1. INTRODUCTION

In this studio, teams will design, build, prototype and develop an autonomous robotic system that will compete in an emulated robo-pool contest. The robotic player that generates the most earnings per game, through successful play and betting strategy, will win the contest.

The design and development of a robotic billiards player poses significant technical challenges. The tasks and functions performed by a skilled human player include precise motions, dexterous manipulation of the cue during the shot, and the execution of a multi-step game strategy. Motion systems to position and manipulate the cue require 5-axis positioning control to emulate the motion of the wrist and must be able to move around the table. One research group, at Queensland University, has developed a gantry-type robotic pool player named “Deep Green.” [1] The cue is held in a purpose-built end-effector and is actuated by an electromagnetic linear actuator. The end-effector, shown in Figure 1, is capable of two-degrees of rotational freedom, simulating a wrist, and is moved about the table using a large gantry-type motion system.

The key challenge lies in the autonomous control. The robotic player must develop a strategy to win the game which involves shot selection – the robot must read the table, assess the options and decide which shot to take that, on completion, leaves the cue ball optimally located for the next shot. The functions inherent in the game play, italicized for emphasis, are high-level cognitive actions that require cutting-edge machine learning techniques.

The autonomous billiards robot developed in this studio must be able to break, without scratching, pocket balls in corner pockets and side pockets, sink the eight ball in the rotating side pocket, and place bets with the bookie to increase the winnings per game. The robotic pool systems review begins at 5:00pm on Friday, April 5, 2013 and the Robo-pool tournament starts with first break at 6:15pm.

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2. CONTEST OVERVIEW

The successful billiards-playing robot will complete four tasks that emulate a billiards game: 1) break, 2) pocket balls, 3) place bets, and 4) avoid scratching. The Billiard Table competition arena is illustrated in Figure 2 and includes a vertical barrier, the Break Gate, at the entrance to each competition zone. Robots will start from one of four Head Spots and must successfully break by raising the gate. Breaking will allow the robot to enter the Billiard Table and attempt to pocket balls and place bets at the Betting Zone.

Figure 2. An illustration of the Billiard Table showing the color-coded operating zones. The Break Gates for the gold and black zones have been removed for clarity.

2.1 Task Element Details and Scoring System

The four (4) competition task elements provide an opportunity for the billiards robot to accumulate points based on successful completion of each task. In addition, the billiards robot will need to take precautions not to scratch, which will cause the robot to forfeit any accumulated points.
**Task 1 – Break to enter the Billiard Table arena**

The billiards robot must break to begin the billiards game. This process is emulated by the Break Gate illustrated in Figure 2. A successful raising of the gate to a height of 14” from the top surface of the starting zone will score **10 points**.

**Task 2 – Score Points by Pocketing Balls**

Competitive billiards robots will successfully pocket all of the balls in play on the table, and will utilize both the corner and side pockets to achieve this. This process is emulated by five (5) racquetballs placed on the Billiard Table, as shown in Figure 3. The center ball is the Eight Ball. The balls will be slightly elevated above the surface of the track. The balls may be placed in any of the four Corner Pockets or two Rotating Side Pockets. The Corner Pockets are located in each corner of the Billiard Table. The Rotating Side Pockets are the cutaway sections in the rotating Betting Zone illustrated in Figure 2 and Figure 3.

Four of the balls score regular points, while the Eight Ball located in center must be pocketed in a specific way. The regular balls may be pocketed in any of the Corner Pockets or one of the two Rotating Side Pockets. Each ball that is placed in a Corner Pocket will score **5 points**, while each ball placed in a Rotating Side Pocket will score **10 points**. To score points with the Eight Ball, it must be pocketed in a Rotating Side Pocket. Successfully placing the Eight Ball in either Rotating Side Pocket will score **20 points**.

**Task 3 – Place Bets with the Bookie**

The billiards robot may place bets using the Bookie. The robot may do this by alerting the Bookie that it wants to place a bet. The Bookie uses two (2) downward-facing IR sensors mounted to the trailing edges of the Rotating Side Pockets, as indicated in Figure 3. The IR sensors are rigidly mounted to the top surface of the betting zone centerpiece. The centerpiece has a rotation speed of 6-7 revolutions per minute. The IR sensor detecting the presence of the robot will simulate the placing of a bet. The bets will be represented by large playing dice that the active centerpiece will deploy into the zone on each detection signal. Teams begin with a multiplier of **1x**, and every dice completely contained within the robot’s operational zone at the end of the competition will add **1x** to the team’s multiplier. There will be a total of six (6) dice in the active centerpiece, so the maximum possible multiplier will be **7x**. This multiplier will be applied to all points scored from pocketing balls (Task 2).

**Task 4 – Avoid Scratching**

Scratching in a billiards game will cost the robot the match. Triggering the Scratch Button located in the middle of each zone, as seen in Figure 3, will emulate scratching. The robot may also fail to break, or scratch on the break. This will be emulated by failing to lift the Break Gate to a height of at least 14” above the top surface of the starting zone (Task 1). If the robot scratches by triggering the button or by failing to successfully break, then the robot will forfeit any accumulated points and the team’s score will be automatically reduced to **0 points**.
Figure 3. The location of the task elements on the Billiard Table competition arena. The white and black zones have been removed for clarity.

The scoring system for each of the task elements is summarized in Table 1.

<table>
<thead>
<tr>
<th>Scoring</th>
<th>Point Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Break to start the game</td>
<td>10</td>
</tr>
<tr>
<td>Pocket Balls in the Corner Pockets</td>
<td>5</td>
</tr>
<tr>
<td>Pocket Balls in the Rotating Side Pockets</td>
<td>10</td>
</tr>
<tr>
<td>Pocket the Eight Ball in a Rotating Side Pocket</td>
<td>20</td>
</tr>
<tr>
<td>Place Bets with the Bookie</td>
<td>Multiplier on scores from balls, add 1x per dice</td>
</tr>
<tr>
<td>Scratch</td>
<td>Score = 0</td>
</tr>
<tr>
<td>Failing to Break / Scratch on the Break</td>
<td>Score = 0</td>
</tr>
</tbody>
</table>
3. CONTEST TIMELINE AND DEADLINES

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

1) Individual Competition (October 16 - 22)

Every student will practice breaking for the individual competition. The individual billiards robots must attempt to complete Task 1. The track will not be rotating. The individual competition robots are due at the start of the studio and will be checked in with the TA or lab instructor. The individual machines are limited in the available energy sources, constrained to gravity and 3 mousetraps. You will trigger the machine by hand in one (1) motion and cannot transfer any significant energy to the machine during the triggering process. The machine will compete by itself on the track. You will have 5 minutes to run your machine at most three times. Your score will be the sum total of your three attempts. Your performance will be ranked against students in all studio sections.

2) Preliminary Team Contest (October 28 – November 1)

The preliminary competition will be the first test for a billiards robot constructed as a team device. The robot must attempt to complete Tasks 1, 3, and 4: Break, Place Bets, and Avoid Scratching. The Betting Zone will be rotating and the Bookie sensors will be active. The robot must carefully avoid the Scratch Button and successfully break to avoid a scratch and forfeiting any accumulated points. For the purposes of scoring points via the betting multiplier, each team will be given one ball already pocketed in a Corner Pocket (for a score of 5 points). The multiplier will then be applied to this score.

The device can utilize the computer controller, the supplied actuators, pneumatics, gravity, and five (5) mousetraps. The robot will be electronically triggered using the start button on the track. The billiards robot will operate alone as 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 sum total of your three attempts. Your performance will be ranked against teams in your studio section.

3) Qualifying Round (November 4 - 8)

Your team’s machine will compete against other machines in all aspects of the design challenge. Note that this requires that all teams' billiards robots are completed and delivered at the start of this studio. You will compete several times during the studio period against a variety of opponents. Your score will be ranked only against teams in your studio section. The results from this qualifying round will be used to seed the brackets for the final billiards tournament.

4) ME2110 Design Contest – Friday, November 15, 2013

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 and present your billiards robot. The judges will score your machine on aesthetics, ingenuity, and presentation.
b) Robotic Billiards “Robo-pool” Tournament: The billiards robots will compete against other machines to score the most points and win the most games. All robots will compete in the first two rounds of the contest. The top 32 teams will advance from these preliminary rounds. The sum of the points scored in the preliminary rounds will be used determine the top 32 teams, and these 32 teams will advance to the next phase of the tournament. Any ties will decided using the initial tournament seeding determined using the results of the Qualifying Round.

During the second phase of the tournament, the top two scoring machines in each game will be declared winners and will advance to the next round. When there are 4 teams remaining, a final round will be played, and the team which scores the most points in this round will be declared the winner of the Robotic Billiards Tournament.

4. CONTEST DETAILS

4.1 Billiards Table

The proving grounds for the billiards robots will be simulated by the Billiards Table competition arena. This is a square arena measuring 7 feet on a side and comprising of four color-coded competition zones as detailed in Figure 4. 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 task elements are presented in Figure 5. The construction of the track is performed with the highest precision possible, but variations of up to 0.375” are possible. Your device should be design to be robust to these uncertainties.
4.2 Building Materials

Your solution should not be expensive or complicated; remember Ockham’s razor. 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 control box. The control box 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 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 billiards robot must be on display throughout this period. Your robot’s performance will be evaluated in the Billiards Table competition arena. The Robotic Billiards Tournament 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 that pocketed their eight ball, 2) the team with the highest number of pocketed balls, and 3) coin toss.

4.5 Grading

The performance of your machine counts towards 15% of your grade for the course and the design review counts for 5%. The 15% 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>
<thead>
<tr>
<th>Maximum Grade</th>
<th>Breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Individual Competition</td>
</tr>
<tr>
<td>2</td>
<td>Preliminary Competition</td>
</tr>
<tr>
<td>2</td>
<td>Qualifying Round</td>
</tr>
<tr>
<td>8</td>
<td>Big Contest</td>
</tr>
</tbody>
</table>

4.5.1 Individual Competition: The individual competition will be the assessment of the individual robot’s ability to break by raising the gate to a height of 14”. Your score will be ranked against all students in all sections. The maximum score will be assigned a grade of 3 and the minimum score will receive a grade of 1. Failure to register a tournament-ready billiards robot (credible effort) will result in a zero grade.

4.5.2 Preliminary Competition: Your score will be ranked against teams in your studio section. The maximum score will be assigned a grade of 2 and the minimum score will receive a grade of 0.2. Failure to compete with a tournament-ready billiards robot (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 0.2.

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 8 grade points; the teams with zero wins get 2 grade points. The other 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 thirty seconds (30s). The next two and a half 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 mouse traps 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. (For example, no additional magnets are allowed.)

7. The pneumatic actuators given to you consist of the pneumatic piston, valves, and the tubing. The air released from the tank must first pass through the tubes and apply air-blowing forces, or the air must extend the piston to apply forces. You cannot create your own pneumatic actuator or cannon to harness the air pressure (things could get dangerous if you do).

8. 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.

9. 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 overlap into the competition area - defined by the outside of the 2x4's.

10. A three-foot perimeter around the proving grounds, marked off by tape, will be off limits during the competition.

11. 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.

12. 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.
13. 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.

14. The costs of any aesthetic materials (e.g., paint) and fasteners (e.g., staples, tape and glue) are not included in the $100 budget.

15. All supplies provided to you (electronics, motors, etc.) must be returned in good working order.

16. The device shall not be permanently bonded in any manner to the competition track or its surroundings in any way.

17. The device must be activated by using the start plugs near the starting zone. The start plug circuits will be closed during the thirty second competition and open otherwise. Your control code must sense the closed circuit and activate its actions.

18. 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.

19. Your device cannot have active (powered applied) components prior to triggering. (i.e. solenoids and motors must be in the dead state).

20. 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.

21. The device must operate autonomously. No remote control is allowed.

22. 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.

23. 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.

24. 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. No part of the machine may leave the three-foot perimeter, nor should the machine cause any object to leave the playing arena such that it crosses the three-foot perimeter (either a projectile or track component). Any violations will result in a disqualification due to safety considerations.

25. The faculty will assign the teams. The teams will remain constant for the duration of the project. The faculty has the right to remove or otherwise penalize disruptive members of any team.

26. Wanton destruction of the opposing devices and/or the course is strictly prohibited.

27. If you don’t play, you can’t win. If your device does not make any noticeable movement, you lose that round of competition or score zero points if this occurs in a preliminary competition.

28. The faculty’s rulings on any clarification or dispute of these rules are binding and final.