SIE 554A

Product Document

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1. Systems Engineering Document: Problem Situation

1.0. Configuration Management

Document Lead: MD
Assistant: RF

Date	Version	Team Members
9/8	0.1	MD,RF
9/11	0.2	MD,RF
9/12	1.0	MD,FD,DH,RF,SS
11/24	1.2	MD, DH
11/30	2.0	MD,FD,DH,RF,SS

1.1 Top Level System Function

The top-level system function is to devise a method to ***accurately*** and ***consistently*** call balls and strikes in a baseball game.

1.2 History of the Problem and the Present System

For over 100 years, from the little to the major leagues, the system used to assess balls and strikes has not changed. Namely, the chief umpire (often referred to as the plate umpire) categorizes a pitch a strike based on the following criteria:

A strike occurs when:

1) The batter swings at or attempts to bunt the ball AND completely misses,
2) GIVEN that the batter has less than 2 strikes, the batter swings at or attempts to bunt the ball AND makes contact, BUT the ball is foul,
3) The batter is struck by the ball while:
   a. Swinging at or attempting to bunt the ball AND / OR
   b. The batter is in the strike zone,
4) The batter does not swing at or attempt to bunt the ball AND any part of the ball passes through any part of the strike zone.

While these represent all the possible ways for a strike to occur, there is only one way to characterize a ball, specifically – the batter does not swing at or attempt to bunt the ball AND no part of the ball passes through any part of the strike zone.[ℵ]

While these criteria seem straight forward enough, the matter of assessing a ball or a strike is not a simple task. First the umpire must visualize the strike zone, an invisible 3-dimensional space which, at its best, is unique to each individual batter[Φ]. Given that he

[ℵ] Note1: A pitch which bounces through the strike zone is automatically assessed as a ball.
[Φ] Note2: While the depth and width of the strike zone do not change, its height varies greatly between

has successfully interpreted this zone, he then must determine whether any part of the ball passes through it. At the major league level, this assessment will occur in roughly 1/100th of a second, as a 90 mph fastball zips across the plate. Adding complexity to this task is the pitcher's ability to place *english*[€] on the ball, causing it to accelerate horizontally or vertically due to its rotation. Finally, we must account for the umpire's necessary but cumbersome protective gear as well as his position behind the catcher, both of which contribute to a less than optimal vantage point. In summary, ***accurately*** categorizing a ball or a strike is difficult, especially when the pitch is on the edge of the zone (a desired and often visited location for the pitcher).

With respect to ***consistency***, similar issues arise. For example, the most generalized lack of consistency has been between the American and National Leagues. While the reason for this is beyond the scope of this text, it is widely known and accepted that the National and American Leagues are the "low" and "high strike" leagues respectively. Moreover, prior to 2001, many umpires had admittedly adopted an individualized strike zone, not in agreement with the league's definition. Finally, to make matters worse, umpires have often given high-performing, veteran pitchers a few extra inches on the corners. To be sure, the difficult task of accurately assessing balls and strikes has been compounded by the inconsistency of those who call them.

Accordingly, our design will be crafted with the fourth criterion in mind. That is, given that the batter does not swing at or attempt to bunt the ball, our system will ***accurately*** and ***consistently*** determine whether or not the ball passes through the strike zone.

1.3 Stakeholders

1.3.1. Umpires

As the umpires currently have autonomy in assessing balls and strikes, the umpires have a huge stake in the system. Specifically, if the system is used in lieu of the umpire, then the umpires should benefit from its implementation. On the other hand, if the system is employed as a check on their performance, then they have a tremendous amount to lose.

1.3.2. Ball players

In general, the ballplayers will be beneficiaries of the system. Knowing confidently that a pitch will be adjudicated accurately and in accordance with the rules, should improve the ability of both batters and pitchers to play and practice smartly.

1.3.3. Team Owners

batters. Defined vertically as the hollow beneath the kneecap to the midpoint between the shoulders and the top of uniform pants, a batter's specific strike zone can even change from one pitch to another in the same at bat!

[€]Note3: The spin given to a propelled ball by striking it on one side or releasing it with a sharp twist.

The team owners may have to foot the bill for any modifications to their existing stadiums, as well as the system itself. On the other hand, the owners might well employ the system as a means of scouting future pitching prospects or diagnosing swing deficiencies.

1.3.4. Fans

The fans should find that the system has improved the overall game, and therefore they should benefit. However, in the end, the fans pay the bills. With this in mind, they may absorb a portion of the system's fielding and maintenance costs as higher ticket or increased concession prices.

1.3.5. Commissioner's Office

The Commissioner's Office will be a clear victor in the successful development and implementation of the system. After all, in 2001 it was the Commissioner Bud Selig himself that reinvigorated the movement to call balls and strikes according to the rulebook.

1.3.6. Operators of the System

Assuming that the system requires operators, these unidentified and currently untrained individuals will benefit from being able to obtain a potential job as an operator of the system.

1.3.7. Financial Investors in the Project

If the system gains league-wide approval and eventually extends below the professional ranks, then the investors have a tremendous amount to gain. To the contrary, if the system is perceived as inaccurate, inefficient, or even questionable, then the league might choose not to adopt the system, and their seed money, as well as the opportunity cost of being leveraged, could evaporate.

1.3.8. Victims

The potential victims of the product are the Major Umpires who may feel threatened by the introduction of technology into their current autocracy. Additionally, the pitchers and batters, who currently exploit the "subjective" strike zone, may be affected. Finally, the purist fans might see any technological solution as an unnecessary addition to the game.

1.4. Technical Personnel and Facilities

We will be using an iterative process going through each of these phases, such as the spiral process. Each phase will have a decision checkpoint to decide if the phase has met the requirements needed to proceed onto the next phase, or if the process needs to be repeated back to a specific phase.

1.4.1. Life Cycle Phase 1 - Requirement Development

Dr. Bahill, as well as the retired systems engineers listed in the SIE 554a Syllabus, will provide their expertise during this phase. Additionally, experts in the rules, officiating, and conduct of baseball will be indirectly consulted through the use of applicable open source documents, abstracts, and interviews.

1.4.2. Life Cycle Phase 2 - Concept Development

The team will operate almost independently during this phase. Specifically, drawing on our creativity, we will aggressively brainstorm and generate many alternatives, some less conventional than others. However, as required, we will consult with appropriate industry experts / academicians in order to determine the feasibility of our solutions.

1.4.3. Life Cycle Phase 3 - Full Scale Engineering Development

The team will conduct Full Scale Engineering primarily through telephonic and electronic transmission. Periodically, the team will meet at Ike's Coffee House on Speedway Avenue, facilitating the face-to-face exchange of ideas and conceptual thought. Throughout this phase, the team will seek the technical assistance and advice of Dr. Bahill.

1.4.4. Life Cycle Phase 4 - System Development

The team will develop the system within its capabilities and under the supervision of Dr. Bahill. Should the system require skills / knowledge beyond the team's ability, the team will seek appropriate external assistance.

1.4.5. Life Cycle Phase 5 - System Test and Integration

The actual testing and integrating of this system would be done by either a test organization or contracted out to another company. Our team would be responsible for overseeing that system test and integration was done as specified.

1.4.6. Life Cycle Phase 6 - Operations Support and Modification

Assuming the system passes its test and is successfully integrated, it will require operators. These operators, either employees of the manufacturer, independent contractors, or league officials, will provide on the spot technical expertise and troubleshooting. In the event of serious material failure or mechanical errors, the manufacturer will provide service and replacement under an appropriate warranty program. Additionally, as with any technology, system upgrades and overhauls will occur as required in order to provide additional / improved capabilities and functionality. The technical personnel and facilities for these modifications are yet to be determined.

1.4.7. Life Cycle Phase 7 - Retirement and Replacement

The system will be retired and replaced when it is no longer useful and / or overmatched by an emerging technology. The technical personnel and facilities for this phase will be selected at a later date.

1.5. System Environment

1.5.1. Social Impact

Baseball is widely known and loved as America's Game. With a proud history and a committed fan base, changes in the game are always met with a wary eye and thorough scrutiny. Accordingly, if the system adequately performs its top level function – accurately and consistently calling balls and strikes – then the social impact on the game should be positive. Specifically, by injecting cold objectivity into the objective task of determining balls and strikes, the matter of winning and losing will fall squarely on the shoulders and skills of the ballplayers, not the judgment of the umpire. Of course, there will be a few die-hard, caustic fans that will miss the days of blaming their favorite team's loss on "Blue"; unfortunately (or fortunately depending on your perspective), this cannot be avoided.

1.5.2. Economic Impact

The financial footprint of baseball is large; even minor changes in the pace and execution of the game may have dramatic consequences. For instance, if the system slows the pace of the game, then the recent initiatives to shorten the game might be undermined. Unfortunately, a long, uneventful format discouraged television viewers and attendees alike, curtailing revenue and shrinking profit margins. In the same way, the implementation of the system would generate unavoidable fielding, training, and maintenance costs that could quickly spiral into the millions. One positive potential economic impact could be less training for the umpires, by alleviating calling balls and strikes from their responsibilities.

1.5.3. Environmental Impact

Every effort will be made to avoid any ill effects on the environment. Where applicable, the system will conform to or exceed all existing ANSI, OSHA, NSF, and other health and safety standards.

1.5.4. Interoperability

The system will adjudicate balls and strikes in accordance with the existing rules of the game. Moreover, the system will be designed such that its installation and employment are possible in all 30 MLB stadiums. Finally, to the maximum extent possible, the system will not detract or interfere with the fans' viewing experience.

1.6. Systems Engineering Management Plan

The team will develop the following eight systems engineering documents throughout the life cycle of the project:

1) Problem Situation
2) Customer Requirements
3) Derived Requirements
4) System Validation
5) Concept Exploration
6) Use Case Model
7) Design Model
8) Models, Mapping and Management

There is an order to which all of these documents should be started in, but they are not necessarily finished in the same order they are started. The documents will be continually updated as the design process proceeds. The initial drafts and the final version of all documents will be finished according to the following schedule

Document	Owner	Due Date
1) Problem Situation	Rhea/Matt	9/12/2005
8) Models, Mapping and Management	Shahan/David	9/12/2005
5) Concept Exploration	Fabian	9/19/2005
6) Use Case Model	Shahan	9/26/2005
2) Customer Requirements	Rhea	10/03/2005
3) Derived Requirements	Matt	10/19/2005
4) System Validation	Rhea	11/02/2005
7) Design Model	Shahan	11/16/2005
Final Version Documents 1-8	Team	12/07/2005

1.7. Alternatives

The following section delineates the alternatives that were used for the system.

Alternative 1 - Home Plate Umpire

As the umpires currently have autonomy in assessing balls and strikes, the umpires have a huge stake in the system. The Home Plate Umpire would continue to rely on his line of site, years of experience, and the rules book provided by Major League Baseball.

Alternative 2 - Radar System

A Radar System can be used to detect a pitch as either a ball or a strike. The Radar System would be calibrated according to the batter. Whenever a pitch is detected within the parameters that have been set as the strike zone, a strike will be called. The Radar system would have a field created in the area of the strike zone. When the ball passes through the radar field, the radar guns will record a higher sound frequency. This system would rely on sound waves being bounced back to the radar guns.

Alternative 3 – Video Target Tracker (UIS Improved)

The Video Target Tracker automatically acquires each pitch and tracks it throughout its flight, gathering information about the ball's speed and trajectory. At the end of the game, the system's operator manually sets the strike zone for each batter on every called ball and strike. Once the operator is finished, the UIS employs an algorithm to recall each pitch's data and calculates whether or not the umpire's call was accurate.

Alternative 4 - Video Target Tracker with Umpire

The Video Target Tracker with Umpire would be a COTS solution. The 'human' judgment of experienced baseball umpires, combined with the scientific methodology used by the Video Target Tracker will generate an efficient system for calling a ball or strike. A video target tracker like analyzes video from cameras mounted in the rafters of each ballpark to precisely locate the ball throughout the pitch corridor; additional cameras are mounted at the field level to measure the strike zone for each individual batter. This collectively lets the automated UIS make a decision on calling a ball or strike.

Alternative 5 - Fiber Optic Viewers

Fiber-optic viewers will be mounted inside of home plate's five corners and calibrated to provide a restricted, framed view of the pentagonal prism formed by the depth and width of the strike zone. The two field-level cameras will be set-up on the left and right-hand side of the plate respectively, allowing the vertical dimension of the strike zone to be set for each batter. Cameras will feed their images into a control room, where 2 operators will observe each pitch. Operator 1, the Depth-Width Judge, will simply determine whether the pitch passes through the depth and width of the strike zone (the fixed dimensions).

Operator 2, the Height Judge, will set the vertical dimension of the strike zone prior to each delivery and assess whether the pitch falls within these limits. If both of the operators determine that a given pitch has passed through their zones, the pitch will be called a strike; otherwise it is a ball. This information will then be relayed to the plate umpire via a small two-way radio, and the umpire will announce the appropriate call.

Alternative 6 - 2-D Box; Infrared Lasers

The Infrared Lasers will make use of 6 eye-safe, infrared lasers; 4 automated guide systems; and 1 infrared monocular. Four of the six lasers will be mounted on the automated guide systems and will demarcate the vertical dimensions of the strike zone. The remaining two lasers will be positioned under the leading corners of home plate and will bracket the horizontal limits of the zone. During the windup, the operator will activate the lasers, generating an invisible, infrared box at the lead edge of the plate. The umpire, wearing an infrared monocular, will be able to see the box clearly.

Alternative 7 - RTSA-MEP System in Baseball

Reconnaissance, Surveillance and Target Acquisition Mission Equipment Package (RTSA-MEP) technology uses an RS-170 frame rate, which at 60Hz will deliver one frame every 16.7ms. A 90mph fastball will be traveling at about 132 feet per second, without modifications to the off the shelf system the ball can be tracked at 2.2 feet per frame. The use of the wide area search (WAS) and super field of view (SFOV) capabilities allows the system to observe and track the entire 60.5 feet distance between the pitcher and batter. The WAS will be used in conjunction to the SFOV, the ATD (automatic target detection) and AiTR (automatic target recognition).

Alternative 8 - Image Processing Umpire Goggles

The umpire goggles would be that an umpire could wear these goggles that use image processing to identify the location of home plate, and the body of the batter next to it. Based on these 2 images, the goggles would then calculate the area and location of the strike zone as it correlates to the midpoint of the batter's torso being the upper limit and the kneecap being the lower limit. The 3-D image of the strike zone would then be virtually superimposed on the original image the umpire sees through the goggles.

Alternative 9 - SuperVision PitchTrax

This idea is also by Questec and would be a COTS solution. Instead of doing a post-game assessment after each game assessment is done after each pitch and at-bat.

Alternative 10- DogTracker Pro

The DogTracker Pro solution utilizes an array of up to three Irish Wolfhounds which are specially trained to declare balls and strikes using their acute visual, auditory, and olfactory senses as well as their superior innate tracking abilities. The dog will signal a ball or a strike through a combination of barking or acrobatic maneuvers. If three dogs are used then the third dog can be used as a tie-breaker if the other two dogs read different calls.

1.8. Metrics of Schedule, Cost, Performance and Risk

The section will include the metrics of schedule, cost, performance and risk.

Values for metrics of the:

Schedule – The schedule will be the time line for the completion time for the requirement.

Cost – The financial impact of completing each requirement. Low, Medium and High.

Performance – The efficiency at which a requirement is to complete its operation. The value will be a number from 1 to 10 with 1 being the lowest value possible and 10 being the highest value possible. A value of 1 indicates a low performance impact. A value of 10 indicates a high performance impact.

Risk – The risk of not implementing the requirement. The value is defined as Low, Medium, or High

Metrics of Schedule, Cost, Performance and Risk Table

Function	Schedule	Cost	Performance	Risk
Time scale	-	Medium	8	Medium
resolution of the system	10 ms	High	10	High
life expectancy	2 years	Medium	4	Medium
Time for pitcher to make pitch	20 Sec	Low	3	Low
Number of pumping motions made by pitcher	2 pumps	Low	2	Low
Umpire function	Full Game	High	10	High
Batter function	Each at Bat	High	9	High
Pitcher function	Full Game	High	9	High
System Retail Value	5 years	Medium	6	Medium
Withstand Environmental Factors	Lifetime	High	10	High
Rain	Full Game	High	10	High
Direct Sunlight	Full Game	High	8	High
winds up to 50 mph	Full Game	High	8	High
temperatures from 0 ºF to 140 ºF	Full Game	High	7	High
projectile impacts at 0 MPH to 120 MPH	Full Game	High	10	High
Meet Standards	Lifetime	High	10	High
Meet MLB Standards	Full Game	High	10	High
Zero Game Interference	Full Game	High	10	High
Meet FCC regulations	Full Game	High	10	High
Input/Output Performance	Lifetime	High	10	High
Accuracy	Full Game	High	10	High
Consistency	Full Game	High	10	High
Timeliness of the call	Full Game	High	9	High
Fan Perception	Full Game	Medium	5	High
Installation Compatibility	Full Game	High	6	High
Portability	Full Game	Medium	4	Medium
Reliability	Full Game	High	10	High
Invasiveness	Full Game	High	10	High
Utilization of Resources	1 year	High	10	High
Design Cost	1 month	High	9	High
Cost to Customer	6 months	Medium	7	Medium
Operating Cost	1 year	High	7	High
Time to Implement	9 months	High	8	High
Time to Design, Test and Decide	3 months	High	8	High
Time to Field/Install	2 days	High	7	High
Time to Train	4 baseball games	High	8	High
Ease of Use	1 day	High	10	High

2. Systems Engineering Document: Product Customer Requirements

2.0. Configuration Management

Document Lead: RF
Assistant: MD

Date	Version	Team Members
9/27	0.1	MD
9/29	0.2	FD
10/3	1.0	MD,FD,DH,RF,SS
11/24	1.2	MD, DH
11/30	2.0	MD,FD,DH,RF,SS

2.1. Deficiency

Since baseball's inception, the system for assessing ***called*** strikes has not changed. Namely, the chief umpire (or plate umpire) assesses the pitch a **Strike** if any part of the ball passes through any part of the **Strike Zone**; otherwise, he calls it a **Ball**. At first glance, this procedure appears simple enough. That is, one man, operating with complete autonomy, applies a one criterion, Boolean test. Moreover, as far as solutions go, the system is simple, and, as the Theory of Occam's Razor reminds us: given several solutions to the same problem, the simplest is normally the most correct. Unfortunately, while the task of assessing a called strike is simple, correctly assessing it is not.

First of all, consider that the Strike Zone represents an invisible 3-dimensional volume which, at its best, is unique to each individual batter. Specifically defined as the right, pentagonal prism that extends from the hollow below the batter's knee to the midpoint between his shoulders and waist, the Strike Zone must be correctly envisioned by the umpire in order for a pitch to be correctly called. Observe Figure 2.1 below, and, then (with your eyes open) attempt to imagine this prism floating in front of you.

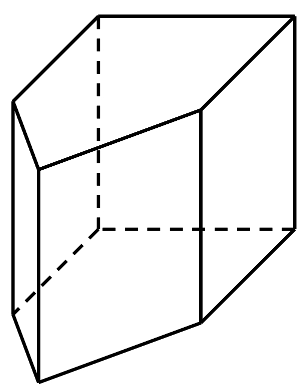


Figure 2.1

Next consider that in the Major Leagues, a 90 mph fastball will pass through this prism in less than the time it takes you to blink your eyes. While pitches thrown down the center of the plate may be simple to assess, pitches on the boundaries are quite difficult and quite common. That is, if a pitcher is good (and most in the Majors are) then they will locate most of their pitches on the boundaries of the Strike Zone, forcing the batter -- and the umpire -- to make a *fine-line* determination as to whether any part of the ball will pass through any part of the Zone.

Adding additional complexity to this already daunting task is the ability of the pitcher to "curve" the ball's trajectory. Specifically, by snapping his wrist at the moment of release, the pitcher can make the ball slide left or right, drop, or literally wiggle (in the case of a knuckleball). Finally, the umpire's vision is necessarily impaired by the bulk of his protective gear, as well as his crouched position directly behind the catcher.

So now, properly restated, we understand the current system as follows: The chief umpire assesses the pitch a **Strike** if he observes (from behind his mask) any part of the "speeding, erratically flying" ball passing through any part of the "variable, imaginary, right pentagonal prism"; otherwise, he calls it a **Ball**. To be sure, correctly assessing a called strike is not easy.

Over the years, this difficultly has manifested itself in the form of open discontent and a departure from the rules. Specifically, umpires struggling with their understanding of the Strike Zone adopted their own; and, pitchers and batters, knowing that each umpire had his own understanding of the Zone, adjusted their play to compensate. In 2001 the deteriorating situation reached its climax, as the Commissioner of Major League Baseball, Bud Selig, instituted a league-wide initiative to reinstate and enforce the regulation Strike Zone.

In order to emphasize his position, the League contracted QuesTec to manufacture and field a device to gauge umpire performance. This system, known as the Umpire Information System or UIS, was immediately fielded and was immediately met with harsh criticism. Currently employed in half of the Major League ballparks, the UIS is slowly gaining acceptance as a "tolerable" if not perfect way of grading an umpire's ability in calling balls and strikes.

However, by lacking a real-time capability and disenfranchising the umpires, the UIS has not effectively satisfied the fundamental requirement to accurately and consistently assess balls and strikes in a baseball game. Accordingly, it is on this backdrop of need and discontent that we develop, test, and implement our design. These are our requirements.

2.2. Input/Output and Functional Requirements

2.2.1. Time scale

The resolution of the system will be measured in milliseconds. The life expectancy of the system will be 2 years.

2.2.2. Inputs

The system has several inputs

- Time for pitcher to make pitch
- Number of pumping motions made by pitcher
- Umpire function
- Batter function
- Pitcher function

2.2.3. Input Trajectories

The umpire will send a signal to the batter to get ready and to the pitcher to throw the ball. The pitcher and batter will move to their positions. The pitcher will take some amount of time to make the pitch, and will take some number of pumping motions prior to the pitch. The batter will respond to the pitch by either swinging or not swinging.

2.2.4. Outputs

The system has one output and that would be the call of a ball, strike or no call. The system will respond with this output for every pitch during the entire length of a baseball game.

2.2.6. Matching function

For every pitch thrown by the pitcher in a baseball game, the output of the system will be the call of a ball, strike or no call.

2.3. Technology Requirements

2.3.1. Available money

The system will be funded by the revenue generated by a portion of ticket, concession and merchandise sales, and should not exceed initial costs of $1 million and should not exceed yearly operating costs of $60,000.

2.3.2. Available time

The system must be deployable by March 2007.

2.3.3. Available components

The restrictions on the components used in the system are that they must be able to withstand rain, direct sunlight, winds up to 50 mph, temperatures ranging from 0 ^{o}F to 140 ^{o}F, and impacts from a baseball or similar projectile at speeds of 0 MPH to 120 MPH.

2.3.4. Available techniques

The techniques that the system may use to call balls or strikes can be done through the use of Commercial-off-the-shelf (COTS) technologies or by the development of a new technology.

2.3.5. Required interfaces

The system must interact with the ball players and any other necessary operators through the use of interfaces such as

1. Touch
2. Sight
3. Sound

2.3.6. Standards, specifications, and other restrictions

The system must conform to Major League Baseball standards, and not interfere with any of the game play. The system must also conform to FCC regulations and all other applicable laws.

2.4. Input/Output Performance Requirements

The system input/output performance will be measured against the following criteria

1. Accuracy
2. Consistency
3. Timeliness of the call
4. Fan Perception
5. Installation Compatibility
6. Portability
7. Reliability
8. Invasiveness

2.5. Utilization of Resources Requirements

The system utilization of resources will be measured against the following criteria

1. Design Cost
2. Cost to Customer
3. Operating Cost
4. Time to Implement
   4a. Time to Design, Test and Decide
   4b. Time to Field/Install
   4c. Time to Train
5. Ease of Use

2.6. Trade-Off Requirements

The trade-off analysis gives equal weight to the performance requirements (50%) and the resources requirements (50%).

2.7. System Test Requirement

This section describes the system test requirements must be accepted for approved use of the system. The system test requirements are:

- Req. STR1: The system must comply with the rules and regulations set forth by Major League Baseball.
- Req. STR3: The system must call strikes within 2ms of the pitch being thrown.
- Req. STR5: The system must call strikes within 0.25 inches of the baseballs perimeter.
- Req. STR6: The system must call strikes with 99.99% accuracy during low visibility and high visibility conditions. (Low visibility: dusk, dawn, dust clouds, cloudy days.; High Visibility: night lights, bright sunny days)
- Req. STR7: The system must allow strike zone adjustments for players at the minimum height of 3 feet and a maximum of 7 feet tall.
- Req. STR8: The system must detect the ball traveling at a minimum of 30MPH and at a maximum of 150 MPH.
- Req. STR9: The system must call a strike or a ball when a player motions into a swing.
- Req. STR10: The system must call a strike or a ball when the catcher moves out of position and attempts to throw out a base runner.
- Req. STR13: The system must relay the pitch all to the lead official within 3 ms after the pitch has past the strike zone.
- Req. STR14: The system must accommodate players of different sizes and weights.
- Req. STR15: The system must allow players using aluminum bats and players using wood bats.
- Req. STR18: The system must not be affected by audible noise, electro-static noise, radio frequency noise, cellular phone technology noise and wireless internet noise.
- Req. STR20: The system must filter out objects that are not baseballs in the strike zone.
- Req. STR22: The system must complete the self-test within 30 seconds.
- Req. STR30: The system must begin to track the ball from the moment the pitcher releases the ball.
- Req. STR33: The system must allow the operator to reset the counts after a homerun.
- Req. STR34: The system must allow full-system reset after out 3.
- Req. STR45: The system must comply with OSHA safety standards.
- Req. STR46: The system must not break down during rainfall.

2.8. Rationale for operational need

The data and specifications were provided by the Major League Baseball Association at the initial bidder's conference and in subsequent correspondence.

3. Systems Engineering Document: Product Derived Requirements

3.0. Configuration Management

Document Lead: MD
Assistant: RF

Date	Version	Team Members
10/11	0.1	MD,DH
10/13	0.2	MD
10/19	1.0	MD,FD,DH,RF,SS
11/24	1.2	MD, DH
11/30	2.0	MD,FD,DH,RF,SS

3.1. The system requirement

The system Design Requirement involves the following components:

a. Input/Output and Functional Requirement
b. Technology requirement
c. Input/Output Performance Requirement
d. Utilization of Resources Requirement
e. Trade-Off Requirement
f. System Test Requirement

3.2. Input/Output and Functional Requirement

The Input/Output and Functional Requirements will be described by the vector IRP1 = (TRP1, IRP1, ITRP1, ORP1, OTRP1, MRP1), where:

3.2.1. Time scale (TRP1)

The resolution of the system will be measured in milliseconds. The life expectancy of the system will be 2 years. Mathematically, we define this as:

TRP1 = IJS [0, End of Life Cycle] where the End of Life Cycle =

$$2\ years\left(\frac{365\,days}{1\ year}\right)\left(\frac{24\,hours}{1\,day}\right)\left(\frac{60\ \text{min}}{1\,hour}\right)\left(\frac{60\ \text{sec}}{1\ \text{min}}\right)\left(\frac{1{,}000\,ms}{1\ \text{sec}}\right) = 45792000000 = 4.5792e10$$

So, TRP1 = IJS [0, 4.5792e10].

3.2.2. Inputs (IRP1)

The set of inputs to the system is defined by IRP1, which consists of the following Cartesian product of its subsets:

IRP1 = I1P1 x I2P1 x I3P1 x I4P1 x I5P1 x I6P1

I1P1 - UIS Reset. This input is a simple Boolean variable where 1 indicates that the system is in its initialized state with no self-test errors; and 0 is otherwise. As a matter of implementation, this input happens automatically following each pitch, or when manually cued by the UIS operator.

I1P1 = {0, 1}

I2P1 - VTTs Ready. This input is also Boolean where a 1 indicates that the UIS Operator has switched the system into its "track" mode; 0 is otherwise. [Note: This input is always cued manually in order to avoid unnecessary wear on the system components or any unintended acquisitions].

I2P1 = {0, 1}

I3P1 - Pitch Acquired. This input represents a successful pitch acquisition by the system. Again, it is a simple Boolean variable, where a 1 represents a successful acquisition; 0 otherwise.

I3P1 = {0, 1}

I4P1 - Ball Position. This input is the position data of the pitch's trajectory at time t. Mathematically, this input is expressed as the 4-dimensional vector of the ball, where:

X = distance to the front of home plate
Y = horizontal displacement from the centerline of home plate
Z = height above the ground
T = elapsed time from pitch acquisition to the measurement

X $\in$ R[0, 62] feet
Y $\in$ R[0, 6] feet
Z $\in$ R[0, 12] feet
T $\in$ R[0, 5] seconds

Note that this vector will be recorded multiple times during a given pitch. For example, a similar military technology which employs an RS-170 frame rate at 60Hz will deliver one frame every 16.7ms. For a 90mph fastball (traveling at about 132 feet per second), the ball can be tracked at 2.2 feet per frame, providing approximately 27 position vectors.[1]

[1] 60.5" / 2.2" = 27.5

I5P1 - Strike Zone Limits. This input defines the vertical limits of the strike zone for a given batter on a given pitch. This input will be manually set by the UIS Operator prior to the pitcher's delivery. Observe that the *pentagonal* dimensions of home plate are constant and define the strike zone from the ground to the heavens. Accordingly, when the UIS Operator enters these limits, he effectively defines the strike zone. Mathematically, this input is expressed as the 2-dimensional vector, where:

L_L = lower limit of the strike zone (e.g., the height of the hollow below the batter's knees)
L_U = upper limit of the strike zone (e.g., the height to the midpoint between the batter's shoulders and waist)

$L_L \in R[0, 5]$ feet
$L_U \in R[0, 8]$ feet

I6P1 – System Override. This input represents a manual override by the umpire, the operator, or both. This input is a single integer and is defined as follows:

I6P1 = IJS [0, 3] where {1a, 1b, 1c, 1d, 1e, 1f, 1g, 1h} $\subset$ 1

0 = no override
1a = umpire override (batter fails to take position)
1b = umpire override (pitcher takes signal from an illegal position)
1c = umpire override (pitch makes more than 2 pumping motions)
1d = umpire override (pitcher takes more than 20 seconds to deliver the pitch)
1e = umpire override (batter intentionally creates catcher's interference)
1f = umpire override (bat makes contact with the pitch)
1g = umpire override (batter swings at the pitch but does not make contact)
1h = umpire override (pitcher makes an illegal pitch (e.g., spitball, etc.))
2 = operator override (the system malfunctions; operator takes corrective action)
3 = both the umpire and operator override the system

3.2.3. Input trajectories (ITRP1)

The set of input trajectories is the set of all possible functions which can be made from TRP1 (the time scale) and IRP1 (the inputs as described above).

ITRP1 = {{f: f $\in$ FNS (TRP1, IRP1)}

for all t $\in$ TRP1, let

f1 = the value of I1P1 at time t
f2 = the value of I1P2 at time t
f3 = the value of I1P3 at time t
f4 = the value of I1P4 at time t

f5 = the value of I1P5 at time t
f6 = the value of I1P6 at time t}

3.2.4. Outputs (ORP1)

The set of outputs to the system is defined by ORP1, which consists of the Cartesian product of the following subsets:

$$ORP1 = O1P1 \times O2P1$$

O1P1 - Extrapolated Trajectory: This output is the position data for the pitch's extrapolated trajectory at from X = 0 to X = 1.41667 feet (the distance from the front edge of home plate to its rear apex). Mathematically, this input is expressed as the 4-dimensional vector of the ball, where:

X = distance to the front of home plate
Y = horizontal displacement from the centerline of home plate
Z = height above the ground

$X \in R[0, 1.41667]$ feet
$Y \in R[0, 6]$ feet
$Z \in R[0, 12]$ feet

O2P1 - Pitch Call: The system has one output: the call of a Ball, Strike or No Call. The system will respond with this output for every pitch during the entire length of a baseball game.

$O2P1 \in$ {No Data, Strike, Ball}

3.2.5. Output trajectories (OTRP1)

The set of output trajectories is the set of all possible functions which can be made from TRP1 (the time scale) and ORP1 (the outputs as described above).

OTRP1 = {g: $g \in$ FNS(TRP1,ORP1);
For every $t \in$ TRP1,
Let g1 be the value of O1P1 for a given t
g2 be the value of O2P1 for a given t }

3.2.6. Matching function

The matching function is described by

MRP1 = {(f,G): $f \in$ ITRP1; $G \in$ OTRP1; G = {g: $g \in$ ORP1; $t \in$ TRP1 then if p4(t) = p5(t) and p6(t) != 1[a-g] then g1 = strike;}

3.3. Technology requirement

3.3.1. Available money

The system will be funded by the revenue generated by a portion of ticket, concession and merchandise sales, and should not exceed initial costs of $1 million and should not exceed yearly operating costs of $60,000.

3.3.2. Available time

The system must be deployable by March 2007.

3.3.3. Available components

The restrictions on the components used in the system are that they must be able to withstand rain, direct sunlight, winds up to 50 mph, temperatures ranging from 0 ^{o}F to 140 ^{o}F, and impacts from a baseball or similar projectile at speeds of 20 MPH to 120 MPH.

3.3.4. Available techniques

The techniques that the system may use to call balls or strikes can be done through the use of Commercial-off-the-shelf (COTS) technologies or by the development of a new technology.

3.3.5. Required interfaces

The system must interact with the ball players and any other necessary operators through the use of interfaces such as

1. Touch
2. Sight
3. Sound

3.3.6. Form, fit and other restrictions

The system must be fit inside of all 30 Major League ballparks.

3.3.7. Standards and specifications

The system must conform to Major League Baseball standards, and not interfere with any of the game play. The system must also conform to FCC regulations and all other applicable laws.

3.4. Input/Output Performance Requirement

The I/O performance of the system will be measured as a weighted average of the criteria outlined below.

3.4.1. Definition of Performance Figures of Merit

The overall Performance Figure of Merit is defined as IF0P1 where

IF0P1 = (ISF1P1 * IW1P1) + (ISF2P1 * IW2P1) + . . . + (ISFnP1 * IWnP1)

n = the total number of I/O Performance Criteria

3.4.2. Lower, upper, baseline, and scoring parameters

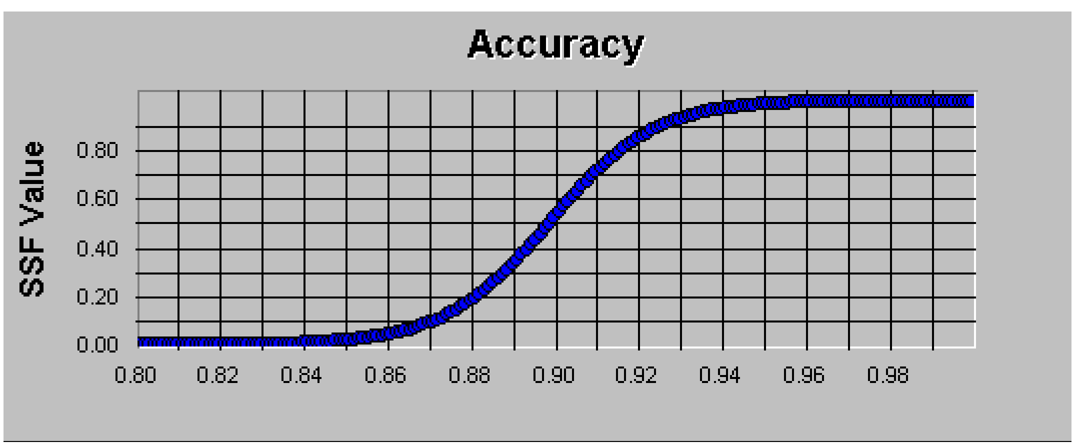
IFiP1 = the i^{th} figure of merit measured per the test plan,
IBiP1 = the baseline value for the i^{th} figure of merit,
ILTHiP1 = lower threshold for the i^{th} figure of merit,
ISFiP1 = score for the i^{th} figure of merit,
ISiP1 = scoring function for the i^{th} figure of merit,
ISLiP1 = slope for the i^{th} figure of merit,
IUTHiP1 = upper threshold for the i^{th} figure of merit,
IWiP1 = weight for the i^{th} figure of merit, and
SSF = standard scoring function

3.4.2.1. Accuracy

Accuracy will be measured as the percentage of 1000 random pitches that an alternative correctly assesses as balls or strikes.

Score: IS1P1 = SSF (ILTH1P1, IB1P1, IUTH1P1, ISL1P1)

Units	% of pitches accurately assessed	
Lower Threshold	ILTH1P1	0
Baseline	IB1P1	.9 (assumed accuracy of the current system)
Upper Threshold	IUTH1P1	1
Slope	ISL1P1	20

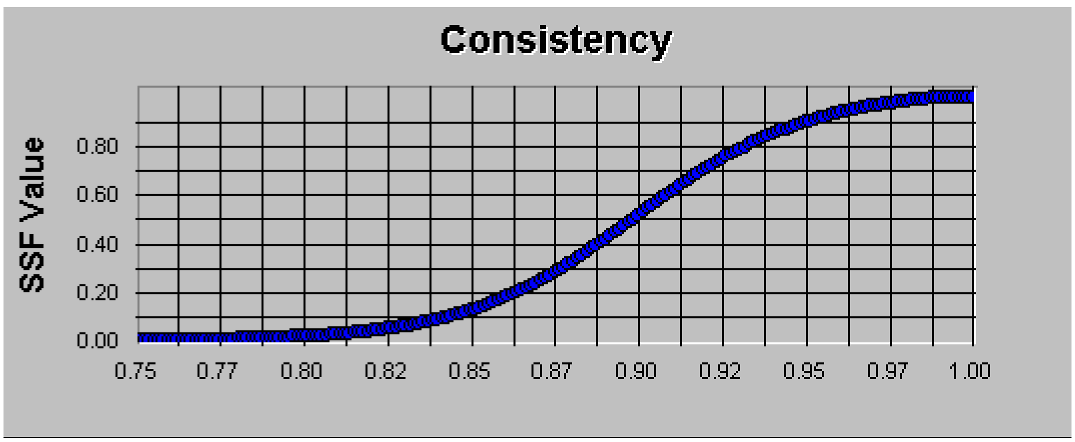


3.4.2.2. Consistency

Consistency will be interpreted as a system's ability to generate the same call for identical pitches. As a matter of testing, these pitches will be divided into 25 groups, namely.

Score: IS2P1 = SSF (ILTH2P1, IB2P1, IUTH2P1, ISL2P1)

Units	% of pitches consistently assessed	
Lower Threshold	ILTH2P1	.5
Baseline	IB2P1	.9 (assumed consistency of the current system)
Upper Threshold	IUTH2P1	1
Slope	ISL2P1	10

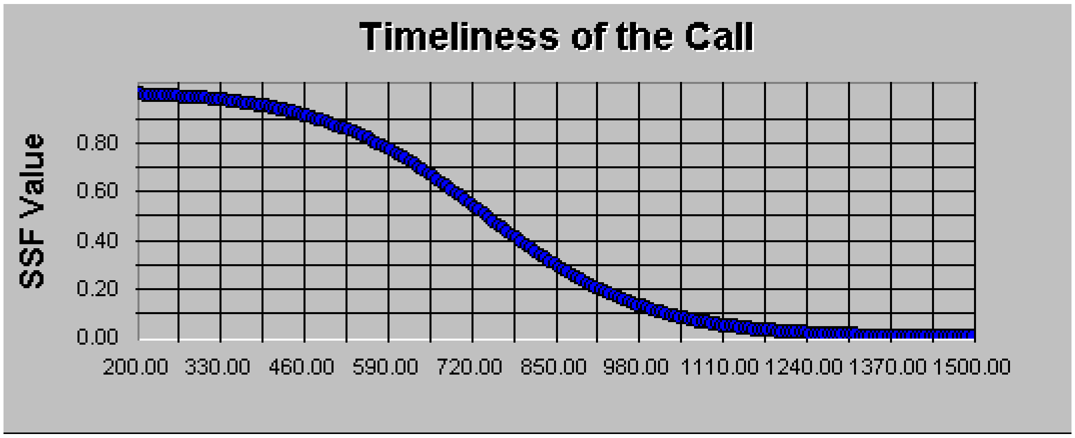


3.4.2.3. Timeliness of the Call

Timeliness of the call is simply the amount of time that elapses between the ball impacting the catcher's glove (or the dirt) and the system rendering the call.

Score: IS3P1 = SSF (ILTH3P1, IB3P1, IUTH3P1, ISL3P1)

Units	milliseconds	
Lower Threshold	ILTH3P1	0
Baseline	IB3P1	750 (assumed timeliness of the current system)
Upper Threshold	IUTH3P1	2000
Slope	ISL3P1	-0.002

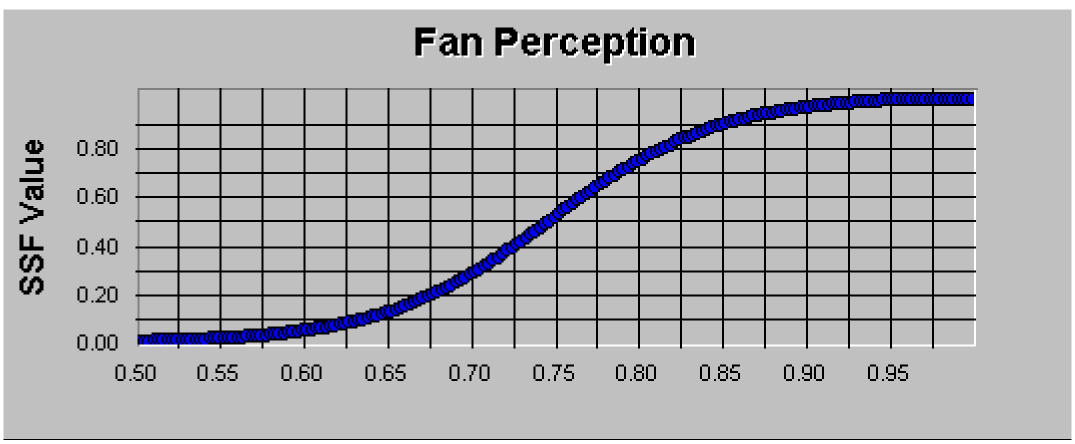


3.4.2.4. Fan Perception

Fan Perception is the percentage of fans that "Like" the system.

Score: IS4P1 = SSF (ILTH4P1, IB4P1, IUTH4P1, ISL4P1)

Units	% of fans that "Like" the system	
Lower Threshold	ILTH4P1	0
Baseline	IB4P1	0.75
Upper Threshold	IUTH4P1	1
Slope	ISL4P1	5

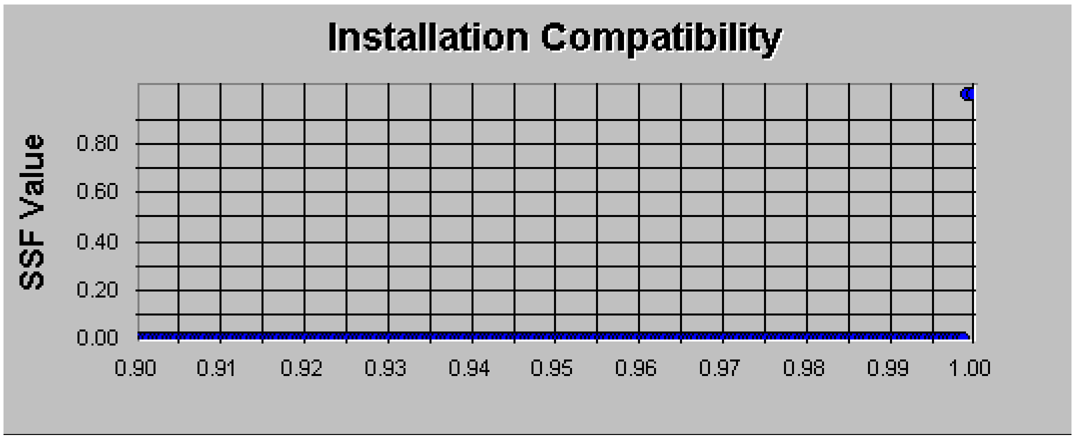


3.4.2.5. Installation Compatibility

In order to be useful across the Major Leagues, a recommended system must be able to be installed in each of the 30 existing ballparks. The CAN / CANNOT nature of this metric makes its determination simple. Specifically, if a system can be installed in all 30 ballparks, it receives a 1; otherwise it receives a 0.

Score: IS5P1 = SSF (ILTH5P1, IB5P1, IUTH5P1, ISL5P1)

Units	N/A (unitless)	
Lower Threshold	ILTH5P1	0
Baseline	IB5P1	1
Upper Threshold	IUTH5P1	1
Slope	ISL5P1	∞

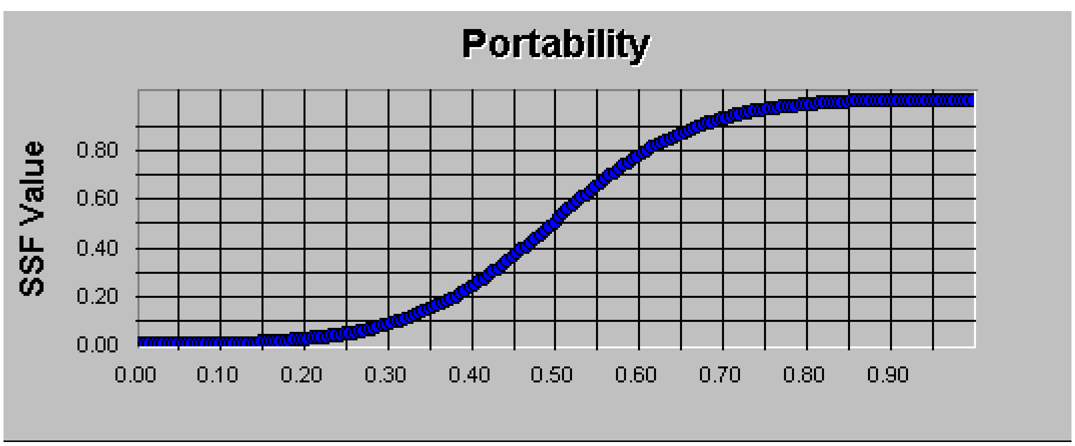


3.4.2.6. Portability

This criterion is more indicative of the future implementation of the system to the minor leagues, off-site training camps, and scouting applications. If a system cannot be moved, it receives a score of 0.

Score: IS6P1 = SSF (ILTH6P1, IB6P1, IUTH6P1, ISL6P1)

Units	% portability (as defined in the Test Requirements)	
Lower Threshold	ILTH6P1	0
Baseline	IB6P1	.5
Upper Threshold	IUTH6P1	1
Slope	ISL6P1	3

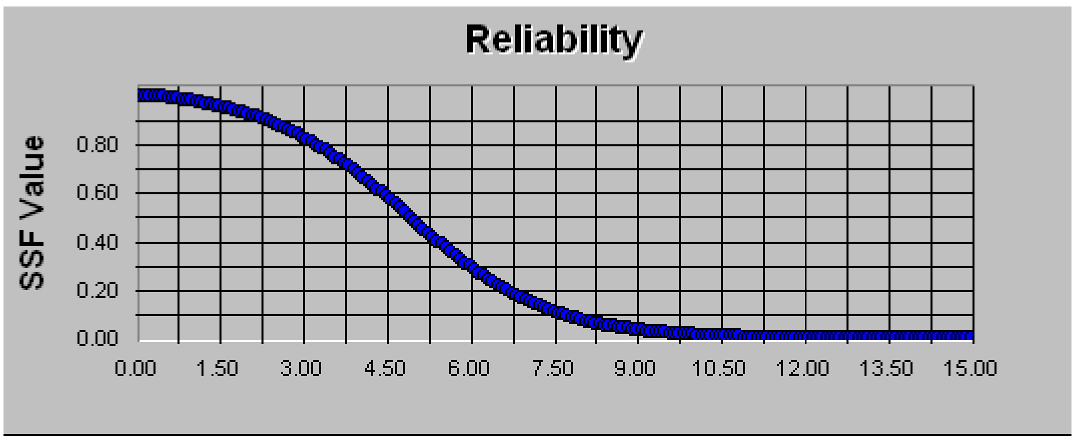


3.4.2.7. Reliability

System reliability will be defined as total number of *significant failures* over 2 consecutive, 15 inning games.

Score: IS7P1 = SSF (ILTH7P1, IB7P1, IUTH7P1, ISL7P1)

Units	Total number of *significant failures* over 2 consecutive, 15 inning games.	
Lower Threshold	ILTH7P1	0
Baseline	IB7P1	5
Upper Threshold	IUTH7P1	30
Slope	ISL7P1	-0.2

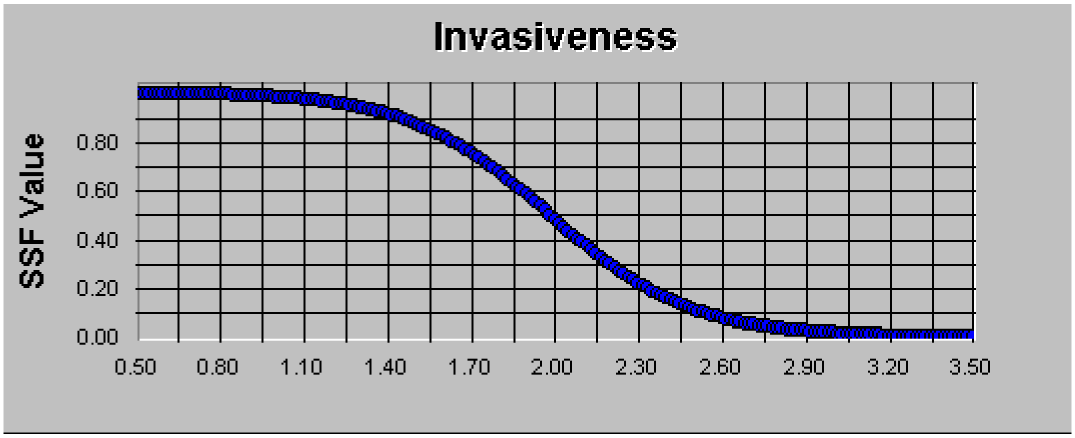


3.4.2.8. Invasiveness

This criterion is highly subjective and will be assessed on a scale from 1 to 10, with 1 being the least invasive (nearly invisible) and 10 being the most.

Score: IS8P1 = SSF (ILTH8P1, IB8P1, IUTH8P1, ISL8P1)

Units	N/A (unitless)	
Lower Threshold	ILTH8P1	0
Baseline	IB8P1	2
Upper Threshold	IUTH8P1	10
Slope	ISL8P1	-1



3.4.3. Weighting criteria

The importance value of each Performance Criteria was gauged on a 1-10 scale (1 being the least important, 10 being the most). The weight for each criterion (IWiP1) was then calculated by taking its importance value and dividing it by the sum of the importance values for all criteria. (Note: The sum of the IWiP1 = 1).

	Criteria	Value	IWiP1
1	Accuracy	10	0.16129
2	Consistency	10	0.16129
3	Timliness of the Call	7	0.112903
4	Fan Perception	7	0.112903
5	Installation Compatibility	10	0.16129
6	Portability	4	0.064516
7	Reliability	7	0.112903
8	Invasiveness	7	0.112903

3.5. Utilization of Resources Requirement

The Utilization of Resources of the system will be measured as a weighted average of the criteria outlined below.

3.5.1. Definition of Resource Figures of Merit

The overall Utilization Figure of Merit is defined as UF0P1 where

UF0P1 = (USF1P1 * UW1P1) + (USF2P1 * UW2P1) + . . . + (USFnP1 * UWnP1)

n = the total number of Utilization of Resources Criteria

3.5.2. Lower, upper, baseline, and scoring parameters

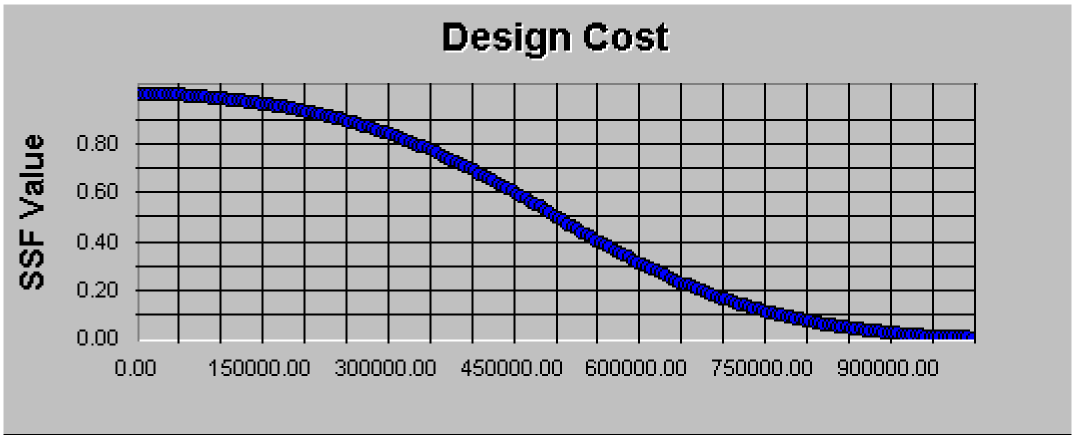
UFiP1 = the i^{th} figure of merit measured per the test plan,
UBiP1 = the baseline value for the i^{th} figure of merit,

ULTHiP1 = lower threshold for the i^{th} figure of merit,
USFiP1 = score for the i^{th} figure of merit,
USiP1 = scoring function for the i^{th} figure of merit,
USLiP1 = slope for the i^{th} figure of merit,
UUTHiP1 = upper threshold for the i^{th} figure of merit,
UWiP1 = weight for the i^{th} figure of merit, and
SSF = standard scoring function

3.5.2.1. Design Cost

Score: US1P1 = SSF (ULTH1P1, UB1P1, UUTH1P1, USL1P1)

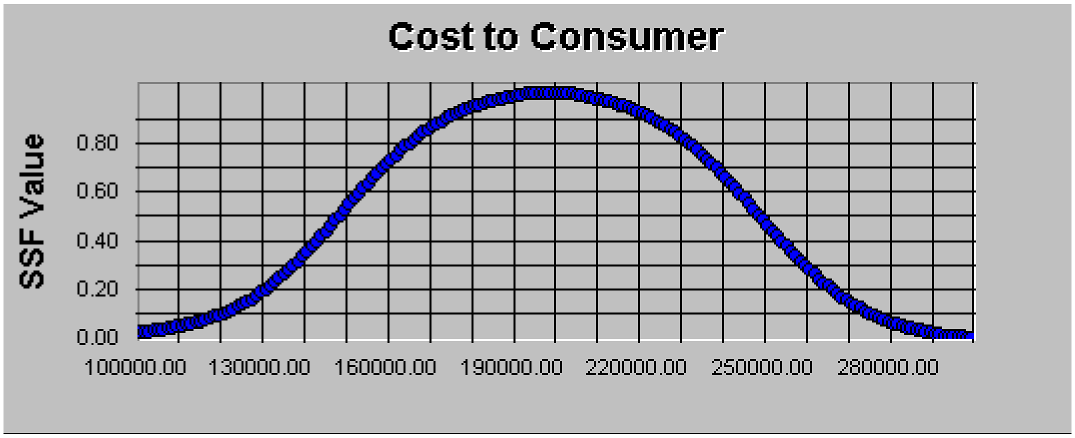
Units	Dollars	
Lower Threshold	ULTH1P1	0
Baseline	UB1P1	500000
Upper Threshold	UUTH1P1	1000000
Slope	USL1P1	-2e-6



3.5.2.2. Cost to Consumer

Score: US2P1 = SSF (ULTH2P1, ULB2P1, ULSL2P1, UOPT2P1, UUB2P1, UUTH2P1, UUSL2P1)

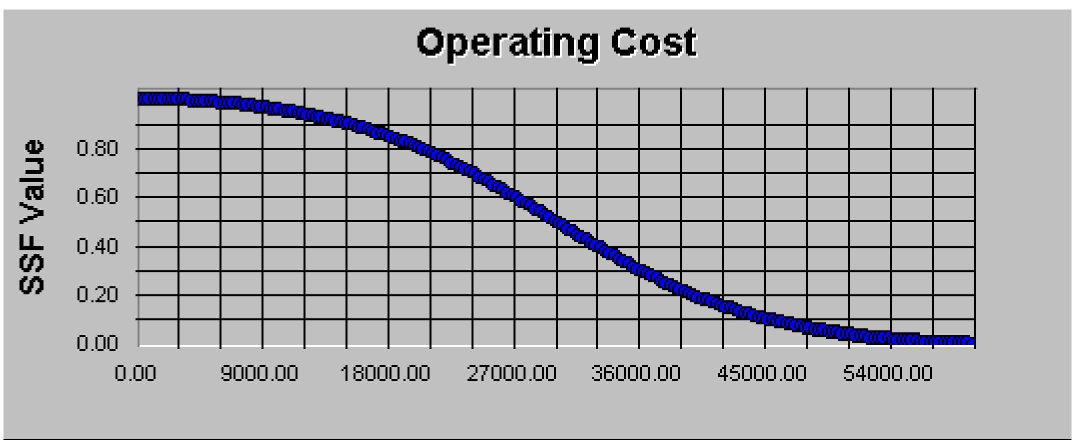
Units	Dollars	
Lower Threshold	ULTH2P1	0
Lower Baseline	ULB2P1	150000
Lower Slope	ULSL2P1	2e5
Optimum	UOPT2P1	200000
Upper Baseline	UUB2P1	250000
Upper Threshold	UUTH2P1	300000
Upper Slope	UUSL2P1	-2e-5



3.5.2.3. Operating Cost

Score: US3P1 = SSF (ULTH3P1, UB3P1, UUTH3P1, USL3P1)

Units	Dollars	
Lower Threshold	ULTH3P1	0
Baseline	UB3P1	30000
Upper Threshold	UUTH3P1	60000
Slope	USL3P1	-3.5e-5

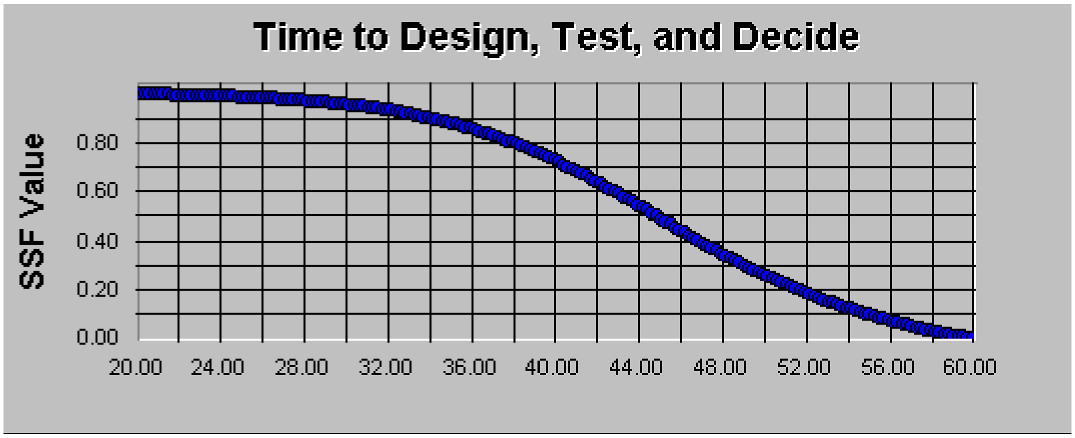


3.5.2.4. Time to Design, Test, and Decide

A full SEMP is required by the SIE 554a syllabus no later than 7 December 2005

Score: US4P1 = SSF (ULTH4P1, UB4P1, UUTH4P1, USL4P1)

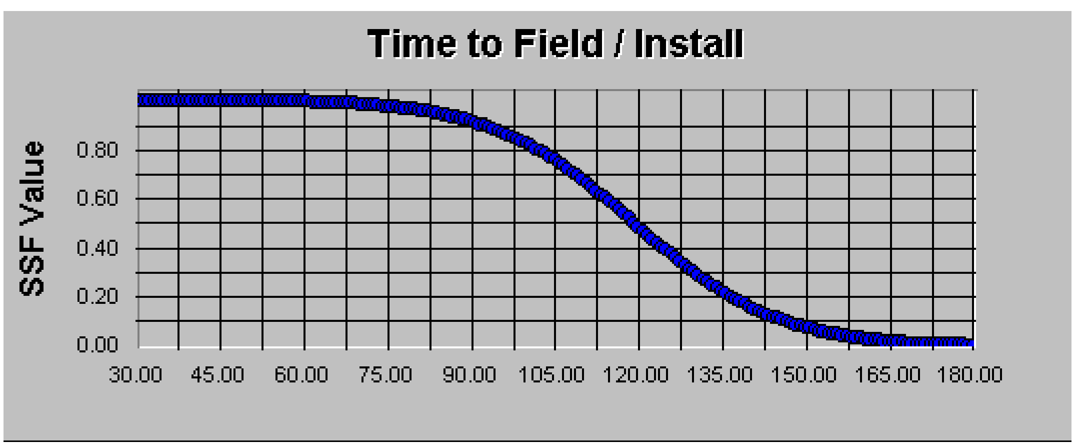
Units	Days	
Lower Threshold	ULTH4P1	0
Baseline	UB4P1	45
Upper Threshold	UUTH4P1	60
Slope	USL4P1	-0.05



3.5.2.5. Time to Field / Install

Score: US5P1 = SSF (ULTH5P1, UB5P1, UUTH5P1, USL5P1)

Units	Days	
Lower Threshold	ULTH5P1	0
Baseline	UB5P1	45
Upper Threshold	UUTH5P1	60
Slope	USL5P1	-0.05



3.5.2.6. Time to Train

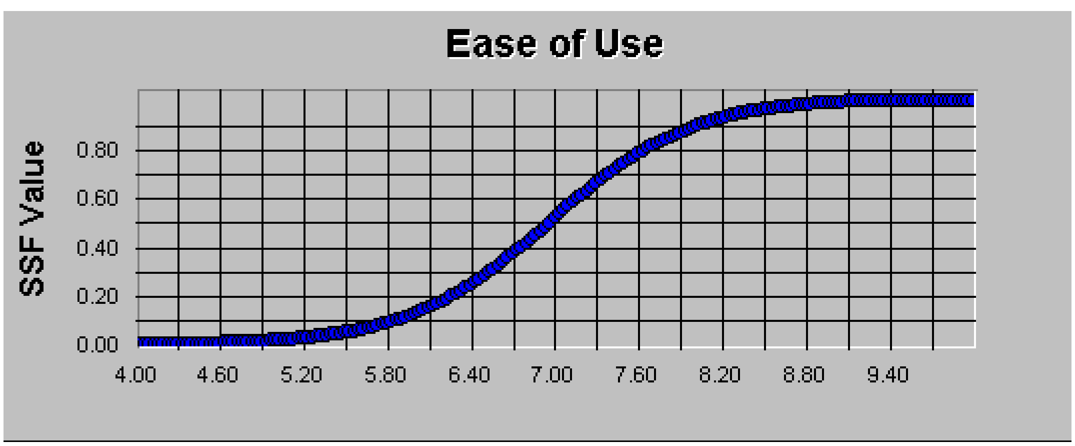
Score: US6P1 = SSF (ULTH6P1, UB6P1, UUTH6P1, USL6P1)

Units	Days	
Lower Threshold	ULTH6P1	0
Baseline	UB6P1	30
Upper Threshold	UUTH6P1	60
Slope	USL6P1	-0.05

3.5.2.7. Ease of Use

Score: US7P1 = SSF (ULTH7P1, UB7P1, UUTH7P1, USL7P1)

Units	Subjective rating from 1 -10 (10 being the simplest → the best)	
Lower Threshold	ULTH7P1	0
Baseline	UB7P1	7
Upper Threshold	UUTH7P1	10
Slope	USL7P1	-0.05



3.5.3. Weighting criteria

The importance value of each Utilization of Resources Criteria was gauged on a 1-10 scale (1 being the least important, 10 being the most). The weight for each criterion (UWiP1) was then calculated by taking its importance value and dividing it by the sum of the importance values for all criteria. (Note: The sum of the UWiP1 = 1).

	Criteria	Value	UWiP1
1	Design Cost	9	0.236842
2	Cost to Consumer	8	0.210526
3	Operating Cost	7	0.184211
4	Time to Implement	8	0.210526
4a	Time to Design, Test, and Decide	10	0.416667
4b	Time to Field / Install	7	0.291667
4c	Time to Train	7	0.291667
5	Ease of Use	6	0.157895

3.6. Trade-Off Requirement

The Trade-Off Requirement (TF0P1) will be calculated as a weighted average of the Total I/O Performance Index and the Total Utilization of Resources Index. We define these variables and their associated weights with the following symbols and values:

Variable Name	Variable Symbol	Weight Symbol	Weight Value
Total I/O Performance Index	IFX0P1	TW1P1	0.5
Total Utilization of Resources Index	UFX0P1	TW2P1	0.5

Accordingly, the Trade-Off Requirement is calculated by the formula:

$$\begin{aligned} TF0P1 &= (IFX0P1 * TW1P1) + (UFX0P1 * TW2P1) \\ &= (IFX0P1 * 0.5) + (UFX0P1 * 0.5) \end{aligned}$$

3.7. System Test Requirement

3.7.1. Test Plan

3.7.1.1. Explanation of Test Plan

The System Test will generate raw values for each of the criteria identified above. These values will then be mapped onto the scoring functions, and the resultant scores will be recorded.

As a matter of technique, the System Test's raw data will be based solely on the team's educated approximations or "best guesses." However, when historical or external evidence is available, sources will be cited and reasonable conclusions will be provided.[2]

Regardless of the data generation technique, in order to be acceptable the system must:

1. Produce *I/O Performance* and *Utilization of Resources* test results that fall within their respective Upper and Lower Thresholds
2. Satisfy all the functional and system-wide requirements identified in this SEMP.

3.7.1.2. Test Trajectory 1

Criteria Tested:	1. Accuracy 2. Consistency 3. Timeliness of the Call 4. Reliability 5. Portability
Preferred Test Location:	Any baseball field with Major League dimensions and spotlights for limited visibility play
Personnel Required:	4 personnel (at least 2 with experience in operating a baseball pitching machine)
Materials Required:	Pitching machine, calibration board, 50 baseballs, stopwatch, prototypes (if available)
Conditions:	Winds $\leq$ 5 mph (required for the consistency test); all other factors in accordance with the system requirements
Sequence of Events for System i:[3]	1. Test Portability (a): System set-up / calibration time will be measured utilizing the personnel on-hand and stopwatch. Results will be recorded. [Note: This test assumes the personnel are familiar with the system and have set it up under instructional circumstances.] 2. Test Accuracy: The calibration board will already be in place as an output of Step 1. At this point, the pitching machine operator will send 1000 randomly selected pitches across home plate. The calibration board will automatically and accurately calculate whether or not each pitch was a ball or a strike, and these results will be compared with the output of the system. 3. Test Consistency: Similar to Accuracy, Consistency will be tested using the pitching machine and a sequence of randomly selected pitches. However, in this case, the operator will

[2] For example, a very similar version of the **UIS with Umpire** alternative is currently installed in roughly 50% of the Major League ballparks. Accordingly, the *Installation Compatibility* criterion of this alternative should be approximated based on this data.
[3] Where i $\in$ [1, number of alternatives tested]

	randomly select pitches from 25 groups, where each group emphasizes a different area of the strike zone. In sum, 10 pitches will be "thrown" for each group, totaling 250 pitches. 4. Timeliness of the Call: On each pitch of Steps 2 and 3, a stopwatch will capture the elapsed time between the ball impacting the calibration board and the system returning a call of "Ball or Strike." 5. Reliability: If we assume that each pitch takes approximately 10 seconds, then Steps 2 and 3 will take 3.5 hours to complete for each system tested. This is roughly the length of one 9-inning game. However, when one considers that there are (on average) 450 pitches in a 9 inning game, the number of pitches required to test accuracy / consistency (1250) should nicely approximate the number in 2 consecutive, 15 inning games. Accordingly, the total number of significant system failures during Steps 2 and 3 will be recorded. 6. Test Portability (b): System tear-down / pack-up time will be measured utilizing the personnel on-hand and stopwatch. Results will be recorded.

3.7.1.3. Test Trajectory 2

Criteria Tested:	Fan Perception, Invasiveness (from the fan's point of view)
Preferred Test Location:	Any conference room capable of seating 100 people
Personnel Required:	3 personnel (1 presenter, 2 assistants)
Materials Required:	Video projection equipment, survey forms, and an automated presentation of the system and its role in the game
Conditions:	N/A
Sequence of Events:[4]	1. Introduction: Fans will be seated and given a brief overview of the system, as well as their role in its design / implementation. 2. Watch Video: Fans will watch a 30 minute video on each system's capabilities, appearance, and potential impact on the game and their viewing experience. 3. Complete Surveys: Fans will complete a 30 question questionnaire that gauges their feelings about each alternative, as well as solicits any recommendations for improvements.

[4] This survey will be conducted 10 times -- each time in a different city, where the locations are evenly divided between National and American League teams.

3.7.1.4. Test Trajectory 3

Criterion Tested:	Installation Compatibility
Preferred Test Location:	30 ML Ballparks
Personnel Required:	2-man installation team
Materials Required:	Plane tickets / travel arrangements, design specifications, and critical dimensions
Conditions:	N/A
Sequence of Events:	Simply put, the installation team will travel to all 30 Major League ballparks and determine if each alternative could be successfully installed.

3.7.1.5. Test Trajectory 4

Criteria Tested:	Invasiveness
Preferred Test Location:	ML Ballparks where the UIS is currently installed
Personnel Required:	5-man polling team
Materials Required:	Plane tickets / travel arrangements, fan satisfaction survey
Conditions:	During the conduct of a game
Sequence of Events:	1. UIS with Umpire: The polling team will travel to all Major League ballparks where the current UIS system is in use. Once on-site, they will attend the game and query the fans, players, coaches, and umpires to determine if and how the system impedes, interferes, obstructs, or detracts from any aspect of the game. 2. For other alternatives (where no prototype is available) the team will describe the alternative and gauge the players, coaches, and umpires reactions. [Note: The fans' point of view on these alternatives will be collected during Test Trajectory 2]

3.7.2. Input/output performance tests

3.7.2.1. Accuracy

Accuracy is one of the two fundamental facets of the top-level system function. Accordingly, it should be maximized whenever possible, and, all else being equal, a system with greater accuracy will be preferred over another with less. In general, any recommended alternative should have an accuracy level greater than or equal to the current system – the home plate umpire. Based on the Boolean nature of a called strike, accuracy will be measured as the percentage of 1000 random pitches that an alternative correctly assesses as balls or strikes.

3.7.2.2. Consistency

Much like accuracy, consistency is a critical component of the top-level system function. Not surprisingly, systems with greater consistency will generally be preferred over those with less. As a matter of definition, consistency will be interpreted as a system's ability to generate the same call for identical pitches. As a matter of testing, these pitches will be divided into 25 groups, namely:

Clear Strikes (5):

Center	Upper Right	Upper Left	Lower Right	Lower Left

Barely Strikes (strikes just on / inside the edge of the zone) (8):

Top Left	Top Center	Top Right	Middle Right	Bottom Right
Bottom Center	Bottom Left	Middle Left		

Almost Strikes (balls just outside the edge of the zone) (8):

Top Left	Top Center	Top Right	Middle Right	Bottom Right
Bottom Center	Bottom Left	Middle Left		

Obvious Balls (4):

Way Inside	Way Outside	Too High	Too Low	

During the test, each system will be exposed to a random sequence of 250 pitches, 10 from each group. A system's consistency will then be calculated as follows:

$$\frac{\sum_{i=1}^{25} Max\left(Balls_i, Strikes_i\right)}{250} \quad where\ i = the\ pitch\ category$$

In this way a consistency of 1 is the best; 0.5 is the worst.

3.7.2.3. Timeliness of the Call

Timeliness of the Call is simply the amount of time that elapses between the ball impacting the catcher's glove and the system rendering the call; less is better. In the current system, this occurs almost simultaneously as the umpire announces his assessment. Accordingly, the "Do Nothing" alternative will serve as the benchmark against which the other alternatives will be judged.

3.7.2.4. Fan Perception

In baseball the perception of the fans cannot be underestimated. Simply put, if the fans express an extreme dislike of a system, regardless of its accuracy or consistency, then the system cannot succeed. Therefore, we will define Fan Perception as the percentage of fans that "Like" the system. In order to generate this metric, we will utilize a simple poling methodology, where 1000 fans will rate their perception of each alternative as: (a) Love It, (b) Like It, (c) Neutral, (d) Dislike It, or (e) Hate It. These answers will receive scores of 4, 3, 2, 1, and 0 respectively. Once the raw data has been accumulated, a given alternative's Fan Perception will be scored as:

$$Fan\ Perception = \frac{Total\ Raw\ Score}{4000}$$

In this way a Fan Perception of 1is the best; 0 is the worst.

3.7.2.5. Installation Compatibility

In order to be useful across the Major Leagues, a recommended system must be able to be installed in each of the 30 existing ballparks. The CAN / CANNOT nature of this metric makes its determination simple. Specifically, if a system can be installed in all 30 ballparks, it receives a 1; otherwise it receives a 0.

3.7.2.6. Portability

This criterion is more indicative of the future implementation of the system to the minor leagues, off-site training camps, and scouting applications. If a system cannot be moved, it receives a score of 0. On the other hand, if the system is portable, its portability will be measured as the amount of time it takes to "tear down / pack up the system" plus the amount of time it takes to "set-up / calibrate the system." Using the following ratings, a system's Portability will be calculated as follows (**X** = time to complete):

Tear Down / Pack Up	TD Score	Set Up / Calibrate	SU Score
X < 30 minutes	4	**X** < 30 minutes	4
30 minutes < **X** < 2 hours	3	30 minutes < **X** < 2 hours	3
2 hours < **X** < 12 hours	2	2 hours < **X** < 12 hours	2
12 hours < **X**	1	12 hours < **X**	1

$$Portability_i = \begin{cases} \dfrac{TD\ Score + SU\ Score}{8} & if\ \ system\, i\ is\ moveable \\ 0 & otherwise \end{cases}$$

3.7.2.7. Reliability

System reliability will be defined as total number of *significant failures* over 2 consecutive, 15 inning games, where a significant failure is any error taking more than 10 seconds to correct. This metric accounts for short-term reliability in an almost worst-case scenario – a double header where each game extends 6 innings beyond the standard 9-inning format. Initially, we will consider the long-term reliability of the system to be less of a concern, as a precondition of any contract will be an aggressive warranty and operational float program. With this in mind, our reliability function will account for uninterrupted performance over a typical game's length, where malfunctions would be extremely distracting to both the players and the fans.

3.7.2.8. Invasiveness

To the maximum extent possible, the system should not impede, interfere, obstruct, or detract from any aspect of the game. This criterion is highly subjective and will be assessed on a scale from 1 to 10, with 1 being the least invasive (nearly invisible) and 10 being the most.

3.7.3. Utilization of resources tests

3.7.3.1. Design Cost

Lower design costs are preferred. Existing technologies and well-developed prototypes will clearly have an advantage here. The maximum design cost will be 1 million dollars.

3.7.3.2. Cost to Consumer

The consumer will obviously prefer a lower purchase and installation price. However, a system which is too cheap may be seen as such. Accordingly, we will target a cost to consumer of $200,000, and we will not exceed $300,000.

3.7.3.3. Operating Cost

Lower operating costs are preferred. These costs will essentially be a conglomeration of any training expenses, operator salaries, and routine / unscheduled maintenance fees. These costs will be not exceed $60,000 yearly.

3.7.3.4. Time to Implement. A three-fold criterion --

> **3.7.3.4.a. Time to Design, Test, and Decide** (less is better): A full SEMP is required by the SIE 554a syllabus no later than 7 December 2005. With this in mind, systems with refined or advanced designs should be preferred over less developed or emerging technologies.

3.7.3.4.b. Time to Field / Install (less is better): The 2005 season is nearing an end, and the 2006 season is approximately 6 months away (March begins spring training). Accordingly, systems that fabricate and install quickly will be preferred, as they will maximize the time to train and educate the players, umpires, and fans.

3.7.3.4.c. Time to Train (less is better): Following fielding the system operators must be trained in its use. An aggressive training schedule combined with practical application should limit this metric for any alternative. However, if the Time to Field extends into the late Spring, the ability of an operator to practice in actual games (prior to opening day) will become very limited. With this in mind, the Time to Train is linked to the Time to Field.

3.7.3.5. Ease of Use

Systems that are comparatively simple to operate are better, and clearly, user friendliness can take many forms: easily understood instructions, good help / troubleshooting files, embedded tutorials, well marked buttons, etc. As such, this criterion will be a subjective rating based on the team's ability to understand and operate the equipment.

3.8. Rationale for operational need

During the course of a normal Major League Baseball season there will be roughly 364,500 called Balls or Strikes. Of these 364,500 decisions, all of which follow a simple, deterministic algorithm, none will be made without bias. Simply put, there is a need to conduct an objective task in an objective way. (See SEMP – Section 2.1: Deficiency, for further information.)

4. Systems Engineering Document: Product Systems Requirements Validation

4.0. Configuration Management

Document Lead: MD
Assistant: RF

Date	Version	Team Members
10/25	0.1	MD
11/9	1.0	MD,FD,DH,RF,SS
11/24	1.2	MD, DH
11/30	2.0	MD,FD,DH,RF,SS

4.1. Input / Output and Functional Design

For over 100 years, the system for calling balls and strikes has not changed. Simply put, the home plate umpire subjectively determines if any part of the baseball passes through any part of the strike zone. Unfortunately, while this sounds simple enough, it is not. Over the years, this difficulty has resulted in each umpire developing his own interpretation of the zone, forcing pitchers and batters alike to adjust their play to compensate. Accordingly, what Major League Baseball needs is a system that will accurately and consistently call balls and strikes, without sacrificing the umpires ability to subjectively manage the game. Our system satisfies this need.

The set of inputs to the system, defined by IRP1, consists of the following subsets:

I1P1 - <u>UIS Reset</u>: This input completely defines the whether or not the system has been reset prior to a pitch being delivered. As a necessary precondition for the system to proceed to the next step, its "Yes / No" value sufficiently describes the system.

I2P1 - <u>VTTs Ready</u>: Much like I1P1, this input completely defines the whether or not the VTT cameras are in their "track" mode prior to a pitch being delivered.

I3P1 - <u>Pitch Acquired</u>. This input completely defines the only 2 acquisition possibilities for the system. That is, the pitch either is or is not acquired.

I4P1 - <u>Ball Position</u>. This input is the 4-dimensional position vector of the pitch's trajectory at time t, where

X = distance to the front of home plate
Y = horizontal displacement from the centerline of home plate
Z = height above the ground
T = elapsed time from pitch acquisition to the measurement

Clearly, this vector describes the ball in three dimensional space at any time t after the system acquires the pitch. In this way, it is a sufficient description of the ball's location.

I5P1 - Strike Zone Limits. In all other dimensions, the strike zone is fixed. Accordingly, when the UIS Operator enters these limits, he effectively defines the strike zone.

I6P1 – System Override. This input represents a manual override by the umpire, the operator, or both, and accounts for all the possible ways for a strike to occur. Clearly, by accounting for every possible scenario, this input effectively allows the system to assess all instances of strike and balls.

The set of inputs to the system, defined by ORP1, consists of the following subsets:

O1P1 - Extrapolated Trajectory: This output is the position data for the pitch's extrapolated trajectory from the front edge of home plate to its rear apex. In this way, it provides the necessary output for the system to assess a given pitch as a ball or a strike.

O2P1 - Pitch Call: Based on O1P1, the system provides an output Ball, Strike or No Call to the user. The system will respond with this output for every pitch during the entire length of a baseball game.

The inputs / outputs listed above are both necessary and sufficient to assess a pitch as a Ball or Strike. In this way, they are correct.

4.2. Technology for the Buildable System

As mentioned in the Derived Requirements documents, the techniques that the system may use to call balls or strikes can be done through the use of Commercial-off-the-shelf (COTS) technologies or by the development of a new technology. Since the chosen approach to implement this system is based on existing technology, it has already been demonstrated that this technology works. Considering this, it is reasonable to assume that the technology should be feasible to use in our system.

4.3. Input / Output Performance Requirement

4.3.1. Accuracy

Accuracy will be measured as the percentage of 1000 random pitches that an alternative correctly assesses as balls or strikes. A baseline value of 90% seems reasonable, based on the current system (an umpire acting without any technological aid).

4.3.2. Consistency

Consistency will be interpreted as a system's ability to generate the same call for identical pitches. Again, this is represented as a percentage of pitches which are correctly assessed and has a baseline value of 90% (a reasonable figure).

4.3.3. Timeliness of the Call

Timeliness of the call is simply the amount of time that elapses between the ball impacting the catcher's glove and the system rendering the call – between 0 and 2 seconds. As the assumed timeliness of the current system is roughly 0.75 seconds, this seems reasonable

4.3.4. Fan Perception

Fan Perception is the percentage of fans that "Like" the system. With a baseline of 75%, this indicates that the system should appeal to at least 3 out of 4 fans. As the fans are the ultimate bill payers, this is acceptable.

4.3.5. Installation Compatibility

In order to be useful across the Major Leagues (the intended market), a recommended system must be able to be installed in each of the 30 existing ballparks. Accordingly, it is reasonable to conclude that if a system can be installed in all 30 ballparks, it receives a 1; otherwise it receives a 0.

4.3.6. Portability

If a system cannot be moved, it receives a score of 0. On the other hand, if the system is portable, its portability will be measured as the amount of time it takes to "tear down / pack up the system" plus the amount of time it takes to "set-up / calibrate the system." Measured in windows of [0 – 30 min), [30 min – 2 hrs), [2 hrs – 12 hrs), [12 hrs - ∞), this criteria essentially categorizes the ability of a system to be functional immediately, just before a game, the night before a game, or at some time requiring extensive notice. In this way, it is a reasonable measure of portability.

4.3.7. Reliability

System reliability will be defined as total number of *significant failures* over 2 consecutive, 15 inning games. This metric accounts for short-term reliability in an almost worst-case scenario – a double header where each game extends 6 innings beyond the standard 9-inning format.

4.3.8. Invasiveness

This criterion is highly subjective and will be assessed on a scale from 1 to 10, with 1 being the least invasive (nearly invisible) and 10 being the most (should have stayed at home).

4.4. Utilization of Resources Requirement

4.4.1. Design Cost

Lower design costs are preferred. Existing technologies and well-developed prototypes will clearly have an advantage here. The maximum design cost will be 1 million dollars.

4.4.2. Cost to Consumer

The consumer will obviously prefer a lower purchase and installation price. However, a system which is too cheap may be seen as such. Accordingly, we will target a cost to consumer of $200,000, and we will not exceed $300,000.

4.4.3. Operating Cost

Lower operating costs are preferred. These costs will essentially be a conglomeration of any training expenses, operator salaries, and routine / unscheduled maintenance fees. These costs will be not exceed $60,000 yearly.

4.4.4. Time to Implement

A three-fold criterion --

4.4.4.a. Time to Design, Test, and Decide

A full SEMP is required by the SIE 554a syllabus no later than 7 December 2005. Accordingly, a timeline of 0 to 60 days is a reasonable interval for this criterion.

4.4.4.b. Time to Field / Install

(less is better) The 2005 season is nearing an end, and the 2006 season is approximately 6 months away (March begins spring training). With a no later than (NLT) decision date of 7 December 2005, a timeline of 0 to 60 days is a reasonable interval to field and install the system (essentially, putting the system into all ML Ballparks NLT February).

4.4.4.c. Time to Train

Following fielding the system operators must be trained in its use – this is the time to train. In order to be ready for the 2006 season, this must occur in the 60 days following installation (placing the system into operation NLT April 2006).

4.4.5. Ease of Use

This criterion represents the team's ability to understand and operate the equipment. It is a reasonable subjective rating on a scale of 1-10 (10 being the simplest → the best).

4.5. Test Requirement

The system test requirements as presented in the Derived Requirements Document, appear to fully test the range of capabilities of the system, as well as the performance of the system. The 4 test trajectories described exhaustively tests all of the requirements needed to determine if the system is acceptable or not. No problems are foreseen in using these methods as acceptance tests.

4.6. Feasible System Design

Only systems which fall within the upper and lower thresholds of all the criteria listed above will be considered feasible. If a concept fails a given criteria, the concept will be redesigned (as time permits) to establish feasibility. However, if the feasibility of a system cannot be achieved without fundamentally changing the concept, then the concept will be discarded as infeasible.

4.7 Real System

The home plate umpire has effectively assessed pitches as Balls and Strikes for over 100 years. Therefore, it is certainly reasonable to assume that we can engineer a new system that performs as well (if not better) than the current one.

5. Systems Engineering Document: Concept Exploration

5.0. Configuration Management

Document Lead: DH
Assistant: MD,SS

Date	Version	Team Members
9/15	0.1	FD
9/15	0.2	DH
9/17	0.3	MD,FD,RF,SS
9/18	0.4	MD,FD,DH,SS
9/19	0.5	MD,RF,DH
9/19	1.0	MD,FD,DH,RF,SS
9/20	1.1	DH
10/16	1.2	DH
10/19	2.0	MD,FD,DH,RF,SS
11/24	1.2	MD, DH
11/30	2.0	MD,FD,DH,RF,SS

The *Concept Exploration Document* is used to study several different system designs via approximation, simulation, or prototypes, or via a combination of these techniques. The best design alternative is suggested by the data. This document will be rewritten many times as more information becomes available.

There will be three areas of concept exploration for the system for calling balls and strikes. The first area will entail the different ways one can call balls and strikes, the second area will entail the different tests that will be performed on the system for calling balls and strikes, the third area will describe the best solution for the system that calls balls and strikes.

5.1. Balls and Strikes Systems

For over 100 years, from the little to the major leagues, the system used to assess balls and strikes has not changed. Namely, the chief umpire (often referred to as the plate umpire) categorizes a pitch a strike based on the following criteria:

A strike occurs when:

5) The batter swings at or attempts to bunt the ball AND completely misses,
6) GIVEN that the batter has less than 2 strikes, the batter swings at or attempts to bunt the ball AND makes contact, BUT the ball is foul,
7) The batter is struck by the ball while:
    a. Swinging at or attempting to bunt the ball AND / OR
    b. The batter is in the strike zone,

8) The batter does not swing at or attempt to bunt the ball AND any part of the ball passes through any part of the strike zone.

While these represent all the possible ways for a strike to occur, there is only one way to characterize a ball, specifically – the batter does not swing at or attempt to bunt the ball AND no part of the ball passes through any part of the strike zone.

While these criteria seem straight forward enough, the matter of assessing a ball or a strike is not a simple task. First the umpire must visualize the strike zone, an invisible 3-dimensional space which, at its best, is unique to each individual batter. Given that he has successfully interpreted this zone, he then must determine whether any part of the ball passes through it. At the major league level, this assessment will occur in roughly 1/100th of a second, as a 90 mph fastball zips across the plate. Adding complexity to this task is the pitcher's ability to place *english* on the ball, causing it to accelerate horizontally or vertically due to its rotation. Finally, we must account for the umpire's necessary but cumbersome protective gear as well as his position behind the catcher, both of which contribute to a less than optimal vantage point. In summary, ***accurately*** categorizing a ball or a strike is difficult, especially when the pitch is on the edge of the zone (a desired and often visited location for the pitcher).

Accordingly, our design will be crafted with the fourth criterion in mind. That is, given that the batter does not swing at or attempt to bunt the ball, our system will ***accurately*** and ***consistently*** determine whether or not the ball passes through the strike zone.

5.1.1. System Design Concept 1 (Home Plate Umpire – The Do Nothing Alternative))

As the umpires currently have autonomy in assessing balls and strikes, the umpires have a huge stake in the system. The Home Plate Umpire would continue to rely on his line of site, years of experience, and the rules book provided by Major League Baseball.

5.1.2. System Design Concept 2 (Radar System)

A Radar System can be used to detect a pitch as either a ball or a strike. The Radar System would be calibrated according to the batter. Whenever a pitch is detected within the parameters that have been set as the strike zone, a strike will be called. The Radar system would have a field created in the area of the strike zone. When the ball passes through the radar field, the radar guns will record a higher sound frequency. This system would rely on sound waves being bounced back to the radar guns.

5.1.3. System Design Concept 3 (Video Target Tracker (UIS Improved))

This alternative is unique among the other proposed designs for a simple and important reason – it has already been tested and implemented at all 30 Major League ballparks. Namely, in 2001, as an effort to re-implement the regulation strike zone, the

Commissioner's Office hired QuesTec[5] to develop and field the Umpire Information System (UIS). Employing proprietary video tracking technology and 5 specially configured cameras, the UIS automatically acquires each pitch and tracks it throughout its flight, gathering information about the ball's speed and trajectory (see Figure 5-1).[6] At the end of the game, the system's operator manually sets the strike zone for each batter on every *called* ball and strike. Once the operator is finished, the UIS employs an algorithm to recall each pitch's data and calculates whether or not the umpire's call was accurate.

Unfortunately, in its current configuration the UIS does not provide real-time feedback. In other words, while the tracking data is readily available, the strike zone determination is deferred until the end of the game. As our top-level system function is to accurately and consistently call balls and strikes **in** a baseball game, this set-up is not acceptable. Accordingly, in order to achieve the timeliness associated with the call, the operator need only establish the strike zone before the pitcher's delivery. Once the zone has been set, the UIS will be free to immediately determine the whether the pitch is a ball or a strike. Following the calculation, the UIS would electronically relay the information to the ballpark's myriad scoreboards, essentially eliminating the umpire from the objective task of calling balls and strikes.

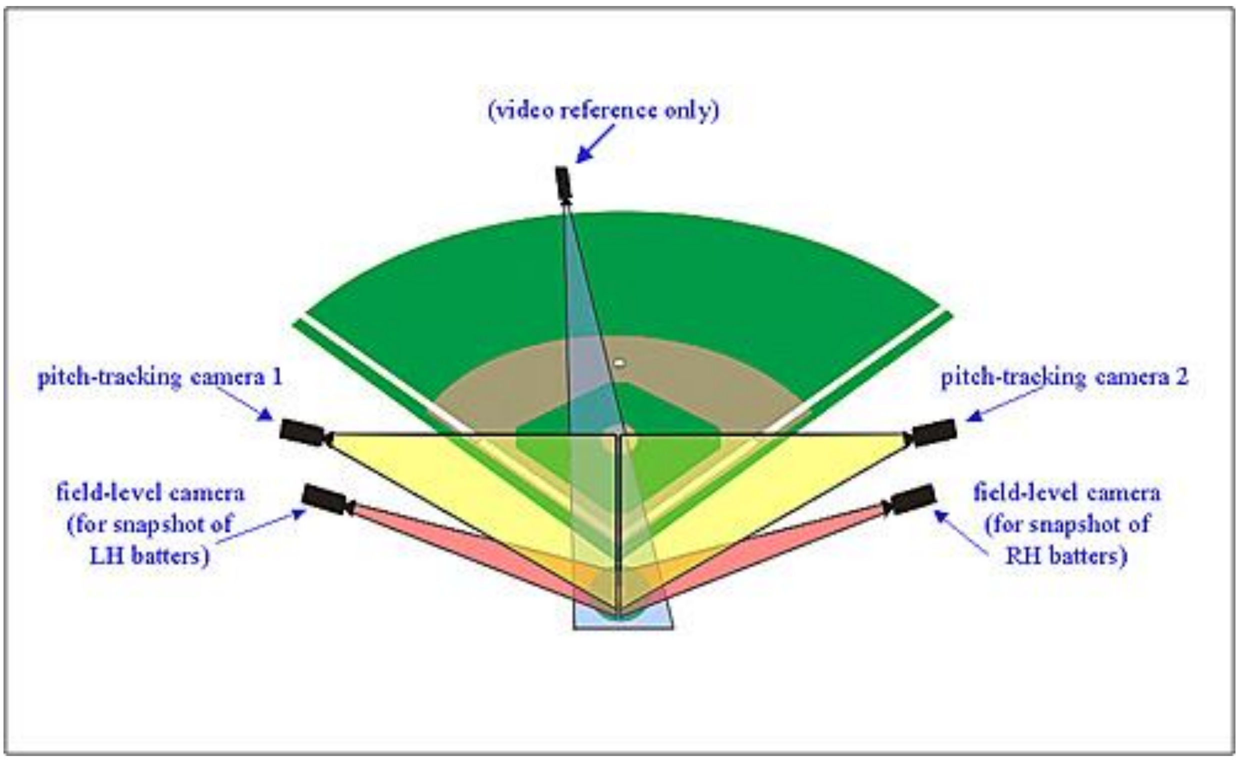


Figure 5-1

5.1.4. System Design Concept 4 (Video Target Tracker with Umpire)

[5] QuesTec is a former military contractor and measurement company.
[6] Figure 5-1 copied from http://www.wired.com/news/technology/0,1282,59208,00.html.

The 'human' judgment of experienced baseball umpires, combined with the scientific methodology used by the Video Target Tracker will generate an efficient system for calling a ball or strike.

A Video Target Tracker like the UIS (Umpire Information System) by QuesTec analyzes video from cameras mounted in the rafters of each ballpark to precisely locate the ball throughout the pitch corridor; additional cameras are mounted at the field level to measure the strike zone for each individual batter. This collectively lets the automated UIS make a decision on calling a ball or strike.

A Video Target Tracker can be prone to mistakes in controversial situations, as it relies on predetermined situations and their results; an experienced Umpire can further assess the results by VTT and make the final decision on a ball or strike. Having an Umpire overseeing the VTT will make the results more reliable.

5.1.5. System Design Concept 5 (Fiber Optic Viewers)

This concept will employ the use of five fiber optic viewers and two field-level cameras in order to accurately assess balls and strikes. Specifically, the fiber-optic viewers will be mounted inside of home plate's five corners and calibrated to provide a restricted, framed view of the pentagonal prism formed by the depth and width of the strike zone. The two field-level cameras will be set-up on the left and right-hand side of the plate respectively, allowing the vertical dimension of the strike zone to be set for each batter (see Figure 5-2).

Throughout the game these cameras will feed their images into a control room, where 2 operators will observe each pitch. Operator 1, the Depth-Width Judge, will simply determine whether the pitch passes through the depth and width of the strike zone (the fixed dimensions). Operator 2, the Height Judge, will set the vertical dimension of the strike zone prior to each delivery and assess whether the pitch falls within these limits. If both of the operators determine that a given pitch has passed through their zones, the pitch will be called a strike; otherwise it is a ball. This information will then be relayed to the plate umpire via a small two-way radio, and the umpire will announce the appropriate call.

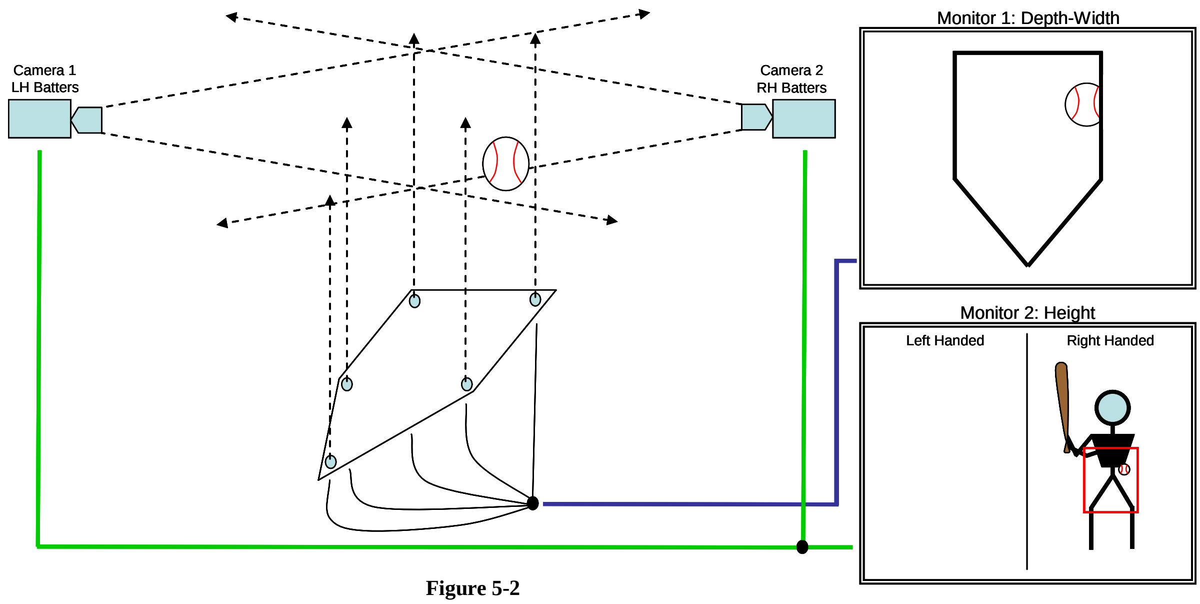


Figure 5-2

5.1.6. System Design Concept 6 (2-D Box; Infrared Lasers)

Concept 3 will utilize 6 eye-safe, infrared lasers; 4 automated guide systems; and 1 infrared monocular. Four of the six lasers will be mounted on the automated guide systems and will demarcate the vertical dimensions of the strike zone. The remaining two lasers will be positioned under the leading corners of home plate and will bracket the horizontal limits of the zone.

Sequentially speaking, before every pitch the system operator will adjust the left or right side lasers in order to set the vertical limits of the strike zone. During the windup, the operator will activate the lasers, generating an invisible, infrared box at the lead edge of the plate. The umpire, wearing an infrared monocular, will be able to see the box clearly. In this way, the matter of calling a ball or a strike will be reduced to the umpire observing the ball passing inside or outside of the box. For close calls, the system will have the added advantage of scattering, as the ball breaks the beam and the laser is reflected towards the umpire. A potential downside of the system is its inability to provide information about the depth of the zone. However, as the ball will travel this distance in 1/100th of a second, this limitation seems almost petty (see Figure 5-3).

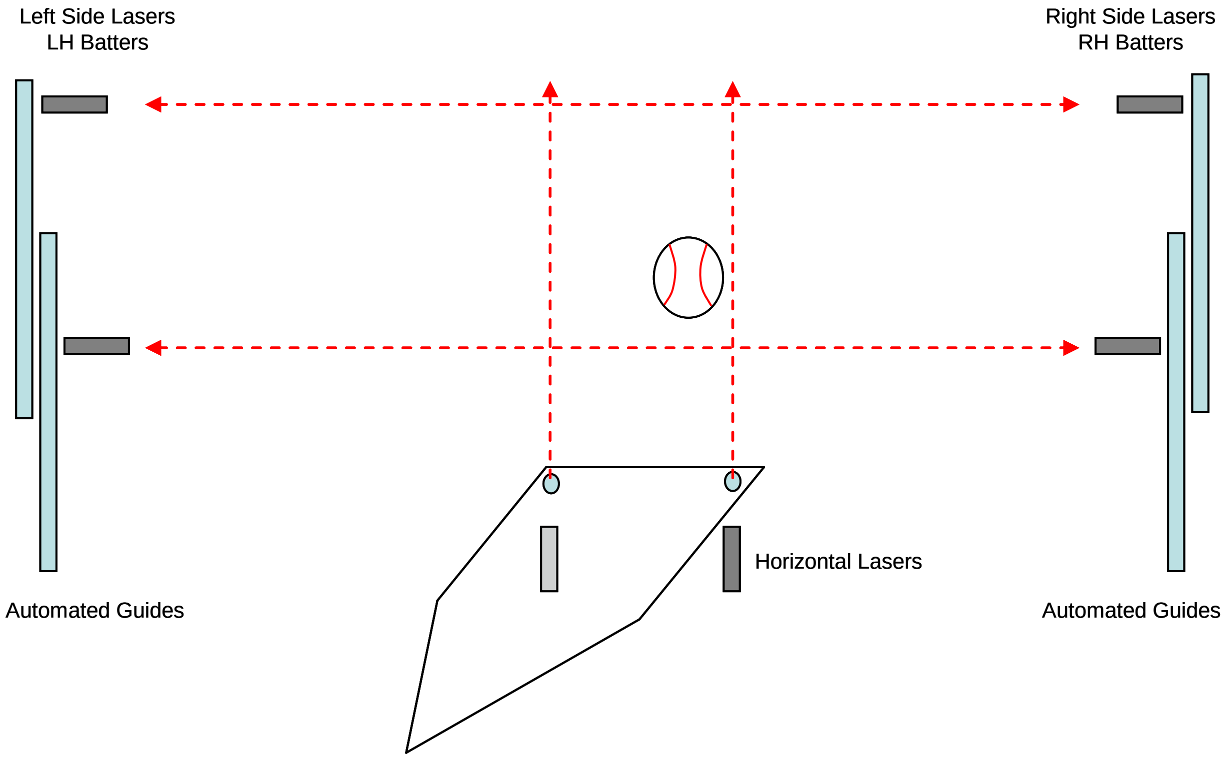


Figure 5-3

5.1.7 System Design Concept 7 (RTSA-MEP System in Baseball)

The system would be categorized as a `roll-your-own' embedded system. The technology has been in existence for two years. Reconnaissance, Surveillance and Target Acquisition Mission Equipment Package (RTSA-MEP) technology uses an RS-170 frame rate, which at 60Hz will deliver one frame every 16.7ms. A 90mph fastball will be traveling at about 132 feet per second, without modifications to the off the shelf system the ball can be tracked at 2.2 feet per frame. The use of the wide area search (WAS) and super field of view (SFOV) capabilities allows the system to observe and track the entire 60.5 feet distance between the pitcher and batter. The WAS will be used in conjunction to the SFOV, the ATD (automatic target detection) and AiTR (automatic target recognition). The system also has the capability to record "soft real time" as well as recording in thermal vision, thus possibly proving useful during night games.

5.1.8. System Design Concept 8 (Image Processing Umpire Goggles)

The idea of special goggles that an umpire could use to determine balls and strikes is a rather novel idea, and there has not been much research done on this possibility as of yet. Therefore, this concept has a great deal of potential for further, more in-depth research and development.

The basic idea behind umpire goggles would be that an umpire could wear these goggles that use image processing to identify the location of home plate, and the body of the batter next to it. Based on these 2 images, the goggles would then calculate the area and location of the strike zone as it correlates to the midpoint of the batter's torso being the upper limit and the kneecap being the lower limit. The 3-D image of the strike zone would then be virtually superimposed on the original image the umpire sees through the goggles. Since the batter is not a still image, but can always be moving, the goggles continuously re-calculate the strike zone, and re-display the image as necessary. Using this virtual image of the strike zone, the umpire can easily and confidently make the determination in real-time of whether a not a pitch has passed through the strike zone or not.

5.1.9. System Design Concept 9 (SuperVision PitchTrax)

This idea is also by Questec and instead of doing a post-game assessment after each game assessment is done after each pitch and at-bat.

5.1.10. System Design Concept 10 (DogTracker Pro)

The DogTracker Pro solution utilizes an array of up to three Irish Wolfhounds which are specially trained to declare balls and strikes using their acute visual, auditory, and olfactory senses as well as their superior innate tracking abilities. The dog will signal a ball or a strike through a combination of barking or acrobatic maneuvers. If three dogs are used then the third dog can be used as a tie-breaker if the other two dogs read different calls.

5.2. System Test

The systems engineering team in SIE 554a will test each alternate system and determine though experimentation and analysis of the data, the system that fits our customer’s needs. The system will use a Major League Baseball Official ball. A machine will eject baseballs attempting to randomly generate balls and strikes at different speeds. A panel of experts will be assembled to determine what is considered a ball and what is considered a strike. Arbitrary strike zones will be set according to the expert panel. Each concept will be explored and compared to each other to determine the best possible solution.

5.2.1. System Test Data

Alternative	Actual Ball	System Ball	Actual Strike	System Strike	Total	Accuracy
Home Plate Umpire	TBD	TBD	TBD	TBD	TBD	TBD
Radar System	TBD	TBD	TBD	TBD	TBD	TBD
Sensors	TBD	TBD	TBD	TBD	TBD	TBD

5.3. System Resolution

5.3.1. System Comparison

5.3.1.1. Evaluation Criteria

I/O Requirements:

1. Accuracy: Accuracy of the current system (higher is better.)
2. Consistency: Percent pitches consistently assessed (higher is better.)
3. Timeliness of the Call: Amount of seconds to make call (lower is better.)
4. Fan Perception: Percentage that fans like the system (higher is better.)
5. Installation Compatibility: Truth value of installation compatibility (higher is better.)
6. Portability: Percent portability of the system (higher is better.)
7. Reliability: Total number of failures per 2 consecutive, 15 inning games (lower is better.)
8. Invasiveness: Score of how invasive the system is (lower is better.)

U/R Requirements:

1. Design Cost: Cost to design the system (lower is better.)
2. Cost to Consumer: Cost to consumer (higher is better for us, lower is better for consumer.)
3. Operating Cost: Cost to operate system (lower is better.)
4. Time to Implement: A three-fold criterion --
   - 4a. Time to Design, Test, and Decide (less is better): Time in days
   - 4b. Time to Field / Install (less is better): Time in days
   - 4c. Time to Train (less is better): Time in days
5. Ease of Use: Score of how easy to use the system is (higher is better.)

5.3.2. Analytical Hierarchy Process

5.3.2.1. Input/Output and Functional Requirements (AHP version)

The Input/Output Functional Requirements scores were fed into an Analytical Hierarchy Process matrix to both validate the relationship between criteria themselves and to also calculate a priority of each requirement.

		Input/Output Criteria										
Input/Output Criteria	Priority	Accuracy	Consistency	Timeliness of the call	Fan Perception	Installation Compatibility	Portability	Reliability	Invasiveness			8th root of product
Accuracy	0.16	1.00	1.00	1.43	1.43	1.00	2.50	1.43	1.43			1.34
Consistency	0.16	1.00	1.00	1.43	1.43	1.00	2.50	1.43	1.43			1.34
Timeliness of the call	0.11	0.70	0.70	1.00	1.00	0.70	1.75	1.00	1.00			0.938
Fan Perception	0.11	0.70	0.70	1.00	1.00	0.70	1.75	1.00	1.00			0.938
Installation Compatibility	0.16	1.00	1.00	1.43	1.43	1.00	2.50	1.43	1.43			1.34
Portability	0.06	0.40	0.40	0.57	0.57	0.40	1.00	0.57	0.57			0.536
Reliability	0.11	0.70	0.70	1.00	1.00	0.70	1.75	1.00	1.00			0.938
Invasiveness	0.11	0.70	0.70	1.00	1.00	0.70	1.75	1.00	1.00			0.938
Total	1	6.2	6.2	8.86	8.86	6.2	15.5	8.86	8.86			8.31
PV		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			

5.3.2.2. Utilization of Resources Requirements (AHP version)

Likewise for the Utilization of Resource requirements we verified that the requirements were in fact valid and generated a priority for each.

Utilization and Resources Criteria	Priority	Design Cost	Cost to Customer	Operating Cost	Time to design, test and decide	Time to field/install	Time to train	Ease of Use				7th root of product
Design Cost	0.16	1.00	1.13	1.29	0.90	1.29	1.29	1.50				1.158
Cost to Customer	0.15	0.89	1.00	1.14	0.80	1.14	1.14	1.33				1.044
Operating Cost	0.13	0.78	0.88	1.00	0.70	1.00	1.00	1.17				0.929
Time to design, test and decide	0.18	1.11	1.25	1.43	1.00	1.43	1.43	1.67				1.27
Time to field/instal	0.13	0.78	0.88	1.00	0.70	1.00	1.00	1.17				0.929
Time to train	0.13	0.78	0.88	1.00	0.70	1.00	1.00	1.17				0.929
Ease of Use	0.11	0.67	0.75	0.86	0.60	0.86	0.86	1.00				0.812
												0
Total	1	6	6.75	7.71	5.4	7.71	7.71	9				7.071

5.3.3. Trade-off matrix

We then normalized the priorities of both sets of requirements on a 10-scale to calculate a metric value to rank each of our previously discussed and numbered alternatives. We then assigned raw scores to each alternative solution and multiplied by the criterion's metric value to achieve solution scores. We then combined both sets of scores by the assigned trade-off weightings to achieve a total final score for each possible alternative.

Input/Output Requirements Ranking of Product Alternatives

Criterion	1		2		3		4		5		6		7		Criterion 8		Maximum Score
Metric Value	1		1		1		2		1		2		2		4		140
Alternative	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Solution Score
Solution 1	6	6	5	5	7	7	1	2	6	6	8	16	4	8	8	32	82
Solution 2	8	8	3	3	6	6	6	12	4	4	6	12	8	16	3	12	73
Solution 3	5	5	7	7	5	5	5	10	3	3	7	14	3	6	4	16	66
Solution 4	3	3	8	8	4	4	4	8	6	6	5	10	9	18	6	24	81
Solution 5	2	2	5	5	8	8	8	16	7	7	3	6	5	10	7	28	82
Solution 6	5	5	4	4	3	3	5	10	5	5	9	18	4	8	2	8	61
Solution 7	4	4	3	3	2	2	3	6	3	3	2	4	8	16	5	20	58
Solution 8	3	3	2	2	1	1	2	4	2	2	3	6	7	14	9	36	68
Solution 9		0		0		0		0		0		0		0		0	0
Solution 10		0		0		0		0		0		0		0		0	0

Utilization and Resources Requirements Ranking of Product Alternatives

Criterion	1		2		3		4		5		6		7		Maximum Score
Metric Value	1		1		1		2		2		3		2		120
Alternative	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Raw Scr	Wtd Scr	Solution Score
Solution 1	6	6	5	5	7	7	1	2	6	12	8	24	4	8	64
Solution 2	8	8	3	3	6	6	6	12	4	8	6	18	8	16	71
Solution 3	5	5	7	7	5	5	5	10	3	6	7	21	3	6	60
Solution 4	3	3	8	8	4	4	4	8	6	12	5	15	9	18	68
Solution 5	2	2	5	5	8	8	8	16	7	14	3	9	5	10	64
Solution 6	5	5	4	4	3	3	5	10	5	10	9	27	4	8	67
Solution 7	4	4	3	3	2	2	3	6	3	6	2	6	8	16	43
Solution 8	3	3	2	2	1	1	2	4	2	4	3	9	7	14	37
Solution 9		0		0		0		0		0		0		0	0
Solution 10		0		0		0		0		0		0		0	0

Combined Score

Solution	1	2	3	4	5	6	7	8	9	10
Total	146	144	126	149	146	128	101	105	0	0
Max	260									

5.3.5. Recommended Alternatives

Based on the initial trade-off analysis and sensitivity analysis we should pick concept 4: Video Target Tracker with Umpire.

5.4. Cognitive Bias

The umpire, pitcher and batter may have their own unique cognitive biases to the system.

5.5. MUAT Analysis

After the prototype evaluation of the alternatives and criteria validation using an Analytical Hierarchy Process and further consideration of the customer's needs we conducted further trade-off studies using a MUAT Analysis.

5.5.1. I/O Performance Criteria Grading

Each alternative was assigned a performance grade (IFXiP0) of how it valued under each criterion.

Criterion	IFXiP0 (FSD1)	FSD2	FSD3	FSD4	FSD5	FSD6	FSD7	FSD8	FSD9	FSD10
Accuracy	0.9	0.8	0.9	0.95	0.876	0.79	0.999	0.89	0.99	0.66
Consistency	0.5	0.85	0.9	0.75	0.5	0.5	0.9	0.5	0.9	0.99
Timeliness	750	500	400	800	210	180	100	250	150	1000
Perception	0.75	0.8	0.2	0.75	0.15	0.75	0.1	0.95	0	0.75
Installation	1	0	1	1	1	1	0	1	0.95	0
Portability	0.5	0.4	0.5	0	0.5	0.5	0.5	0.5	1	0.9
Reliability	5	6	7	8	4	8	9	7	9	3
Invasiveness	2	7	2	1	2	2	10	7	9	4

5.5.1.1. I/O Performance Criteria Scoring

The performance grades were entered into the scoring functions for each criterion and a score was generated (ISFiP0).

Criterion	IFXiP0 (FSD1)	FSD2	FSD3	FSD4	FSD5	FSD6	FSD7	FSD8	FSD9	FSD10
Accuracy	0.5	0.00033	0.5	0.98461	0.12784	0.00014	0.99999	0.31002	0.99996	0
Consistency	0	0.11889	0.5	0.00221	0	0	0.5	0	0.5	0.99372
Timeliness	0.5	0.88363	0.94742	0.40129	0.99252	0.99507	0.99894	0.9878	0.99696	0.11833
Perception	0.5	0.73187	0	0.5	0	0.5	0	0.99206	0	0.5
Installation	1	0	1	1	1	1	0	1	0	0
Portability	0.5	0.23059	0.5	0	0.5	0.5	0.5	0.5	1	0.99696
Reliability	0.5	0.31	0.16785	0.08292	0.69068	0.08292	0.03886	0.16785	0.03886	0.8368
Invasiveness	0.5	0	0.5	0.98461	0.5	0.5	0	0	0	0.00031

5.5.1.2. I/O Performance Criteria Weighting

Using the weighting schema discussed in Document 3 the following overall I/O Performance Criteria were generated by summing the product of each alternative's score times each criterion's valued weight.

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
IF0P1	0.5000	0.2515	0.5372	0.5427	0.4607	0.4282	0.3914	0.4860	0.4234	0.3889

5.5.2. Utilization of Resources Criteria Grading

Each alternative was assigned a performance grade (UFXiP0) of how it valued under each criterion. The values for installation time were automatically calculated from its sub-criteria and automatically scored in section 5.5.5.

Criterion	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
1. Design Cost	150K	1 M	1.8 M	1 M	10 M	25 M	100 M	9 M	0	10 K
2. Consumer Cost	150K	3 M	370 K	210 K	50 M	45 M	100 M	1.6 M	1.5 M	25 K
3. Operating Cost	150K	3 M	200 K	60 K	216 K	5 K	100 M	50 K	1.5 M	1 K
4. Installation Time										
4a. Design Time	45	30	30	0	90	180	30	730	7	365
4b. Field Time	45	60	90	0	30	180	30	365	60	365
4c. Train Time	30	90	45	30	45	30	30	60	0	365
5. Ease of Use	7	5	8	9	9	4	1	6	9	10

5.5.2.1. Utilization of Resources Criteria Scoring

The performance grades were entered into the scoring functions for each criterion and a score was generated (USFiP0).

Criterion	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
1. Design Cost	0.96	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	1.00
2. Consumer Cost	0.50	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
3. Operating Cost	0.00	0.00	0.00	0.00	0.00	0.99	0.00	0.04	0.00	1.00
4. Installation Time	0.40	0.44	0.45	0.61	0.13	0.05	0.59	0.00	1.00	0.00
5. Ease of Use	0.50	0.60	0.45	0.39	0.39	0.65	0.83	0.55	0.39	0.00

5.5.2.2. Utilization of Resources Criteria Weighting

Using the weighting schema discussed in Document 3 the following overall I/O Performance Criteria were generated by summing the product of each alternative's score times each criterion's valued weight.

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
UF0P1	0.4947	0.1878	0.1665	0.6366	0.0892	0.2951	0.2543	0.0950	0.5089	0.4209

5.6. Trade-Off Requirement

In accordance with Document 3, the Trade-Off Requirement was calculated with an equal weighting of the I/O and U/R criteria.

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
TF0P1	0.4974	0.2197	0.3519	0.5897	0.2749	0.3616	0.3228	0.2905	0.4662	0.4049

5.7. Sensitivity Analysis

In order to show no bias in our MUAT analysis we ran trade-off weights at values from 0 to 100% by increments of 10% for both I/O and U/R Requirements. This table shows that Alternative 4 is not sensitive to changes in either I/O or U/R Requirements.

% I/O	% U/R	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
0	100	0.4947	0.1878	0.1665	0.6366	0.0892	0.2951	0.2543	0.0950	0.5089	0.4209
10	90	0.4953	0.1942	0.2036	0.6272	0.1263	0.3084	0.2680	0.1341	0.5004	0.4177
20	80	0.4958	0.2005	0.2407	0.6179	0.1635	0.3217	0.2817	0.1732	0.4918	0.4145
30	70	0.4963	0.2069	0.2777	0.6085	0.2006	0.3350	0.2954	0.2123	0.4833	0.4113
40	60	0.4968	0.2133	0.3148	0.5991	0.2378	0.3483	0.3091	0.2514	0.4747	0.4081
50	50	0.4974	0.2197	0.3519	0.5897	0.2749	0.3616	0.3228	0.2905	0.4662	0.4049
60	40	0.4979	0.2260	0.3889	0.5803	0.3121	0.3749	0.3365	0.3296	0.4576	0.4017
70	30	0.4984	0.2324	0.4260	0.5709	0.3492	0.3883	0.3502	0.3687	0.4491	0.3985
80	20	0.4989	0.2388	0.4631	0.5615	0.3864	0.4016	0.3639	0.4078	0.4405	0.3953
90	10	0.4995	0.2451	0.5001	0.5521	0.4235	0.4149	0.3777	0.4469	0.4319	0.3921
100	0	0.5000	0.2515	0.5372	0.5427	0.4607	0.4282	0.3914	0.4860	0.4234	0.3889

Note that Alternative 4 is the clear winner at all sensitivities. This confirms that the original AHP Prioritized Trade-Off Scoring is indeed a valid alternative to the traditional MUAT analysis.

5.8. Technology Requirement

In sync with our Document 3 technological requirements and having selected Alternative 4 (as confirmed by two separate trade-off studies), if we select COTS components we will incur a $0 development cost. However, we have capped initial costs at $1million as a precaution. According to our product schedule, we can deploy this technology by March 2007, also in line with our Document 3 technology requirements. As this technology is currently installed in all 30 Major League ballparks, it also meets out predetermined form and fit specifications.

6. Systems Engineering Document: Product Use Case Model

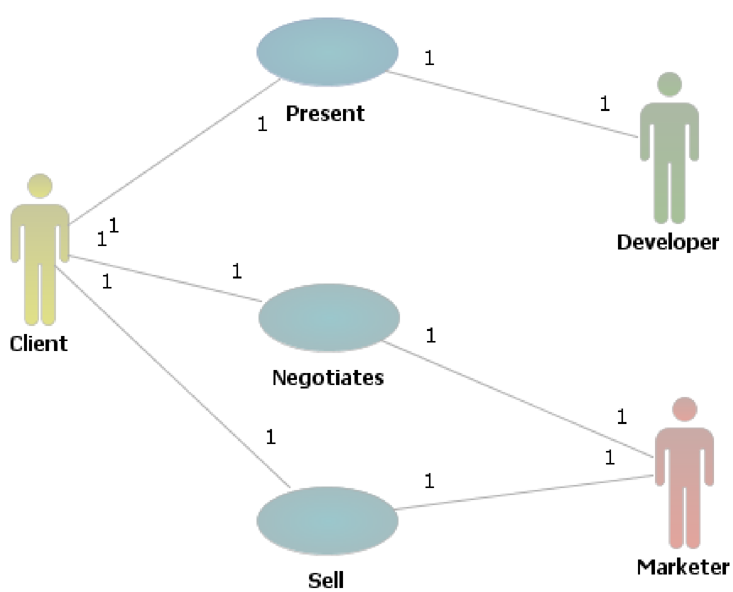
6.0. Configuration Management

Document Lead: SS
Assistant: DH

Date	Version	Team Members
9/20	0.1	DH,SS
9/21	0.2	MD,SS
9/24	0.3	FD
9/24	0.4	SS
9/24	0.5	MD
9/25	0.6	FD
9/26	1.0	MD,FD,DH,RF,SS
11/8	1.1	MD,DH
11/24	1.2	MD, DH
11/30	2.0	MD,FD,DH,RF,SS

The *Use Case Model* contains aspects of the use case report, use case diagrams and the use case requirements specification. This will model the system at high and low levels and consider the functional, non-functional and supplementary requirements. This model will also contain a business use case, modeling the business and financial qualities of the intended system.

6.1. Business Use Case



6.1.1. Business Model

Like any product, the UIS must be successfully marketed and sold for a profit. Accordingly, the target audience and potential customer of our ***UIS with Umpire System*** is Major League Baseball (MLB). The rationale for this decision is based on two equally compelling factors, namely, (1) MLB's clear desire for the capability our system provides, and (2) MLB has the financial resources to pay for it.

Specifically, consider that MLB has already installed the current version of QuesTec's UIS in roughly half of its ballparks. This fielding, beginning in 2001, was a direct response to the Commissioner's desire to enforce the strike zone as stated in the Rules of the Game. Simply put, the umpire's ability and motivation to consistently and accurately call balls and strikes had deteriorated to the point of open mockery; accordingly, the UIS was meant as a technological means of getting them back "on board."

Predictably, the umpires immediately called foul, questioning everything from the UIS' algorithm to the experience of its operators. This discontent was further fueled by the inflammatory comments of baseball broadcasters and writers, who questioned the impact on the technology on the purity of the game.

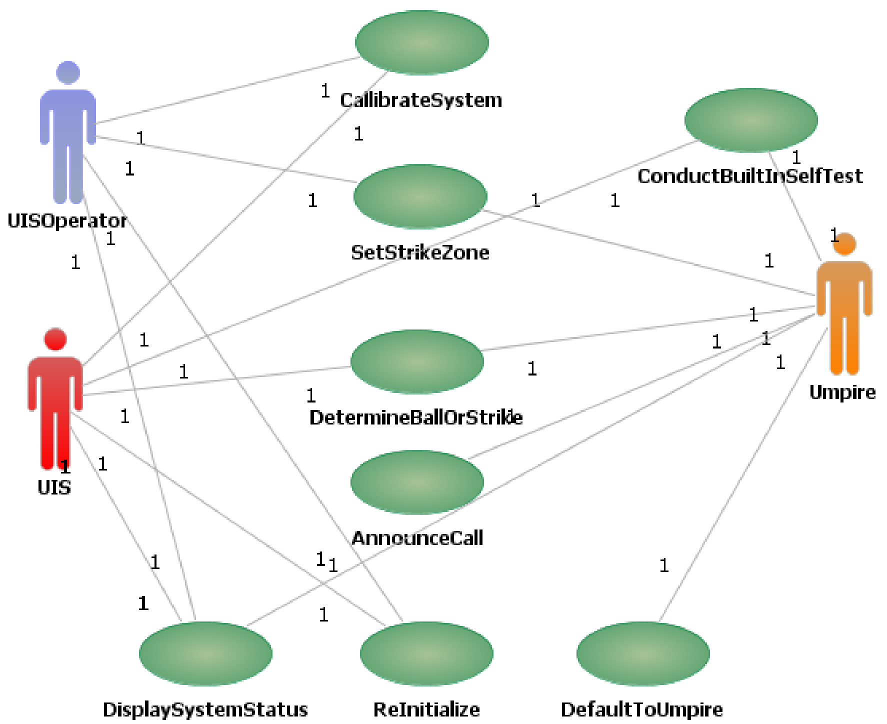
With this in mind, we know that:

a. The League wants a way to call balls and strikes in accordance with the rules
b. MLB is willing to and capable of paying for a high tech solution
c. The umpires (and the game's traditionalists) do not like the current fix

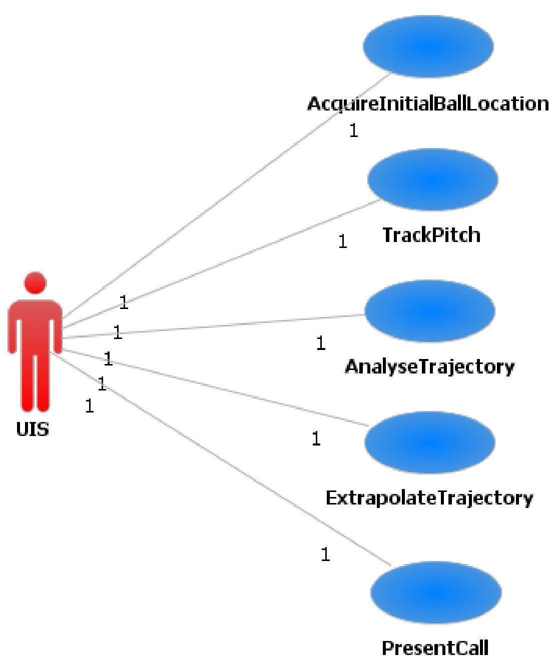
Drawing on these facts, we feel that our system – a system which merges the advantages of technology with the fundamental, traditional role of the umpire – will appeal to the League and be quite marketable. Moreover, by gaining the approval of MLB, we may easily elicit the future support of the NCAA and expand our market 10-fold.

6.2. Use Case Model: Product

6.2.1. High Level



6.2.2. Low Level



6.3. Use Case Report

6.3.1 High Level Use Cases

```
Name: Default to Umpire
Level: High
Description: This use case describes a top-level overview of the
   interaction between umpire, pitcher, batter and catcher.
Scope: One at-bat
Actors: Plate Umpire
Preconditions: All bases are unoccupied.
Main Success Scenario
1.  The system is in reset state and the Pitcher has the ball.
2.  The Plate Umpire instructs the batter to get ready.
3.  IF the Batter fails to take position THEN
         3.1. A STRIKE is called.
         3.2. GOTO 9.
       ELSE continue.
4.  The Plate Umpire signals the pitcher to throw ball.
   4.1. IF the Pitcher takes the signal from an illegal position THEN
         4.1.1. A BALL is called.
         4.1.2. GOTO 9.
       ELSE continue.
   4.2. IF the Pitcher takes more than two pumping motions THEN
         4.2.1. A BALL is called.
         4.2.2. GOTO 9.
       ELSE continue.
   4.3. IF the Pitcher takes > 20 seconds to deliver the pitch THEN
         4.3.1. A BALL is called.
         4.3.2. GOTO 9.
       ELSE continue.
5. The pitcher proceeds to throw the ball.
   5.1. IF the Pitcher makes an illegal pitch THEN
         5.1.1. A BALL is called.
         5.1.2. GOTO 9.
       ELSE continue.
6.  IF Batter steps back / swings to create catcher's interference THEN
      6.1. A STRIKE is called.
      6.2. GOTO 9.
    ELSE continue.
7. IF the ball is fouled THEN
      7.1. IF there are less than two strikes THEN
            7.1.1. A STRIKE is called.
            7.1.2. GOTO 9.
          ELSE IF the ball is foul tipped THEN
            7.1.3. A STRIKE is called.
            7.1.4. GOTO 9.
          ELSE IF the ball is bunted and not caught legally THEN
            7.1.5. A STRIKE is called.
            7.1.6. GOTO 9.
          ELSE continue.
   ELSE continue.
8. IF the ball is NOT swung at by the Batter THEN
      8.1. IF the pitch enters the strike zone THEN
            8.1.1. A STRIKE is called.
```

```
            8.1.2. GOTO 9.
          ELSE continue.
      8.2. IF the pitch does NOT enter the strike zone THEN
            8.2.1. A BALL is called.
            8.2.2. GOTO 9.
          ELSE continue.
   ELSE IF the ball is swung at THEN
      8.3. IF the Batter misses the ball THEN
            8.3.1. A STRIKE is called.
            8.3.2. GOTO 9.
          ELSE continue.
      8.4. IF the Batter misses and is struck by the ball THEN
            8.3.1. A STRIKE is called.
            8.3.2. GOTO 9.
          ELSE continue.
9. IF there are three strikes THEN exit use case.
   ELSE IF there are four balls THEN exit use case.
   ELSE IF an exit ruling is made THEN exit use case.
   ELSE GOTO 1.
```

Post-conditions: Batter is on base, out, or ejected.
Issues: Some of the calls may change if there are runners on base.

Name: **Calibrate System**
Level: High
Description: UISOperator shall calibrate the system to ensure that the cameras are properly trained on the target area and capable of tracking the pitch from the mound to the strike zone. Additionally, he will conduct an extensive diagnostic test.
Frequency: Prior to the start of each game or each week whichever is sooner.
Scope: A UIS system in a major league ballpark.
Trigger: The UISOperator directs the system to conduct calibration.
Primary Actor: UISOperator
Secondary Actor: UIS
Preconditions: The UIS passes a built-in self test and is powered on. Pitching machine is set-up, manned, and prepared to deliver balls into the center of the strike zone. Pressure sensitive calibration board is in place and prepared to record strike data.
Main Success Scenario
1. The UISOperator directs the system to conduct calibration.
2. UIS moves into its Initialized State and is prepared to acquire the ball.
3. UISOperator sets the strike zone in accordance with the Calibration board.
4. UISOperator directs the pitching machine operator to send a ball into the center of the strike zone; ball is sent.
5. UIS acquires, tracks, analyzes, and extrapolates the trajectory of the pitch.
6. UIS compares the trajectory to the strike zone and assesses the pitch as a ball or a strike.
7. UISOperator compares the extrapolated trajectory to the real point of impact as recorded by the calibration board.
8. If the absolute error (Euclidian norm) of the real and Extrapolated impact differ less than .25”, then the system is “calibrated.” [Exit Use Case]

9. Else, the UIS operator inputs an appropriate correction; return to Step 4.

Post-conditions: The UIS is properly calibrated.
Author: Matt Dabkowski, Version 1, 21 SEP 05

Name: **Set StrikeZone**
Level: High
Description: The UISOperator establishes and inputs the strike zone for an individual batter.
Frequency: Prior to each pitch.
Scope: An at bat in a Major League Ballpark.
Primary Actor: UISOperator
Secondary Actor: Umpire
Preconditions: The UIS is powered up, functioning properly and ready to acquire a pitch. Batter is in the batter's box, feet set, and ready to swing. Pitcher has not yet delivered the ball.
Main Success Scenario

1. UISOperator observes the appropriate side-view monitor to gain the proper perspective.
2. UISOperator establishes the lower vertical limit of the strike zone to the hollow beneath the batter's knees.
3. UISOperator establishes the upper vertical limit of the strike zone to the midpoint between the batter's waist and shoulders.
4. UISOperator enters the upper and lower limits into the UIS database.
5. UIS confirms the receipt of the limits. [Exit Use Case]

Post-conditions: UIS has received all the inputs required to construct the strike zone for Batter X on Pitch Y.
Author: Matt Dabkowski, Version 1, 21 SEP 05

Name: **Determine Ball Or Strike**
Level: High
Description: The UIS acquires the initial ball location, tracks the pitch. If batter does not attempt to make contact with the pitch, the UIS analyzes / extrapolates the ball's trajectory and presents the call.
Frequency: Prior to / during / and after each pitched ball.
Scope: A UIS system in a major league ballpark during / after a pitch.
Primary Actor: UIS
Supporting Actor: Umpire
Preconditions: The UIS is powered-up and prepared to acquire a pitch. Additionally, the UIS has received the vertical limits of and constructed the strike zone.
Main Success Scenario

1. UIS is observing the area surrounding the pitcher's mound and scanning for a projectile.
2. Pitcher enters wind-up and releases the ball.
3. UIS identifies the ball at the moment of release. [include **Acquire Initial Ball Location**]
4. UIS utilizes its VTT-cameras to track the pitch and beings to collect position, velocity, and acceleration data [include **Track Pitch**]
5. If UIS observes a radical change in acceleration (indicative of a ball which is struck or redirected prior to or just after

entering the strike zone), then [End Use case] [extend **Default to Umpire**]
6. Otherwise, UIS conducts regression on the data to project the ball's trajectory through the strike zone. [include **Extrapolate Trajectory**]
7. UIS compares its prediction with the strike zone to asses the pitch as a ball or a strike. [include **Analyze Trajectory**]
8. UIS sends the results to the UISOperator's monitor as well as the Umpire's heads-up display. [**Present Call**]

Post-conditions: A given pitch has been assessed as a Ball or Strike.
Author: Matt Dabkowski, Version 1, 21 SEP 05

Name: **ReInitialize**
Level: High
Description: UIS shall reinitialize itself after each pitch.
Scope: One pitch
Primary Actors: UISOperator, UIS
Preconditions: UIS has successfully **Present Call** for previous pitch.
Main Success Scenario
1. UISOperator instructs UIS to reinitialize.
2. UIS will recalibrate its camera positions.
3. UIS backs up previous data set.
4. UIS purges its internal RAM of previous data set. [End Use Case]

Post-conditions: UIS has successfully purged its memory and positioned cameras to the init state.
Author: David Haas, Version 2, 21 SEP 05

Name: **Conduct Built In Self-Test**
Level: High
Description: UIS shall conduct built in self-tests to ensure the proper functionality of the system components.
Scope: One Pitch
Actors: UIS, UISOperator
Preconditions: UIS has successfully finished the last call
Main Success Scenario
1. UIS is "inactive"
2. UIS pings left and right VTTs

3a. VTTs return status, no errors

4. UIS checks connectivity with Umpire's voice and graphic interfaces, no errors.

5a.UIS conducts internal diagnostic, no errors

6. UIS awaits "instructions."

Alternative Flows:
3b. If VTT camera returns an error, UIS displays error message to UIS operator with an estimated/expected effect.
5b. If there is error in voice communication with Umpire, default to graphical only.
Post-conditions: UIS fully operational, awaiting next pitch.
Author: Shahan Sikander, Version 1, 21 SEP 05
Author: Matt Dabkowski, Version 2, 8 NOV 05

6.3.2. Low Level Use Cases

This will contain the low level use case reports from the low level use case diagrams.

Name: **Acquire Initial Ball Location**
Level: Low
Description: UIS acquires and identifies the ball as it leaves the pitcher's hand.
Frequency: Every pitch.
Scope: A UIS system in a major league ballpark prior to / just after a pitch.
Primary Actor: UIS
Preconditions: UIS is powered up, scanning the area surrounding the pitcher's mound, and observing the wind-up.
Main Success Scenario

1. Pitcher releases the ball.
2. UIS VTT cameras detect a projectile moving horizontally, at a high velocity, away from the observed area.
3. UIS VTT cameras focus on the projectile and compare its signature to a set of identification criteria.
4. UIS identifies the projectile as a baseball. [End Use Case] [extend **Determine Ball or Strike, Step 4**].

Post-conditions: UIS has acquired and identified the ball.
Author: Matt Dabkowski, Version 1, 21 SEP 05

Name: **Track Pitch**
Level: Low
Description: UIS
Frequency: Every Pitch
Scope: A UIS system in a major league ballpark just after the pitcher has released the ball.
Primary Actor: UIS
Preconditions: UIS has acquired and identified the ball immediately following the pitcher's release.
Main Success Scenario

1. UIS VTT cameras follow the pitch throughout its flight.
2. UIS collects periodic data points of the trajectory, capturing the ball's position, velocity, and acceleration.
3. UIS follows the ball until the VTT cameras can no longer view the ball, the ball stops, OR the ball experiences a radical change in acceleration. [End Use Case] [extend **Determine Ball or Strike, Step 5**].

Post-conditions: UIS has tracked the pitch and collected myriad data points capturing the ball's trajectory.
Author: Matt Dabkowski, Version 1, 21 SEP 05

Name: **Extrapolate Trajectory**
Level: Low
Description: UIS utilizes a regression model to extrapolate (project) the trajectory of the pitch through the final / unobservable portion of its flight.
Frequency: After every pitch that the batter does not attempt to make contact with.
Scope: A UIS system in a major league ballpark just after a pitch leaves the VTT's observable area.

Primary Actor: UIS
Preconditions: The UIS has successfully tracked a pitch from its release to the catcher's glove or when its view becomes obstructed (whichever comes first).
Main Success Scenario
1. The UIS conducts regression on the data points collected during the ball's flight.
2. The UIS extrapolates the trajectory until its length reaches 63 feet (this is to ensure the trajectory is extended through the strike zone). [extend **Determine Ball or Strike, Step 7**]

Post-conditions: The UIS has reconstructed the flight of the baseball through a distance that includes the strike zone.
Author: Matt Dabkowski, Version 1, 21 SEP 05

Name: **Analyze Trajectory**
Level: Low
Description: The UIS compares the extrapolated trajectory to the strike zone, and assesses whether any portion of the ball was in any portion of the strike zone.
Scope: A UIS system in a major league ballpark just after a pitch.
Primary Actor: UIS
Preconditions: UIS has successfully extrapolated a pitch, which the batter has not attempted to make contact with.
Main Success Scenario
1. The UIS overlays the extrapolated trajectory on its projected strike zone.
2. If the any portion of the ball enters any portion of the strike zone, then the UIS assess the pitch a strike.
3. Otherwise, the UIS assess the pitch a ball. [extend **Determine Ball or Strike, Step 8**]

Post-conditions: The UIS has assessed a pitch as a ball or a strike.
Author: Matt Dabkowski, Version 1, 21 SEP 05

Name: **Present Call**
Level: Low
Description: The UIS sends its assessment of ball or strike to the Umpire's heads-up display and the Umpire announces the call.
Scope: A UIS system in a major league ballpark just after a pitch.
Primary Actor: UIS
Supporting Actor: Umpire
Preconditions: The UIS has determined whether a pitch is a ball or a strike.
Main Success Scenario
1. UIS sends its assessment to the umpire via electronic message.
2. Umpire receives the message on his heads-up display.
3. Message reads Ball, Strike, or NoData.
4a. Umpire decides whether the pitch is a ball or a strike.
5. Umpire announces call. [End Use Case]

Post-conditions: Game continues; ready for next pitch.
Alternative Flow:
4b. If the pitch was not a ball or a strike, then Umpire will announce other conditions such as balk or ejection.

Author: Matt Dabkowski, Version 1, 21 SEP 05
Author: Matt Dabkowski, Version 1, 8 NOV 05

6.4. Use Case Requirements Specification

6.4.1. Specific Requirements

- Req. SR1: The system shall determine whether a pitch was a ball or a strike in the case that the batter does not swing.
- Req. SR2: The system shall not interfere with the batter.
- Req. SR3: The system shall not interfere with the visibility of the catcher.
- Req. SR4: The system shall not interfere with the visibility of the Home Plate Umpire.
- Req. SR5: The system shall not interfere with the visibility of the batter.
- Req. SR6: The system shall not interfere with the visibility of the pitcher.
- Req. SR7: The system shall fit within the baseball field.
- Req. SR8: The system shall not consume more than x watts of electricity per game.
- Req. SR9: The system shall have components that are replaceable within 10 minutes.
- Req. SR10: The system shall have components that are maneuverable by one person.
- Req. SR11: The system shall be user-friendly.
- Req. SR12: The system shall have an interface for the user.
- Req. SR13: The system shall be able to distinguish flying objects and determine what is a baseball and what is an external flying object.
- Req. SR14: The system shall not weigh more than 100lbs per major component.
- Req. SR15: The system shall allow the user to power off the system manually and logically.
- Req. SR16: The system shall determine “strike-zone” on a batter per batter basis.
- Req. SR17: The system shall maintain a rolling record of each batters previous strike zones.
- Req. SR18: The system shall withstand rain.
- Req. SR19: The system shall withstand direct sunlight.
- Req. SR20: The system shall withstand winds up to 50MPH.
- Req. SR21: The system shall withstand temperature ranging from 0 ^{o}F and 140 ^{o}F.
- Req. SR22: The system shall withstand impacts stemming from a baseball or similar projectile at speeds of 0 MPH to 120MPH.
- Req. SR 23: The system shall allow the user to perform extensive diagnostic testing.
- Req. SR24: The system shall allow the UIS operator to calibrate the system.
- Req. SR25: The system shall perform a built-in self test after calibration every time it is powered on.
- Req. SR26: The system shall have a pressure sensitivity calibration board in place and prepared to record strikes.
- Req. SR27: The system shall be calibrated using a pitching machine.
- Req. SR28: The system shall be in an initialized state in order be calibrated.

- Req. SR30: The system shall have the strike zone set by the UIS operator in a per batter basis.
- Req. SR31: The system shall only allow the strike zone to be set once all of the monitors have gained the appropriate view.
- Req. SR32: The system shall have the strike zone lower and upper vertical limits set by the UIS operator.
- Req. SR33: The system shall have the strike zone lower and upper vertical limits save in a database.
- Req. SR34: The system shall use the VTT-cameras to track the location of the ball.
- Req. SR35: The system shall send the results to the Umpire's heads-up display.
- Req. SR36: The system shall use a regression model to extrapolate the trajectory of the pitch through the final/unobservable portion of the flight.
- Req. SR37: The system shall conduct a regression on the data points gathered during the ball's flight.
- Req. SR38: The system shall relay that pitch call to the umpire via an electronic message.
- Req. SR39: The system shall recalibrate its cameras after each pitch.
- Req. SR40: The system shall purge the data from each pitch to a database.
- Req. SR41: The system shall display the system status upon request to display system status from the UIS operator.
- Req. SR42: The system shall recalibrate the cameras upon a request to re-initialize the system.
- Req. SR43: The system shall display current status from the information residing in RAM.
- Req. SR44: The system shall conduct the built-in self-test when the UIS operator requests a built-in self-test.
- Req. SR45: The system shall recalibrate the camera positions.

6.4.2. Functional Requirements

- Req. FR1: The system shall be capable of accommodating left-handed and right-handed batters.
- Req. FR2: The system shall have a display with the image of a batter.
- Req. FR3: The system shall have a display with the outcome of a pitch.
- Req. FR4: The system shall have a display where the user can view the trajectory.
- Req. FR5: The system shall have camera like equipment to track the ball.
- Req. FR6: The system shall have sensors feeding data to the system with a lapse of less of 1ms.
- Req. FR7: The system shall be capable of detecting foul balls.
- Req. FR8: The system shall have an external power button.
- Req. FR9: The system shall run on AC Power connections.
- Req. FR10: The system shall save back up data to an external source. (Source can be DVD/VHS/Unix/Windows machine)
- Req. FR11: The system shall have an interface similar to a computer.

- Req. FR12: The system shall have a keyboard interface.
- Req. FR13: The system shall have a mouse or arrows to navigate through the menus.
- Req. FR14: The system shall perform calculations and calibrations via a computer program.
- Req. FR15: The system must back up data to the external source during each inning.
- Req. FR16: The system shall operate with wireless communication between sensors and the main operating console.
- Req. FR17: The system shall call a strike or a ball upon registering a pitch.
- Req. FR18: The system shall report a pitch call on the user interface.
- Req. FR19: The system shall inform the pitch call to the umpire via an electronic message.
- Req. FR 20: The system must allow the user to perform extensive diagnostic testing.
- Req. FR21: The system shall use a software/menu driven interface where the user can set the system into initialized state.
- Req. FR22: The system shall use only allows users with the appropriate level of authority to set the system into initialized state.
- Req. FR23: The system shall collect information on the trajectory of the pitch.
- Req. FR24: The system shall be capable to accommodate left-handed and right-handed pitchers.
- Req. FR25: The system shall have the capability to be reset when certain conditions are met.
- Req. FR26: The system shall allow a user to reset the system manually and automatically
- Req. FR27. The system shall reset itself after it has recorded and processed the pitch as either a ball or a strike.
- Req. FR28: The system shall reset itself when an external situation has occurred such as batter interference, catcher interference, and pitcher not throwing the ball after a windup.
- Req. FR29: The system shall be able to detect the presence of a batter inside of the batters box.
- Req. FR30: The system shall call a strike if a batter is not detected in the batters box.
- Req. FR31: The system shall have a maximum allotted time frame between the time the batter enters the batters box and a pitch is thrown.
- Req. FR32: The system shall have an internal clock that registers the time between the pitch call (ball or strike) and the time the batter enters the batters box and prepare for the next pitch.
- Req. FR33: The system clock shall restart after every pitch has been registered by the system.
- Req. FR34: The system clock shall be restarted when the Plate Umpire instructs the batter to be ready.

- Req. FR35: The system shall detect the pitchers position when the Plate Umpire signals the pitcher to throw the ball.
- Req. FR36: The system shall detect the pitchers position to determine whether or not the pitcher is in a legal position to throw the ball.
- Req. FR37: The system shall automatically call a ball if the pitcher throws the ball from an illegal position.
- Req. FR38: The system shall detect the pitcher in wind up motion.
- Req. FR39: The system shall reset the count if the pitcher winds up for a pitch and does not throw the ball.
- Req. FR40: The system shall detect the amount of times the pitcher pumps the ball before the ball is pitched.
- Req. NFR41: The system shall call a ball if the pitcher pumps the ball more than two times.
- Req. FR42: The system shall detect when the pitcher has stepped off of the pitchers bag.
- Req. FR43: The system shall detect the difference between a pitcher throwing to first, second, or third base in an attempt to force a runner out.
- Req. FR44: The system shall detect the ball being thrown to first, second, or third base and not call a ball or a strike.
- Req. FR45: The system shall call a ball when the pitcher has been given the signal from the Plate Umpire to throw the ball and does not throw the ball within 20 seconds from the time the Plate umpire gave the signal.
- Req. FR46: The system shall detect the pitch and signal it as a legal or illegal pitch.
- Req. FR47: The system shall detect the motion of the batter and determine if the batter has swung the bat or not.
- Req. FR48: The system shall detect the batter not making contact with the ball and the bat passing home plate.
- Req. FR49: The system shall register a bat not making contact with a pitched ball.
- Req. FR50: The system shall register a bat making contact with a pitched ball.
- Req. FR51: The system shall register a strike when the bat has not made contact with the ball and the bat has been swung past home plate.
- Req. FR52: The system shall analyze a bunt, a check swing, and a full swing to determine if the bat has not made contact with the ball and call a strike when the condition is met.
- Req. FR53: The system shall reset itself when a pitch has hit a batter.
- Req. FR54: The system shall reset the time when a player or official in the game calls for time.
- Req. FR55: The system shall allow the UIS operator to force a re-initialization of the UIS.
- Req. FR56: The system shall display on the heads-up display a message “ball” for a ball, “strike” for a strike, or “No Data” for a pitch not read.
- Req. FR57: The system shall register a foul ball and determine whether a strike shall be called.
- Req. FR58: The system shall register a foul ball and determine whether a no call shall be made.

- Req. FR59: The system shall register a bunted ball and determine whether a ball shall be called a strike based on the ball not being legally caught.
- Req. FR60: The system must allow the user to modify the ball, strike, out count upon receiving a contradictory call from a game official.
- Req. FR61: The system shall detect a pitched ball when the batter does not swing.
- Req. FR62: The system shall have the "strike zone" set by the UIS operator.
- Req. FR63: The system shall determine "strike-zone" on a batter per batter basis.
- Req. FR64: The system shall call a ball if none of the ball enters the strike zone.
- Req. FR65: The system shall call a strike when a ball has entered the "strike-zone"
- Req. FR66: They system shall call a ball when the ball has not entered the "strike-zone"
- Req. FR67: The system shall call a ball when a wild pitch has been thrown.
- Req. FR68: The system shall reset if a strike is called and the strike count has reached three.
- Req. FR 69: The system shall reset if a ball is called and the ball count has reached four.
- Req. FR 70: The system shall reset if the ball count and strike count has been reached.
- Req. FR71: The system shall reset for each team after each inning.
- Req. FR72: The system shall allow itself to be overruled by an assembly of field umpires.
- Req. FR73: The system shall set the strike zone to the lower vertical limit.
- Req. FR74: The system shall set the strike zone to the upper vertical limit.
- Req. FR75: The system shall extrapolate the trajectory after a pitch leaves the VTT-camera's observable area.
- Req. FR76: The system shall call a strike if any portion of the ball falls within the strike zone.
- Req. FR77: The system shall call a ball if a pitch does not enter strike zone.
- Req. FR78: The system shall allow a two-way communication between the UIS Operator and the Home Plate Umpire.

6.4.3. Nonfunctional Requirements

- Req. NFR1: The system shall have the capability to be reset within 5 seconds.
- Req. NFR2: The system shall be able to detect the presence of a batter inside of the batter's box within 2 seconds.
- Req. NFR3: The system shall call a strike if a batter is not detected in the batters box after 20 seconds have lapsed since the umpire called the batter into play.
- Req. NFR4: The system shall have a maximum allotted time frame between the time the batter enters the batter's box and a pitch is thrown of 20 seconds.
- Req. NFR5: The system shall have an internal clock that registers the time between the pitch call (ball or strike) and the time the batter enters the batter's box and prepare for the next pitch.
- Req. NFR6: The system clock shall restart after every pitch has been registered by the system within 30ms.

- Req. NFR7: The system clock shall be restarted when the Plate Umpire instructs the batter to be ready within 30ms.
- Req. NFR8: The system shall detect the pitchers position when the Plate Umpire signals the pitcher to throw the ball within 2 seconds.
- Req. NFR9: The system shall detect the pitcher's position to determine whether or not the pitcher is in a legal position to throw the ball within 2 seconds.
- Req. NFR10: The system shall automatically call a ball/strike when the ball has passed the strike/ball zone within 5ms.
- Req. NFR11: The system shall perform the built-in self-test in less than 20 seconds.
- Req. NFR12: The system shall detect the difference between a pitcher throwing to first, second, or third base in an attempt to force a runner out within 5ms.
- Req. NFR13: The system shall detect the ball being thrown to first, second, or third base and not call a ball or a strike within 5ms.
- Req. NFR14: The system shall call a ball when the pitcher has been given the signal from the Plate Umpire to throw the ball and does not throw the ball within 20 from the time the Plate umpire gave the signal.
- Req. NFR15: The system shall register a bat not making contact with a pitched ball within 30ms.
- Req. NFR16: The system shall register a bat making contact with a pitched ball within 30ms.
- Req. NFR17: The system shall reset the time when a player or official in the game calls for time within 30 ms.
- Req. NFR18: The system must allow the user to modify the ball, strike, out count upon receiving a contradictory call from a game official within the 20 seconds a batter has to be called into the batters box.
- Req. NFR19: The system shall reset for each team after each inning within 1 minute.
- Req. NFR20: The system shall only perform the built-in self-test after the UIS has successfully finished the last call.
- Req. NFR21: The system shall have an absolute error of .25".
- Req. NFR22: The system shall locate the ball from the release point of the pitcher.
- Req. NFR23: The system shall collect data from the ball via VTT-cameras. The data will be position, velocity, and acceleration.
- Req. NFR24: The system shall analyze a radical change in acceleration and position to determine if the bat has hit the ball.
- Req. NFR25: The system shall track every pitch that is thrown.
- Req. NFR26: The system shall track projectiles from 0 MPH to 150 MPH.
- Req. NFR27: The system shall track the trajectory of the ball at different points of the pitch in intervals of 2 ms.
- Req. NFR28: The system shall invoke the regression model after every pitch the batter does not attempt to make contact with.
- Req. NFR29: The system shall determine the end location of the ball as the catcher's glove.
- Req. NFR30: The system shall stop tracking the ball if there are external debris or view obstructions.

- Req. NFR31: The system shall read the trajectory at a length of 63 feet.

6.4.4. Supplementary / System Wide Requirements Specification

- Req. SRS1: The system will send the pitch call to the heads-up display then home plate umpire shall announce the call.
- Req. SRS2: The system shall aid the Home Plate Umpire on his calls of balls and strikes.
- Req. SRS3: The umpire shall also have a say on a ball or a strike call.
- Req. SRS4: The system shall be built to have robust connections between each link.
- Req. SRS5: The system shall have emergency shutdown switches to remove power in case of a danger.
- Req. SRS6: The system shall operate with less than 120 Volts per major unit.
- Req. SRS7: The system computer shall be maintained with the highest security available to avoid hacking, worms, and viruses.
- Req. SRS8: The system shall be built with power redundancy in order to avoid power outages.
- Req. SRS9: The system shall allow the umpires to overrule a call on the system.
- Req. SRS10: The system shall filter out unwanted audible interference.
- Req. SRS11: The system shall filter out unwanted electro-magnetic interference.
- Req. SRS12: The system shall filter out unwanted motion interference.
- Req. SRS13: The system shall filter out unwanted radar interference.
- Req. SRS14: The system shall be effective in low visibility conditions such as fog.
- Req. SRS15: The system shall have self-cleaning in lenses on the VTT-cameras.
- Req. SRS16: The system shall reside in a location away from fan interference.

7. Systems Engineering Document: Product Design Model

7.0. Configuration Management

Document Lead: SS
Assistant: DH

Date	Version	Team Members
11/3	0.1	MD,DH,SS
11/7	0.2	MD,DH
11/9	1.0	MD,FD,DH,RF,SS
11/24	1.2	MD, DH
11/30	2.0	MD,FD,DH,RF,SS

7.1. System interfaces

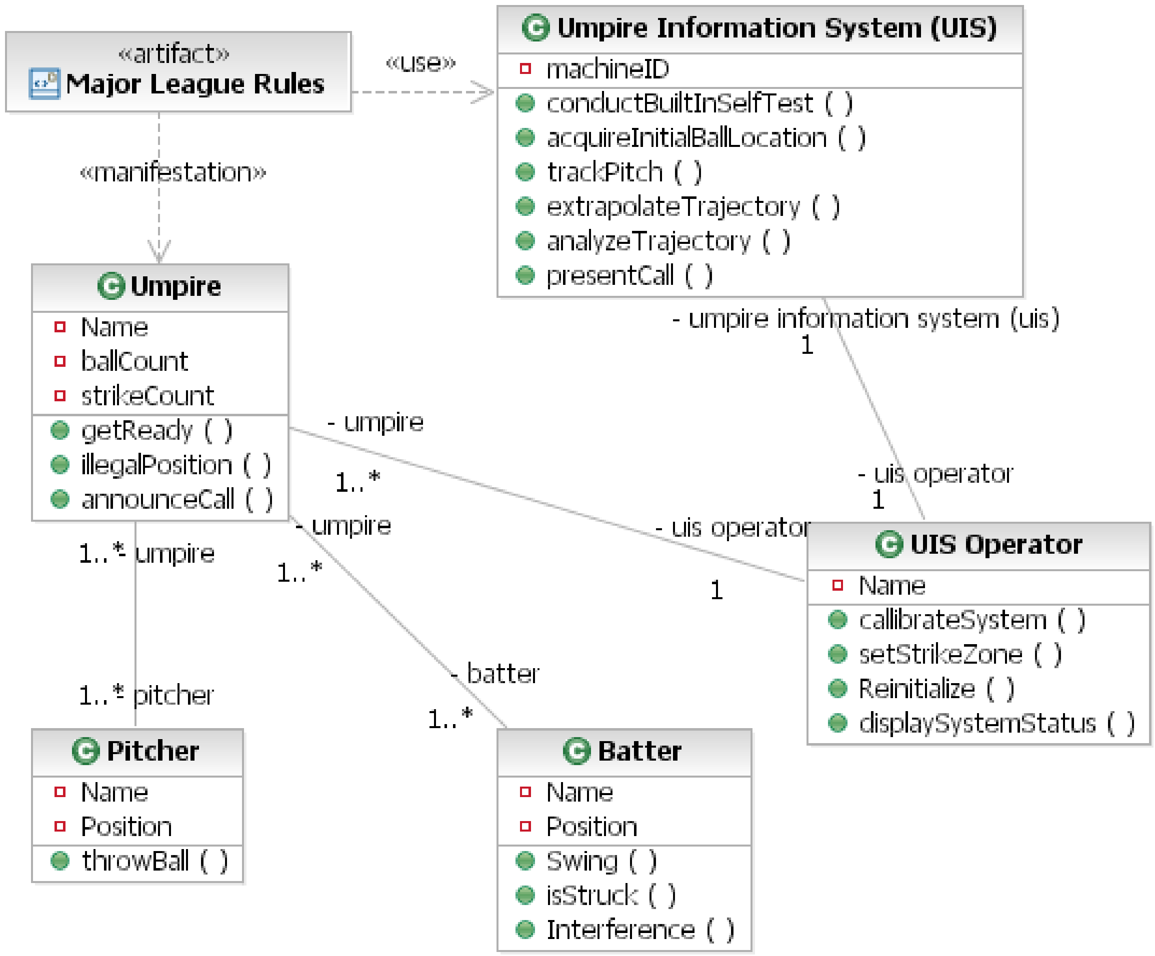
The system interfaces will be designed based on the application of concept exploration onto the customer requirements based upon the object model of Document 6. Operator notifications are designed into the system in order to provide feedback.

7.2. Design model\

The design model is the product of the requirements model and the analysis model and will eventually evolve into the implementation model, the testing model, and finally the operational model.

7.2.1. Class diagram

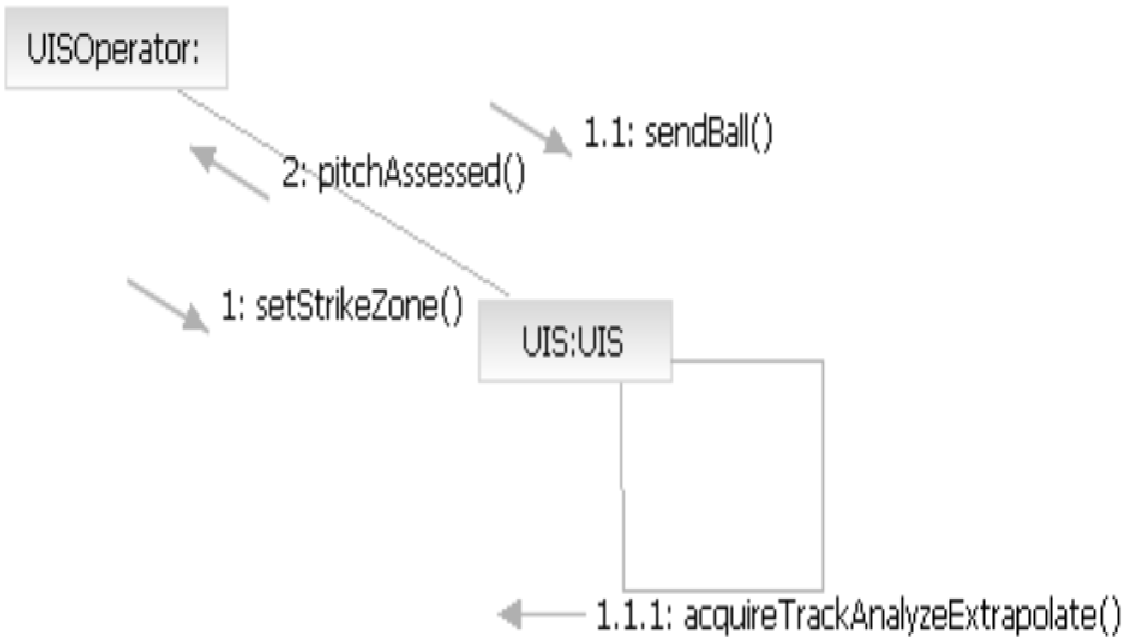
This class diagram shows the main classes involved in our top level system function:



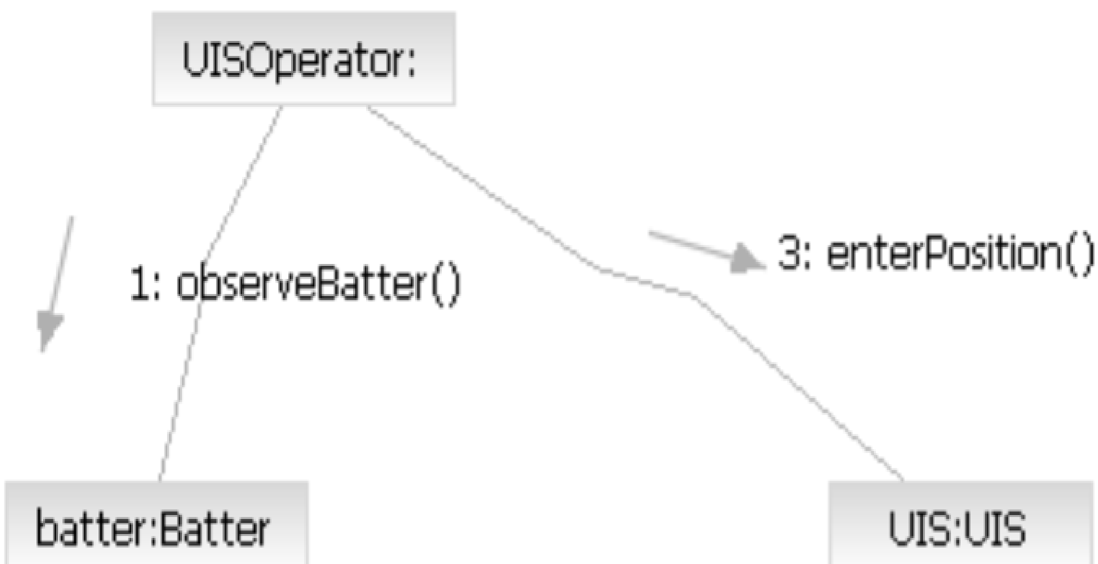
7.2.2. Communication diagrams

Returns from calls are not shown on the communication diagrams. See the sequence diagrams for return information.

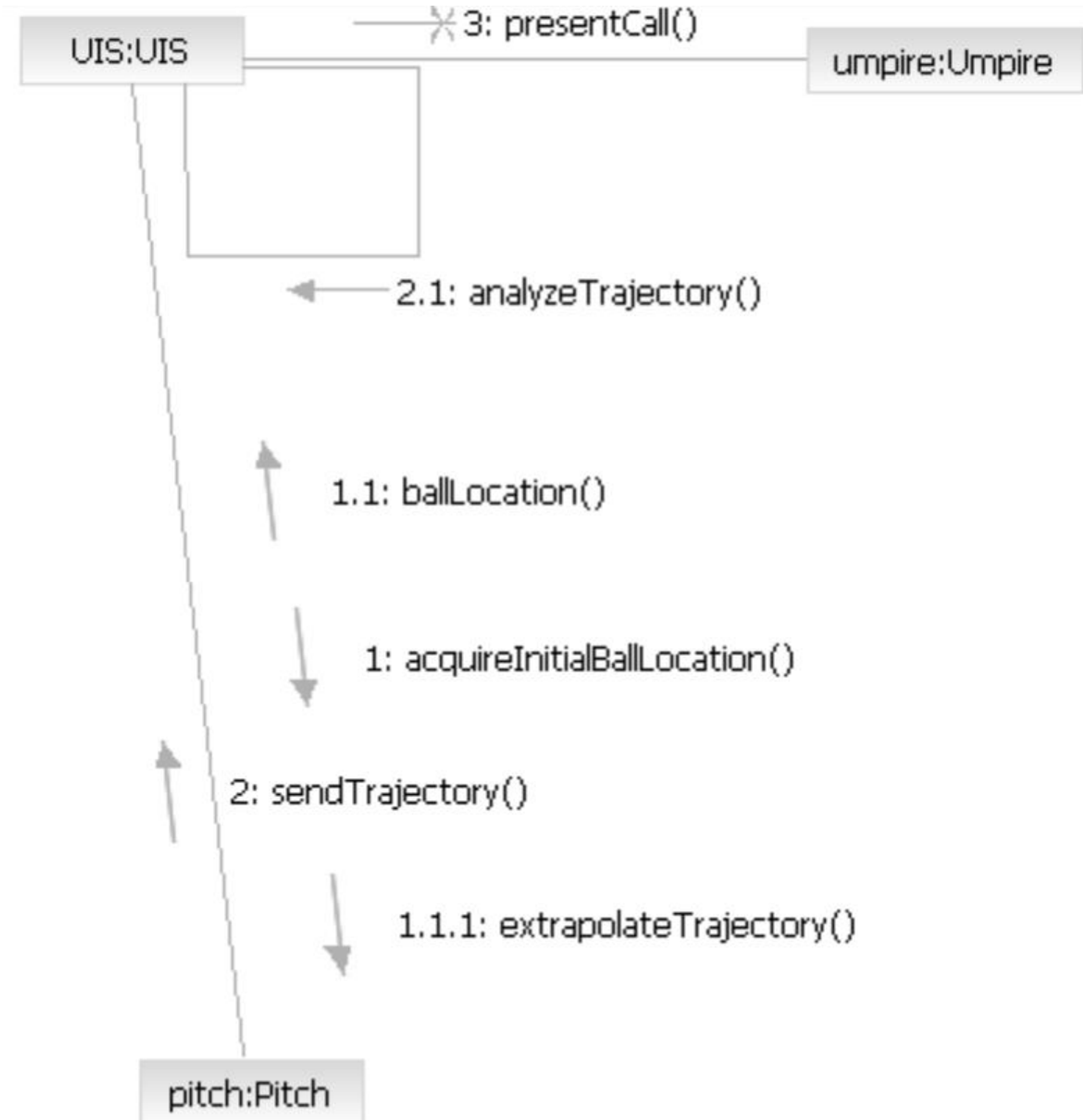
7.2.2.1. Commo diagram for Calibrate System use case



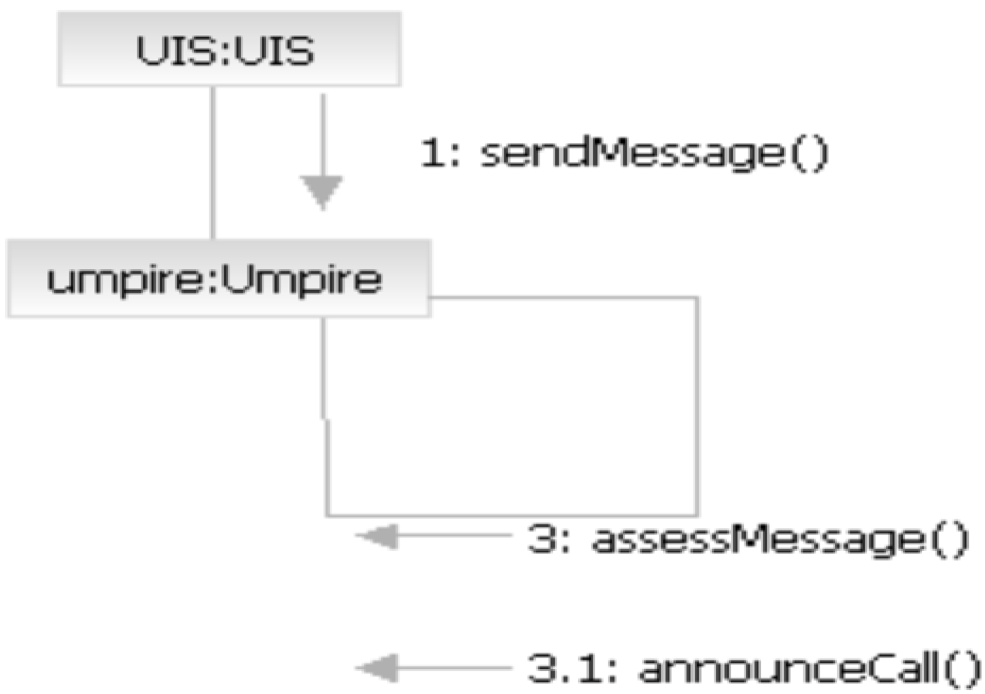
7.2.2.2. Commo diagram for Set StrikeZone use case



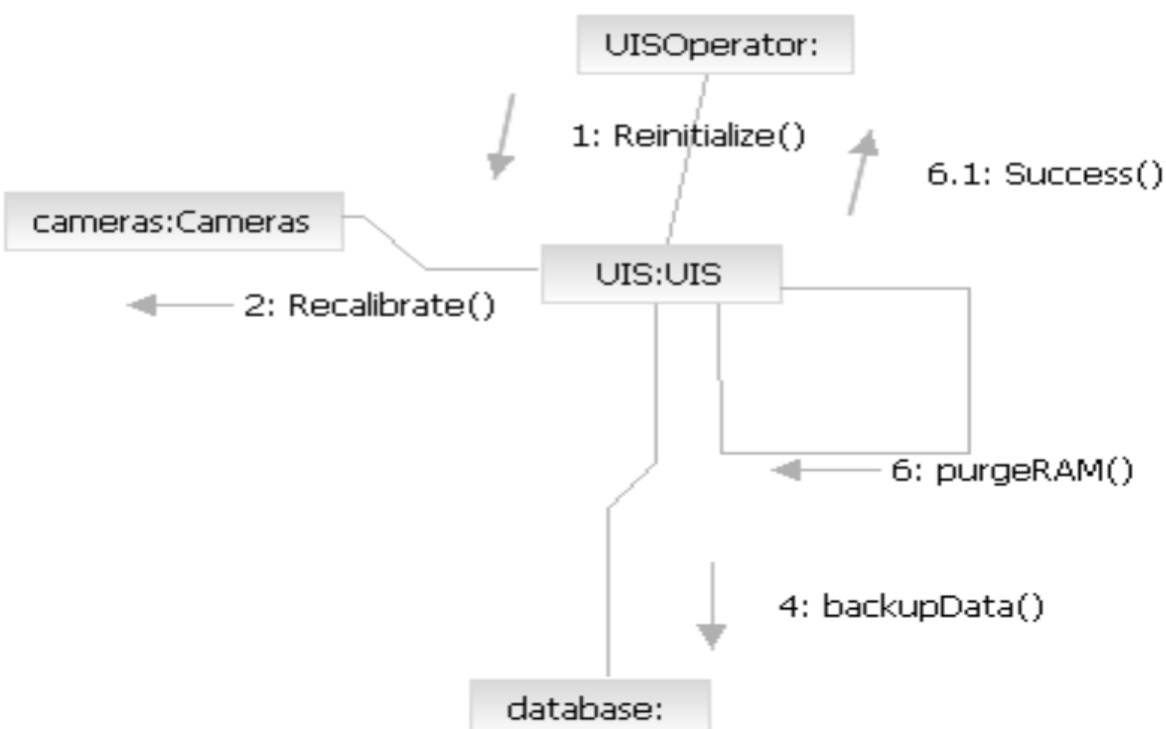
7.2.2.3. Commo diagram for Determine Ball Or Strike use case



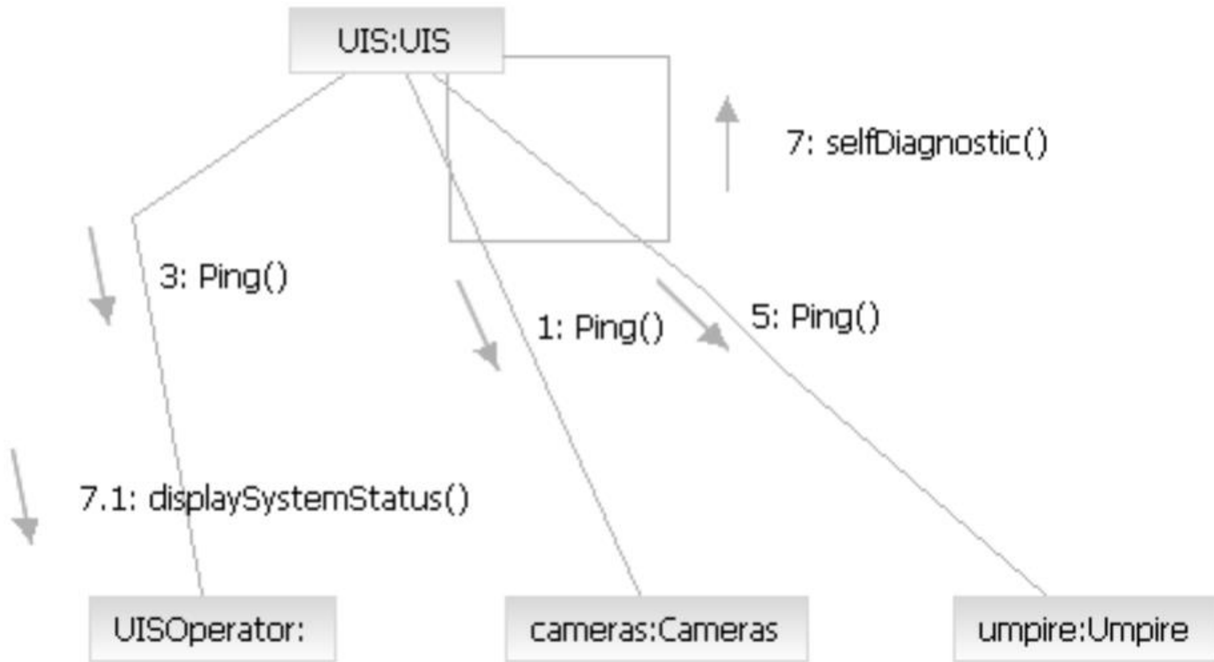
7.2.2.4. Commo diagram for Present Call use case



7.2.2.5. Commo diagram for ReInitialize use case

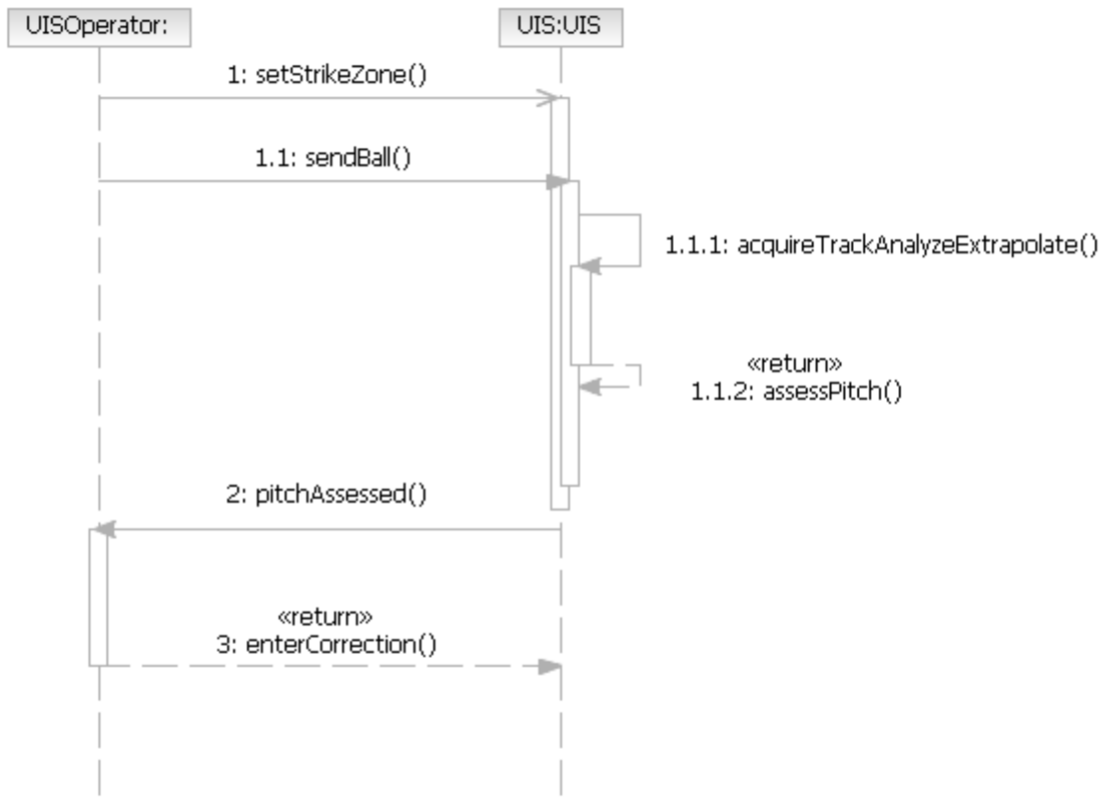


7.2.2.6. Commo diagram for Conduct Built In Self-Test use case

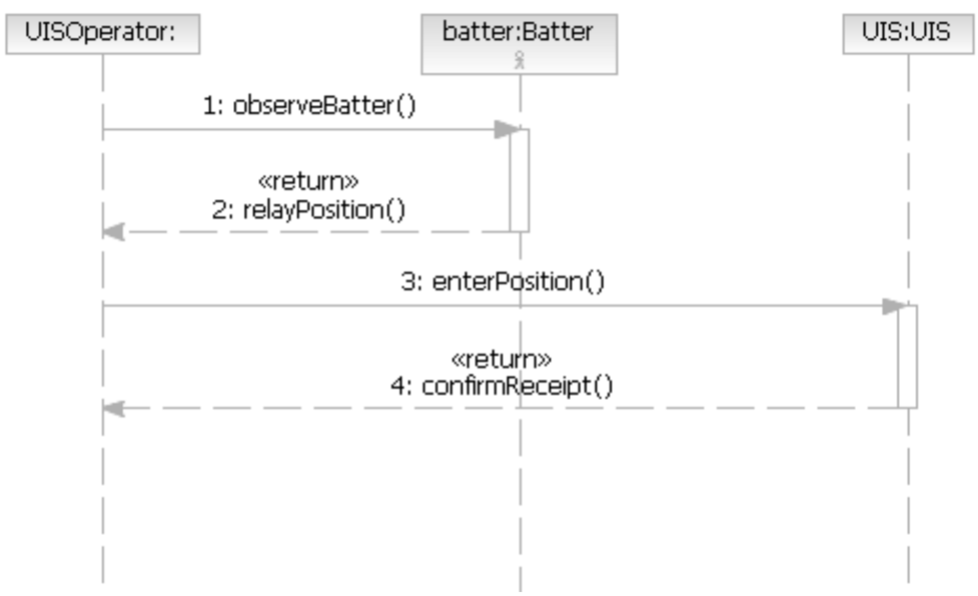


7.2.3. Sequence diagrams

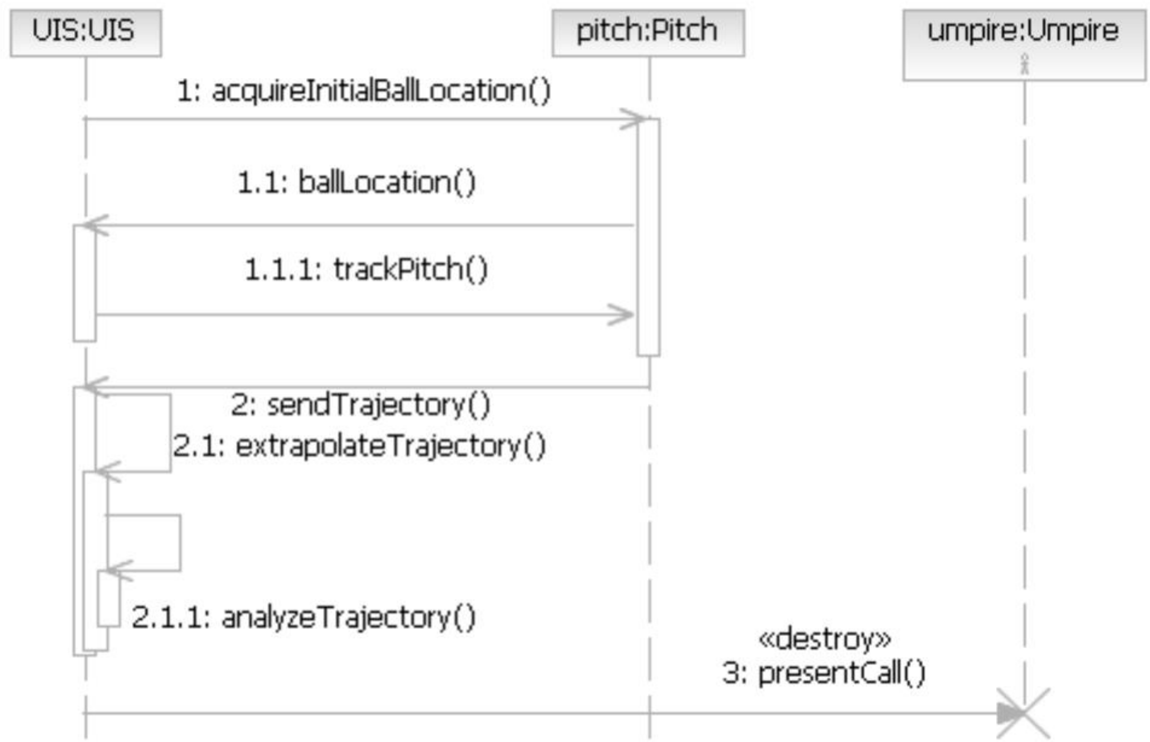
7.2.3.1. Sequence diagram for Calibrate System use case flow



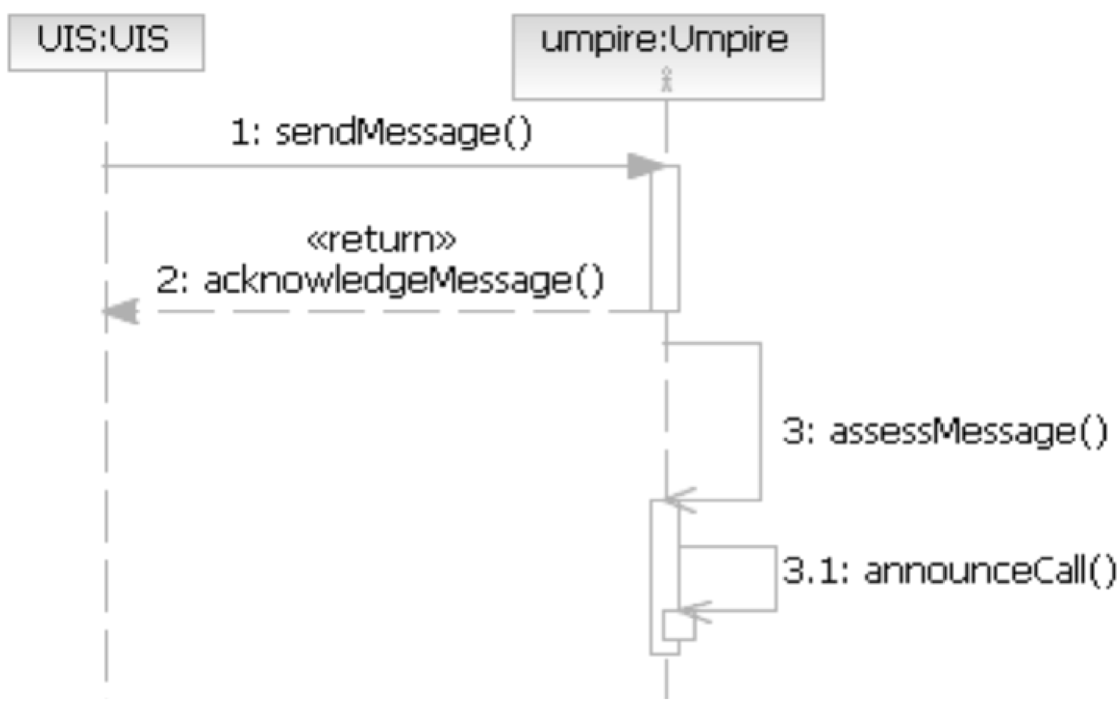
7.2.3.2. Sequence diagram for Set StrikeZone use case flow



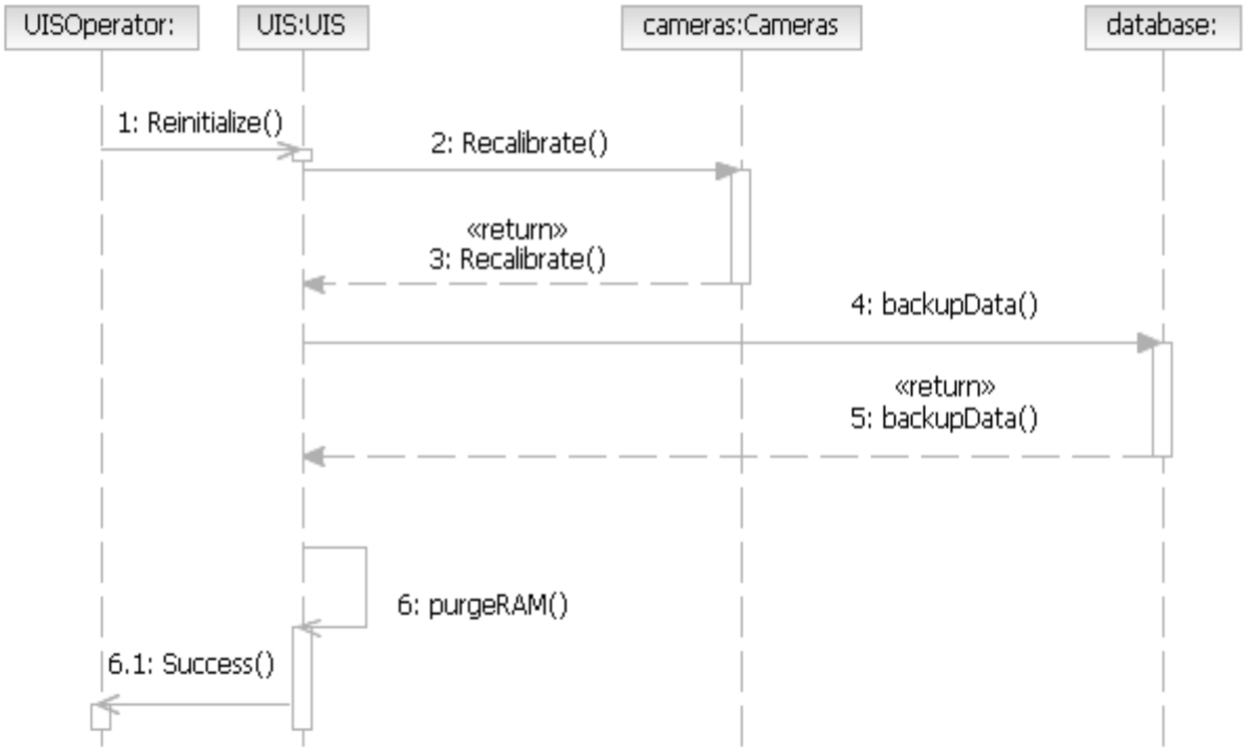
7.2.3.3. Sequence diagram for Determine Ball Or Strike use case flow



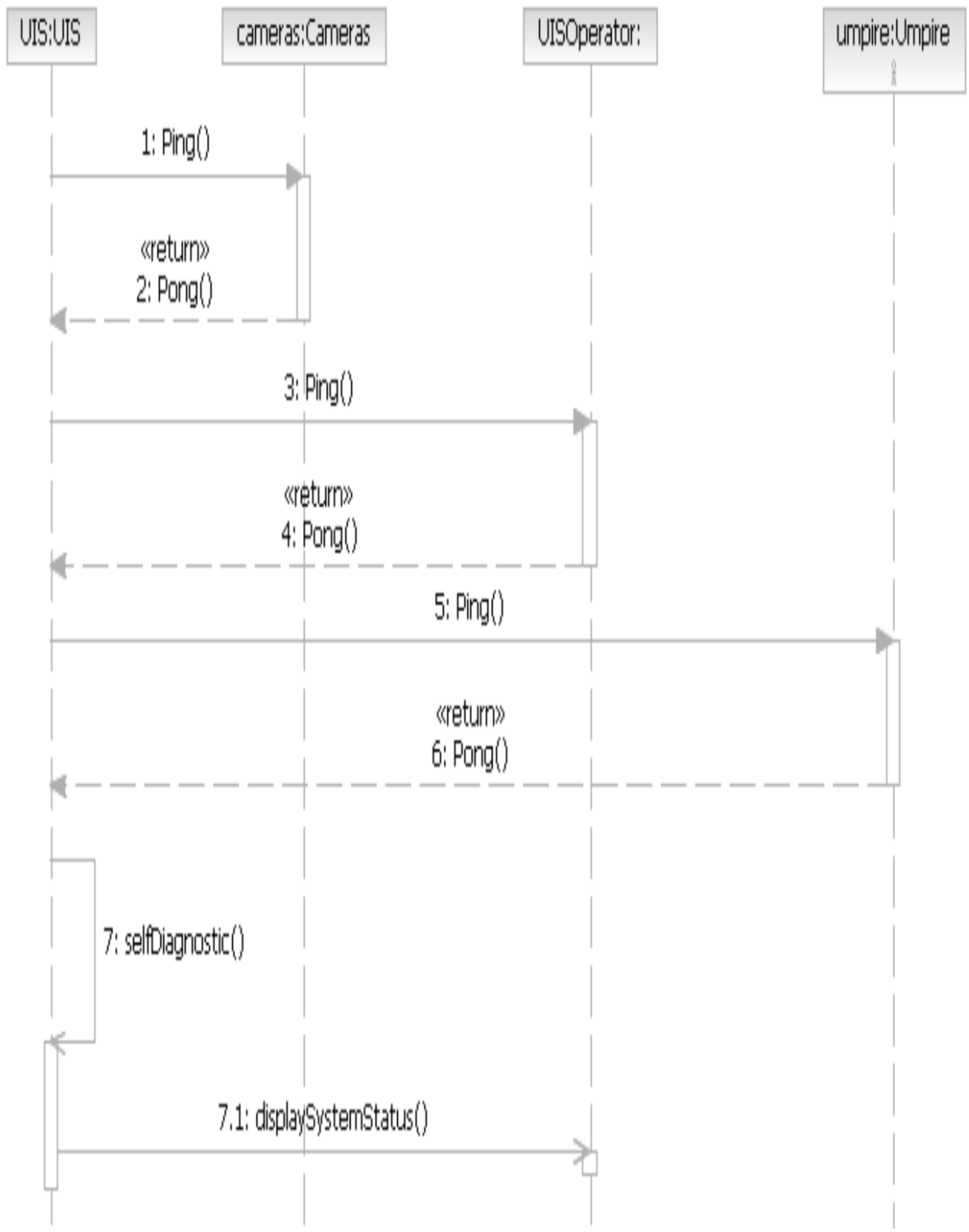
7.2.3.4. Sequence diagram for Present Call use case flow



7.2.3.5. Sequence diagram for ReInitialize use case flow

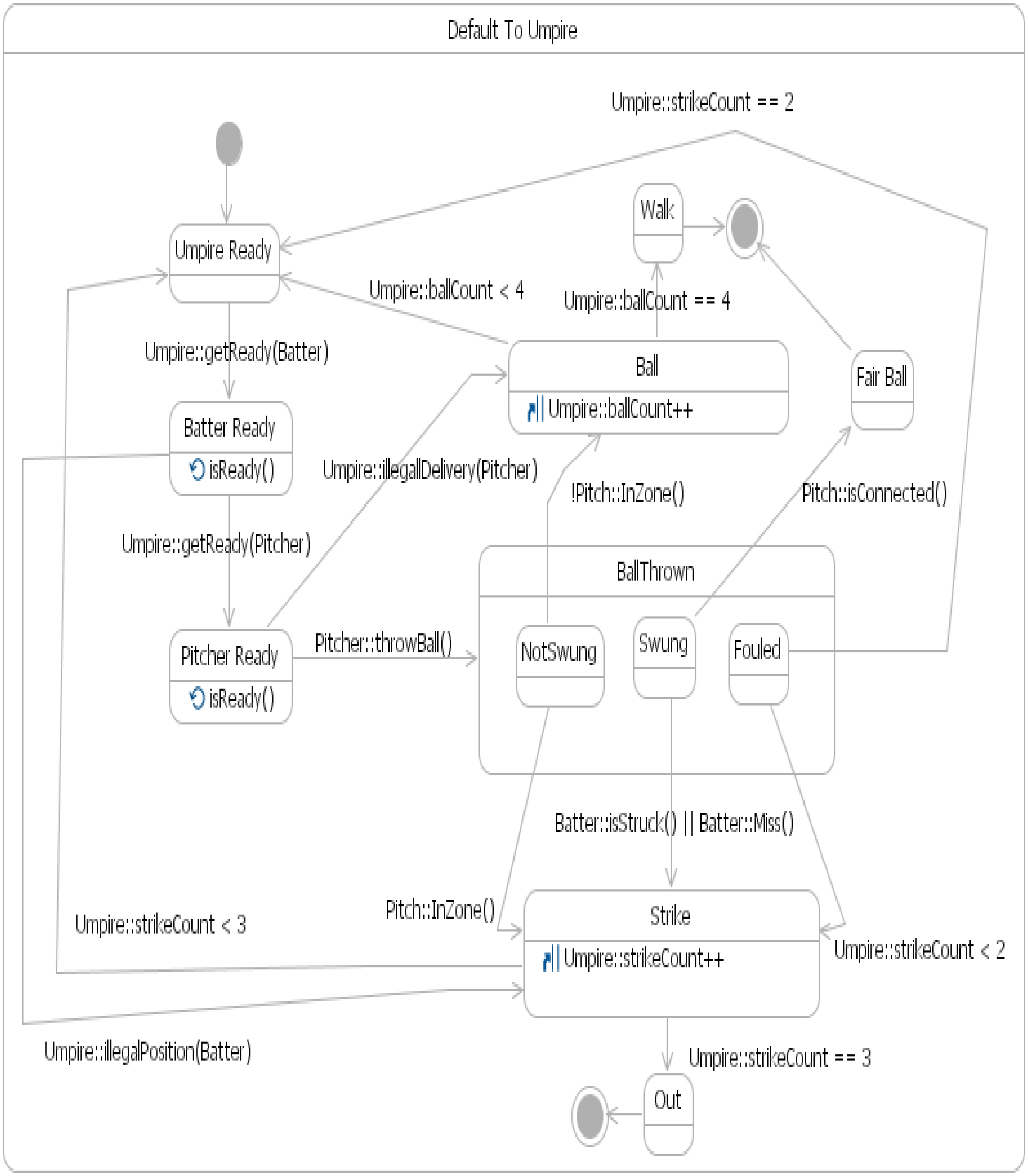


7.2.3.6. Sequence diagram for Conduct Built-In Self-Test use case flow

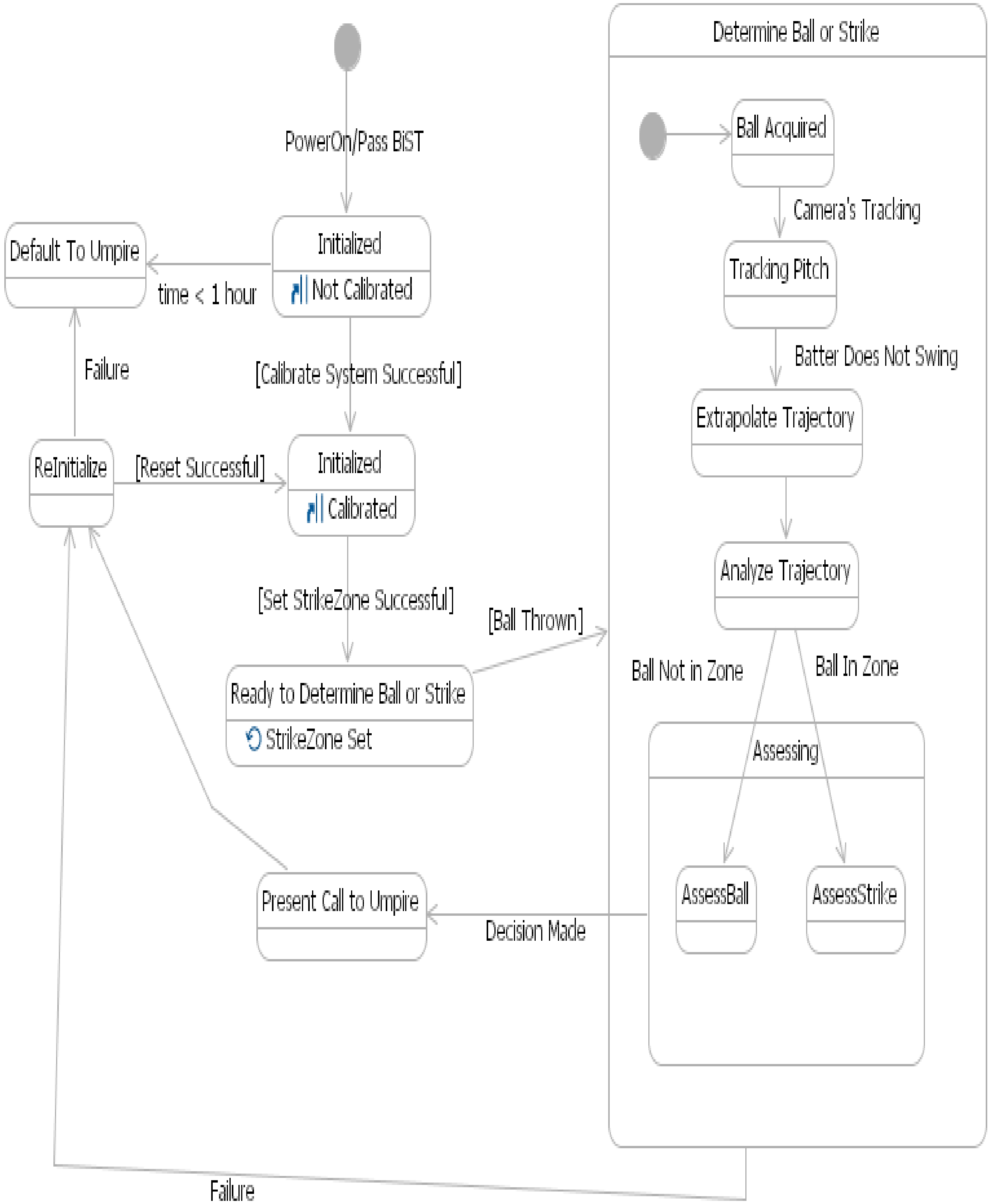


7.2.4. State chart diagrams

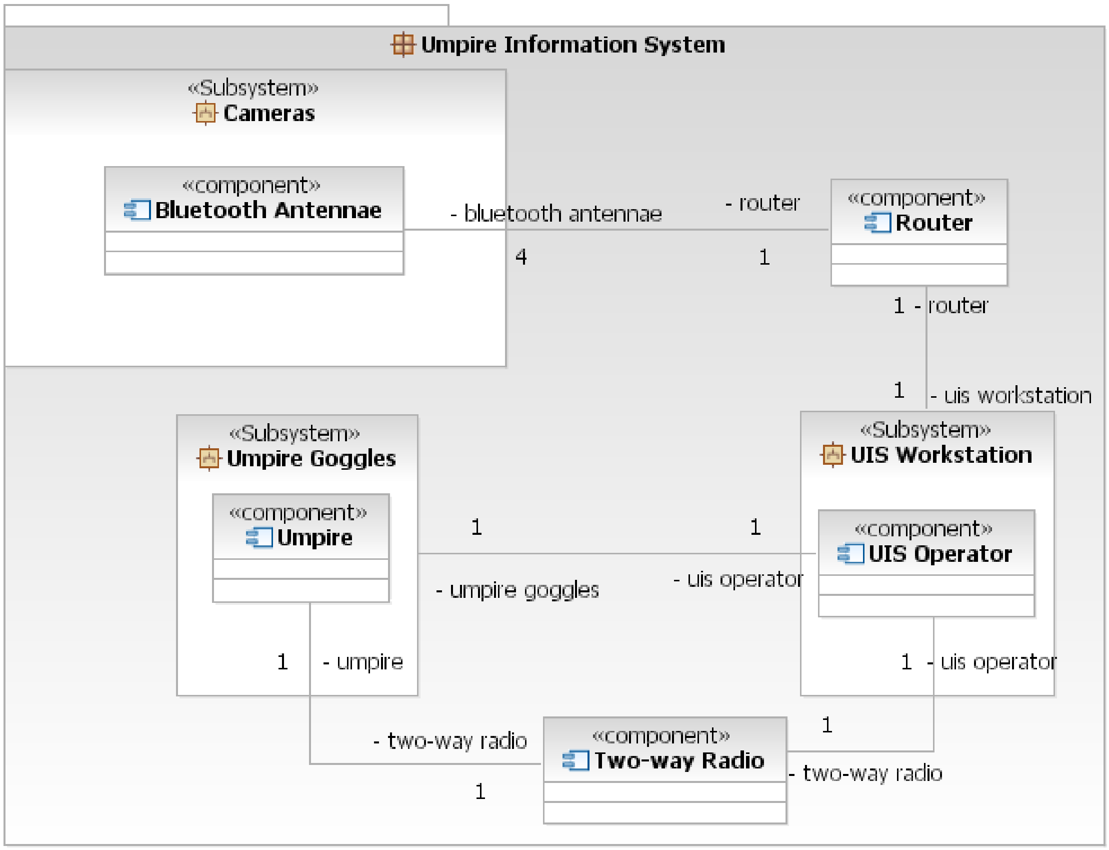
7.2.4.1. State chart diagram for Default To Umpire



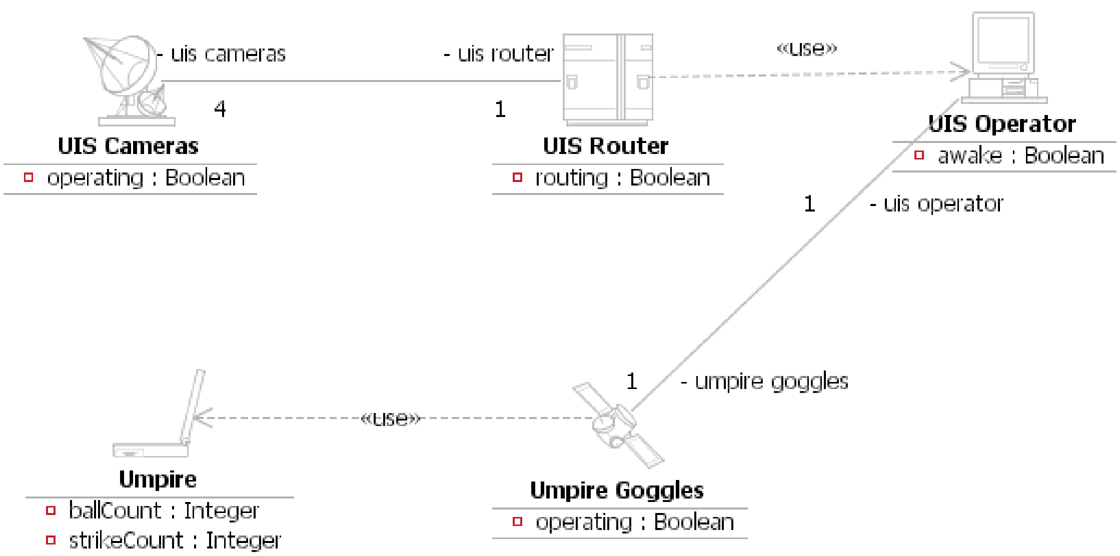
7.2.4.2. State chart diagram for UIS State Machine (High Level)



7.2.5. Component diagram



7.2.6. Deployment diagram



7.3. Implementation model

The implementation model is our final cut at the system which will be validated into the testing model.

7.4. Operational model

The operational model is the actual production system after the testing model has been validated to ensure all customer requirements are met.

8. Systems Engineering Document: Models, Mapping and Management

8.0. Configuration Management

Document Lead: DH
Assistant: SS

Date	Version	Team Members
9/8	0.1	DH,SS
9/9	0.2	DH,SS
9/12	1.0	MD,FD,DH,RF,SS
11/16	1.1	MD
11/24	1.2	MD, DH
11/30	2.0	MD,FD,DH,RF,SS

8.1. Document Structure

This document shows how the requirements, verification plan, evaluation criteria, use case and object models map to each other.

8.2. Document Mappings

The document mapping table shows in what order our team will be writing these documents in relation to each other.

8.2.1. Product Mappings

Requirements	Document 2 Customer Requirements	Document 3 Derived Requirements	Document 5 Concept Exploration	Document 6 Use Case Model	Document 7 Design Model
Input/ Output and Functional Requirements	2.2	3.2	5.3.2.1	6.4	7.1
Technology Requirements	2.3	3.3	5.8	6.4	7.1
Input/ Output Performance Requirements	2.4	3.4	5.3.2.1, 5.5.1	6.4	7.1
Utilization and Resources Requirements	2.5	3.5	5.3.3.1, 5.5.2	6.4	7.1
Trade Off Requirements	2.6	3.6	5.3.3.1, 5.6	6.4	7.1
System Test Requirements	2.7	3.7	5.2	6.4	7.1
Rational Operational Need	2.8	3.8	5.1	6.4	7.1

The above table illustrates that documents 2 through 7 each has seven different requirement sections (Input/Output and Functional, Technology, etc.) that is found within each document.

8.3. User Manual

See Appendix B.

8.4. Risk Analysis

Risk analysis will be performed on performance, schedule and cost.

8.4.1. Quantitative Risk List

Scenario	Probability of Occurrence (one game)	Severity (in millions of dollars per occurrence)	Risk (cost of failure in millions of dollars / per game)
System costs too much	10^{-3}	100	10^{-1}
System Breaks	10^{-1}	10	10^{0}
System too dangerous	10^{-4}	100	10^{-2}
System does not meet expected percentage of accurate calls	10^{-3}	10	10^{-2}

8.4.2. Qualitative Risk List

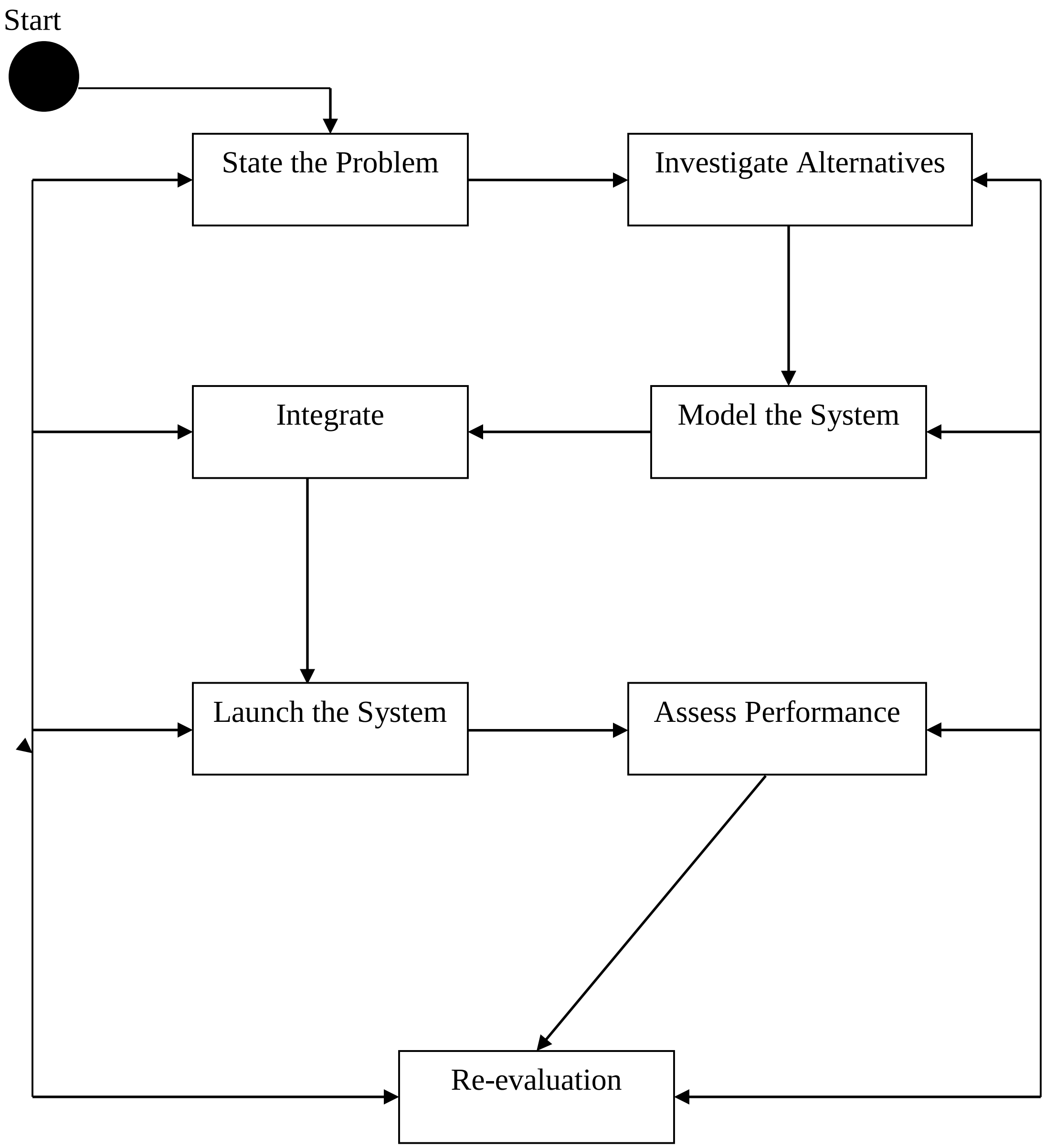
Priority	Risks	Possible Consequence	Risk Level	Response
1	System is not accepted by clients	No contract	Very High	Work more closely with customer
2	System is not accepted by Umpire	Animosity	High	Establish trust relationship with Umpire
3	System is not accepted by fans	Tougher selling point	Medium	Establish fan education of system
4	System is not accepted by players	Tougher selling point	Medium	Establish player education of system
5	System destroys the concept of baseball	Baseball is ruined	Low	Work closely with governing boards

8.5. Schedule

8.5.1. Product Schedule

Task Name	Time Frame
State the Problem	3rd Quarter 2005
Investigate Alternatives	4th Quarter 2005
Model the System	1st Quarter 2006
Integrate	2nd Quarter 2006
Launch the System	4th Quarter 2006
Assess Performance	4th Quarter 2006
Re-evaluation	1st Quarter 2007

8.5.2. Project Activity Diagram



8.6. Project Work Breakdown Structure

Task Name	**Responsible Department**
State the Problem	Lead Technical Team
Investigate Alternatives	Systems Engineering
Model the System	Mechanical Engineering
Integrate	Electrical Engineering
Launch the System	Product Development Team
Assess Performance	Test Department
Re-evaluation	Marketing

Appendix A: Glossary of Terms

Ball – when used as a call to describe a favorable condition to the batting team; four of which will result in an automatic base advancement for the batting team.

Calibration Board - a pressure sensitive, portable board used to calibrate the UIS with umpire alternative. As a matter of procedure, this board is emplaced to the rear of home plate prior to the start of the game. Once in position, the board returns the actual location of a given pitch's final location.

COTS – Commercial-Off-The-Shelf. Used in reference to a technology that can be bought today off the shelf.

English – to put a spin on the ball as in billiards.

Out – when used as a call after three strikes are declared this signals the next batter in batting order to take the plate. Three outs result in the batting and pitching teams reversing roles.

PitchTrax – A more expensive solution by Questec to allow in-game assessment after each pitch.

Real-time Surveillance and Target Acquisition Mission Equipment Package (***abbreviation: RSTA-MEP***) – A solution by Raytheon.

Strike – when used as a call to describe a favorable condition to the pitching team, three of which will result in an automatic out.

Strike Zone – an imaginary polygon used to declare a ball or a strike.

Umpire Information System (***abbreviation: UIS)*** – A solution by Questec to allow post-assessment of each game.

Video Target Tracker (***abbreviation: VTT***) – A device pioneered by Imago Trackers which does real-time target acquisition.

Appendix B: Product User Manual

User's Manual for the ***UIS with Umpire*** System

***Overview*:** Since baseball's inception, the system for assessing *called* strikes has not changed. Namely, the plate umpire assesses the pitch a Strike if any part of the ball passes through any part of the Strike Zone; otherwise, he calls it a Ball. At first glance, this task seems simple enough; that is, one person makes one decision. Unfortunately, while making a single decision is simple, making accurate, consistent decisions over the course of a game (and season) is not.

Over the years, this difficultly has manifested itself in the form of open discontent and a departure from the rules. Specifically, umpires struggling with their understanding of the Strike Zone adopted their own; and, pitchers and batters, knowing that each umpire had his own understanding of the Zone, adjusted their play to compensate. In 2001 the deteriorating situation reached its climax, as the Commissioner of Major League Baseball, Bud Selig, instituted a league-wide initiative to reinstate and enforce the regulation Strike Zone.

In order to emphasize his position, the League contracted QuesTec to manufacture and field a device to gauge umpire performance. This system, known as the Umpire Information System or UIS, was immediately fielded and was immediately met with harsh criticism. Currently employed in half of the Major League ballparks, the UIS is slowly gaining acceptance as a "tolerable" if not perfect way of grading an umpire's ability in calling balls and strikes.

However, by lacking a real-time capability and disenfranchising the umpires, the UIS has not effectively satisfied the fundamental requirement to accurately and consistently assess balls and strikes in a baseball game. Accordingly, it is on this backdrop of need and discontent that we present an integrated, compromising approach -- the ***UIS with Umpire***.

Procedure: The ***UIS with Umpire*** system injects cold objectivity into the objective task of determining balls and strikes, while reemphasizing the umpire's fundamental role as the sole arbiter of the game. Specifically, through the use of two specialized video cameras, the UIS acquires and tracks each pitch, collecting information about the ball's location, speed, and trajectory. This data is then quickly analyzed and extrapolated through the strike zone, allowing the pitch to be correctly assessed as a Ball or a Strike. Finally, this Ball / Strike determination is relayed to the umpire through a miniature heads-up display, allowing the umpire to consider and state his final judgment in a seamless way.

Participants: For calibration, the UIS Operator and one pitching machine operator are required. In its operational mode, the UIS Operator, Umpire, Pitcher, and Batter are mandatory, while the Catcher (nearly always present) is a luxury.

Materials: UIS (with all components), calibration board, baseballs, baseball field, active electrical outlets

Purpose: The purpose of the ***UIS with Umpire*** is to accurately and consistently call balls and strikes in a baseball game

Instructions:[ℵ]

Calibration - As with any precise measurement device, the UIS must be calibrated prior to use. With this in mind, the following steps outline the procedure to prepare the UIS for Operation.

1. Set-up a pitching machine on the pitcher's mound, no further than 60'6" from the lead edge of home plate.
2. Erect the calibration board at the rear apex of home plate such that the board is parallel with the front edge of the plate.
3. Turn the system ON.
4. Wait for the UIS to conduct its Built-in-Self Test. If the system returns a GREEN status, continue to Step 3; otherwise, refer to the Troubleshooting Section of the Set-Up Manual.
5. Using the Control Unit's Mouse, select "Calibrate" from the Main Menu.
6. Again, using the Control Unit's Mouse, adjust the upper and lower stadia lines to the calibration board's red and blue horizontal lines respectively. The Strike Zone is now set.
7. Using the pitching machine, deliver a pitch across home plate and into the calibration board.
8. If the absolute error is less than 0.25", then the UIS is calibrated. Select "Return to Main Menu" at the bottom of the Control Unit's screen. However, if the absolute error is greater than 0.25", continue to Step 9.
9. Using the Control Unit's Mouse, click on the orange crosshairs superimposed on the digital image of the Calibration Board; this is the calculated Point of Impact (POI). Move these orange crosshairs over the green dot, the actual POI, and click the mouse again. Your UIS should now be calibrated.
10. Deliver an additional pitch across home plate and into the calibration board. If the absolute error is less than 0.25", then the calibration has been successful. Select "Return to Main Menu" at the bottom of the Control Unit's screen. However, if the absolute error is greater than 0.25", return to Step 9 and repeat the process.[∇]

Operation[¥] – The UIS is a completely automated system and requires no input other than setting the strike zone and entering a re-initialize command.

[ℵ] Note: These instructions assume that the UIS has already been installed in your facility. If this is not the case, refer to the Installation / Set-up Manual or contact ***Dabkowski, Duarte, Haas, Frondozo, and Sikander*** at 1-800-STRIKES.

[∇] Note: If the UIS cannot be calibrated in 3 passes or less, there is probably a technical difficulty with the calibration board. If this is the case, call 1-800-STRIKES for further information.

[¥] Note: These instructions assume the UIS is powered up, functioning properly and ready to acquire a pitch. Additionally, the batter is in the batter's box, feet set, and ready to swing. Pitcher has not yet delivered the ball

1. Prior to the pitcher's delivery and using the Control Unit's Mouse, adjust the upper and lower stadia lines to the midpoint between the batter's waist / shoulders and the hollow below his knees respectively. The Strike Zone is now set.
2. Throughout the pitcher's delivery and the batter's response, observe the Control Unit's status bar and note any error messages. If an error occurs, inform the Umpire via the two-way radio. Otherwise, remain silent.
3. Immediately following the ball's impact with the catcher's glove, select "Re-initialize" from the Main Menu, and return to Operation Step 1.