UNIVERSITY OF CALIFORNIA, SANTA CRUZ
BOARD OF STUDIES IN COMPUTER ENGINEERING

CMPE-118/L: INTRODUCTION TO MECHATRONICS

THE SLUGNIFICANT SEVEN

Background Briefing:

A small village of farmers find themselves beset by raiding bandits who torment the villagers and steal their crops. One villager overhears the bandits planning their next attack, and brings this terrible news to the village. After much discussion, the villagers resolve to hire gunslingers to protect the village. However, the farmers are poor, and cannot come up with enough money to hire the mercenaries they need for protection. One of the younger farmers has heard of strange electro-mechanical automata called 'droids, and is convinced that they are the answer. Now, it's up to you, the *Slugnificant Seven*: can the Mechatronics class develop dueling droids that will defend the village? Their fate is in your hands.

Purpose:

The purpose of this project is to provide an opportunity to apply all that you have learned in CMPE-118 to solve an open-ended problem. Your task is to build an autonomous robot that will navigate the game field, locate and shoot your dueling opponent (using your ping pong ball ammo), and either win by points or with a very well-aimed decapitation shot.

Project Requirements:

A. Team and robot meet three Design Reviews (Brainstorm, Mid-Project Review, Final Check-Off)
B. Team maintains an active lab notebook (or website) detailing their progress and designs
C. Each and every week team satisfies Check-offs and meets with their mentor
D. All loaned parts returned to TAs (IO stack, etc.) after tournament
E. Lab cleaned up before end of finals week
F. Final Report due at end of finals week
G. Participation in Public Tournament (0% of your grade; 100% fun)

If your robot can demonstrate robust Final Check-Off one week before the final deadline Gabe will personally buy your team beer. The beer check-off has rarely been awarded.

Project Overview

Your task is to build a small autonomous robot ('droid) that can effectively and robustly navigate a standardized field, locate and advance through the field by hiding behind obstacles for a limited time, and then shooting their opponent with ping pong ball ammo. The match is won by shooting the tin can off your opponent's beacon, or by points for hitting the opponent robot. You will be doing this in teams of three, over the next five weeks, during which time you will design, implement, test, and iterate until you can reliably complete the task. There will be practice fields in the labs, and lots of help and guidance available to you. Don't panic. Yet.

The field of play is a large white 4'x8' surface with a 2" black tape boundary (going out of bounds disqualifies the robot). There are three standard obstacles randomly on their respective lines across the field. The obstacles are marked with track wire (at the standard 24-26 KHz) that runs vertically down the obstacle edges to the field. You will start in the "starting zone" in a random orientation, and must move to the "initial firing zone" before firing on your opponent. There are no restrictions on how to get balls to your opponent—that is entirely up to you.[†]

Once you have navigated back to the initial firing zone (IFZ), you can advance to more forward firing zones by hiding behind the obstacle that marks the next forward firing zone.

[†] Note that there will be a gap between the field and the opponent robot; rolling your ammo across might prove very difficult. Also hits are direct hits, not bounces off of obstacles and other ricochets.

Hiding is indicated by stopping all motion while behind the obstacle. However, you are not allowed to remain hiding behind the obstacle for more than a set time.‡

Your robot will start in the starting zone (roughly 1 ft. square at the front center of the field, and at least half of your robot will be within the tape) in a random orientation. The 2KHz IR beacon on the opponent (and the one that you carry) will be illuminated for the entire match. At least half of your robot must remain within the black tape line at all times or your robot is out of bounds and will be disqualified.§

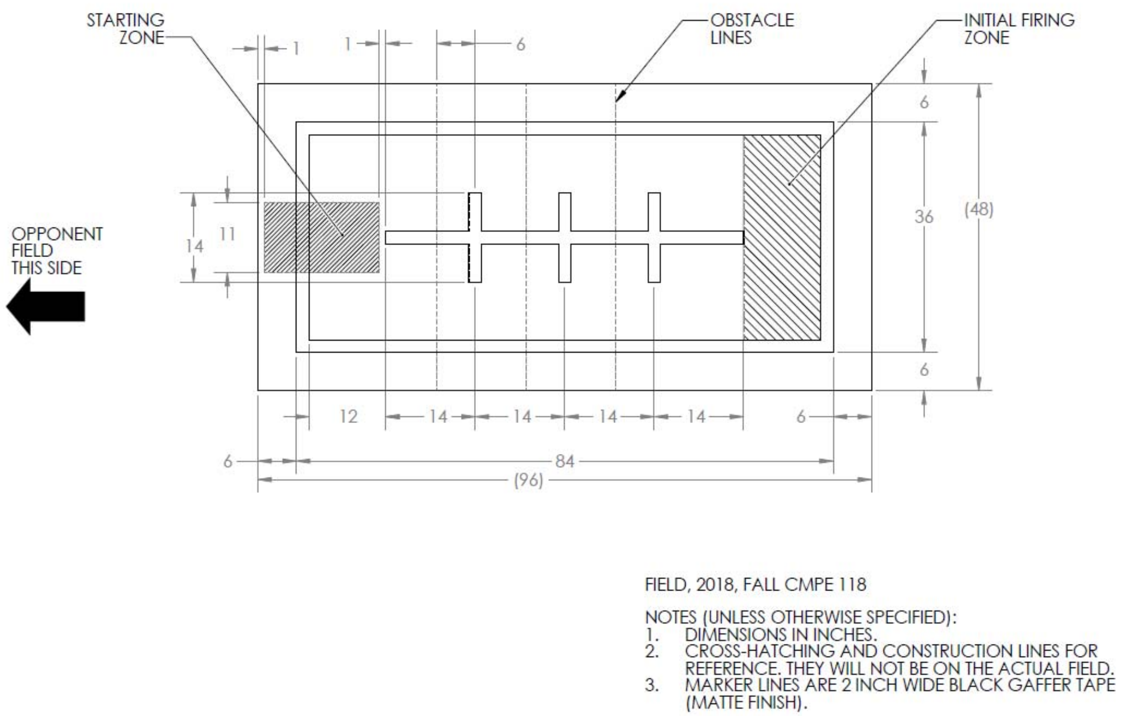

Figure 1: Field of Play for the Slugnificant Seven. Black tape boundaries and alignment marks are 2" thick PVC tape. Obstacles can be anywhere on the obstacle lines. Both your robot and the opponent robot carry a 4" wide IR beacon at 2KHz at 11" above the field.

The obstacles are 10 inches wide and 10 inches tall, and 3 inches deep. They are marked with 24-26KHz track wire extending vertically from the field to 3 inches in height. The obstacles also emit IR at one or both of the off frequencies (1.5 or 2.5KHz). Note that there will be three obstacles each round, they will always be randomly placed on their respective line across the field.**

‡ Exact time TBD, current thoughts are 1 second hide, 5 second max time.

§ This is for your own protection, the robot field is high off the ground and several robots have attempted suicide by driving off the table before.

** These lines are NOT marked onto the field, but are logical.

The initial firing zone is designated by the rearmost horizontal stripe of black tape, extending 6” beyond the center stripe to either side. Your robot must be fully inside the initial firing zone before it can fire on the opponent robot. In order to advance to closer firing position, your robot must first hide behind the next closest obstacle for a minimum of 1 second, and then move into the next zone. Hiding is defined by stopping behind the obstacle (robot fully behind) before moving on. Your robot is not allowed to stay behind the obstacle for too long or will be disqualified (see note above). Collisions (contact) with the obstacle must be resolved within 5 seconds. Failure to do so means your robot is disqualified.

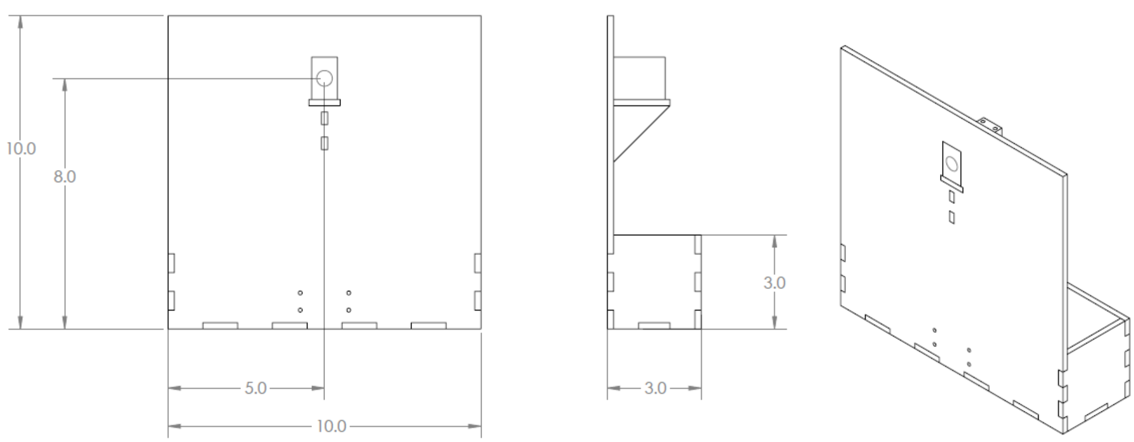

Figure 2: Obstacles are 10 inches wide and 10 inches tall, and are marked with 24-26KHz track wire extending vertically from the field to 3” height. Obstacles emit IR modulated at 1.5 or 2.5KHz towards the front. Note that the front plate of the obstacle may not or may not be solid, but will be within the 10x10” panel specification.

Each obstacle line is 6” below the corresponding horizontal black tape, such that if your robot is tracking the line in the center it will pass within ½” of the obstacle (assuming that the robot can track the line, and is the full 11” wide).

Each droid must start the match within an 11” cube volume (parts may move after the round begins) and remain intact throughout the match. Jamming your opponent in any way is disallowed. Robot sizing will be checked with the *Cube of Compliance*.[††]

Your robot is required to stay within the field (marked by 2” black tape boundary), defined by keeping half of the robot within the black tape. Robots exiting the playing field (more than half the robot past the black tape boundary) will be disqualified. Your robot is required to detect collisions and resolve them (e.g. if the obstacle is blocking your path; you need to be able to maneuver around any immovable obstacle). You are required to

[††] We have (and will) require you to modify your robot because it does not fit inside the dreaded Cube of Compliance. Remember to take into account things that stick off your robot (e.g.: wires).

break contact within 5 seconds or be disqualified.[‡‡]

While every attempt has been made to finalize the project specifications and rules, understand that this is a work in progress. As the project evolves, we will be making (minor) tweaks to the specs as we discover what flaws we have not anticipated. These will be announced in class, and posted on Piazza. They are not meant to destroy your winning design, but only to make things work smoothly. Your understanding is appreciated.

Minimum Specification Checkoff:
In order to pass this class, your robot must demonstrate that it can complete the task.[§§]

While the rules and specifications are below, teams are free to embellish, go beyond, and otherwise have fun—however, we suggest you aim for “min spec” first, and then go back (and go nuts).

Your robot begins the round randomly placed within the starting zone of playing field in a random orientation (see Fig.3 for an example min-spec scenario). The opponent robot is placed in any valid location on the opposing (identical) field. The obstacles on both your field and the opposing field are randomly distributed on their respective lines.

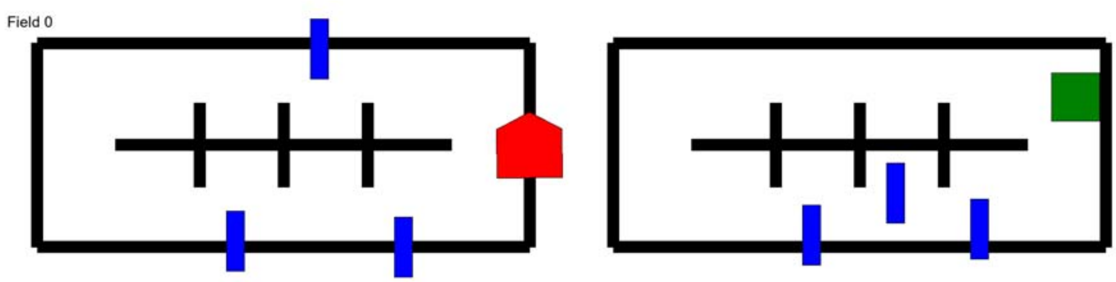

Figure 3: A generated field for checkoff specifiations. Note that your droid will be the red one, and that the target droid is shown in green. The blue rectangles are the obstacles.

Note that for min-spec checkoff, it is guaranteed that there is a clear line of sight from the center position of the bottom tape (center of the starting zone) to the opponent droid. Note that we are being *very* nice here.

At the start of every round, your droid must contain all ping pong ball ammo that will be used during the match. Both your droid and the opposing one will have their 2KHz IR beacons illuminated, and each of the obstacles will have their IR beacons (1.5/2.5KHz, forward facing) illuminated.

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‡‡ Pushing an obstacle out of the way is not allowed.

§§ Yes, we have had teams go well into winter break before they finished. No one passes the class without passing min-spec.

Your robot should move from the starting zone to the initial firing zone. At this point your robot is free to fire at your opponent robot. You may advance down the field by hiding behind the obstacles or you may stay in the initial firing zone and fire. Hiding behind an obstacle is specified by stopping your robot for at least one (1) second fully behind and adjacent to the obstacle. You must move on from the obstacle before 5 seconds are up.

Shooting from an invalid firing zone will disqualify your robot.

Min-spec is defined as two hits to the opponent robot body, or a single hit to the tin can on top of the opponent robot beacon.

Should it become apparent that a robot will not complete a round (for example, if it fails to resolve a collision for more than 5 seconds, or lacks sufficient ammo for shooting the opponent robot, your robot will be disqualified and the round will end.

Tournament:
In the tournament, you play against another team; teams will start on each of their respective fields (with randomly set obstacles) that are back to back. Consider the duel: you take 10 paces (to the IFZ) and fire.

If you win the match, your robot advances in the tournament. *If neither team succeeds in this challenge*, *the victory will be awarded by points*. Should a tie occur, we will attempt a rematch.[***]

Points are awarded as follows (each may be invoked exactly once per robot per round):

10 points:	Make it to the Initial Firing Zone
20 points:	First hit to opponent robot body
40 points:	Second hit to opponent robot body
100 points:	Hit to opponent tin can

Robots will be disqualified for going out of bounds (more than half the robot over the black tape boundary), or for failing to resolve collisions (must break contact by 5 seconds).

We may (will) update these rules and/or points should (when) flaws become apparent.

Droid

The droid must be a stand-alone entity that fits in an 11”x11”x11” cube at the beginning

[***] If you both continuously tie, we will flip a coin and move on.

of the round. Your machine must contain all ping-pong ball ammo at the beginning of the round (no reloading allowed). It should be capable of meeting all specifications while drawing power only from batteries. It must be able to detect bumps at a height of 3.0" above the ground. The droid must be able to detect and resolve collisions with an obstacle (break contact after 5 seconds). Droids should be able to keep themselves on the field (half of the robot within the black 2" tape boundaries).

Droids will be programmed in C, using the standard MPLAB-X IDE. Your droid behavior will be constructed using the ES_Framework from Lab 0 (however you may NOT use the Roach projects you wrote).††† You may reprogram your droid between rounds if you desire, but you may not alter it once the field configuration is established.

Each droid will be equipped with a remote power switch (using the remote switch header on the Uno stack). At the beginning of the round, you will switch on your droid, and may not interfere with it until the round ends.

Materials

Each team will be provided with one Uno Stack, one H-Bridge, one Stepper Board (if needed), one DS3658 board, one battery, and one ULN2003. There will be also wire, regulators, and solder freely available in the 118 labs.

Each team should not exceed a budget of $150 total for other parts on the robot, and must maintain an up-to-date bill of materials (BOM). If we spot a nice $5K gyro on your bot, we will hand you $150 and take it. We don't want the project to be an arms race over who can purchase better stuff. We will have MDF and Foamcore available for purchase at cost. We will maintain a list of Amazon suggestions for motors, perf board, and other components within the first week of the project. BELS, Ace Hardware, Fastenal, and Home Depot are all decent local sources. HSC and Tap Plastic (Acrylic for $1) are most excellent resources in the Bay Area (get together and caravan). McMaster-Carr will deliver nearly any piece of hardware within a couple days but they tend to be expensive. Amazon Prime is free to students for a three-month trial, and will get things to you in two days (or in one day for an extra $5 for shipping).

Available Tools

It should go unsaid that all work needs to be done by the team and not contracted out. You will have the resources in BE111, BE113, and BE115 as well as the drill press, tool chest, and Laser cutter in BE138. Your circuits must be soldered on perfboards, no breadboards. Those of you thinking about PCB houses, you won't get turn-around in time without blowing your $150 budget. Off-the-shelf sensor boards, such as those sold by Sparkfun or Adafruit, are fine (but understand that the software integration for these

††† If we see a Roach_HSM file we will delete all of your code. Seriously, write it from scratch.

sensors can take much longer than you anticipate—manage your time carefully).

Field Specifications:

We will have a Solidworks model of the field, targets, and beacon mount available after the midterm. The model in Fig. 1 will be available on the website in higher resolution, and is drawn to scale. Modifications (if any) to the field will be noted on Piazza.

Further questions or clarifications about the field specifications should be posted to the Piazza forum.

Safety:

The machines should be safe to the user, the lab, and the spectators. For this project, excessively high velocity ball delivery will be discouraged (so go ahead and forget about that CO2 PVC pipe launcher you were thinking about.) Voltages are limited to the rechargeable batteries in the lab (you may purchase your own if you'd like, but consider 10V an upper limit), and intentional jamming or blocking of the opposing robot or masking of any beacon/trackwire is considered foul play and not allowed. 'Bots deemed unsafe will be disqualified.

NOTE: Young children line the competition field; take this into consideration when designing your launch mechanisms. Each team will be required to take three Ping-Pong ball shots from their own robot on bare flesh at a distance of 3ft from the barrel of their 'bot. <u>All members of the team must do this</u>.[‡‡‡]

Prior to competition your robot should not transcend space or time in any way, nor should your robot alter gravity within our Solar System. However, during competition, gravity and space-time may be altered at will.

Evaluation:

Performance testing procedures: All machines will be operated by at least one of the team members. There will be one round for grading purposes done in the lab to evaluate 'droid performance. The public tournament is purely for entertainment purposes (though if you have not yet checked off, successful completion of the min-spec tasks during the public demo counts as a valid late checkoff).

Grading evaluation: Each machine will be graded based on its performance in the testing before the class competition at the end of the quarter. Each machine will have up to 2 minutes to solve the challenge. Grading is not based on point values, but how robustly your robot performs.

[‡‡‡] Yes, we have pictures of students with ping-ping ball induced welts on their backs.

Grading Criteria:

1. Concept (20%): This will be based on the technical merit of the design and coding for the machine. Included in this grade will be evaluation of the appropriateness of the solution, as well as innovative hardware and software and use of physical principles in the solution.

2. Implementation (20%): This will be based on the prototype displayed at the evaluation session. Included in this grade will be an evaluation of the physical appearance of the prototype and the quality of construction. We will not presume to judge true aesthetics (though we might comment on it), but will concentrate on craftsmanship and finished appearance.

3. Report (10%): This will be based on an evaluation of the written report. It will be judged on clarity of explanations, completeness and appropriateness of the documentation.

4. Performance (20%): Based on the results of the performance during the evaluation session.

5. Design Evaluations (30%): Based on check-off completion.

Project Milestones:

Each week, your team will need to achieve a list of check-offs to stay on schedule and each partner will need to work as part of the team. **IF YOU DO NOT STAY ON SCHEDULE WITH THE CHECK-OFFS** you will NOT finish in time and be forced to stay through winter break until your robot is complete: **STAY ON SCHEDULE**.

Your weeks will essentially break into the following:
Week 1: Design, Schedule, and Group Order (Design Review I)
Week 2: Electronics and Mechanical Prototyping
Week 3: Working Prototype for moving robot and ball launcher; State Machine (Design Review II)
Week 4: Finalizing robot and getting everything to work together.
Week 5: Competition and Final Check Off (Design Review III)

There will be **weekly checkoffs**, **three design reviews** throughout the project, **one lab report**, and **one and only one competition.**

Half of this project is communicating well and documenting progress to stay on schedule. With that in mind, we expect each team to maintain and update a lab notebook with everything you are doing and copious notes.[§§§] We very (very) strongly recommend that your lab notebook stays with the robot in lab. We will use this to verify your check-offs for each week. We recommend sharing some form of file/team drive/GIT repo to help you keep your selves on task, but do not require it. That said, each team will need to submit their lab notebook and schedules for the Design Review #1. See "check-offs" section for further details. Note that if you want to use GIT for your storage for the project, you will be able to create a repo on the SOE GITLAB server.

A report describing the technical details of the machine will be required. The report should be of sufficient detail that any skilled CMPE118 alum could understand, reproduce, and modify the design.

<u>Design Review 1:</u> Thursday, post midterm (PDR)

Team Concepts, present your best design to the class for three minutes

Come up with 3 team concepts for your design from your individual ideas and a bit of brainstorming (you will present your best 2). Mix and match between the best of your designs. How are you and your team going to accomplish your project goals? Schedule out your time as well as your team's.

You will need to upload your designs to CANVAS, and present your lab notebook to the tutors/TAs for checkoff. Submit your best team design and backup design before class on Thursday (see CANVAS assignment). You will have 3 minutes to present your design (and get some feedback on it). Have a primary and a backup in case it is too similar to someone else's.

<u>Design Review 2: Mid-Project Review:</u>

Full Prototype, presented to the staff for 15 minutes.

Present your currently working parts and your full design to the instructors for review and insight into potential roadblocks. Every system (both mechanical and electrical) should be prototyped at this point.

Mechatronics Beer Challenge:

Each team gets exactly three consecutive tries on the field to successfully complete your final check-off. If you can complete the task 3 out of 3 attempts, AND your robot still functions (i.e.: meeting min spec) in the public demo, you get beer. In the history of mechatronics only three teams have succeeded (and it was easier then). Note that in the beer challenge, the field is NOT random, but (possibly) set in a way to be difficult for your particular robot. We reserve the right to be evil here.

<u>Design Review 3: Final Check-Off:</u>

[§§§] If you want to use WordPress, Wiki, or Google website for the project posting block diagrams, sketches, pictures, schematics, videos, etc., we don't mind but a paper and pencil version is still required.

Present your final check-off robot to the staff. You get three tries to succeed on the field in each session.

Deliverables are:

- Robot that meets all requirements and completes the challenge.

Competition: **Friday 07-Dec-2018,** the public demo off your finished, operational machines. This fun performance will likely have a large and enthusiastic audience. It will be held in Media Theater M110, starting at 6:00 PM. You will be expected to arrive at 5:20.

There will be a post-tournament beer, dancing, decompress at one of the Santa Cruz watering holes (traditionally Woodstock Pizza). We will post plans on Piazza.

Clean-up and Class Review: Monday after Public Demo

Lab Report:

Electronic copy of your lab report, turned in as a group assignment in CANVAS.
Create a section for each design and write an evaluation of each aspect of your design: what went well and what didn't. Make sure to include pictures and links to video as necessary. Also include your final BOM.

Check Off Schedule:

CheckOff's are used to ensure that you are on track and keeping up. It allows the teaching staff to allocate their resources to help teams out in an appropriate way. Treat them seriously and your project will be completed well and on time.

Check-off 1:

Using the five concepts that each of you created for the midterm, now that you are assigned to teams, come up with 3 team concepts for your design. Mix and match between the best of your individual designs. How are you and your team going to accomplish your project goals? Get some details written down in your engineering notebook.

Deliverables are:

- 3 detailed TEAM concepts for solving the project.
- Make copies of them for your teammates and yourself.

Check-off 2:

Basic project management and system component design. This is where you define who is primary/secondary on which tasks. How you will coordinate time and schedules, etc.

Deliverables are:

- Time schedules
- Personnel assignments
- System Block Diagram
- Mechanical Design Sketches
- Working beacon detectors on perf-board with LEDs (at least one) with accompanying schematics****

Check-off 3:

Mechanical and Software Designs. You should at this point have your final robot design completed in appropriate CAD software, and your state machines should be entirely drawn out (neatly). Your mechanical design should easily fit within an 11" cube. While both of these may need to be updated as you progress, they should be in close to final form.

Deliverables are:

- State Machine(s)
- Final Mechanical Design (Solidworks)

Check-off 4:

Sensors and Actuators. Your full sensor suite should be functional and documented at this point. All ball launch mechanisms should be prototyped and tested for range and accuracy (this gives time to redesign if necessary).

Deliverables are:

- Working sensors (breadboard is ok) and schematics
- Actuators (breadboard is ok) and schematics

Check-off 5:

Final Sensor and Actuator designs. Final working (perfboard) prototypes of all sensors and actuators that your robot will use. Fully tested, fully documented.

Deliverables are:

- Final sensors and final schematics
- Final actuators and final schematics

Check-off 6:

Mobile platform with basic reactive navigation. Your platform should be integrated into a moving droid, which can keep itself on the field (tape sensing)

**** This should be the best one from Lab 2 among your team. If you really, truly, have to build a new one, make sure you use the best of the designs from the lab.

and resolve collisions (bump sensors).

Deliverables are:

- Autonomous platform that can move and sense
- Reverse off of a collision sensor
- Keep itself on the field

Check-off 7:

Basic Navigation. Robot that can move from the starting zone to the Initial Firing Zone and fire at a beacon. If your launch mechanism cannot reach the opponent location, be able to navigate down the field hiding behind the obstacles.

Deliverables are:

- Robot that can autonomously navigate to the IFZ, locate opponent, and score points
- Robot fits entirely within the *Cube of Compliance*.

Specifications Check-Off:

Min Spec. Your robot should be able to meet the minimum specifications. After that you may go home and celebrate (or sleep).

Deliverables are:

- Robot that meets minimum specifications

Notes on successful projects management: There are a few rules of thumb to follow that will make your project much more successful, and keep you working well as a team.

The first rule is a bit paradoxical, but nonetheless important: *Do what you are bad at*. That is, if you are good at software but bad at mechanics, then you take the lead on mechanical stuff, and take a secondary role in software design.

The second rule: Double-team every single task you need done. That means one person is primary/lead the other is secondary. Note that if you follow the first tip, then likely the secondary is better at the task than the primary. Do **NOT** attempt to split tasks up so that each one of you go off and do it and then come back—this never works and is *always* slower in the long run.

When crunch time comes, you can run a rotation with your three team members such that one sleeps, two work (the just woken up one works under the one who has been up). Then the lead goes to sleep, the secondary goes into lead position (on another task), and the sleeping one gets woken up to be secondary. While this is not sustainable beyond a couple of weeks, you can get an enormous amount done this way.[††††]

Be careful about sleeplessness and cars/bikes/etc. There are plenty of couches around to crash on, and a number of students live in GSH (200 ft. from the lab). Don’t think you can keep yourself awake long enough to drive/bike home. Be smart about this. We really don’t want to see anyone get hurt through a senseless crash.[‡‡‡‡]

PS: With this many people in the lab, it is going to be very important that you keep the lab clean and not leave your things lying around. We will be assigning I/O boards and batteries to each team, and they will be yours until the project is over.

People occasionally donate random parts, and if you happen to find surplus printers, or other random electronics that people no longer want, feel free to dismantle and salvage what you want. However, please discard all parts that are not salvageable in an appropriate e-waste container so as to reduce clutter in the lab.

Drive motors have, in general, been a make-or-break part of the project. I would strongly suggest you consider purchasing some gearhead motors from Jameco, MPJA.com, or Amazon.com. Ordering them early (i.e.: now) would ensure that you have a set that will work by the time you need them. I will post on Piazza what I think are decent motors—if you have prime, they will get here quickly.

PPS: *The Mechatronics Beer Challenge*—any team that is able to complete the beer challenge spec (see above) with a fully functioning and finished ‘droid a full week ahead of the deadline gets a case of beer or other equivalent adult beverage (within reason) supplied by Gabe. Only three teams have ever collected this. See rules above.

[††††] I personally have kept this up for approximately 21 days—not recommended but boy did we get a lot done (DoD deadline)

[‡‡‡‡] If you need a ride home and are too sleepy, call one of the staff—we will come get you or find a couch for you.