ME 350 Design and Manufacturing II
Winter 2018

Ball Collection Project

1. Project Overview

The goal of this project is to design, build, and test a powered mechanism that will automatically catch falling balls in a cup and deposit them into a basket. The balls fall from two chutes, and you will control the release of the balls from these chutes. The device that you will develop needs to detect when the ball has been caught, the color of the ball (color sensor will be provided) and move the ball to drop it into a square basket (if the ball color is maize or blue). It must also reject any balls that are the wrong color (red or white), by tossing them away into a net next to the basket. It will use a DC electric motor in a closed loop position control system to move the cup to the desired position and orientation accurately enough to catch each ball, and quickly enough to catch and deposit as many balls as possible within a specified time period.

You are expected to apply the knowledge you will learn in lectures and labs to a model-based design in three modular phases:

1. **Module 1: Motion Generation.** You will apply your knowledge of mechanisms to design a mechanism capable of moving the cup to the desired positions and orientations with a single motor and single cup. You will use SolidWorks to create a detailed design of the mechanism and you will use ADAMS to create a dynamic model of the mechanism and determine the validity of the dynamic response by comparing the requirements of the desired motion (i.e., maximal power) with the provided motor. The designed mechanism must have a low moment of inertia to ensure a fast dynamic response.
2. **Module 2: Energy Conversion/Transmission.** You will apply your knowledge of motors and transmissions to design a transmission that, in combination with the supplied motor, minimizes travel time while meeting speed and torque requirements. The transmission will be designed using an "Inertia Matching" method in which the reflected inertia of the motor is matched with the inertia of the load, thereby theoretically ensuring an optimal dynamic response. In addition, the transmission must have a low moment of inertia and an appropriate stiffness to provide a good dynamic response. Finally, the transmission ratio must result in a high enough resolution at the output, so that the motor can repeatedly position the cup accurately.
3. **Module 3. Safety and Motor Control.** You will apply your knowledge of sensors and controllers to safely move your mechanism into the desired position and orientation in time to intercept each ball as it is dropped. This will be achieved using an Arduino microcontroller board, limit switch, and toggle switch.

The purpose of this project is to reinforce the material learned in the lectures and to provide a realistic experience in model-based design. Details of each step of the project are provided in the design labs and lectures as the semester moves along. Students are required to build the prototype in the ME student machine shop using the materials provided (see below). Note that work in the machine shop cannot begin until each group member has completed the required machine shop training.

The project is set up as a system design task that is decomposed into the major subsystems of motion generation (mechanism), energy conversion/transmission (motor/transmission), and motor control (sensors and controller). We will design using model-based methods and will fabricate and test each integrated subsystem as we build up the full device. At each stage there will be gate reviews (Checkpoints in the form of written reports and presentations) that provide the necessary feedback to your GSI in order to assess progress. For example, teams must pass a gate review with their GSI prior to fabrication in order to ensure that the manufacturing plans are reasonable and safe. These written reports are designed to be portions of the final report, such that the effort to create the final report becomes reasonable. A report template will be provided to guide students in the length and important content in each section. The reports should be well written and contain good writing flow. Deadlines are assigned to deliverables, and it is highly recommended that students try to complete the activity when possible some time before the checkpoint date in order to provide a buffer if things do not proceed as expected.

2. General Safety Precautions

- When testing out your system, do not wear long sleeves, jewelry, or loose-fitting clothing.
- Long hair should be pinned up.
- Be aware that if the power to the motor or controller (see below) is shut off and then restored, the controller will continue to run the program it was previously running.
- Keep parts of your body out of the path of motion of the mechanism.
- Do not touch the spinning shaft of the motor.
- Connect your motor to the power supply only under GSI supervision.
- When testing out your motor, always start with the voltage at the lowest possible level, and gradually increase it until you can get the motor to move.
- Expect the unexpected.

3. General Project Specifications and Individual Expectations

Playing Field: The playing field is shown in Figure 1. The chutes are located 19.5 inches above the ground. Marbles are dropped one at a time from the chute each time the playing field receives a signal from your Arduino microcontroller. The target basket is located as shown in the front view (Figure 3). All dimensions given in these figures are approximate.

You will attach your mechanism to the mounting holes at the bottom of the playing field. A pattern of mounting holes for 3/8-16 screws is provided. For better alignment of your mechanism to the playing field, dowel holes are also provided.

The playing field will send a signal to your mechanism's Arduino microcontroller indicating which chute is ready to drop a ball. At this point, your mechanism should move to the indicated chute and then notify the playing field to drop a ball. This notification is done by sending a 5V signal to the playing field, greater than 100ms in duration, via a digital I/O pin on your microcontroller (specific pins for each chute will be specified in the mechatronics lab assignments).

To simulate a real-world design situation, a CAD solid model of the playing field is not provided. You are expected to take your own measurements on the physical playing field. Critical dimensions are shown in Figure 2 and 3, but should be considered as approximate. The playing field will be available for you to take measurements in the X50 Assembly Room (1510 GGB). This room is accessible using your M-Card. Details for getting access to the X50 Assembly Room will be provided in a Canvas announcement.

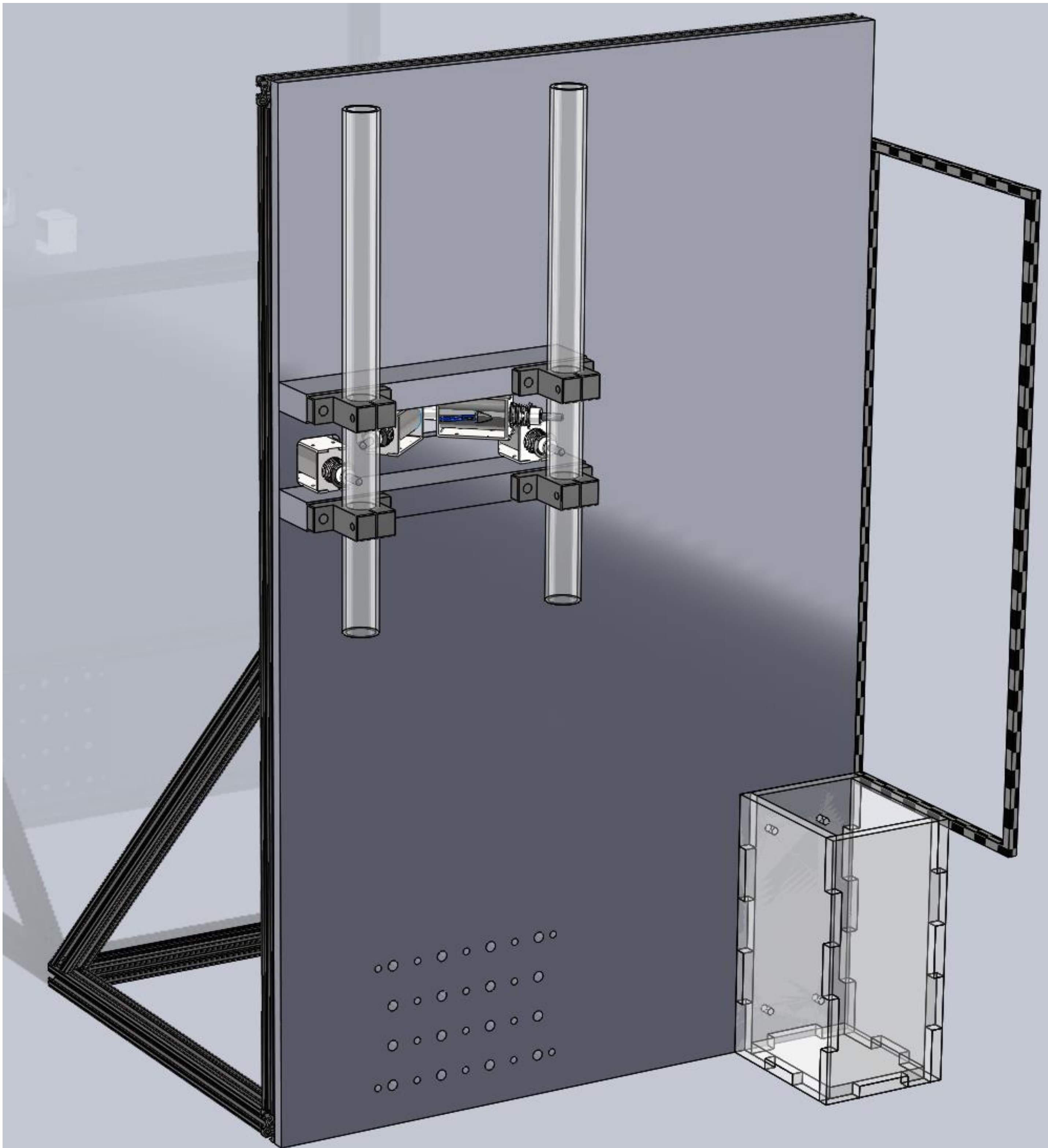

Figure 1: Playing Field, showing the two chutes and the basket

Balls: Each team will receive one set of 4 (Red, White, Maize and Blue) marble balls that the team can use for development.

Cup: The cup is the only part of the mechanism that may be used to catch the balls. Each team will receive a piece of hollow pipe to make the cup. The dimensions of the provided pipe are approximately 2” (1" for bonus points) in inner diameter, 3" in length, and 1/8” thick (Standard Polycarbonate pipe). Refer to the parts list in section 6 “Project Kit Items”, for the supplier and model number of the cup. The only holes that teams may cut into the cup are holes for mounting the cup itself. (All balls must enter and leave the cup through the standard opening.) If any part of your mechanism (other than the cup) touches a ball, the ball will be removed from play by the GSI. Your team is allowed to cut the cup *only* for the purpose of modifying its length. Any cuts you make must leave both ends of the cup parallel to each other. Ask your GSI before modifying your cup.

Color sensor: Each team will be provided with an Adafruit TCS34725 RGB color sensor. (A step by step tutorial on how to use it is given here). Teams are supposed to mount this sensor inside the collection cup on the coupler of the mechanism. Teams are also responsible for ensuring the safety of the sensor during the task, i.e., ensuring that balls do not hit the sensor directly when falling into the cup.

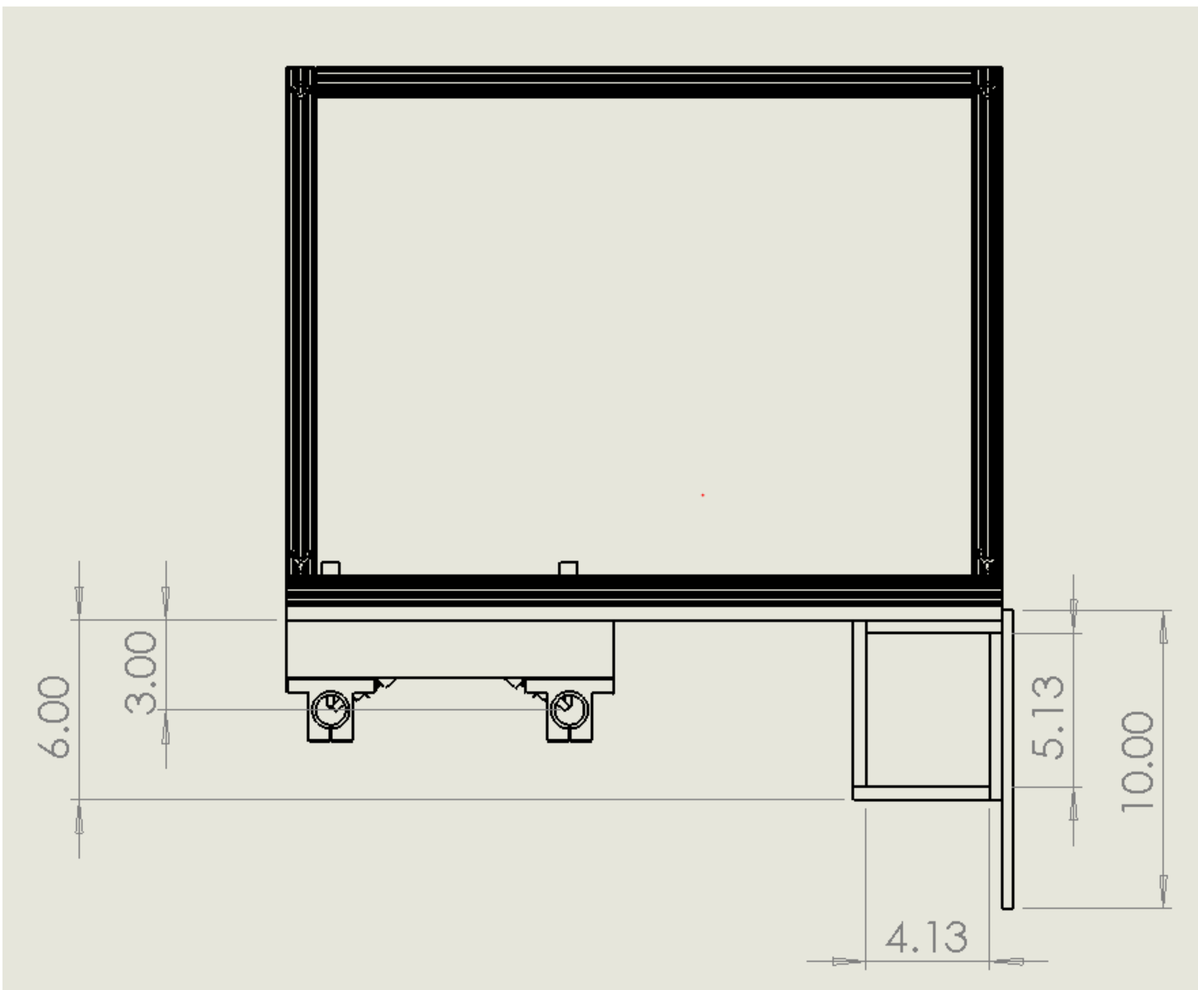

Figure 2: Playing Field, Top View

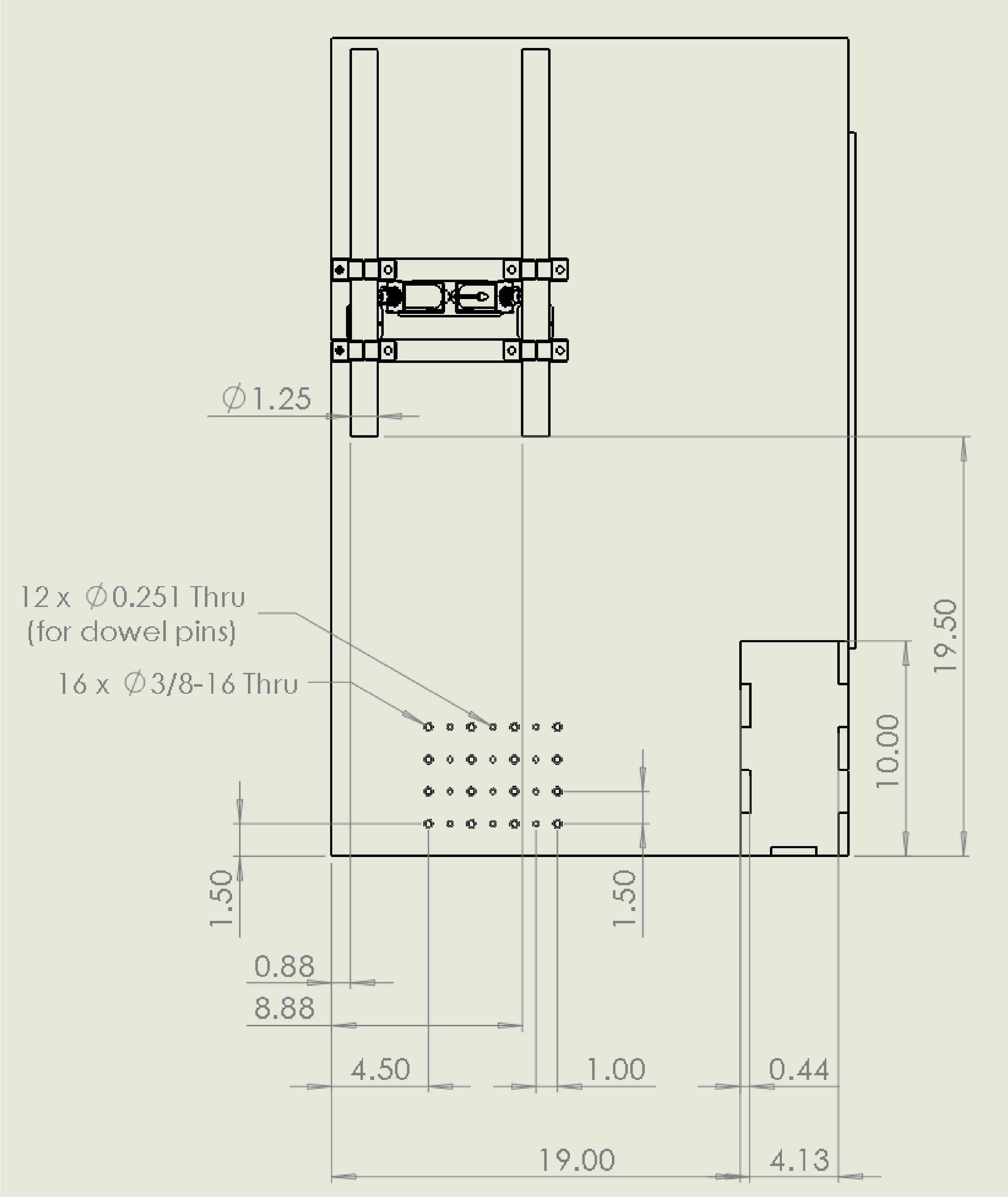

Figure 3: Playing Field, Front View

Detection of ball presence and color: Your mechanism needs to detect when it has caught a ball in the cup and also detect the color of the ball, both using the color sensor mentioned above. Based on the color of the ball, the team should maneuver the mechanism to drop the ball in the basket or throw it out in the net next to the basket.

Hard Stops: The mechanism should come to a hard stop (also known as a positive stop) on both ends of its desired range of motion. In other words, one part of the mechanism should contact a hard detail, to provide a repeatable limit to the motion and prevent overshoot. Each team will design and build their own hard stops. The hard stops must be mounted to your ground link, explained in "mechanism connection" below (not installed as separate pieces on the playing field) so that only the ground link needs to be bolted and unbolted to the playing field.

Limit Switches: One limit switch is provided, and could be used to calibrate the limits of the mechanism's range of motion. The limit switch detects the presence of the mechanism by direct physical contact with a linkage component. When the contact is made, a lever on the limit switch activates, sending a signal to the controller that the linkage is at either limit of its range of motion.

Motor: Each team will receive one Pololu electric motor, model #2823. All motion of the mechanism must be driven by this motor. The motor is a DC permanent magnet motor. For this project, the motor will run at 10V. Although this motor is capable of operation at higher voltages, do not connect the motor to voltages higher than 10V. This constraint is imposed to limit the torque and speed of the motor. For testing and measurement, a power supply set to 10V is provided, but lower voltages can be used if desired. **Teams must mount their motor to their ground link, and plan space for the motor and transmission (gears or pulleys) in their design.**

Encoder: The motor contains an integrated encoder that the teams will use to determine the position of the mechanism. The encoder sends a signal back to the controller, which the teams can use to determine the position of the motor shaft. More information will be given in the Mechatronics lab assignment.

Transmission: To achieve the desired performance of the mechanism, you will have to design and build a transmission. The transmission can consist of a timing belt and pulleys, gears, or other mechanical elements. You will have to determine the transmission ratio based on an "inertia matching" technique that will be taught in class. At the same time, the transmission ratio should not produce a poor resolution at the output. Before finalizing the transmission design, make sure you have taken adequate steps to minimize friction in your linkage mechanism**.**

Craftsmanship: It is important that this mechanism is well-made and can reliably operate many cycles. The device should be robust, efficient and predictable. Play in joints, friction, and unnecessary mass must be kept to the absolute minimum. Proper materials should be utilized (e.g., do not use duct tape). Your machine should have a professional look. Do not paint your mechanism – we want to see the machined parts and their surfaces directly. The same holds for your Arduino code. Make sure it is readable for others. See section 8 below for further details on craftsmanship.

Each member of the team is expected to develop one mechanism concept for the "Linkage Design and Conceptualization" stage. This will provide the team more options for the final design and allow each student to have experience with SolidWorks and ADAMS. We encourage each student to seek assistance from their fellow team members as well as from the GSIs during design. The division of the remaining tasks and report writing is up to the team. However, each member must contribute actively to the manufacturing process.

To simulate a more realistic design scenario, we will continue to distribute information throughout the semester. Although this may be frustrating, this is normal in the design processes. We encourage you to lay out your calculations and your drawings on the computer (spreadsheets, CAD system, etc.) so that you can make changes quickly and easily.

4. Testing and Design Specifications

Mounting: For testing, you will be given 5 minutes max to set up your project and 5 minutes max to take it down from the playing field. Set up consists of attaching your project to the playing field and connecting all electronics.

Initial Position: After your linkage is securely mounted to the playing field, a GSI will move your linkage to a random starting position within its range of motion. Your linkage will be required to move to contact the limit switch to calibrate the encoder count. Students will write calibration instructions into the controller code to achieve this function. If your linkage cannot be set to a random initial position by a GSI (and your team dictates the initial position instead), a 100 point penalty will be assessed to that testing trial.

Testing: After the initial position is set and the linkage is calibrated, each mechanism will be subjected to the same standardized test. Once the calibration is done, each team will have two (2) minutes to capture as many balls as possible from the chutes and put them in the basket or net. Each team will perform three trials with the best performance used for grading. After each trial, you will have 2 minutes to adjust your mechanism.

Design Specifications: The performance of the mechanism in these tests will be judged based on the following specifications, described in detail below and organized in Table 1.

1. Weight: The weight of the mechanism should be as small as possible. We will measure the weight of your device including all elements such as the linkage, hard stops, sensors, mounts, motor, etc., (but not including the Arduino, H bridge, breadboard, and their mounting). The color sensor and limit switch and their wiring/mounting are included in this measurement, but the toggle switch is not. All spacers, bolts, and dowel pins used to connect your mechanism to the arena are included in this measurement.

2. Transmission Angle Deviation: The transmission angle is defined as the angle between the coupler and output link for a four-bar-linkage. The transmission angle is a measure of how effectively force is being transferred between the coupler and output link and the ideal value is 90°. As a rule of thumb, the transmission angle should always lie between 30° and 150° and these will be the upper/lower bounds. The transmission angle deviation of the mechanism is defined as the largest absolute value of the transmission angle of the mechanism minus the ideal transmission angle of 90° in the useful range of the mechanism (i.e. between the hard stops). The ideal deviation is 0°.

3. Performance Score: The performance score of the mechanism is defined as the number of balls that are placed in the correct basket or net, assessed at the end of the round. This is represented below in Table 2. Note that using a 1" cup instead of a 2" cup results in a 1.5x multiplier for all point values. The performance score should be maximized.

Table 1. Ball Collection Project Design Specifications

Specification	Description	Target	Min	Max	Measurement Method
Weight	Mechanism's weight (excluding Arduino, H bridge, breadboard)	Minimize	N/A	3 kg	Scale
Transmission Angle Deviation	Defined as the largest absolute value of the transmission angle of the mechanism minus the ideal transmission angle of 90°.	0°	-60°	60°	Machinist's protractor
Performance Score	Based on the number of balls that are correctly placed inside the bucket or thrown away in the net based on the color, assessed at the end of the round	Maximize	0%	100%	Visual inspection

Table 2. Performance Scoring

Action	Description	Point Value (per ball unless specified)
Catching	1st Ball Left Chute	50
	1st Ball Right Chute	50
	Each Ball Caught	10
Put In Basket	First Ball (Any color)	50
	Each Maize or Blue Ball (Correct)	10
	Each Red or White Ball (Incorrect)	5
Put In Net	First Ball (Any Color)	50
	Each Red or White Ball (Correct)	15
	Each Maize or Blue Ball (Incorrect)	5
No Calibration	Unable to calibrate	-100
Team touches their linkage during final testing	Each physical contact	-25
Bonus Points if all balls were caught (5 points for each second remaining under 2 minutes)		5 pts. /second left

5. Manufacturing

The teams may use the G. G. Brown machine shop and assembly area as well as the X50 mechatronics lab for this project. Work in the machine shop cannot begin until each group member has completed the required shop training outlined in the syllabus. Before you fabricate any parts in the machine shop, you must follow the procedure below:

1. Create detailed drawings and manufacturing plan of each part, including all dimensions and tolerances.
2. The drawings and manufacturing plans are reviewed and approved by the GSI.
3. Finally, the drawings and manufacturing plans must be approved by the machine shop.

The manufacturing portion of the course will incorporate a principle called distributed manufacturing. This applies only to the first portion of the course when the teams manufacture the first components of their four-bar linkage. Under this system, the manufacturing drawings and plans will first be approved by the GSI. Then, the drawings and plans will be passed to another team within the same section, with the new team being responsible for fabricating the parts according to the drawings. **Communication between teams will be extremely crucial for success**. It is the responsibility of the team providing the drawings and plans to ensure that there is sufficient stock material available and that the drawings/plans are properly dimensioned and toleranced. The drawings and plans must also be **clear and readable**. It is the responsibility of the team completing the fabrication that the parts are made exactly according to the drawings and plans. The drawings, plans, and fabricated parts will be graded by the GSIs (see craftsmanship in section 7 below) as well as reviewed by the team that receives them. If a fabricated part is not to specification, the team which provided the drawings may either request that the fabricating team remake the part, or they may remake the part themselves. Ultimately, it is the responsibility of the paired teams to communicate and work together to achieve a solution.

After the distributed manufacturing portion of the course is complete, each team will be responsible for producing their own manufacturing changes or additional parts required.

Note: Projects will be stored in the cabinets of the X50 assembly area.

6. Project Kits and Available Materials

The following list of materials will be available for the fabrication of your prototype. Materials outside of the list and not found in the shop must be approved by your GSI. *Note: all dimensions below are nominal and may have some variation; if critical you should measure the stock material.*

Each team will be provided with a kit consisting of the following items:

Project Kit items	Make and Model #	Supplier	Qty per team
Aluminum Plate, 1/4" x 12" x 18"	21430300	Alro Steel	1
Aluminum Angle, 2.5" x 2" x 1/4" thick, 6" long	Custom	Alro Steel	1
Aluminum round stock, 1" Diameter, 12" Long	Custom	Alro Steel	1
SAE 841 Sleeve Bushing for 1/4" Shaft Diameter, 1/4" Length	6391K126	McMaster-Carr	10
Needle Thrust Bearing, Bore .250	4XFL8	Grainger	4
30:1 Metal Gearmotor 37Dx52L mm with 64 CPR Encoder	2823	Pololu	1
Bracket for 37D mm Metal Gearmotors (w/ 9 M3 screws)	1995	Pololu	1
Snap Action Switch (a.k.a. limit switch, microswitch)	187733	Jameco	1
Toggle Switch Single Pole Single Throw (On-Off)	76523	Jameco	1
400-point Breadboard	351	Pololu	1
Arduino Uno microcontroller board	DEV-09950	Sparkfun	1
H-bridge (L298 Motor Driver -- preassembled)	K CMD	Solarbotics	1
Mounting Board for Arduino, H-bridge, and breadboard	Custom	N/A	1
Cup-Polycarbonate Tube 2" (or 1") ID x 3" Long x 1/8" Thick	Custom	McMaster-Carr	1
Colored marble balls-1" Diameter	66411	Moon Marbles	4
Adafruit RGB Color Sensor	TCS34725	Adafruit	1

Available in the machine shop or X50 assembly area (1510 GGB):

Nylon Unthreaded Spacers, 5/8" OD, ½" Length, for ¼" ID	94639A694	McMaster-Carr
Shoulder Screw, ¼" Diameter x ½" Shoulder, 10-24 Thread *(Other lengths of shoulder screws will also be available)*	91259A537	McMaster-Carr
Oil-Embedded Thrust Bearing (Washer) for ¼" Shaft Diameter, 5/8" OD, 1/16" Thick	5906K531	McMaster-Carr
Nylon Locknut, 10-24 Thread Size	90631A011	McMaster-Carr
Socket Head Cap Screw, 3/8"-16 Thread, 2" Length	91251A632	McMaster-Carr
Socket Head Cap Screw, 3/8"-16 Thread, 2-½" Length	91251A634	McMaster-Carr
Socket Head Cap Screw, 3/8"-16 Thread, 3" Length	91251A636	McMaster-Carr
Socket Head Cap Screw, 3/8"-16 Thread, 3-½" Length	91251A638	McMaster-Carr
Socket Head Cap Screw, 3/8"-16 Thread, 4" Length	91251A640	McMaster-Carr
Washers, 3/8"	91083A031	McMaster-Carr
Washers (3/8" hi-collar spring lock)	91104A031	McMaster-Carr
Socket Head Cap Screw, 2-56 Thread, ½" Length	91251A081	McMaster-Carr
1/4" ground and polished steel dowel pins, 1" Length	98381A542	McMaster-Carr
1/4" ground and polished steel dowel pins, 1-½" Length	98381A546	McMaster-Carr
1/8" ground and polished steel dowel pins, ½" Length	98381A471	McMaster-Carr
Spring Pins	Various	
Nylon Cable Tie, 3" Long, 10 lb. Break Strength, White	7130K101	McMaster-Carr
Nylon Cable Tie, 7-½" Long, 50 lb. Break Strength, White	7130K19	McMaster-Carr

Available in the X50 Lab:

- Electrical wiring components
- Soldering supplies

In addition to the kits, each team may spend up to $100 on project supplies that they have reviewed with their GSI. Teams are encouraged to use part of their $100 discretionary funding to purchase parts for the **transmission** (i.e. timing belts and plastic pulleys, or metal gears) to reduce the speed and increase the torque from the motor to the linkage. **These parts should be ordered no later than 2 days after Gate Review 2** in order to meet the project deadlines. Note that you can often get small parts quickly at a local hardware store, such as Stadium Hardware or Carpenter Brothers in Ann Arbor, and materials from Alro Metals on South Industrial Highway in Ann Arbor.

When 3D printing parts, you will not need to purchase material. You will be using the Printrbots in the Dude and will be charged a flat rate of $10 per printing session. This $10 fee is not charged by the staff in the 3D lab; however, you must add this $10/session to your bill of materials. You must subtract it from your $100 budget.

Teams must keep their original receipts and fill out a petty cash form before the last day of classes in order to get reimbursed. Please designate one team member to handle all finances and submit only one reimbursement form (with original receipts attached) with the instructor's signature.

Any donated components (for instance, scrap pieces from the machine shop) must also be approved by a GSI.

a. Donated component values will be included in the team spending limit of $100. See McMaster.com or another website to assess the value of donated components. (For some small parts, there is a minimum purchase quantity. In these cases, you should only count the cost of the parts that you actually use.)

b. Bartering among groups with standard kit components is permitted.

c. Shipping cost is included in this budget.

7. Grading and Assignment Submission

The project grade will be divided into the following:

30% - **Final Report**, see details below

5% - **Design Report #1**

10% - **Design Report #2**

25% - **Test Results,** as defined later in "Final Testing" section

20% - **Prototype Craftsmanship** - overall design, quality of workmanship, surface finish, tolerance and fit, noise level, size, aesthetics, etc. This is further divided as follows:

- 10% assessed immediately after the distributive manufacturing portion of the course (assessed to the fabricating team, not the design team)
- 10% assessed to the design team after final testing. This includes all parts of the final mechanism (including parts which may have been fabricated during distributive manufacturing). Teams may choose to remake parts to improve craftsmanship at any point in the semester.

10% - **Final Report Quality** - Clearly written, well organized, free of spelling/grammar mistakes, ease in reading and ease in understanding concepts and analysis. We recommend that you use lots of graphics and subheadings that are well formatted along with a table of contents that includes the appendices.

Note: The main purpose of Gate Review 1 and 2 is to provide teams with feedback from their GSI for the final project, final report, and testing.

All team project work will be documented via shared Google Drive folders and Google Docs. More information regarding the team folders and submitting reports will be provided as the semester progresses.

8. Prototype Craftsmanship

Craftsmanship is very important. It can affect the performance, safety, and appeal of your machine. You should be diligent in your planning and execution of your manufacturing and assembly of your system**. Each student is expected to machine at least one part.** Everyone is responsible for the end product, thus the full system will be graded as a group – so make sure to help out each other. When making your system, make sure it is:

- **Safe:** Ensure that you have filed all sharp edges so there are no burrs. (We will do a bloody finger test). Threads on bolts should not protrude out more than 1.5 times the bolt diameter. When possible, countersink your holes so the fasteners do not protrude. Try to avoid creating pinch points when possible.
- **Aligned:** Make sure that the parts are in alignment with each other.
- **Sturdy:** Minimize the play between your parts. When designing your mounts, allow for adjustment (especially if using a timing belt system) by using slotted holes and/or fitting spacers. If there is not enough tension in the timing belt, it could jump teeth on the pulleys.
- **Well-designed and assembled:** Think about how you are going to put the parts together. Think about how to get the screwdriver in to tighten screws – will it fit between the parts that you have already assembled? How accessible are the parts that may need to be adjusted?
- **Well-machined:** Make sure when machining that you end with a good surface finish – this will help to reduce friction and make your system work better and closer to prediction.
- **Aesthetically pleasing:** Make your system look professional. Don't use materials like duct tape or excessive amounts of glue. Do not use Velcro.
- **Spacers:** Do not use stacked washers as spacers; instead, use a single piece of material that you have machined to the proper dimension.
- **Arduino Code:** Write readable code. Structure it well, indent nested loops and functions, provide comments for everything you do.

9. Gate Review Requirements

Separate documents specifying the requirements for each gate review will be distributed after teams are formed. These documents will detail what content is required for the design report associated with each gate review. A template will be provided to guide students in the length and important content in each section.

10. Final Report

Refer to the course schedule for the due date of the final report. A report template will be provided to guide students in the length and important content in each section. The gate reviews should make a significant contribution to the final report, but the final report should still be well written and contain good writing flow. Be sure to take any feedback on the design reports from the GSIs into account when writing the final report.

The final report is worth 30% of the project grade, and the grammar and formatting of the report counts for an additional 10% of the project grade.

11. Peer Reviews

All students will complete a peer review at two phases during the project. The peer reviews are confidential. Students must review all their team members including themselves. A form with more details will be provided later in the semester. The peer reviews will be reflected in the final course grade for each student. (Refer to the grading section of the syllabus.) **If you do not turn in a peer review, you will receive a zero for your peer review score.**

These scores should represent the following key aspects of teamwork:

1. **Professionalism:** To what extent did a member take ownership of the project? Did they show the necessary initiative or leadership in certain aspects of the project? What was their level of communication with the rest of the team? Did they stay in sync with all team decisions? Did they keep everyone else in the team informed about their decisions? Did they attend all team meetings? If a member shows a lot of individual initiative, but does not involve other team members in key decisions, or intentionally leaves out one or more members in the project implementation, that should be considered negatively in assigning the Peer Review score for this individual.
2. **Work Quantity:** You have to take stock of all the work that was involved during a certain grading component of the project (Gate Review 1, Gate Review 2, or Final), and determine if a particular member carried a fair share of the work load. Did an individual simply do what they were asked to do? Or did they seek the appropriate project tasks on their own, without being asked by others repeatedly? This should be evaluated based on the quantity of **results produced**, rather than simply the amount of time or effort expended by an individual to produce results.
3. **Work Quality:** Was the member thorough and reliable in the work he/she performed? This often is a reflection of whether the member took ownership of a task and pursued it with passion to a degree of perfection, so that other team members did not have to come in and fix/redo things repeatedly. If the member took charge or was assigned the responsibility to finish a task, how much could the team trust that the task would be done to everyone's satisfaction on time?