Project Part 1: Understanding the Problem

1. System Overview

Many sports and recreational activities have incorporated automatic scoring systems (e.g., basketball, darts, bowling). And as the computational power of modern systems increase it is expected that this trend will continue. Automatic scoring systems allow for the activity to be enjoyed by participants without shifting attention to administrative tasks that may detract from the enjoyability of the activity itself. Scoring may involve simple points tallies, or may be more complex involving multiple arithmetic operations that can be performed much easier by computer systems than humans. For example, calculating the odds of poker hands for a viewing audience or summing individual scores times multipliers in darts is better handled automatically. Automatic scoring systems are beneficial because they offload such tasks to a computing system so that human interaction is only necessary in the unlikely event that the system has made a mistake.

In this project, we propose the creation of an automatic scoring system for pool/billiards games that would be useful for competitive match settings. Competitive pool leagues, such as the American Poolplayers Association (APA) and TAP league, are recreational team-based leagues that involve complex scoring systems which are cumbersome for the scorer. During a match, numerous statistics must be accurately derived, and may include: number of pocketed balls, dead balls (balls made during a fault), missed balls, timeouts, defense shots, balls made on the break, and balls left on the table. [2], [3]. Scoring may actually hinder game progression if players desire to shoot quickly but must wait for human scorers to catch-up. If players score their own match, their attention may be divided between gameplay and administrative tasks hurting individual performance, scoring accuracy, or both. By using an automatic scoring system, players' attention may be centered on gameplay alone while still ensuring that careful and accurate has been handled. The goal of the proposed automatic pool/billiards scoring system is to score accurately the aforementioned statistics with an intuitive menu system for human correction. The development of a prototype for scoring will be based upon “straight pool” games--the type of pool with the least-contextual scoring system of the three most popular pool type (straight pool, 8-ball, and 9-ball).

The proposed system will be composed of three main components for video capturing, video processing, and score reporting[1]. A web camera may be mounted atop a light fixture that is located above the pool table. From this viewpoint, the webcam will be able to observe all events that occur during the game while remaining unobtrusive to the players. Video obtained from the webcam may then be streamed to a computing device which will be used to analyze the video and determine scores for each player. The computing device may be a laptop, embedded system, or some other portable computing device to ensure easy setup and mobility. As players take turns at the table, the automatic

[1] Throughout this document, pool terms are used which may unknown to the reader. Figure 4 shows an diagram of a typical pool table, containing labels of all pertinent terms.

scoring system will use computer vision principles in order to score points for individual players. Video will be analyzed in real-time to track a number of statistics for each player, and include: points this turn, total points, number of misses, and the current player's turn. The system should provide accurate scoring with short response times in order to assist with the scoring process. If the system incorrectly scores a turn, an interface will be available to the players to alter the score easily.

2. Characteristics of Users

Users will be playing the game and accessing the system usually while standing upright or at least capable of viewing the top of the table (in the case of users with a wheelchair). And they will at least be able to reach the height of the pool table around all of its edges. We also assume the players are able to read some English wording as well as to relate scoring play with on-screen scores. While this may exclude some children, mentally challenged, or those utterly unfamiliar with pool (e.g. from a culture without any knowledge of billiards), it is assumed that individuals playing pool within a pool hall would have the basic requisite knowledge. The purpose of the system is not to educate users on how to play pool, but rather to automate scoring. Computer-specific knowledge required from users is limited to operating touch screens or simple mouse navigation (i.e., click-selection, movement, and buttons/forms fields). Given that most pool halls have sophisticated touch screen gaming equipment (MegaTouch systems) and other video games, it is assumed that the vast majority of users will have the technical ability to operate the system without assistance.

It is also assumed that users have knowledge of basic game mechanics such as holding the cue stick and shooting at object balls. This assumption is reasonable because the environment of system deployment is located within a pool hall, where persons congregate to play pool. The knowledge of detailed rules about specific types of games (e.g. straight pool) may be known to varying degrees by the users, and so advanced rule knowledge cannot be assumed. For instance, many pool novices have accumulated anecdotal rules specific to their particular bar or pool hall (so-called "bar rules"), which do not follow those found in professional/competitive settings. Users' knowledge may also vary to the extent in which users are familiar with game-specific terminology. For example, novice players would probably be familiar with terms such as cue ball, object ball, cue stick, ball, rack, triangle, table, chalk, felt, and cushion. Knowledge of other terms such as carom, masse, english, deflection, and safety would not be expected from the user. Because of this difference in terminology familiarity among users, the system may only use more simple terminology when describing the rules. To validate our list of simple pool vocabulary, we may perform a short survey of a sample pool player population.

3. Characteristics of Existing Systems

To the extent of our knowledge, no equivalent system has been previously developed to perform automatic game scoring. Nevertheless, match scoring is a necessary task during play, so many techniques exist which can be assessed.

Manual entry is the technique currently adopted by most pool players. In order for the proposed system to be effective, it must follow a conceptual model that may be easily identified and recognized by players. Therefore, the developed system should include similarities with manual entry-based methods for improved usability.

Alternative systems have also been identified which perform real-time scoring of pool matches, which are posted to web-based forums. In this scheme, human observers provide input to a system which compiles entered data to provide summaries and statistics to site visitors. While this method is useful to individuals after the game has been completed, it still requires third-party intervention for manual scorekeeping and data entry. In contrast, the proposed auto-scoring billiards system will require very little human interaction to keep score.

An automatic scoring system is also evaluated, which performs the automatic scoring of billiards games given unrealistic assumptions regarding equipment modification and total cost. In this study, the authors developed a rudimentary prototype which was never extended on an actual pool table.

The last method, called PoolShark, is not designed to keep score, but instead focuses on helping improve individual play. Even though the goals of the systems are different, similarities such as the use of computer vision exist between PoolShark and the proposed system.

a. Manual Entry

Traditionally, score keeping has been performed by each player during play. Although score may be kept on scraps of paper, more sophisticated forms of scorekeeping are typically located on--or in close proximity to--the table. Since score may both increase and decrease during play, scoring apparatuses must allow for easy adjustment in both positive and negative directions. Figure 1 shows three types of scoring systems that are commonly used in the scoring of straight pool. Figure 1 shows a beads score counting scheme. Beads are typically strung above the light fixture lengthwise across the table. Although the beads are typically too high to be adjusted by hand, players typically use their cue sticks to slide beads back and forth. At the beginning of play, all beads are slid towards the right indicating that both players' scores are zero. During play, each player slides over a bead for each pocketed ball that results in a point. (For the distinction between earned points and possible penalties, refer to the straight pool rules summary within the Task Analysis section.) Bead scoring systems are the older, more traditional form of counting in straight pool. Variants of beads scorekeeping methods may also include wall-mounted plaques and rail score counters. Rail score counters are usually found on tables embedded within the foot rail--the rail from which breaking occurs.

Beads score counter	
Wall-mounted score counter	
Rail score counter	

Figure 1: Various methods for keeping ball point scores

Manual scorekeeping systems are very accurate when scoring is performed by a trustworthy third party, but are typically unavailable for most casual or competitive matches. Therefore, many players record their own score during play, which presents its own set of challenges. Players may interrupt play in between each successful shot to adjust their score, but doing so can interfere with the "rhythm of play" and break players' concentration. Players may also adjust score after their turn has ended, which is more common, but requires that players remember the exact number of points that were pocketed during a turn. If the number of acquired points is small, this is not a problem. Since skilled players typically pocket many balls during a turn, exact score keeping may be a burden. For this reason, many players have a “sandbox area” during the scoring of a straight pool game. Scores from previous racks are committed to the total score, while the points earned from the current rack are held separate until the entire rack has been pocketed and score for all 15 balls is credited.

b. Real-time Human-Assisted Scoring

A real-time human-assisted scoring system [7] has been previously developed, which provides a web-based graphical user interface for third-party scorekeeping (Figure 2a), and current game statistics (Figure 2b). Data entry is performed through a series of command events, which are compiled by the system to provide a summary of match and current game totals. An interface is also provided to allow the user to correct possible inaccuracies that have been previously entered.

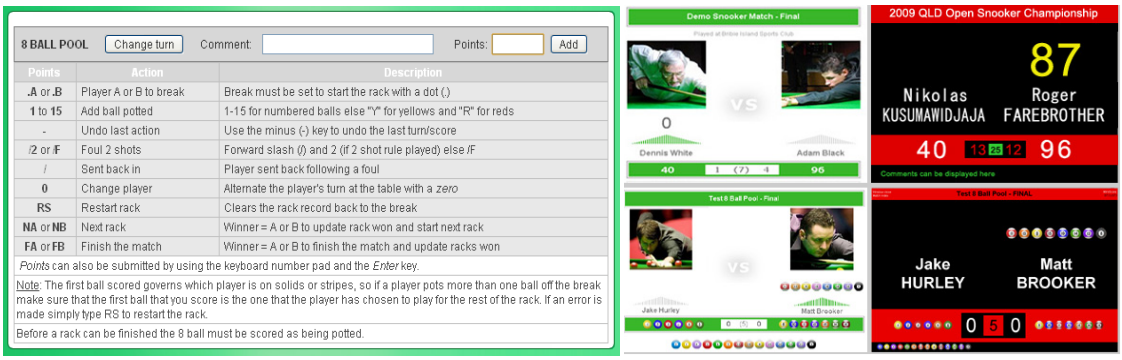

Figure 2: (a) score entering GUI, (b) score viewing GUI

Because data entry is dependent upon human observers, this system represents a third-party manual scoring method. Unless multiple observers are watching a particular match, then the utility of this system may be limited to populated competitive settings. This system would not benefit recreational league play, which currently relies upon manual scorekeeping. The usability of the interface provided in this web-based system is also lacking because commands are not intuitive. Observers must therefore be experienced with the system in order to enter game events in real-time. The game summary interface requires less knowledge by users, but does not provide precise information regarding field information. Users who are accustomed to watching billiards games may be equipped to understand the meaning such summaries, but the average user may need additional explanation. For example, the average user may understand the ball icons indicate that the player has pocketed those balls and the scores to the left and right of the middle box indicate current games won. However, the game objective in the middle is unclear because matches may either be "best-of" or a "race-to" format. In a "best-of" format, the winner with the most games out of the objective game count is the winner. In a "race-to" format, the first player to win the objective game count is the winner.

c. An Auto-Scoring Billiards System

Tang J. and Wang P.K. present in [8] a method to automatically score a billiards game. The scoring techniques utilizes RFID (Radio Frequency IDentification) tags, which are embedded within each object ball and table pocket. Pressure sensors are also added to the cue sticks for player detection, and infrared sensors are used to detect player position around the table. Together, data from RFID scanners, pressure sensors, and infrared sensors are transmitted to a computer system for processing. The system then determines if balls where pocketed, and if so, which player to credit. Score data is then transmitted to the players and to the audience for review. After processing they can infer which ball fell in which pocket and which player played. This information is used to compute the score and can be transmitted to the player and to the audience. As mentioned in the article, by using a database the computer can easily keep track of statistics such as temporal statistics (average time per shot, the length of the game, etc.) or play statistics (number of shots missed, number of shots with more than two pocked ballsa, etc.).

Therefore this system can provide an autonomous way of keeping score with no computer close to the pool table.

Figure 3 - RFID Tag in the ping-pong ball

Although the system is used to perform automatic scoring of pool matches, there are many drawbacks to this approach. For example, the proposed system was not actually implemented using a real pool table. Instead, the authors used used ping pong balls to insert the RFID tag at a lower cost as shown in Figure 3. Further, the transmission system between the RFID captors and the computer is not described. In addition the cost of RFID scanners, sensors, and other modified equipment was very high, which was estimated at $1571.43 (excluding the modification of pool balls to include RFID). No details regarding their GUI interface or user feedback are given. Additionally, the insertion of RFID tags into the balls may affect player shots, which is not discussed.

d. Pool Shark, Digitally Assisted Billiards

A preexisting billiards system [12] with an observation camera and computer was demonstrated in the Fall of 2008 [10] and Spring of 2009 [11] as a senior design project by a team of ECE students at Georgia Tech. The system observes the pool table from far above with a camera to observe ball and cue stick locations. The system would then recognize the cue stick and draw predicted paths of balls given a straight shot using a projector aimed onto the table surface. The system was not quite real-time likely due to hardware processing constraints.

As demonstrated in the videos of the system, there was no appearance of a scoring system or anything beyond assistance of the present table configuration. Although it is reasonable that the camera's ability to detect precise ball positions would supersede the demands of counting balls on the table. Using more powerful hardware and not calculating trajectories would ameliorate the responsiveness delay for the user. Balls pocketed might be accompanied in real-time with a cash register bell sound to indicate a point or a negative sound to signal a scratch, etc.

4. Task Analysis

Historically, straight pool was a very popular pocket billiards game in the US, which was immortalized in the 1961 film, "The Hustler" [4]. Played by pocket billiards legends such as Minnesota Fats and Willie Mosconi [4], straight pool dominated competitive game play until overtaken by faster paced games such as 9-ball. In fact, our team name was inspired by Willie Mosconi who still holds the world record over 55 years later by pocketing 526 balls in a row on a single turn of a straight pool game [5].

In order to perform a task analysis on the straight pool scoring system, it is important to first describe the general rules of play. A brief but thorough definition of straight pool rules is presented in this section. A complete explanation of all possible corner cases is outside of the scope of this exercise, but may be referenced in [1].

Straight pool (also called 14.1 continuous pool) is a call-your-shot game, which includes calling a ball on the break. The object of straight pool is to be the first player to legally pocket a predetermined number of balls (traditionally 150). Both players agree upon the ball count prior to starting the game, which may be 50, 100, or any other arbitrary number. After the object ball count has been established, players determine the order of play by lagging, or by flipping a coin. Lagging is performed by placing two balls behind the head string of the table. Each player then hits their ball into the foot cushion with the goal of getting closest to the head cushion. The lag winner then decides which player will break. For specific details regarding table nomenclature, refer to Figure 4.

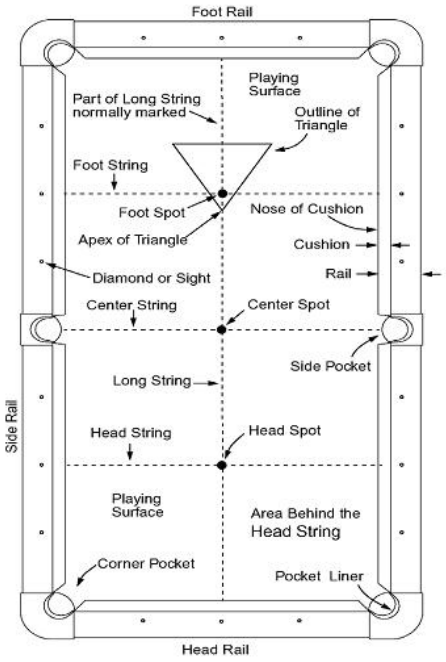

Figure 4: Parts of a Pool Table [6]

On the first rack of straight pool, all 15 object balls are arranged in a standard triangle configuration at the foot string of the table. The person breaking places the cue ball

behind the headstring and then breaks the rack. Because straight pool is a call-your-shot game, most players do not break the initial rack, opting instead to play a safety. If a safety is played, at least two object balls and the cue ball must touch a rail, otherwise the shot results in a foul. If a foul is committed during the break, the opponent has the option to either make the shooter break the rack again, or taking over the shooter's turn. The player committing the foul is penalized two points (note that scores may be negative in certain conditions).

A player's turn continues as long as balls are legally pocketed, or until the objective number of balls has been reached. Each ball that is legally pocketed results in a point for the shooter. A ball is legally pocketed when the shooter makes a ball into the pocket that was called (and no fouls occurred), where any additional balls that are pocketed are also credited to the shooter. Object balls that were illegally pocketed or jumped from the table are spotted (they are placed) as close as possible to the foot spot between the foot spot and the foot rail.

Fouls result in a number of situations, but the most common are scratches (the cue ball is pocketed), jumping the cue or any other ball off the table, missing all object balls, or no rail after contact. The "no rail after contact" foul condition occurs if, after the object ball has been touched by the cue ball, no ball is pocketed or hits a rail. Fouls result in subtracting a 1-point penalty from the shooter's score. And then the opponent may place the cue anywhere behind the head string after a foul.

After the first 14 balls have been pocketed from the first rack, with the cue ball and one additional object ball on the table, the 14 balls are reracked in a triangle configuration with the ball at the apex of the triangle missing. The purpose of this configuration is to exploit the 15th ball to "break-out" the new rack. The shooters goal is to pocket the 15th ball and to have the cue separate the newly racked balls to create more potential shots. For this reason, strategic placement of the 15th object ball and cue ball after the first 14 balls have pocketed is crucial to ensure a good "break-out." When balls are reracked, if the 15th ball or cue ball are in the way of the rack, then the 15th ball is spotted in the triangle apex, and the cue is spotted behind the head string.

a. Characteristics of tasks performed by users

When a user walks up to a pool table with the system, they may choose to use it at will. The system should be able to detect when a new game has been racked and begin scoring automatically if the previous game was completed. The system may wait indefinitely for the users to return so to preserve the scores in case the users take an extended break and return. This will not interfere with new players because they may at any time clear the scores and start fresh. Based on the type of racking, the system could try to determine what kind of game is beginning. All of these possibilities so far do not require the user to do anything other than what they would do to begin a game, and so the system's interference is minimized.

Users may possibly be able to login to the system's server if one were to be created. This server would require a username and password and allow the tracking of stats at various locations and times. Otherwise, a name entry screen would be provided if the users wish not to play merely as Player One, Player Two, etc.

Users may then begin playing pool and the system will passively observe and record the actions it has seen. At a minimum, the players would merely play pool as they would were the system not present. They are given the option of checking the score on the system's screen occasionally whenever needing that information. As such, this information should be visible on the screen during regular play. Possibly, the number of balls sunk in the most recent shot could also be present on the screen and available to the user at a glance.

If the score were somehow incorrect, the user would then interact with the system to correct the score. A button to initiate changing the score would allow GUI elements to change the numbers appearing. Upon clicking these elements, sounds and bright images would show on-screen to make the score changing visible from across the table. The ability to change the number and types of balls sunk and the total scores would be open from this screen. As well, the option to undo the score change should be present on the screen with an Undo or Cancel Changes button. This lack of restrictions, while possibly allowing some types of cheating, would reduce the irritation of false scoring. If the system accuracy were trusted enough, the score correction mechanism could be changed to require both player's consent during competition play.

Play would commence, re-racking and all while the user is checking scores, the system is auto-incrementing, and possibly the user makes adjustments to the scores. The system may be able to recognize when the players ought to end their turn based on the state of the table going from active to static or if the player did not perform the required play. Eventually the users would abandon the game, complete the game, or the power would go out. In the case of the latter, some kind of resume mechanism should be in place to prevent the frustration of losing game state data mid-game. Once the game is over, the play history would be open to viewing on screen and be able to be deleted if desired. As well, there may be the potential to email the game history and statistics if the user wishes. The user, if this feature existed, would be able to select an email statistics button and type an email address to receive the scores. This may be done a limited number of times per completed game. After this point, the statistics would remain on screen until the user presses Clear Scores or Start New Game.

b. Characteristics of task environment

It is very important that the proposed system does not interfere with the pool hall environment to which the users are accustomed. The goal of the system is simply to enhance the user experience by alleviating their attention to a typically dull task. Pool halls can have a staggering number of tables (see Figure 5), and while our system will be initially built for a single table, ideally the system could be available for as many tables as desired. We also want to make sure that we do not interfere with typical play. Pool

tables are typically spaced so to minimize player interference between games while maximizing the number of tables that are available. Figure 5 shows an example of a typical pool hall, the Marietta Billiard Club in Marietta, Georgia, which contains 38 nine-foot pool tables.

Figure 5: Marietta Billiard Club (Marietta, GA) during league play

In terms of avoiding interference with the physical space of the players, our camera will need to be placed high enough above the table so that it is out of the players' sight while they are shooting (to prevent player distraction). It will also need to be placed so that players' pool cues do not accidentally hit the camera or the console (this needs to be taken into account for both the table being scored and any adjacent tables). It is also important that any interactive system does not interfere with the players. The screen and any other hardware components will need to be placed in a spot that is both convenient to use and out of the way. Another concern with the interface is that it needs to fit aesthetically into a typical pool hall. If it looks too high tech, it could look out of place and even intimidating to pool players who are not tech-savvy. It should also be clear which table or tables the system is used for, and it should be easy to set up. If it takes longer to set up the automated scoring than it does to do it simply by hand, we will have failed.

Lighting (in terms of both the physical amount of light and the fixtures themselves) is also a major concern. Tables themselves are generally well lit, with lighting coming from directly above the table. Since our system will also be placed above the table, we will need to take into account how our system can be placed next to a wide variety of lighting fixtures without interfering with any of them. Lights can be as small as lamps hung from strings or be large fluorescent fixtures, and are discussed in Section 8.

While tables themselves are typically well-lit, the rest of the hall may be quite dark and smoky (for states that have not outlawed smoking indoors). Our system will need to be placed so that not only does it avoid inhibiting the light fixture's function, but it avoids awkward lighting for the sake of the camera. We may also need to take into account how smoke may affect the camera.

Ultimately, a primary design goal of the system is to complement any generic pool hall environment, rather than requiring pool halls to be constructed around the system. The proposed system should seamlessly integrate with existing tables and, aside from the user interface, be barely noticeable. If there is a giant camera blocking the light fixtures or wires running all over the place getting in the way of player's shots, then our system will not provide high usability.

c. Structured Task Analysis

Creating a structured task analysis is the process of determining the way people do their jobs, the things that they do, the things that they act on, and the things that they need to do when performing a task [9]. In this section, a textual Hierarchical Task Analysis (HTA) was performed to decompose the tasks associated with the play of straight pool. The purpose of a structured task analysis is to help contribute to the statement of requirements that are necessary for an automatic pool scoring system. The HTA decomposition, shown in Figure 6, is not limited to the scoring activities of the system alone, to allow later system design to integrate holistically into gameplay.

1. In order to play a game of straight pool
    a. Determine venue:
        i. Play at home
            1. All equipment must be personally owned
        i. Play at pool hall
            1. All equipment is provided
                a. most players bring their own cue sticks
                b. many players bring their own chalk
    b. Obtain necessary equipment (for home or at pool hall)
        i. Equipment needed: stick, chalk, 16 pool balls (15 numbered + 1 cue), triangle, pool table
        ii. Optional equipment: multiple cue sticks (break/jump/extra) cues, cue stick case, glove, baby powder, chalk holders, cue stick stands, scotch-bright pad, towel, tapping tool, etc.
    c. Find an opponent (2 players total to play a game)
    d. Approach Pool Table
    e. Determine straight pool game objective (how many balls to shoot to win the game)
    f. Lag / flip coin to determine who breaks (break player will break, rack player will rack)
    g. Play Straight Pool Game
        i. Rack setup
            1. on the 1st opening rack
                a. Rack player racks 15 numbered balls in triangle on the foot spot
                b. Break player places cue behind the head string
            2. on subsequent racks
                a. Rack player racks 14 numbered balls in triangle on the foot spot leaving the apex of the triangle position missing
                    i. If the cue is in the way of the rack
                        1. place cue behind the head string
                    ii. If the 15th ball is in the way of the rack
                        1. place 15th ball in the apex of the triangle
        ii. Shooting Player
            1. shoot balls while legally pocketed balls (a ball is sunk in the called pocket free of fouls) or player has reached objective score

a. for each pocketed ball on each legal turn: opponent gets 1 score for each pocketed ball
b. if only 1 object ball remaining:
    i. goto 7.1.2 opponent is rack player and reracks/ shooting player's turn continues
c. Player's turn ends if:
    i. foul is committed: scratch, object ball leaves table, cue ball leaves table, no foot on floor, push shot, double hit, no ball hits rail (and no ball is pocketed), balls still moving during shot
        1. assess penalty:
            a. if initial rack subtract 2 from shooter's score
                i. opponent takes over turn or has shooter re-break
            b. o/w subtract 1 from shooter's score
        2. Spot any object or cue balls that left table
            a. Opponent enters turn and places cue ball anywhere behind the head string
    ii. player misses shot
    iii. player makes ball in uncalled pocket
        1. ball is spotted without penalty
    iv. player calls a safety
        1. shooter is allows one more shot (presumably defensive)
            a. any made balls are spotted at the foot spot

iii. If shooting player's turn has ended
    1. if game is not over
        a. switch players
        b. goto 7.2
    2. if game is over and the players want to play a new game
        a. goto 1.5

Figure 6: Hierarchical task analysis: playing a game of straight pool

5. Larger Social and Technical System or Context

Entering into a pool league is a daunting task for the vast majority of people. Pool is a skill game that above all requires practice and discipline (not to mention some basic understanding of geometry and physics). If our system can make the idea of entering into a pool league (or just starting a small one with a few friends) a less daunting endeavor for casual pool players, we will have done our job.

More importantly, however, we want to use technology to make scoring in a pool league simpler and more hands-free. Keeping score is a complicated and time-consuming process, and the number one goal is simply to make that process easier. Scores could even be kept up-to-the-minute much like fantasy football websites, so league members can track how their competitors are doing from home. We are not currently planning on that stage, but in the event that our system becomes popular, that is a logical next step. Looking at the boom in popularity of fantasy sports in the past decade with the advent of

online tracking, it is not a fantastic leap in logic that a comprehensive online pool scoring system could--at the very least--make a modest positive impact on the pool community.

However, it is unreasonable for us to expect our users to be technology-savvy. Our users may be the type of people who can't figure out how to forward an email. Thus, the device itself must be fairly easy to understand. It is also important that it can be navigated with one hand so that a person can use the system without having to put down their pool cue, beer, cigarette, etc. Our system should be no more complicated than an automated bowling scorer during typical play, although we strive to be more advanced than that without sacrificing usability. The main focus is to keep continuing and detailed scoring for a league. Unlike bowling, it is very easy for keep track of who is winning in a single game of pool. It's when stats are kept over a long period of time and for league-governed games that it starts to get tedious.

6. Usability Criteria

Our system's usability criteria can be divided into two parts: first is the technical performance, and second is the quality of the human-computer interface.

Our system is meant to be used by typical pool players and should therefore not affect their way of playing but only relieve them of the tedious score-keeping task and provide them accurate information about the current game. Therefore, one of the most important criteria of usability will be the accuracy of the system. Indeed we do not expect our system to be perfect--video processing is not trivial and the computer will necessarily make mistakes. But this is acceptable as long as the mistakes do not occur too often and the users can correct them. We can evaluate the accuracy by counting the number of times that user intervention is required for correction.

The problem with video processing is that it is computationnally intensive but we do not want the user to wait after each shot for the computer to update the score. This is why the responsiveness of our system should be one of the usability criteria. Responsiveness should be evaluated by timing the delay between user action and system feedback.

Feedback is also important when considering the human-computer interface. The quality of the feedback is an important usability criteria. We need to evaluate how redundant is the system's feedback (sound, visual) and if it is effective. This can be done by observing user behavior when new information is provided through the system.

Another important criterion which is common to almost all design is how people generally enjoy using the system. This should be split in categories such as how the user likes the interface design, organization, and appearance. Was the system improving their gameplay experience? Do they want to keep using our system while playing pool? This can be evaluated by taking a survey after users have tried our system.

Sticking with the general design usability benchmark, we need to evaluate how easy-to-use our system is. Does it require any training or is it intuitive enough to let people learn

by using it for the first time? We can evaluate this in a few different ways. First, testers will use the system in hopes of needing no help but they will be allowed to ask questions of the designer to prevent them from being stuck and frustrated. These questions will reflect flows in the design and should therefore be counted as problems about the system usability. In addition, in the survey conducted after testing, users should be asked how easy they found the system to be, how easy it was to navigate through the interface, how easy it was to correct scoring mistakes, and how easy it was to understand the feedback provided by the system. Lastly, we can objectively evaluate the ease of use of our system by observing how long it takes for the user to understand and get comfortable playing pool with the system.

7. Data Integrity

Information for this project was gathered from a variety of sources, including documentation, observation, and interviews. Documentation of straight pool rules from the World Pool-Billiards Association [1] was gathered to provide a set of standardized rules, invariant to geographical location. (Many pool novices have accumulated anecdotal rules specific to their particular bar or pool hall, which do not follow those found in professional/competitive settings.) Additionally, one of the team members (Paul Bryan) has played in competitive pool leagues for over 8 years, and can be considered an expert in the domain. Interviews were also conducted with other domain experts, including: Matt St. Clair, Chris Dubose, Harold Dorden, Christina Farthing, and Travis White, whom together have over 40 years of experience in competitive pool leagues and standardized play. Experiences from the domain experts are a combination of observations from many different league settings, including TAP, APA, 8-ball Express [13], and Masters leagues, and therefore are not biased for any particular league subset.

Additional information was obtained through internet-based searches, IEEE ACM and Xplore databases, and patents databases to identify any systems that are similar to the proposed methodology. Unfortunately, data obtained from issued patents was of limited use because working prototypes are not a prerequisite of the patent application process.

8. Implications

Ease of use is key to the user experience of the automated pool scoring system. The intent of this system is not to perform some complicated task but instead to streamline the process of scoring a pool game while in progress. As such, we will assume that any developed interface will only require a single hand to be free at any time because users will likely be holding their cue stick. A touch screen would be the best in this environment for a number of reasons, but may be too expensive for the scope of this project. So a simple mouse interface will likely be the main method of providing input to the system. The user's distance from the screen will be farther than in a typical desktop scenario. Players should be able to read the score on the screen from across the length of the table. On the main playing screen, user scores should be visible without too much

clutter beside them. A simple menu interface will bring the user to different sections of the system's capabilities.

SCREEN	Select Game / Play	Change Score	Rules	Stats	(Email Stats)
Icon	Animated break / shot	Scorecard	Rule Book	Graphs	Envelope
Buttons/User Actions	Select Game Type Start New Game Change Player Name (Login)	Up/Down per player	Index of sections on left	Clear Stats	Type email Send
Info	Current Scores Whose Turn (cue stick icon)	same as [Play]	Text description at right	Score history with totals	Overview of Stats Email Address to send
Sounds/Visual Splash	Name type Change goal match score New Game Pocket ball - point Pocket ball - scratch Player wins	Up score Down score	Click on info section	Clear stats	Email address type Email sen

Table 1: List of GUI Screens (optional screens in parenthesis)

The screen may be laid out in a row of icons at the top for each main screen. This row would stay the same across all screens giving the user a consistent way to see and access the whole system. A mouse or touch screen could be used to manipulate the system.

Figure 7: Various fixtures used to provide lighting above pool tables.

The camera will possibly be mounted on the overhead lighting fixture. The feasibility of this plan can be tested once we choose a camera and begin testing prototypes within a pool hall environment. The camera will transmit data via wires or wirelessly. If a wired camera is used, we will need to consider routing issues of cables to connect the wire to the computer. This might interfere with table navigability if the wires are not long enough. Perhaps mounting a mirror for the camera to observe the table's reflection could relieve some of the wiring problems, but that technique is less mobile and likely has more configuration problems. If the camera is wireless, it will likely be more expensive (a significant limiting factor for this project) and would solve wire routing issues but would introduce battery issues. The camera should have a clear line of sight onto all parts of the table to see the pool balls. Being above the table near the light, it shouldn't interfere with

any of the game. Exactly how the camera should be attached is not yet clear. It would be preferable for the camera to mount to a variety of fixture types, examples of which are shown in Figure 7. Another issue is that the camera might not have a wide enough field of view to see the entire table from the lamp height. If this were the case then another position would be needed or perhaps two cameras instead of one. The location of the computer would preferably be on a nearby table. But it is unclear if it would optimally be somehow quite near the table instead.

The camera will be used to do some relatively simple computer vision techniques. The main tasks of the vision system would be to perceive the balls on the table and when they are pocketed. The vision system would be attached to something like a laptop or netbook. This machine would be required to do all of the computing for the system. The video stream from the vision system would recognize some key states of the scene. These states include: the table cannot be seen, the table is partially obstructed by a player, the balls are still in motion, and the ball are at rest. If the table cannot be seen, an appropriate error message should display on the system's screen. Perhaps the system could still be used for manual scoring in such an event. If a player is partially obstructing the table, the camera could wait until more is visible. If balls are in motion on the visible table, the camera could either wait or possibly catch sight of balls as they are pocketed to tell the system to play a sound, increase score, etc. Once the table is at rest, the system can instruct the players to change turns if necessary and the score can be verified compared to the last time the table was at rest.

In the event that the computer makes a mistake, the user should easily be able to update the system. As well, users may wish to change scores for handicap, or unforeseen reasons. All of these combined make it clear that the user should be able to control the scores as they see fit so that the system does work for the user. At any time, the users should be able to clear the scores and begin a new game as well. When a new game is begun, the target total of balls sunk can be selected if the default value isn't desired. This value should be editable as the game progresses in case players change their minds.

The environmental conditions are the pool hall may vary in terms of brightness and noise level. However, light variations should not be too much of a problem as the camera could adjust its exposure time. One possible problem, though, is that the camera might become less able to interpret motion under dim conditions. The ambient brightness will affect the frame rate at which the camera will be able to track the game state. One consideration is that lights might create lens glare on the camera; ways to solve this potential problem can be developed on the spot with better knowledge of conditions during actual testing. If for some reason a keyboard is to be used in a dark pool hall, a backlit or glow-in-the-dark keyboard may be used. Smoke present from people smoking should not interfere with the vision system. And background noise might interfere with the ability for system sounds to be perceived by users as feedback. These sounds may be present during key game events such as a player winning, players changing turns, pocketing balls, and also when users interact with the GUI.

9. References

[1] "14.1 Continuous Pool Rules of Play", World Pool-Billiard Association. [Online]. Available: http://www.wpa-pool.com/index.asp?content=rules_141
[2] 8-ball scoresheet. American Poolplayer's Association (APA). [Online]. Available: http://www.poolplayers.com/documents/8ball-scoresheet.pdf
[3] TAP scoresheet. TAP League LLC. [Online]. Available: http://www.tapleague.com/forms/scoresheet.pdf
[4] Straight Pool. [Online]. Available: http://en.wikipedia.org/wiki/Straight_pool
[5] The New York Times. Obituary. "Willie Mosconi, 80, Who Ruled The World of Billiards With Style." [Online]. Available: http://www.nytimes.com/1993/09/18/obituaries/willie-mosconi-80-who-ruled-the-world-of-billiards-with-style.html?pagewanted=1
[6] World Standardized Rules. Canadian Cue Sport Association (CSS). [Online]. Available: http://www.cdnqsport.com/worldrules.aspx
[7] Live Scoreboards. [Online]. Available: http://www.ballstream.com/about_scoreboards.asp
[8] Tang, J.; Wang, P.K., "An auto-scoring billiards system," *Machine Learning and Cybernetics, 2009 International Conference on* , vol.6, no., pp.3305-3309, 12-15 July 2009
[9] A. Dix, J. Finlay, G. D. Abowd, R. Beale. Human-Computer Interaction. 3rd ed. Prentice Hall, 2004.
[10] Needham, Justin and Matthew Straub, "Georgia Tech Digitally Assisted Billiards." [Online]. Available: http://www.youtube.com/watch?v=QaYJe62_KXQ
[11] Needham, Justin and Matthew Straub, "Poolshark Demo." [Online]. Available: http://www.youtube.com/watch?v=hWVXbW3ngmc
[12] Halfacree, Gareth. "Hackers Create Digitally Assisted Billiards." [Online]. Available: http://www.bit-tech.net/news/2008/12/12/hackers-create-digitally-assisted-billiards/
[13] 8-ball Express Pool League -- Homepage. [Online]. Available: http://www.8ballexpress.com/national/modules/news/