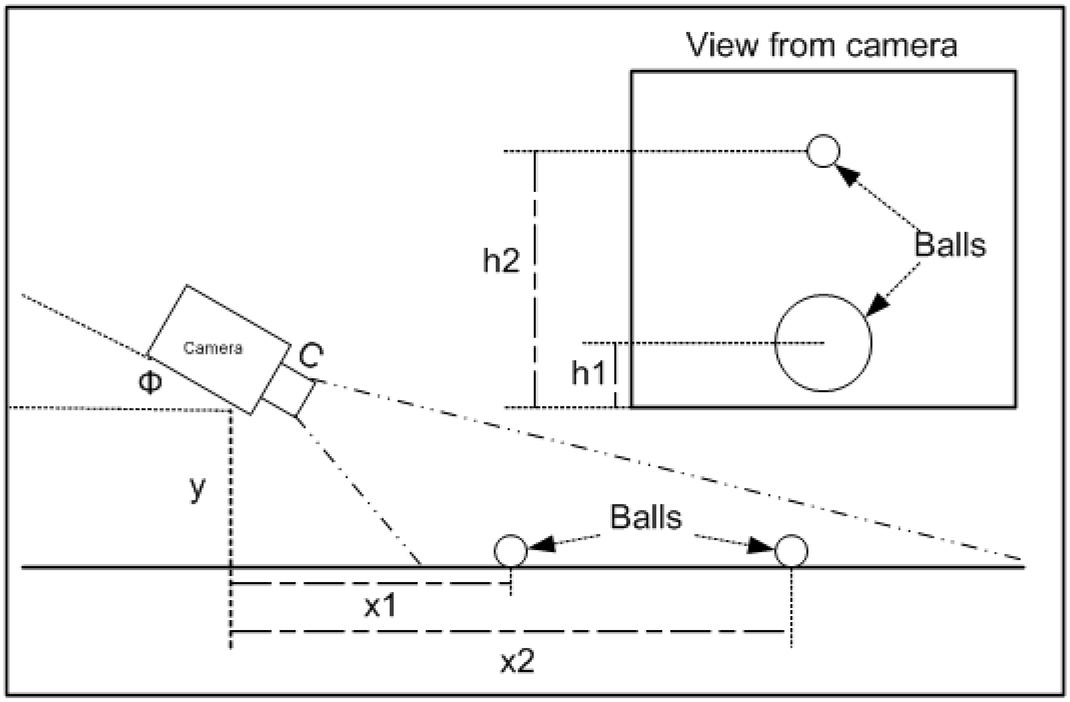
16.2 Area of Operation



16.3 Collection Strategy Flow Chart



16.4 Vision System Geometry



16.5 Pickup Mechanism Decision Matrix

The following criteria were used to judge the three potential ball pick-up methods:

- *Complexity (Duration)
  - Weighting of 6
- Effectiveness
  - Weighting of 7
- Speed
  - Weighting of 4
- Durability
  - Weighting of 5
- *Cost
  - Weighting of 5

*A higher complexity and cost result in a lower score for this criterion

	Method #1 (Spinning Disc)	Method #2 (Paddle Wheel)	Method #3 (Bristle Wheel)
Complexity(6)	2	7	8
Effectiveness (8)	7	8	5
Speed (7)	6	7	6
Durability (5)	5	6	7
Cost (6)	2	6	5
Total	**147**	**221**	**195**

The optimal ball pick-up mechanism, as determined by the decision making matrix, is Method #2 - The Paddle Wheel.

16.6 Chassis Decision Matrix

The Following criteria were used to judge four potential robot chassis and their associated acquisition and/or construction.

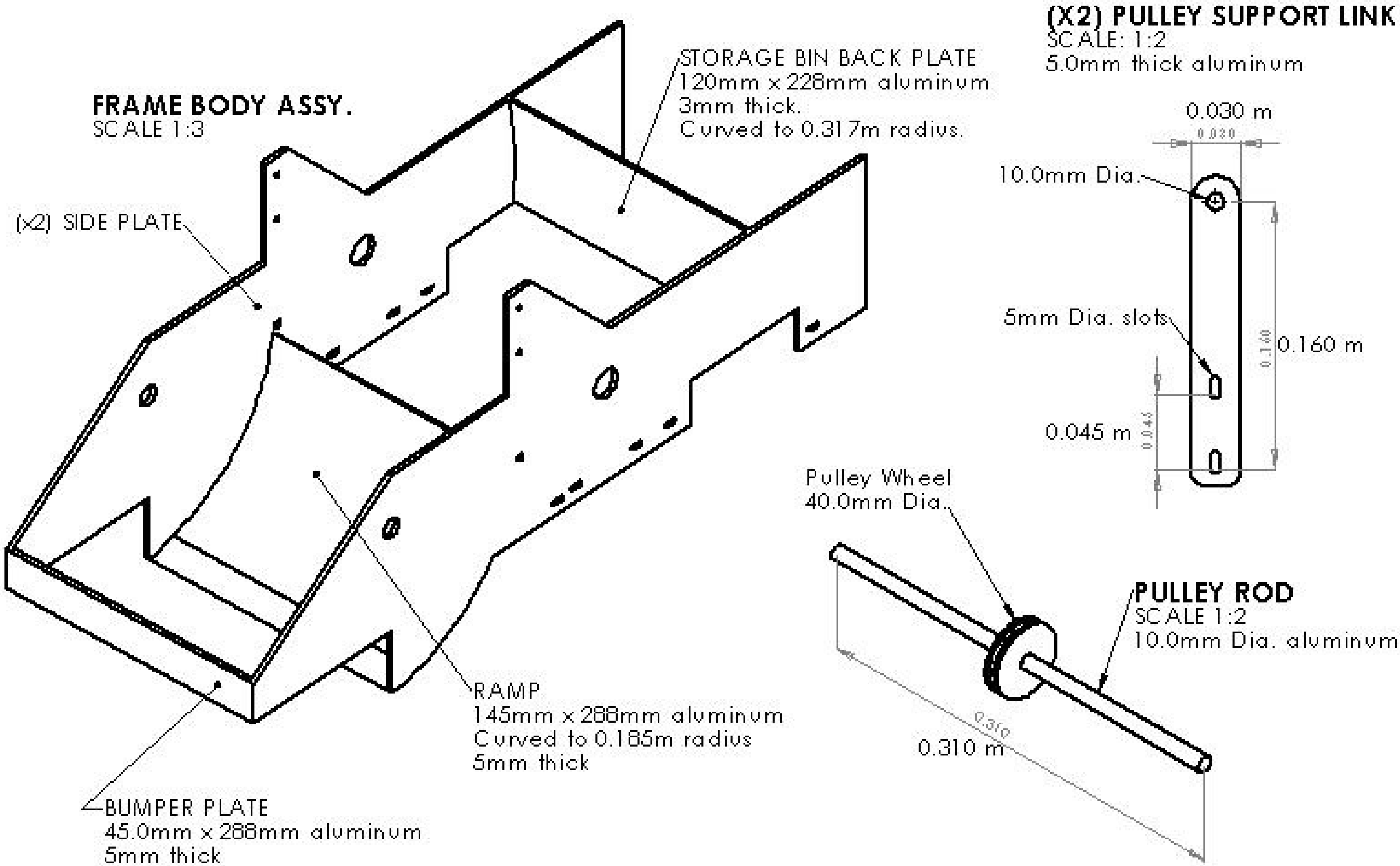
- Time to Implement
  - Weighting of 4
- Size
  - Weighting of 7
- Strength
  - Weighting of 8
- Power
  - Weighting of 7
- *Cost
  - Weighting of 3

*A higher results in a lower score for this criterion

	Traxter**2**	**Stinger**	**Marauder**	**Kodiak**
Time (4)	9	9	4	7
Size (7)	2	2	8	8
Strength (8)	6	6	7	7
Power (7)	4	4	7	7
Cost (3)	2	4	10	10
Mobility (5)	6	7	5	4
Total	**162**	**173**	**232**	**239**

The optimal robot chassis, as determined by the above decision making matrix, is the Kodiak.

16.7 Pickup Mechanism Components



SIDE PLATE

SCALE: 1:2

5mm thick aluminum

Dimensions in meters