Studio 4 – Big Design Project

Autonomous Surgical Robotic Systems

Significant breakthroughs have been achieved in health care during the last decade through advances in minimally invasive surgery and biomedical implants. These advances in biomedical implants have revolutionized the treatment of many conditions in particular heart arrhythmia conditions that are addressed with cardiac implants commonly referred to as "pace-makers." In addition to the advancement of implants, the development of surgical robotic systems has provided similar game changing opportunities for surgical intervention and care. Minimally invasive procedures avoid the massive additional trauma experienced with more conventional surgical intervention techniques and, as a result, allow for marked reduction in recovery times. The daVinci® surgical system, by Intuitive Surgical, Inc., is presented in Figure 1. It is an industry-leading example of these systems, as it enables the surgeons to make micro-cuts and to achieve high precision, complex motions that would be impossible to recreate with even the most skilled hands.

(a) **(b)**

Figure 1. The da Vinci® surgical robotic system (a) used in minimally invasive surgical procedures uses (b) advanced mechatronic systems to augment the precision of small surgical motions.[Figures from www.intuititvesurgical.com]

The design project effort for this studio will consider the development of a new generation of autonomous surgical robotic systems. Each design team will design, build, test and finalize an autonomous mechatronic device that will compete against other devices in a simulated autonomous surgical robotics evaluation trial. The devices must perform a simulated operation scenario that aims to reattach a dislodged cardio implant and repair the internal damage at the initial attachment site. To achieve this operation successfully the device will need to make the initial incision, repair any damages due to the detachment of the implanted device, locate the dislodged implant, and reattach the implant in the appropriate location. Each team will have to present their design to a team of independent experts during a critical design review. The performance of each device will be assessed through a series of competitive emulated surgical trials. The design review begins at 5:00pm on Friday, November 11, 2011 and the surgical trials begin at 6:15pm.

2. CONTEST OVERVIEW

The performance of each autonomous surgical robot will be assessed based on the total number of points scored by completing various task elements in a simulated autonomous cardiothoracic surgery scenario in which a dislodged pacemaker must be reattached to continue to function correctly. The robots will complete the simulated surgical scenario in the surgical trial operating theaters, illustrated in Figure 2. The operating theater comprises four color coded zones, accessed through the zone opening at the front end of the starting zones, and a rotating centerpiece, called the Implant Zone, that contains the implant reattachment zones. The robots must be positioned completely within the boundaries of the starting zone for the assigned operational zone at the start of any competition. The device will be triggered electronically, except during the Individual Competition, in which each device is manually triggered; the device will have no more than 60 seconds to attempt to complete the task elements.

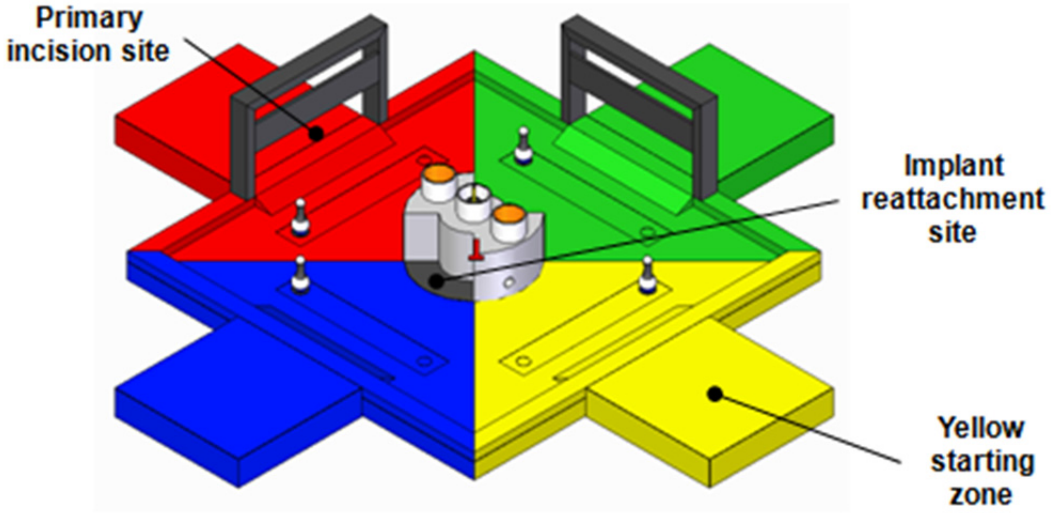

Figure 2. An illustration of the autonomous surgical robot trial operating theater showing the color coded operating zones. The primary incision sites for the blue zone and yellow zone have been removed for clarity

2.1 Task Element Details and Scoring System

There are three (3) competition task elements, detailed in the sections below, that provide an opportunity for the autonomous surgical robot to score points based on successful completion of each task element. There are penalties associated with imprecise motions that lead to additional traumas and resultant internal bleeds, and the device will need to minimize the risk in order to score maximum points in a contest. Furthermore, a significant penalty is assessed for the failure to accomplish the reattachment of the implant, which is consistent with the trauma and risks to the patient caused by an additional, preventable, surgery.

Task 1 – Perform Initial Incision

The surgical robot must first gain access to the surgical zone by making an incision in the patient. This task will be accomplished by opening the Primary Incision Site, which will be represented by a frame that is 30" wide. This frame will have a movable gate with a 4-inch gap below it, and this gate can be raised as high as 18 inches. Surgical robots should minimize the size of the incision; accordingly, points for the successful completion of the incision are awarded as follows:

Opening of greater than 15 inches: **5 pts**.

Opening of less than 15 inches: **10 pts**.

Task 2 – Repair detachment site

Repair the damage caused when the implant became dislodged. The surgical robot will need to place one or two sutures to close the wound. A suture will be emulated by soft rubber balls (squash balls), and these balls may be preloaded onto the robot prior to the start of the competition. There are two (2) detachment sites that are represented by 6" PVC pipe sections mounted to the top surface of the rotating rescue zone. The detailed dimensions of the location, height and radius of the zones are provided in a later section of this handout. A repair of the detachment will be considered successful if the sutures (balls) are completely contained within the boundaries of either one of the detachment sites.

Successful execution of a suture will score **15pts per suture**.

Task 3 – Locate and reattach implant

The surgical robot must locate an implanted pacemaker that has become dislodged from its original attachment site, and it must reattach that pacemaker at a new attachment site. Because MRI images can sometimes have shadows, the dislodged implant's location is not precisely known; however, it has been narrowed down to two possible locations in the surgical zone.

The dislodged pacemaker is represented by a plastic bowling pin that has been mounted on a 2.75" diameter rigid base. The plastic bowling pin is approximately 8.5" high, 2.5" in diameter at its widest part and has a 1" neck diameter. The dislodged pacemaker member will be placed within an 6" x 30" rectangular zone in front of the incision site, either on the left-hand side or right-hand side of this zone. The surgical robot must position this bowling pin at the Implant Reattachment Site in the Implant Zone. The repositioned bowling pin must be in a vertical orientation in order to score points for completion; a horizontal orientation indicates that the implant has not been successfully reattached and may require further surgical intervention. The implant will be considered to be vertical if the major-axis of the bowling pin is within 10° of vertical (normal to the playing surface.)

A successful reattachment of the implant support will score **50 pts**.

The implant must be repositioned quickly, efficiently and precisely. If the procedure is performed inaccurately the nearby arterial walls maybe damaged, either through direct incision or excessive

pressure, leading to dangerous, life-threatening bleeding. The problem of arterial damage associated with an imprecise procedure will be emulated by the function of two (2) rotating IR sensors mounted to the trailing edges of the rotating Implant Zone. The IR sensors are rigidly mounted to the top surface of the rotating Implant Zone and traverse the zones at a rotation speed of 6-7 revolutions per minute. If the IR sensor detects the presence of the robot, this will simulate a procedure that has damaged the arterial wall, triggering unnecessary bleeding. The bleeding will be represented by large playing dice that the active track will deploy into the playing area on each detection signal. Every die contained within each operational zone at the end of the competition will result in a **-2 pt penalty per die** being assessed to the corresponding zone.

Completing the Surgery

Surgery is considered to be complete when the Surgical Robot has left the surgical zone via the incision, after successfully reattaching the dislodged implant. Failure to complete the surgery is defined as:

1) Failure to reattach the implant,

2) Robot remaining inside the surgical zone.

The border of the surgical zone is defined by the gate at the Primary Incision Point.

Penalty for failure to complete the surgery: **-30 pts**.

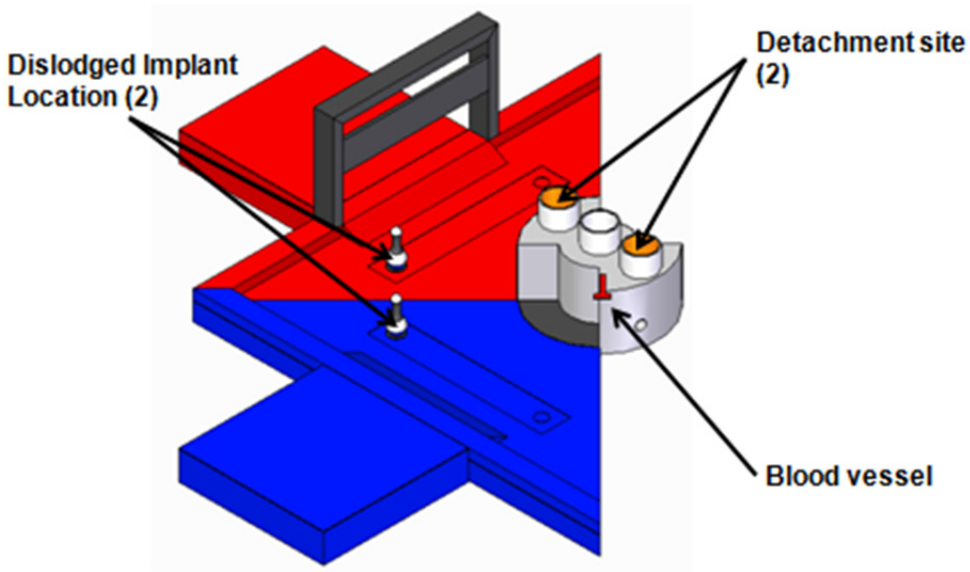

Figure 3. The location of the task elements in the autonomous surgical robot operating theater zone

The scoring system each of the tasks elements is summarized in Table 1 below. A maximum score of 90 points is possible for an error-free mission.

Table 1. Contest scoring summary.

Scoring	Point Value
Perform primary incision	10 pts
Repair detachment site	15 pts/suture
Locate and reattach implant	50 pts
Penalties	
Damage arterial wall / blood vessel	-2 pts/bleed
Incomplete surgery	-30 pts

3. CONTEST TIMELINE AND DEADLINES

Your devices will be tested in four (4) rounds of competition:

1) Individual Competition (Week 8 (beginning October 10))

Every student will field a device for the individual competition. The autonomous surgical robots must complete Task 1, the primary incision. The individual competition robots are due at the start of the studio and will be checked in with the TA or section instructor. The individual machines are limited in the available energy sources, constrained to the allowable gravitational potential and 3 mousetraps. You will trigger the machine by hand in one (1) motion; you may not transfer any significant energy to the machine during the triggering process. The machine will compete by itself; no other devices will be on the surgical trial arena. You will have 5 minutes to run your machine at most three times. Your score will be the cumulative total of your three attempts. Your performance will be ranked against students in all studio sections (class wide).

2) Preliminary Team Contest (Week 10 (beginning October 24))

The preliminary competition will be the first contest of team devices. Each team will field an autonomous device that is capable of performing the primary incision (Task 1) and staunching the bleeding at the detachment site (Task 2). The center piece of the arena will be rotating; however the arterial bleed system will not be active, and no penalties will be possible. The device must utilize the computer controller and any combination of the supplied actuators, pneumatics, allowable gravitational potential, and the five (5) mousetraps provided. The autonomous surgical robot will be electronically triggered using the start button on the track. Only one device will compete in any contest; there will be no other robots active in any of the operational zones. You will have 5 minutes to run your machine at most three times. Your score will be the cumulative total of the three attempts. Your performance will be ranked against students in your studio section (section specific).

3) Qualifying Round (Week 11 (beginning October 31))

In the qualifying round each machine will compete against other machines in all aspects of the design challenge. Your autonomous device will compete several times during the studio period against a variety of opponents. Your grade will be based purely on the relative performance of your device compared to the other devices in your section (section specific). However, all total scores from the qualifying round will be used to seed the brackets for the final tournament.

4) ME2110 Design Contest – Friday, November 11, 2011

Your machine will compete in two events:

a) Design Review: Between 5:00pm and 6:00pm a panel of judges will perform a design review of your machine. You will need to describe your machine quickly and clearly to the judges that visit your machine. The judges will score your machine on aesthetics, ingenuity, and presentation.

b) Autonomous Surgical Robotics Trial: The devices will compete against other machines to achieve the best score. In each contest the top two scoring machines will be declared winners. The contest will follow a double elimination format for the first round of competition from which a final bracket will be determined. The final bracket will follow single elimination in which the device will need to win to advance further in the competition.

4. CONTEST DETAILS

4.1 Surgical Trial Operating Theaters

The surgical trial theaters will be simulated by a square arena measuring 7 feet on a side and comprising four color-coded competition zones as illustrated in Figure 2. The surface is supported by 2x4's, so it is elevated approximately 4 inches above ground. There are also 2x4's around the top perimeter to keep items from rolling out. The area is divided into 4 equal size zones. The zones are bounded by the inside edge of the 2x4 perimeter, the diagonal dividing lines to the left and right sides of each zone, and the rotating center. The volume of space above the zone boundaries is also part of the zone. The locations of the various task elements within each zone are presented in Figure 4. The heights of the rotating rescue zone and the initial size of the access passage are presented in Figure 5. The construction of the track is performed with the highest precision possible. However variations of up to 0.25" are possible. *Your device should be designed to be robust to these uncertainties.*

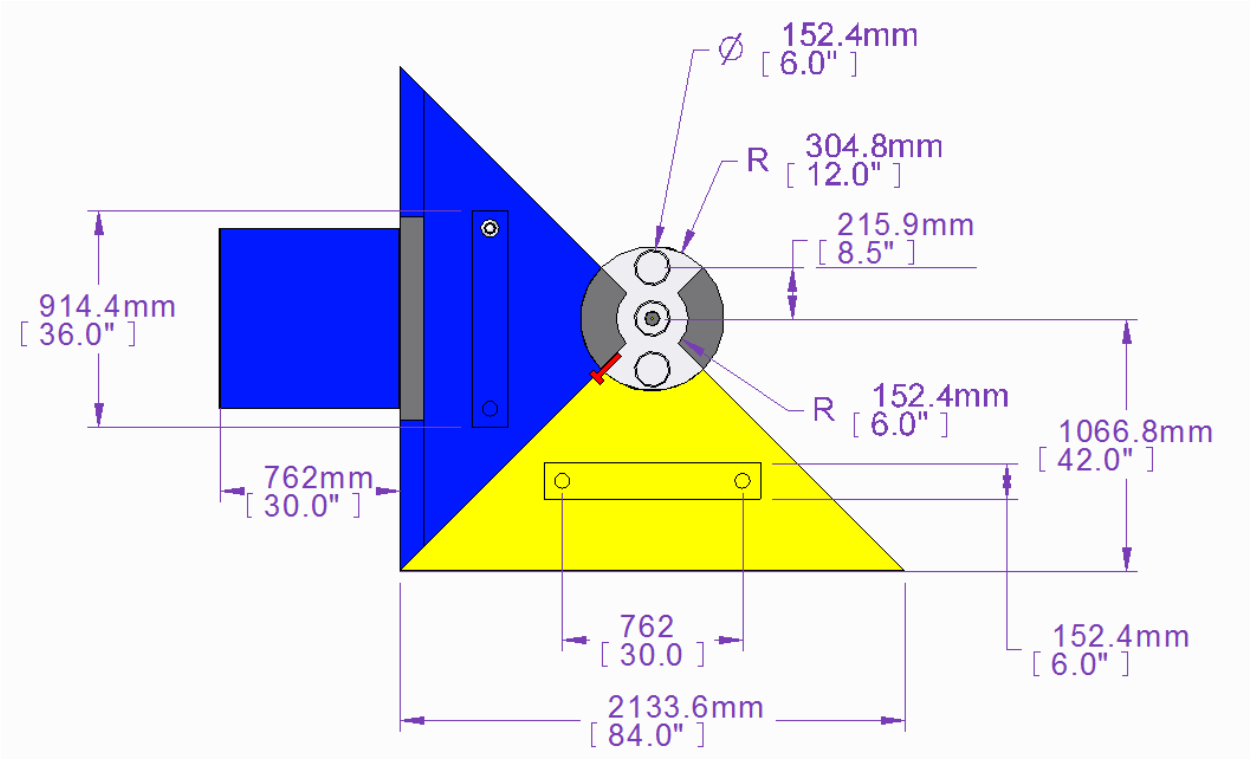

Figure 4. The detailed location and dimensions of the track and task elements within the operational zones. Primary units are millimeters and secondary units are inches.

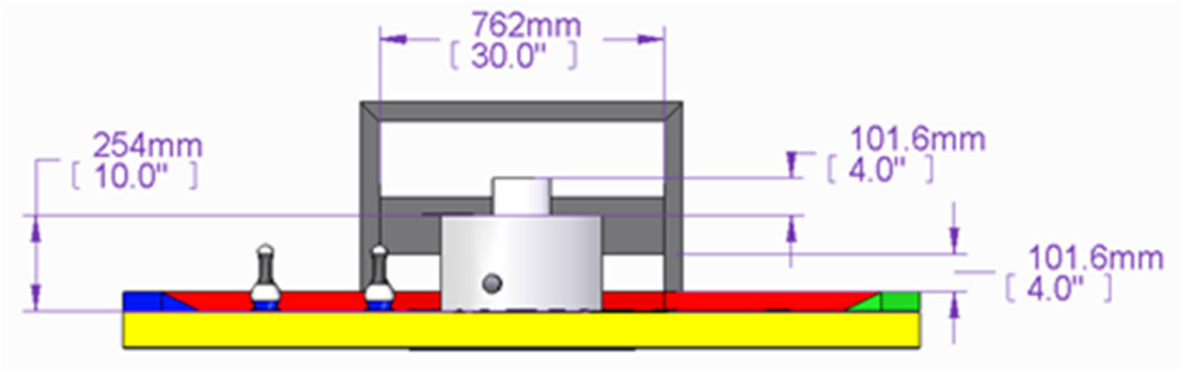

Figure 5. A dimensioned schematic of the rotating centerpiece and the zone gate that emulates the location of the initial incision.

4.2 Building Materials

Your solution should not be expensive or complicated. To limit the expense and complexity of your design, you are permitted to use energy only from the supplied controller, the supplied pneumatics, five (5) mousetraps, and gravity. Your team will be provided with a set of actuators, such as motors, solenoids, and pneumatic cylinders. No other actuators may be driven by the computer. The computer also powers the sensors, which include: an IR range detector, some switches, and an encoder. You may purchase additional building materials and sensors as long as your team's total budget remains under $100.

4.3 Contest Format

From 5:00pm-6:00pm your devices will be on display in the MARC building for the design review. The design review score incorporates aesthetics, ingenuity, and presentation. You are allowed to "dress up" yourselves, your machine, and your presentation area in order to maximize your score. All team members will need to be in attendance during the design review to discuss the features of your machine. Your device must be on display throughout this period. The performance of your device will be evaluated during the competitions in the surgical trial operating theaters. The trials will begin at 6:15pm.

4.4 Tie Breaker Procedure

In the case of tied contests, the following tiebreakers will be applied in order until one team is declared victorious: 1) the team with the least number of bleeds (dice), 2) the team with the greatest number of sutures completed (balls) and 3) dice roll.

4.5 Grading

The performance of your machine counts towards 14% of your grade for the course, and the design review counts for 5%. The 14% of your grade that comes from the performance of your machine is awarded across each of the four competition stages according to the breakdown presented in Table 2. The grade points assigned at each competition is listed in Table 2, below, and the details of the mechanisms used to calculate the grades are presented in the preceding sections.

Table 2. Summary of competition grading

Maximum Grade	Breakdown
1	Individual Competition
2	Preliminary Competition
2	Qualifying Round
9	Big Contest

4.5.1 Individual Competition: Every student will field a device for the individual competition. The devices must attempt to complete Task 1. Your score will be ranked against all students in all sections. The maximum score will be assigned a grade of 1 and the minimum score will receive a 0.1 grade. Failure to field a capable machine (credible effort) will result in a zero grade.

4.5.2 Preliminary Competition: Your score will be ranked against teams in all studio sections. The maximum score will be assigned a grade of 1 and the minimum score will receive a 0.1 grade. Failure to field a capable machine (credible effort) will result in a zero grade.

4.5.3 Qualifying Round: Each team will compete several times. The total points will be used to rank the teams within the studio section ONLY. The maximum grade is 2; the minimum grade is 0.1.

4.5.4 Big Contest: Your grade points are based on the number of **victories** scored by your machine. The team with the most victories earns 9 grade points; the teams with zero wins get 1 grade point. The grades for the remaining teams are scaled linearly between these values proportionate to their win count.

4.5.5 Design Review: The judges' scores will be summed and divided by the number of judges that evaluate each machine. These average scores will be ranked across all sections. The maximum score earns 5 grade points; the minimum score earns 1 grade point.

5. CONTEST RULES

1. If a team is disqualified for a rules violation, then they lose the current match in which they are competing. If the team can eliminate the violating offense, then they are eligible for future matches.
2. For the design contest, your device will be assigned to a 7-minute time block. All competing devices will be automatically activated at the 4-minute mark, and must be removed from the track by the 7-minute mark. Thus, you will have 4 minutes to setup your device and then it will compete for 1 minute. The next two minutes will be used for scoring and cleaning up. By the end of the 7-minute period, you must remove your device (and any bits and pieces) and clean up the competition track. Disqualification can be imposed for taking longer than your allotted time.
3. Once it has been activated, you may not touch the device or enter the competition area until the field official indicates it is time to clear out your machine. Doing so results in a disqualification.
4. It is your responsibility to be on time with a working machine. If you are not present during your assigned time, you are disqualified for that match.
5. The source of power in your device is limited to the five mousetraps provided to you, a compressed-air tank provided to you, the controller box power, and gravity.
6. The only permitted actuators are those supplied to you by the ME 2110 staff.
7. Your machine must fit within a 24 x 12 x 18 (length x width x height) inch box. The 12 inch dimension describes either the width or the length of the device. The 18 inch dimension is the maximum starting height of your system. Your device will be measured with a go-no-go box during the 4 minute setup period. When the box is removed, your machine may not "bloom" out and occupy a larger volume. Doing so will require a re-boxing of the machine. If your machine has not been sized by the time there are 15 seconds remaining before the trigger, you will be disqualified for that match.
8. The device must be launched from within the 2.5 X 2.5 foot starting zone. The outside of the lumber perimeter defines one of the sides of the starting zone. You may place your device in any configuration or orientation within the starting zone; however, the go-no-go box must be able to fit over the device immediately prior to its start. You can only reposition your device after it has been checked for size; you cannot set triggers, adjust components, turn on your controller, etc. Your machine cannot overhang into the competition area - defined by the outside of the 2x4's.
9. A three-foot perimeter around the proving grounds, marked off by tape, will be off limits during the competition.
10. The device must be safe. It must not injure bystanders or yourself. It must not damage, stain, or permanently change the competition area or its surroundings. It must not scratch the floor. The faculty will disqualify any device they deem unsafe.
11. Each team may not spend more than a total of $100 on the device. You will be required to document the cost of your materials by submitting your receipts, as well as a table of materials and costs in your final report. Material may be prorated for costs. The cost of an object is defined to be that which Joe P. Citizen must incur in obtaining the object. For donated, recycled or scrounged material, an equivalent price must be specified.
12. The cost of the kits supplied to you is NOT included in the $100. The $100 is out of pocket expense; you will not be reimbursed for the expense by the School.
13. The costs of any aesthetic materials (*e.g.*, paint) and fasteners (*e.g.*, staples, tape and glue) are not included in the $100 budget.
14. All supplies provided to you (electronics, motors, etc.) must be returned in good working order.
15. The device shall not be permanently bonded in any manner to the competition track or its surroundings in any way.

16. The device must be activated by using the start plugs near the starting zone. The start plug circuits will be closed during the 1 minute competition and open otherwise. Your control code must sense the closed circuit and activate its actions.
17. Power to the computer will be available from outlets near the starting zones. If your computer travels far out into the competition area, you must supply your own extension cord.
18. Your device cannot have active (powered applied) components prior to triggering. (i.e. solenoids and motors must be in the dead state)
19. The device must shut down (i.e., no electric motor operating) at the end of the one minute competition when the start-plug circuits are opened. Failure to do so will result in a disqualification.
20. The device must operate autonomously. No remote control is allowed.
21. The device may touch or otherwise utilize any part of the arena or its surroundings. It may not utilize or interact with any living person or living object, such as trained monkeys, during the competition.
22. False starts that disrupt the playing field such that it cannot be reset in time for the scheduled start will result in a disqualification of the offending device.
23. While machines may go outside of the playing field, there are no guarantees as to what will be located outside of the track, *e.g.*, a wall or motor or people may be located outside of the track area.
24. The faculty will assign the teams. The teams will remain constant for the duration of the project.
25. Wanton destruction of the opposing devices and/or the course is strictly prohibited.
26. If you don't play, you can't win. If your device does not make any noticeable movement, you lose that round of competition by disqualification.
27. The faculty's rulings on any clarification or dispute of these rules are binding and final.