Autonomous Pool Playing Robot

Verification & Validation

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Date	Revision #	Comments	Authors
27/02/2017	0	- Initial document creation	Eric Le Fort
21/03/2017	0	- Revision 0 completion	Eric Le Fort Guy Meyer Ernest Selman Andrew Danha Derek Savery Max Moore
23/04/2017	1	- Testing performed, results included - Certain testing cases grouped into single testing blocks.	Eric Le Fort

Table 1: Revision History

1 Introduction

This document will provide the specification of a test plan for this automated pool playing robot and report on the results of that plan.

1.1 Overview

This document breaks down the required testing for each domain of the system. It begins with the hardware aspect, then moves to the electrical side and then finishes with software. Each section will go into further detail to describe each test case. Lastly, a summary of the results of testing will be provided to conclude the document.

1.2 Purpose

The aim of this document is to illuminate any design flaws, software bugs, or other issues in the system. Once these issues are discovered, the engineering team will be able to work on eliminating them or minimizing their frequency and consequences.

1.3 Naming Conventions & Definitions

This section outlines the various definitions, acronyms and abbreviations that will be used throughout this document in order to familiarize the reader prior to reading.

1.3.1 Definitions

Table 2 lists the definitions used in this document. The definitions given below are specific to this document and may not be identical to definitions of these terms in common use. The purpose of this section is to assist the user in understanding the requirements for the system.

Term	Meaning
X-axis	Distance along the length of the pool table
Y-axis	Distance across the width of the pool table
Z-axis	Height above the pool table
End-effector	The end of the arm that will strike the cue ball
θ	Rotational angle of end-effector
Cue	End-effector
Personal Computer	A laptop that will be used to run the more involved computational tasks such as visual recognition and the shot selection algorithm
Camera	Some form of image capture device (e.g. a digital camera, smartphone with a camera, etc.)
Table State	The current positions of all the balls on the table
Entity	Classes that have a state, behaviour and identity (e.g. Book, Car, Person, etc.)
Boundary	Classes that interact with users or external systems
Double	Double-precision floating point numbers

Table 2: Definitions

1.3.2 Acronyms & Abbreviations

Table 3 lists the acronyms and abbreviations used in this document.

Acronym/Abbreviation	Meaning
VR	Visual Recognition
PC	Personal Computer
μC	Micro-Controller
CRC	Class Responsibility Collaboration

Table 3: Acronyms and Abbreviations

2 Testing Policy

The primary purpose of the testing of this system will be to ensure the requirements are met in order of their importance. To achieve this goal, both unit and system tests will be necessary. The process of the testing will be to perform the unit tests of the physical system and any software which does not interact with the physical system first. Once those tests are satisfied, the systems will be integrated and the unit tests which deal with both elements will be tested. Finally, the systems tests will be run to ensure final validation of the system.

The implementations and evaluations of tests are all described for the specific test in its description further in this document. In order to sufficiently cover the full problem space, tests will be designed to focus on both sides of all edge cases. Testing resources such as dummy files will also be created in order to emulate conditions that are necessary for certain test cases.

3 Traceability Matrix

The following traceability matrices will demonstrate that the tests to be performed prove that each of the specified requirements have been tested.

Functional Requirements Traceability Matrix

Req IDs	Reqs Tested	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18
Test Cases	140	4	4	5	15	6	4	10	2	16	9	9	19	4	6	11	9	3	4
1.1	3												X			X	X		
1.2	3												X			X	X		
1.3	2												X				X		
1.4	3												X	X			X		
1.5	6									X		X	X	X		X	X		
1.6	2																X	X	
1.7	0																		
1.8	0																		
1.9	0																		
1.10	0																		
1.11	1																		X
1.12	0																		
1.13	0																		
1.14	1									X									
1.15	1									X									
1.16	4									X			X			X	X		
2.1	3									X					X	X			
2.2	4										X	X	X			X			
2.3	4										X	X	X			X			
2.4	4										X	X	X			X			
2.5	4										X	X	X			X			
2.6	0																		
2.7	0																		
2.8	0																		
2.9	0																		
2.10	1																		X
2.11	0																		
3.1.1	2				X	X													
3.1.2	1				X														
3.1.3	1				X														

Table 4: Functional Requirements Traceability Matrix - 1

Req IDs	Reqs Tested	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18
3.1.4	1					X													
3.1.5	1					X													
3.1.6	1					X													
3.1.7	1			X															
3.1.8	3				X		X	X											
3.1.9	1				X														
3.1.10	1				X														
3.1.11	1				X														
3.1.12	1				X														
3.1.13	2				X		X												
3.1.14	1				X														
3.1.15	1				X														
3.1.16	2				X	X													
3.1.17	2				X	X													
3.2.1	3	X	X	X															
3.2.2	3	X	X	X															
3.3.1	5							X		X			X		X	X			
3.3.2	5							X		X			X		X	X			
3.3.3	4							X		X			X		X				
3.3.4	3							X		X	X								
3.3.5	4							X		X			X		X				
3.3.6	4							X		X			X		X				
3.3.7	2							X		X									
4.1	15	X	X	X	X		X	X	X	X	X	X	X	X			X	X	X
4.2	15	X	X	X	X		X	X	X	X	X	X	X	X			X	X	X
4.3	0																		
4.4	0																		
4.5	4									X	X	X	X						
4.6	4									X	X	X	X						
4.7	0																		
4.8	0																		
4.9	0																		

Table 5: Functional Requirements Traceability Matrix - 2

Non-Functional Requirements Traceability Matrix

Req IDs	Reqs Tested	LF1	UH1	UH2	UH3	P1	P2	P3	P4	OE1	MS1	MS2	S1	S2	S3	S4	S5	S6	S7	CP1	L1
Test Cases	60	2	5	3	2	4	12	1	2	2	1	1	2	10	2	4	2	1	3	1	0
1.1	2		X			X															
1.2	2		X			X															
1.3	1		X																		
1.4	0																				
1.5	0																				
1.6	0																				
1.7	4	X	X	X	X																
1.8	3		X	X	X																
1.9	1							X													
1.10	1								X												
1.11	1									X											
1.12	2	X																X			
1.13	2															X			X		
1.14	1						X														
1.15	1						X														
1.16	0																				
2.1	0																				
2.2	0																				
2.3	0																				
2.4	0																				
2.5	0																				
2.6	3			X									X		X						
2.7	1														X						
2.8	1																X				
2.9	1															X					
2.10	1																X				
2.11	1									X											
3.1.1	0																				
3.1.2	0																				
3.1.3	0																				
3.1.4	0																				
3.1.5	0																				
3.1.6	0																				
3.1.7	0																				
3.1.8	1						X														

Table 6: Non-Functional Requirements Traceability Matrix - 1

Req IDs	Reqs Tested	LF1	UH1	UH2	UH3	P1	P2	P3	P4	OE1	MS1	MS2	S1	S2	S3	S4	S5	S6	S7	CP1	L1
3.1.9	1						X														
3.1.10	2						X														
3.1.11	1						X							X							
3.1.12	1						X														
3.1.13	1						X														
3.1.14	1						X														
3.1.15	0						X														
3.1.16	0																				
3.1.17	0																				
3.2.1	0																				
3.2.2	0																				
3.3.1	0																				
3.3.2	0																				
3.3.3	0																				
3.3.4	0																				
3.3.5	0																				
3.3.6	0																				
3.3.7	0																				
4.1	2					X	X														
4.2	2					X	X														
4.3	2															X			X		
4.4	2															X			X		
4.5	0																				
4.6	0																				
4.7	3										X		X	X							
4.8	1																			X	
4.9	2								X			X									

Table 7: Non-Functional Requirements Traceability Matrix - 2

4 Mechanical Components

Test ID: 1.1	**Synchronous Motion in X Rail**	Status: PASS
Description: Verify that X-Rails can synchronously move to the same location at the same speed without getting stuck while loaded		
Pass/Fail Condition: If rail moves adequately and quickly as expected		
Pre-Conditions: None Input: Location along x-direction (i.e. 2000 steps)		
Expected Results: Smooth and consistent motion along axis until position is met. Followed by an immediate stop	Actual Results: Motion in the X-rail performs as required.	
Post-Conditions: Rails are stationary with no slip.		

Table 8: Synchronous Motion in X Rail

Test ID: 1.2	**Motion in Y Rail**	Status: PASS
Description:Verify that Y-Rail can move to a location without getting stuck while loaded		
Pass/Fail Condition: If rail moves adequately and quickly as expected		
Pre-Conditions: None Input: Location along y-direction		
Expected Results: Smooth and consistent motion along axis until position is met. Followed by an immediate stop	Actual Results: Motion in the Y-rail performs as required.	
Post-Conditions: Rail is stationary with no slip.		

Table 9: Motion in Y Rail

Test ID: 1.3	**End-Effector Orientation**	Status: PASS
Description: Verify that EE-Base Motor can orient to a specific angle without getting stuck while loaded		
Pass/Fail Condition: If motor turns adequately and quickly as expected to correct angle		
Pre-Conditions: None Input: Angle of orientation with respect to the x-axis		
Expected Results: Smooth and consistent motion until orientation is met. Followed by an immediate stop	Actual Results: The end-effector moved as expected.	
Post-Conditions: Motor is stationary.		

Table 10: End-Effector Orientation

Test ID: 1.4	**Shooting Mechanism Orientation**	Status: PASS
Description: EE is positioned correctly and waiting command to power piston		
Pass/Fail Condition: Piston is settled at correct orientation, awaiting command to actuate piston		
Pre-Conditions: Motors orient piston to proper orientation Input: Position and orientation components sent to Arduino		
Expected Results: System moves to desired location and waits for piston signal.	Actual Results: The end-effector was in the correct position and struck the cue ball as expected.	
Post-Conditions: Piston can be safely actuated and strike cue ball		

Table 11: Shooting Mechanism Orientation

Test ID: 1.5	**Perimeter Coverage**	Status: PASS
Description: EE will be moved around the table to ensure that it is able to reach all locations and orientations		
Pass/Fail Condition: EE is capable of completing a full trip around the perimeter without stops		
Pre-Conditions: None Input: Motion command from Arduino		
Expected Results: EE will travel around perimeter of table. Inspection that its location is sufficient for shot-taking is required.	Actual Results: The machine is easily capable of reaching the full perimeter of the table.	
Post-Conditions: System awaits next command.		

Table 12: Perimeter Coverage

Test ID: 1.6	**Ball Avoidance**	Status: PASS
Description: As the EE is moving around the table it much avoid the balls to not interfere with gameplay		
Pass/Fail Condition: Able to move randomly around table without moving rolling or stationary balls		
Pre-Conditions: Ball in motion OR stationary Input: Random motion along table		
Expected Results: EE travels directly over balls and does not make contact	Actual Results: The end effector does not interfere with the balls while moving.	
Post-Conditions: None		

Table 13: Ball Avoidance

Test ID: 1.7	**Table Visibility**	Status: PASS
Description: The amount of table visible is approximated.		
Pass/Fail Condition: This test is passed if players are able to see 100% of the table setup upon their turn.		
Pre-Conditions: Machine is in a position where it is ready for a "Take a Shot" command. Input: Percentage visibility of the table.		
Expected Results: Player can see 100% of the table without excessive effort or movement.	Actual Results: The player can see the whole table when its their turn.	
Post-Conditions: None.		

Table 14: Table Visibility

Test ID: 1.8	**System Obstruction**	Status: PASS
Description: The machine will be placed in positions which make it as difficult as possible to take a shot. The difficulty of the shot will then be determined.		
Pass/Fail Condition: This test is passed if the design of the machine allows users to take any shot they would normally be able to make.		
Pre-Conditions: The machine and balls should be setup in a way that makes a shot as difficult as possible. Input: Difficulty of shot.		
Expected Results: Player is able to make their shot with no more than a low degree of difficulty relative to the shot difficulty without the machine.	Actual Results: The system makes it slightly more difficult for users to take shots due to the distance the arms protrude from the table. However, the user would still be able to play the game and so the conditions are met.	
Post-Conditions: None.		

Table 15: System Obstruction

Test ID: 1.9	**System Weight**	Status: PASS
Description: The components of the machine will be weighed and those weights will be added together to get the total weight.		
Pass/Fail Condition: This test is passed if the weight of the machine is less than 250 lbs.		
Pre-Conditions: None. Input: Weights of all components used.		
Expected Results: Machine weighs less than 250 lbs.	Actual Results: The machine weighs about 40kg.	
Post-Conditions: None.		

Table 16: System Weight

Test ID: 1.10	**Rigidity of Machine Body**	Status: PASS
Description: The machine must be rigid such that nominal strain < 0.1		
Pass/Fail Condition: This test is passed if the body of the machine is rigid such that nominal strain < 0.1		
Pre-Conditions: None. Input: The impulse from the strongest shot on the machine in multiple locations and directions.		
Expected Results: The machine body should not suffer deformation greater than magnitude 0.1 nominal strain.	Actual Results: The machine is sufficiently rigid.	
Post-Conditions: The machine body should return to its initial state.		

Table 17: Rigidity of Machine Body

Test ID: 1.11	**Transformer Stability**	Status: PASS
Description: Machine will move around the table as sharply as possible in typical execution and the transformer will be checked for stability.		
Pass/Fail Condition: This test is passed if the transformer remains sturdy and secured.		
Pre-Conditions: None. Input: Quickest movement along the table in each direction.		
Expected Results: The transformer remains secured in position.	Actual Results: The transformer is in no risk of becoming unsecured.	
Post-Conditions: None.		

Table 18: Transformer Stability

Test ID: 1.12	**User Proximity Safety**	Status: PASS
Description: The machine will move to the furthest points it can reach and the distance from the table will be measured.		
Pass/Fail Condition: This test is passed if the machine is never further than 2 ft away from the table.		
Pre-Conditions: None. Input: End-effector moved in various locations to test the extreme distances it can reach.		
Expected Results: Mechanism extends less than 2ft from the perimeter of the table at all times.	Actual Results: The machine remained within 2ft of the perimeter.	
Post-Conditions: None.		

Table 19: User Proximity Safety

Test ID: 1.13	**Shut Down Button Locations**	Status: FAIL
Description: The distance from pinch points to a stop button is measured.		
Pass/Fail Condition: This test is passed if there are shut down buttons located within the smallest reach of a typical adult of pinch points.		
Pre-Conditions: None. Input: The distance from pinch points when the system is moved to various positions.		
Expected Results: Shut down buttons are always less than the smallest reach of a typical adult from pinch points.	Actual Results: There is only one stop button located on the side with the Arduino. The other side is lacking a stop button.	
Post-Conditions: None.		

Table 20: Shut Down Buttons

Test ID: 1.14	**Striking Force - Strong**	Status: PASS
Description: Ensure shot is strong enough so that the cue ball can reach the whole table with sufficient force		
Pass/Fail Condition: At maximum strength the cue ball can cover the length of the table and return to half after hitting a bank		
Pre-Conditions: Cue ball placed along one maximum x position Input: Maximum strength shot		
Expected Results: The cue ball rolls across long edge of table, bounces off the bank and returns to at least the halfway point.	Actual Results: The cue ball achieved the minimum range.	
Post-Conditions: Balls are stationary and Shooting mechanism is retracted		

Table 21: Striking Force - Strong

Test ID: 1.15	**Striking Force - Soft**	Status: FAIL
Description: Ensure shot is soft enough so that the cue ball can reach nearby balls with control		
Pass/Fail Condition: At minimum/low strength the cue ball can lightly strike a nearby ball (within 20 cm) while moving no more than 20 cm after the hit		
Pre-Conditions: Cue ball placed within 20 cm of another ball Input: Minimum strength shot		
Expected Results: Cue ball rolls towards other ball, makes contact and quickly comes to a stop	Actual Results: Machine not capable on modifying shot strength, therefore a soft shot is not possible.	
Post-Conditions: Balls are stationary and Shooting mechanism is retracted		

Table 22: Striking Force - Soft

5 Electrical System

Test ID: 1.16	**Sufficient Acceleration and Stepping Consistency**	Status: PASS
Description: At maximum loading capacity the system can accelerate to a terminal speed at which the EE is moved quickly enough		
Pass/Fail Condition: While the physical construction is finished the system will be told to move long distances several times to ensure repeatability and consistency in acceleration		
Pre-Conditions: System is stationary Input: Move EE between opposite corners multiple times (x10 cycles)		
Expected Results: After completion the EE should return to its original location within a couple of steps	Actual Results: The system successfully maintained its step count.	
Post-Conditions: Balls are stationary and Shooting mechanism is retracted		

Table 23: Sufficient Acceleration and Stepping Consistency

Test ID: 2.1	**User Input to Arduino**	Status: PASS
Description: User applies input, then the Arduino indicates a message was received		
Pass/Fail Condition: Arduino output to console correct desired status		
Pre-Conditions: None Input: User pressed input button		
Expected Results: The console will output "make shot," "cancel," or "move," depending on the button pressed	Actual Results: The console had the correct output.	
Post-Conditions: None		

Table 24: User Input to Arduino

Test ID: 2.2	**Current Physical State: X-Rail**	Status: PASS
Description: Verify that the system can detect the machine's current physical state at certain locations along the x-rail.		
Pass/Fail Condition: This condition is passed if both sensors are triggered.		
Pre-Conditions: None Input: Attempt to move system along the x-rail to the lower-limit position then the upper limit position.		
Expected Results: X-rail sensors indicate that the system is in lower-limit/upper-limit positions and motion is stopped.	Actual Results: Sensors operate as expected.	
Post-Conditions: None		

Table 25: Current Physical State: X-Rail

Test ID: 2.3	**Current Physical State: Y-Rail**	Status: PASS
Description: Verify that the system can detect the machine's current physical state at certain locations along the y-rail.		
Pass/Fail Condition: This condition is passed if both sensors are triggered.		
Pre-Conditions: None Input: Attempt to move system along the y-rail to the lower-limit position then the upper limit position.		
Expected Results: Y-rail sensors indicate that the system is in lower-limit/upper-limit positions and motion is stopped.	Actual Results: Sensors operate as expected.	
Post-Conditions: None		

Table 26: Current Physical State: Y-Rail

Test ID: 2.4	**Current Physical State: Rotation**	Status: PASS
Description: Verify that the system can detect the machine's current physical state at certain angular positions.		
Pass/Fail Condition: This condition is passed if the sensor indicates that the system in the position the machine is actually in to within 0.3 degrees.		
Pre-Conditions: None Input: Rotate the end-effector to various set positions.		
Expected Results: Sensor indicates that the system is in reference position.	Actual Results: The sensors were reliably triggered as expected and the rotational accuracy is within the requirements.	
Post-Conditions: None		

Table 27: Current Physical State: Rotation

Test ID: 2.5	**Current Physical State: End-Effector**	Status: PASS
Description: Verify that the system can determine the machine's current physical state at certain locations along the end-effector's range of motion.		
Pass/Fail Condition: This condition is passed if the stored location correctly indicates that the system is in the target position within 2 millimetres.		
Pre-Conditions: None Input: Predetermined target locations		
Expected Results: End-effector sensors indicate that the end-effector is in the target location.	Actual Results: The sensors were reliably triggered as expected and the end-effector is moved within the required tolerance of the ordered coordinates and orientation.	
Post-Conditions: None		

Table 28: Current Physical State: End-Effector

Test ID: 2.6	**Check for Exposed Circuitry**	Status: FAIL
Description: Circuitry will be inspected to ensure none is exposed.		
Pass/Fail Condition: This test is passed if no circuitry is exposed.		
Pre-Conditions: None. Input: Result of wire inspection.		
Expected Results: No exposed circuitry.	Actual Results: There is still some exposed circuitry to allow for alterations if necessary.	
Post-Conditions: None.		

Table 29: Check for Exposed Circuitry

Test ID: 2.7	**Sensitive Component Isolation from High Voltage**	Status: PASS
Description: The voltage near sensitive components will be measured to ensure they are at safe levels.		
Pass/Fail Condition: This test is passed if wires connected to sensitive components fall within their maximum parameters as specified by the device.		
Pre-Conditions: None. Input: Inspect wires connected to electrical equipment stated above.		
Expected Results: All components are isolated from unsafely high voltage.	Actual Results: Sensitive components are adequately shielded.	
Post-Conditions: None.		

Table 30: Sensitive Component Isolation from High Voltage

Test ID: 2.8	**Voltage Regulation**	Status: PASS
Description: The circuit to the μC will be provided various voltages and t. Pass/Fail Condition: This test is passed if the output voltage from the transformer is within the required μC voltage requirements.		
Pre-Conditions: None. Input: Reading of voltage fed into μC using a multimeter.		
Expected Results: Voltage is within 7 V DC - 12 V DC.	Actual Results: The voltage remains within the required range.	
Post-Conditions: None.		

Table 31: Voltage Regulation

Test ID: 2.9	**Circuit Breakers**	Status: PASS
Description: High voltage will be applied to components to ensure that the circuit breakers perform as expected.		
Pass/Fail Condition: This test is passed if the circuits to all high voltage components are broken before unsafe voltage is applied.		
Pre-Conditions: None. Input: Sufficiently hight voltage.		
Expected Results: All circuits with unsafe voltages are broken.	Actual Results: The circuits have appropriate breakers.	
Post-Conditions: None.		

Table 32: Circuit Breakers

Test ID: 2.10	**AC/DC Converter**	Status: PASS
Description: Verify that the transformer converts 110 AC, 60 Hz to DC ranges that power the μC at the appropriate voltage.		
Pass/Fail Condition: This condition is passed if the output voltage is a DC voltage within 7-12		
Pre-Conditions: None Input: Multimeter output voltage readings from the transformer.		
Expected Results: The output voltage is a DC voltage within 7 - 12 VDC	Actual Results: Power is converted correctly.	
Post-Conditions: None		

Table 33: AC/DC Converter

Test ID: 2.11	**Power Supply from Standard Socket**	Status: PASS
Description: The system will be plugged into a standard wall socket and functionality will be assessed.		
Pass/Fail Condition: All components of the system are supplied with sufficient power.		
Pre-Conditions: None Input: The power from a standard wall socket.		
Expected Results: The system has enough power to perform normally.	Actual Results: The system is successfully powered using a wall socket.	
Post-Conditions: None		

Table 34: Power Supply from Standard Socket

6 Software System

The software system is comprised of four main components: a control system running on an Arduino microcontroller, an automated image capture application running on an Android smartphone, as well a visual recognition program and smart shot selection program running on a PC. On top of the typical suite of unit tests to verify correctness of methods, rigorous system testing will also be crucial to adequately test this system.

6.1 Unit Tests

This section will provide a plethora of test cases which aim to prove correctness of the program. Each individual class will be tested in order to make finding specific test cases easier.

6.1.1 PC Controller Program

Ball Tests

Test ID: 3.1.1	Module: Ball	Status: PASS
Ball Constructor Tests		
Description: Builds a new Ball object.		
Pass/Fail Conditions: This test is passed if all the fields inside of the Ball are correctly initialized or if the correct exception is thrown.		
Pre-Conditions: The Ball object points to a null value. Inputs: 1, 0.7, 0 1.87658, 0.7, 0 1, 0.94958, 0 -1.001, 0.7, 0 1, -1.001, 0 1, 0.7, -1 1, 0.7, 16		
Expected Results: - A new ball with x-coordinate 1, y-coordinate 0.7, and the value 0. - An IllegalArgumentException has been thrown. - An IllegalArgumentException has been thrown. - An IllegalArgumentException has been thrown. - An IllegalArgumentException has been thrown. - An IllegalArgumentException has been thrown.	Actual Results: The same as expected.	
Post-Conditions: A new Ball object should be available or if an exception is expected, the Ball should still point to null.		

Table 35: Ball Constructor Tests

InferenceEngine Tests

Test ID: 3.1.2	Module: InferenceEngine	Status: PASS
Updating Table State		
Description: Updates the current table state being tested.		
Pass/Fail Conditions: This test is passed if all post-conditions are met.		
Pre-Conditions: None Input: A 16-by-2 array of doubles that are valid positions, BallType.STRIPES		
Expected Results: 0	Actual Results: 0	
Post-Conditions: 1. Stored BallType is BallType.STRIPES. 2. The stored positions array is the same as the one passed in. 3. The stored best shot is null. 4. The stored table state reflects the positions passed in.		

Table 36: Updating Table State

Test ID: 3.1.3	Module: InferenceEngine	Status: PASS
Selecting an Optimal Shot		
Description: Runs the method which simulates all direct shots that can be made.		
Pass/Fail Conditions: This test is passed if a reasonable Shot is returned.		
Pre-Conditions: The current table state is not null and the current ball type is not null or BallType.CUE. Input: None		
Expected Results: A reasonable Shot (no bank shots, shooting the right ball, valid x-/y-coordinates).	Actual Results: A Shot as described in expected.	
Post-Conditions: The best shot for the current table state is stored.		

Table 37: Selecting an Optimal Shot

PCCommunicator Tests

Test ID: 3.1.4	Module: PCCommunicator	Status: PASS
Read Valid Table State from File		
Description: Reads a table state from a file.		
Pass/Fail Conditions: This test is passed if the output matches the data in the text file.		
Pre-Conditions: None. Input: A text file with 16 ball positions		
Expected Results: The 16 ball positions stored in the text file.	Actual Results: The same as expected.	
Post-Conditions: None.		

Table 38: Read Valid Table State from File

Test ID: 3.1.5	Module: PCCommunicator	Status: PASS
Read Table State from Non-Existent File		
Description: Attempts to read from a non-existent table state file.		
Pass/Fail Conditions: This test is passed if a FileNotFoundException is thrown.		
Pre-Conditions: None. Input: None.		
Expected Results: A FileNotFoundException is thrown.	Actual Results: The same as expected.	
Post-Conditions: None.		

Table 39: Read Table State from Non-Existent File

Test ID: 3.1.6	Module: PCCommunicator	Status: PASS
Read Table State from File with Invalid Data		
Description: Attempts to read from a file that is not correctly formatted.		
Pass/Fail Conditions: This test is passed if an InputMismatchException is thrown.		
Pre-Conditions: None. Input: A file containing the text "Bad data".		
Expected Results: A NumberFormatException is thrown.	Actual Results: The same as expected.	
Post-Conditions: None.		

Table 40: Read Table State from File with Invalid Data

Test ID: 3.1.7	Module: PCCommunicator	Status: PASS
Initiating the VR Program		
Description: Runs the method which automatically invokes the VR program.		
Pass/Fail Conditions: The test is passed if the VR Program has been run.		
Pre-Conditions: None. Input: None.		
Expected Results: Program is run and TableState.csv has been updated.	Actual Results: The program was run and the file was created.	
Post-Conditions: TableState.csv contains the results of the VR Program.		

Table 41: Initiating the VR Program

Shot Tests

Test ID: 3.1.8	Module: Shot	Status: PASS
Shot Constructor Tests		
Description: Attempts to build various Shots with both acceptable and marginally unacceptable inputs.		
Pass/Fail Conditions: This test is passed if the Shot is successfully created and stores the correct information or if the inputs are not valid, the expected exception.		
Pre-Conditions: The Shot object points to null. Input: 1, 0.5, 3.5, 1 1.87658, 0.5, 3.5, 1 -0.001, 0.5, 3.5, 1 1, 0.94958, 3.5, 1 1, -0.001, 3.5, 1 1, 0.5, 6.284, 1 1, 0.5, -0.01, 1 1, 0.5, 3.5, 1.001 1, 0.5, 3.5, 0		
Expected Results: - A new Shot with an x-coordinate of 1, a y-coordinate of 0.5, an angle of 3.5, and a power of 1. - An IllegalArgumentException is thrown. - An IllegalArgumentException is thrown. - An IllegalArgumentException is thrown. - An IllegalArgumentException is thrown. - An IllegalArgumentException is thrown. - An IllegalArgumentException is thrown. - An IllegalArgumentException is thrown. - An IllegalArgumentException is thrown.	Actual Results:	
Post-Conditions: Shot has been created if the inputs are valid or the Shot still points to null otherwise.		

Table 42: Shot Constructor Tests

SimulationInstance Tests

Test ID: 3.1.9	Module: SimulationInstance	Status: PASS
Simulation Instance Constructor Good Inputs Not Shooting 8-Ball		
Description: Builds a new SimulationInstance that is not shooting for the 8-ball.		
Pass/Fail Conditions: This test is passed if the array of Balls is created, the 8-ball is not the target ball, and the initial velocity of the cue ball is set.		
Pre-Conditions: InferenceEngine.myBallType = BallType.SOLID Input: A 16-by-2 array of doubles with at least one ball of type "solid" on the table, 2, 0.4		
Expected Results: A SimulationInstance has been created with an array of Balls with positions corresponding to the array, the initial velocity vectors of the cue ball have been set according to the power and angle.	Actual Results: The same as expected.	
Post-Conditions: A SimulationInstance has been created.		

Table 43: Simulation Instance Constructor Good Inputs

Test ID: 3.1.10	Module: SimulationInstance	Status: PASS
Simulation Instance Constructor Good Inputs Shooting 8-Ball		
Description: Builds a new SimulationInstance that is shooting for the 8-ball.		
Pass/Fail Conditions: This test is passed if the array of Balls is created, the 8-ball is the target ball, and the initial velocity of the cue ball is set.		
Pre-Conditions: InferenceEngine.myBallType = BallType.SOLID Input: A 16-by-2 array of doubles with no balls of type "solid" on the table, 2, 0.4		
Expected Results: A SimulationInstance has been created with an array of Balls with positions corresponding to the array, the initial velocity vectors of the cue ball have been set according to the power and angle.	Actual Results: The same as expected.	
Post-Conditions: A SimulationInstance has been created.		

Table 44: Simulation Instance Constructor Good Inputs

Test ID: 3.1.11	Module: SimulationInstance	Status: PASS
Simulation Instance Constructor Large Power		
Description: Builds a new SimulationInstance with a power that is too large.		
Pass/Fail Conditions: This test is passed if an IllegalArgumentException has been thrown.		
Pre-Conditions: None Input: A 16-by-2 array of doubles, 2, 1.001		
Expected Results: An IllegalArgumentException has been thrown.	Actual Results: The same as expected.	
Post-Conditions: An IllegalArgumentException has been thrown.		

Table 45: Simulation Instance Constructor Large Power

Test ID: 3.1.12	Module: SimulationInstance	Status: PASS

Check for Walls

Description: Runs the method which checks for a wall at the given coordinates.

Pass/Fail Conditions: This test is passed if the expected results are equal to the actual results.

Pre-Conditions: None

Inputs:
(0.07070, true)
(0.07072, true)
(0.866, true)
(0.868, true)
(0.980, true)
(0.982, true)
(1.776, true)
(1.778, true)
(0.07070, false)
(0.07072, false)
(0.849, false)
(0.851, false)

Expected Results:	Actual Results: The same as expected.
false true true false false true true false false true true false	

Post-Conditions: None.

Table 46: Check for Walls

Test ID: 3.1.13	Module: SimulationInstance	Status: PASS

Get Angle from Coordinates

Description: Run the method which uses an x- and a y-coordinate to obtain the angle from that imaginary triangle.	
Pass/Fail Conditions: This test is passed if the expected results are within 0.0001 of the actual results. Notably in the case where x = y = 0, the angle will be $\frac{3}{2}\pi$ which is not technically correct but that does not matter for this project.	
Pre-Conditions: None Inputs: (1, 0) (2, 1) (0, 1) (-1, 2) (-1, 0) (-1, -5) (0, -1) (2, -3)	
Expected Results: 0 0.463647609 $\frac{\pi}{2}$ 2.034443936 π 4.514993421 $\frac{3\pi}{2}$ 5.300391584	Actual Results: The same as expected.
Post-Conditions: None.	

Table 47: Get Angle from Coordinates

Test ID: 3.1.14	Module: SimulationInstance	Status: PASS

Ball-Wall Collision

Description: Runs the method which evaluates the resulting velocities from ball-wall collisions.	
Pass/Fail Conditions: This test is passed if the expected results are within 0.0001 of the actual results.	
Pre-Conditions: None Inputs: (5, true) (-1.2, false) (0, true) (0, false) (-15.24, true) (0.0001, true)	
Expected Results: -4.33 -1.2 0 0 13.19784 -0.0000866	Actual Results: The same as expected.
Post-Conditions: None.	

Table 48: Ball-Wall Collision

Test ID: 3.1.15	Module: SimulationInstance	Status: PASS

Check if in Pocket

Description: Runs the method which checks whether the given coordinate would result in a ball being sunk into a pocket.

Pass/Fail Conditions: This test is passed if the expected results are equal to the actual results.

Pre-Conditions: None

Inputs:
(1, 0.5)
(0,0)
(0.08, 0.05)
(0, 0.921)
(0.08, 0.895)
(0.924,0)
(0.92, 0.02)
(0.924, 0.921)
(0.967, 0.921)
(1.848, 0)
(1.828, 0.07)
(1.848, 0.921)
(1.8, 0.87)

Expected Results:	Actual Results: The same as expected.
false true false true false true false true false true false true false	

Post-Conditions: None.

Table 49: Check if in Pocket

TableState Tests

Test ID: 3.1.16	Module: TableState	Status: PASS
TableState Constructor Tests		
Description: Builds a new TableState.		
Pass/Fail Conditions: This test is passed if the TableState is successfully created and stores the correct information or if the expected exception is thrown.		
Pre-Conditions: The TableState points to null. Input: - A 16-by-2 array of doubles that hold the position of the balls - A 17-by-2 array of doubles - A 15-by-2 array of doubles - A 16-by-2 array of doubles, except one has a length of 1. - A 16-by-2 array of doubles, except one has a length of 3.		
Expected Results: The same as expected	Actual Results:	
Post-Conditions: TableState has been created or if the inputs were invalid, the TableState still points to null.		

Table 50: TableState Constructor Tests

Test ID: 3.1.17	Module: TableState	Status: PASS
TableState Deep Copy		
Description: Runs the method which returns a deep copy of the TableState passed in.		
Pass/Fail Conditions: This test is passed if the array of Balls returned have the same values but are not the same Objects.		
Pre-Conditions: A TableState exists in memory. Input: None.		
Expected Results: An array of Balls that have the same positions as those in the TableState.	Actual Results: The same as expected.	
Post-Conditions: None.		

Table 51: TableState Deep Copy

6.1.2 PC VR Program

Test ID: 3.2.1	Module: PC VR	Status: PASS
Ball Recognition and Colour: Test 1		
Description: An image of the table is provided and the results of the VR		
Pass/Fail Conditions: The measured positions are within 5 millimetres of the actual positions.		
Pre-Conditions: None. Input: Image of table		
Expected Results: (1350, 510) (390, 450) (1350, 460) (1300, 490) (1350, 410) (1400, 540) (1460, 510) (1400, 430) (1400, 480) (1300, 430) (1450, 350) (1250, 460) (1800, 60) (1450, 460) (1450, 400) (1450, 560)	Actual Results:	
Post-Conditions: Results are written to TableState.csv		

Table 52: Ball Recognition and Colour: Test 1

Test ID: 3.2.2	Module: PC VR	Status: PASS

Ball Recognition and Colour: Test 2

Description: An image of the table is provided and the results of the VR	
Pass/Fail Conditions: The measured positions are within 5 millimetres of the actual positions.	
Pre-Conditions: None. Input: Image of table	
Expected Results: (690, 410) (1150, 290) (1060, 540) (970, 440) (1140, 440) (1140, 430) (470, 570) (310, 350) (-1, -1) (-1, -1) (-1, -1) (-1, -1) (-1, -1) (-1, -1) (-1, -1) (-1, -1)	Actual Results:
Post-Conditions: Results are written to TableState.csv	

Table 53: Ball Recognition and Colour: Test 2

6.1.3 μC Program

Certain functions of this program (such as functionality of sensors) are tested in the electrical section and so will NOT be tested again here.

Test ID: 3.3.1	**Signal steps for X Motion**	Status: PASS
Description: Generates the signals to move the machine to the destination.		
Pass/Fail Conditions: System is capable is tracking an arbitrary number of steps upon request of motion (concurrently with all axes and rotations).		
Pre-Conditions: None. Input: Motion request in X axis (system repeats arbitrary motion 10 times).		
Expected Results: After testing cycle the system step count should match theoretical count.	Actual Results: The system generated the appropriate steps.	
Post-Conditions: None.		

Table 54: Signal steps for X Motion

Test ID: 3.3.2	**Signal steps for Y Motion**	Status: PASS
Description: Generates the signals to move the machine to the destination.		
Pass/Fail Conditions: System is capable is tracking an arbitrary number of steps upon request of motion (concurrently with all axes and rotations).		
Pre-Conditions: None. Input: Motion request in X axis (system repeats arbitrary motion 10 times).		
Expected Results: After testing cycle the system step count should match theoretical count.	Actual Results: The system generated the appropriate steps.	
Post-Conditions: None.		

Table 55: Signal steps for Y Motion

Test ID: 3.3.3	**Signal steps for Rotational Motion**	Status: PASS
Description: Generates the signals to rotate the machine to the destination angle.		
Pass/Fail Conditions: System is capable is tracking an arbitrary number of steps upon request of motion (concurrently with all axes and rotations).		
Pre-Conditions: None. Input: Motion request in X axis (system repeats arbitrary motion 10 times).		
Expected Results: After testing cycle the system step count should match theoretical count.	Actual Results: The system generated the appropriate steps.	
Post-Conditions: None.		

Table 56: Signal steps for Rotational Motion

Test ID: 3.3.4	**Calculation of Steps Required**	Status: PASS
Description: A target location will be used to compute the required signals to move the machine to that location.		
Pass/Fail Conditions: Is capable of converting between linear or rotational displacement and number of steps		
Pre-Conditions: None. Input: Linear or rotational distance (repeat this test with a vareity of values (both positive and negative)).		
Expected Results: Output to console of the actual number of steps corresponding to the theoretical values.	Actual Results: The system successfully calculates the required steps.	
Post-Conditions: The machine should not have moved or be moving.		

Table 57: Calculation of Steps Required

Test ID: 3.3.5	**Signal for Pneumatic Extension**	Status: PASS
Description: Generates the signals to fire the piston as appropriate.		
Pass/Fail Conditions: System powers on 12V DC signal to power pneumatic valve necessary for piston extension.		
Pre-Conditions: None. Input: System request signal for pneumatic piston extension.		
Expected Results: 12VDC detected and at output (use multimeter or oscilloscope) and output to console.	Actual Results: The pneumatic is controlled as needed.	
Post-Conditions: None.		

Table 58: Signal for Pneumatic Extension

Test ID: 3.3.6	**Signal for Pneumatic retraction**	Status: PASS
Description: Generates the signals to retract the piston to its default position.		
Pass/Fail Conditions: System powers on 12VDC signal to power pneumatic valve necessary for piston retraction.		
Pre-Conditions: None. Input: System request signal for pneumatic piston retraction.		
Expected Results: 12VDC detected and at output (use multimeter or oscilloscope) and output to console.	Actual Results: The pneumatic is controlled as needed. Furthermore, it was able to be operated so that it can escape the area where the balls move as quickly as possible.	
Post-Conditions: None.		

Table 59: Signal for Pneumatic Extension

Test ID: 3.3.7	**Signal Steps for Rotational Motion of Air Flow Controller**	Status: FAIL
Description: Generates the signals to rotate the air flow valve		
Pass/Fail Conditions: System is capable is tracking an arbitrary number of steps upon request of motion (concurrently with all axes and rotations).		
Pre-Conditions: None. Input:rotational distance (repeat this test with a variety of values (both positive and negative)).		
Expected Results: After testing cycle the system step count should match theoretical count.	Actual Results: This functionality was not implemented.	
Post-Conditions: None.		

Table 60: Signal Steps for Rotational Motion of Air Flow Controller

6.2 System Tests

Test ID: 4.1	Module: System	Status: INCONCLUSIVE
Aligned Shot		
Description: The user will press the "Take Shot" button, the system will go through its whole process and then shoot the cue ball to sink the target ball.		
Pass/Fail Conditions: This test is passed if the target ball is sunk by the machine 50% of the time and the shot should be made within 90 seconds (as per the *Summary and Goals* document).		
Pre-Conditions: Machine must not be currently moving or taking a shot. There are three balls on the table, the cue ball, the target ball, and the eight ball. The cue ball, target ball, and one of the pockets are aligned near perfectly along an imaginary line. The eight ball is not in a position to interfere with motion of the balls along that line. Input: *Take Shot* button pressed.		
Expected Results: Only the target ball should be sunk.	Actual Results: The results of this test seem promising. However, additional testing will be performed immediately to verify correctness to a much higher degree of certainty.	
Post-Conditions: The eight ball should remain on the table. The target ball should be sunk. There are no requirements for the cue ball, but bonus points if it remains on the table.		

Table 61: Aligned Shot

Test ID: 4.2	Module: System	Status: INCONCLUSIVE
Angled Shot		
Description: The user will press the "Take Shot" button, the system will go through its whole process and then shoot the cue ball to sink the target ball.		
Pass/Fail Conditions: This test is passed if the target ball is sunk by the machine 50% of the time and the shot should be made within 90 seconds (as per the *Summary and Goals* document).		
Pre-Conditions: Machine must not be currently moving or taking a shot. There are three balls on the table, the cue ball, the target ball, and the eight ball. There should be a shot that can be made with a modest angle that will sink the target ball. The eight ball is not in a position to interfere with expected motion of the balls. Input: *Take Shot* button pressed.		
Expected Results: Only the target ball should be sunk.	Actual Results: The results of this test seem promising. However, additional testing will be performed immediately to verify correctness to a much higher degree of certainty.	
Post-Conditions: The eight ball should remain on the table. The target ball should be sunk. There are no requirements for the cue ball, but bonus points if it remains on the table.		

Table 62: Angled Shot

Test ID: 4.3	Module: System	Status: PASS
Shot Cancelled Before Motion		
Description: The user will press the "Take Shot" button, the system will begin going through its process. Before motion begins, the "Cancel" button will be pressed. The system will then cease its prior execution.		
Pass/Fail Conditions: This test is passed if the machine does not move.		
Pre-Conditions: None. Input: *Take Shot* button pressed, Then *Cancel* button pressed before machine moves.		
Expected Results: The machine should cancel the instruction and not move.	Actual Results: The system stops moving immediately after the button is pressed. This is different than expected since we always move the system to allow for a shot before communicating to the PC, however, it should still be considered as a successful result.	
Post-Conditions: The machine should not have moved or be moving.		

Table 63: Shot Cancelled Before Motion

Test ID: 4.4	Module: System	Status: PASS
Shot Cancelled During Motion		
Description: The user will press the "Take Shot" button, the system will begin going through its process. After motion begins, the "Cancel" button will be pressed. The system will then cease motion.		
Pass/Fail Conditions: This test is passed if the machine ceases movement within 2 seconds.		
Pre-Conditions: None. Input: *Take Shot* button pressed, Then *Cancel* button pressed while machine is moving.		
Expected Results: The machine should cease movement.	Actual Results: The machine ceased its movement immediately.	
Post-Conditions: The machine should not be moving.		

Table 64: Shot Cancelled During Motion

Test ID: 4.5	Module: System	Status: PASS
Move Request (To Zero X-Coordinate)		
Description: The user will press the “Move” button. The machine will then move to the zero x-coordinate.		
Pass/Fail Conditions: The machine moves to the zero x-coordinate within 20 seconds.		
Pre-Conditions: Machine’s y-rail is located closer to the large x-coordinate. Input: *Move* button pressed		
Expected Results: The machine should move to the zero x-coordinate of the table.	Actual Results: The system moved appropriately.	
Post-Conditions: The machine should be located at the zero x-coordinate.		

Table 65: Move Request (To Zero X-Coordinate)

Test ID: 4.6	Module: System	Status: PASS
Move Request (To Largest X-Coordinate)		
Description: The user will press the “Move” button. The machine will then move to the largest x-coordinate.		
Pass/Fail Conditions: The machine moves to the largest x-coordinate within 20 seconds.		
Pre-Conditions: Machine’s y-rail is located closer to the zero x-coordinate. Input: *Move* button pressed		
Expected Results: The machine should move to the largest x-coordinate of the table.	Actual Results: The system moved appropriately.	
Post-Conditions: The machine should be located at the largest x-coordinate.		

Table 66: Move Request (To Largest X-Coordinate)

Test ID: 4.7	**Shot Power Modification**	Status: PASS
Description: Users should not be able to modify system to perform unsafe actions such as setting the power of a shot beyond a certain safe value. The test will attempt to make the system do just that.		
Pass/Fail Condition: This test is passed if the user cannot modify the power the shot beyond system parameters.		
Pre-Conditions: None. Input: User attempts to take a shot with power outside of system parameters.		
Expected Results: System does not take a shot at that level of force.	Actual Results: The same as expected (the maximum power of the pneumatic is within safe operational power).	
Post-Conditions: None.		

Table 67: Shot Power Modification

Test ID: 4.8	Module: System	Status: PASS
Check For Political Correctness		
Description: Colleagues will be asked whether the machine has any direct references to any religious or political groups.		
Pass/Fail Conditions: All interviewees agree that there are no direct references to any religious or political groups.		
Pre-Conditions: None. Input: 20 colleagues will be asked to give their opinion on whether the system created has no direct reference to any religious or political groups.		
Expected Results: Colleagues decide that there are no direct references to any religious or political groups.	Actual Results: The same as expected.	
Post-Conditions: None.		

Table 68: Check For Legality and Political Correctness

Test ID: 4.9	Module: System	Status: PASS
Assessment of Durability		
Description: The machine will play through 3 games.		
Pass/Fail Conditions: The machine is still in full functional order.		
Pre-Conditions: None. Input: The machine will be used to play 3 full games.		
Expected Results: The machine is still fully functional.	Actual Results: The machine remained in full working order.	
Post-Conditions: None.		

Table 69: Assessment of Durability

7 Summary of Results

Only four of the sixty-one test cases were failed. The test cases that were failed are: ensuring all pinch points have emergency stops, ensuring a soft strike can be performed, ensuring there is no exposed circuitry, and calculating the steps required for controlling air flow to the compressor. The second and fourth of these requirements are non-consequential since it is not crucial for the system to have multiple shot strengths in order to satisfy the intended functionality. The circuitry requirement is slightly more severe. However, this issue is simple to fix and can be rectified before completion of the final prototype. Furthermore, the wiring that is still exposed does not pose any significant danger to users. The only truly significant shortcoming of the system as discovered through these tests is the lack of a second emergency stop on the opposite end of the y-rail. This issue will be the first item to be corrected time permitting.

In relation to our set requirements, the traceability matrices provided early in this document show that thorough coverage was ensured in proving that all outlined requirements have been met. The only exception is the legal requirement of the system since no members of the team are adequately educated enough in legal matters to perform any necessary tests of that nature.

Tracing back to our outlined success criteria, it is probable that our system has achieved that mark! The only concern holding the result as "probable" rather than confirmed is a lack of quantity of tests. To confidently say that "50% of the time, the system should be able to sink the intended ball if it?s a straight shot," many more systems test must still be performed. In terms of the mid-level goals, it is possible that this level of success has also been achieved. The most questionable of the goals are concerning its marketability. It would be hard to argue that the system would sell many units as is. However, as a prototype it is fairly well polished considering.

As a final summary, the results of the aforementioned testing indicates that the system is performing well.