Virtual Baseball

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Abstract

Virtual Baseball is the conceptual design of a Virtual Reality game driven by a systems engineering approach and market considerations. The emphasis is placed on quality of participation to emulate actual baseball and not by current limitations of the technology. The design process is described first from a set of objectives then to requirements and on to a set of specifications. A range of implementations are considered including both conjugate and immersive. The market considerations for Virtual Baseball are examined to provide a practical framework for the positioning of the game, its derivative products and cost.

Introduction

The design of a Virtual Reality (VR) system is no different than other complex systems and products intended for market. The process includes: definition of requirements, assessment of the market and the integration of technology. This paper describes the system engineering processes used to develop a conceptual game called Virtual Baseball. The purpose is to illustrate steps and techniques used to go from a concept to an initial design. Market considerations are also described which include product positioning, pricing and quality of play. This paper demonstrates, through example, that developments in both the foundation technologies and industrial base for VR will happen when there is a synergism of the markets, technology and products which meet consumer needs.

The resulting Virtual Baseball design uses a combination of both a virtual environment and a physical environment. The fast moving ball is displayed in an optical system within the batting helmet while the rest of the image scene is projected onto a batting sphere in which the participant stands to play the game. The helmet optics are of a combiner type which allows the batter to see both the ball and the rest of the scene. The batter swings a bat implemented for the game. It has an inertial platform for tracking and eight pads embedded in the handle of the bat where the hands grip the bat. These pads are inflated by CO_2 cartridges which are timed in synchronism to the hit of the ball and provide the player with a sense of the bat and ball contact. The baseball helmet is also instrumented for tracking. Audio is also provided of both the batting and game play sounds.

Design Approach

VR technology is embryonic. Most systems are based on existing technology and little has been done in R&D to further system development and integration. Designs are bottom up based on present technology. This process is shown on the right in Figure 1. On the left is a top down approach. With a bottom up approach a design is based on existing technology and the key question to market is - will a market form around the product? However, this is an inherently risky proposition. From a strategic business management perspective it is better to let the needs of the market drive the development process, as shown on the left. The critical question with this approach is - will the technology support the product development? We explore this issue by formulating a baseball game based on VR concepts to accomplish new levels of realism and accuracy of play.

System Objectives

The Virtual Baseball design approach, shown at the top of Figure 2, is a realistic batting game in two versions: arcade and professional. The arcade game provides play realism while the professional

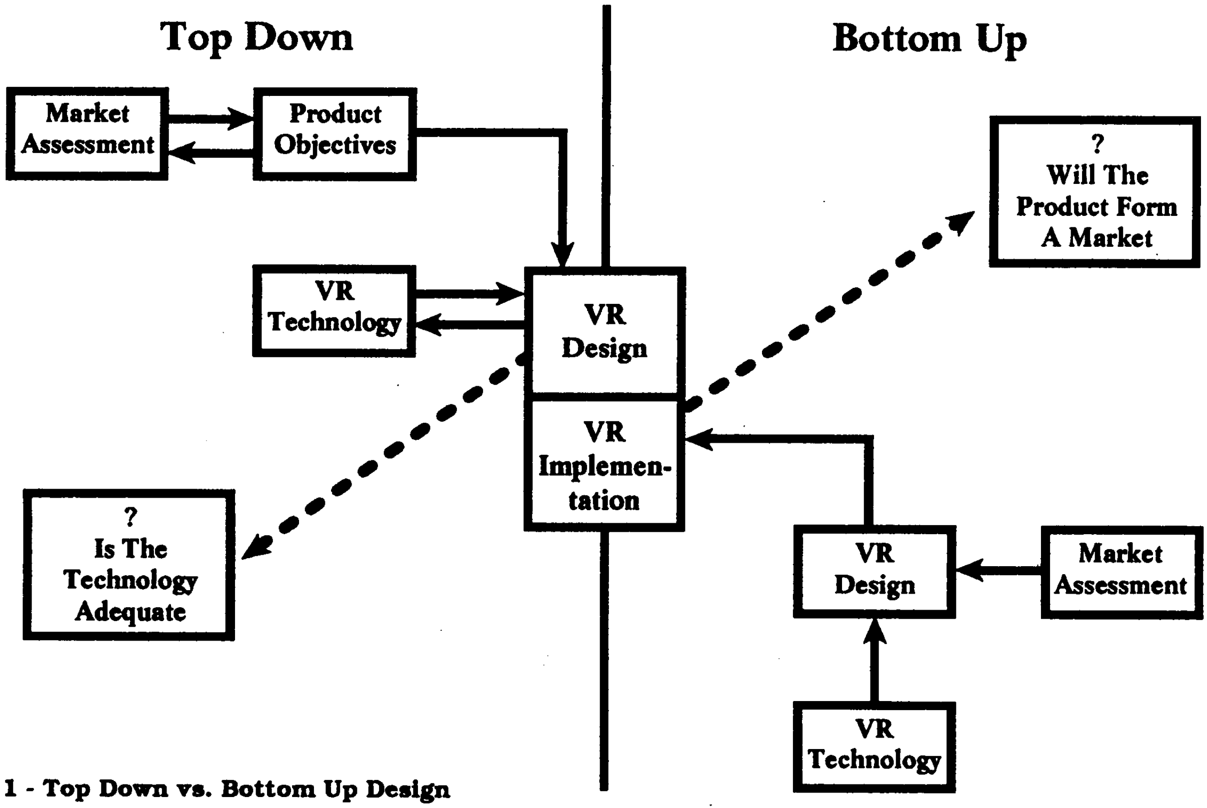


FIGURE 1 - Top Down vs. Bottom Up Design

version is for skill improvement up to and including professional players. Both of these applications have the same basic objectives, but the relative importance of these objectives differ with the applications. A logical growth path would be a total baseball game simulation with teams on the playing field, however, even the batting game is sufficiently complex to consume this initial design effort.

A fundamental element in this design process included the use of two key concepts: accuracy and realism. Accuracy implies the precision with which the game is played. It is quantitative and objective. Factors such as the ball speeds and ball and bat position/tracking are all elements in making the game an accurate rendition of real batting. Realism is qualitative and subjective. The player's impression of the game is based on the level of realism. Crowd noise, for example, plays a role in forming such an impression.

One discriminate between levels of realism and accuracy is in the accuracy of the hitting process. The accuracy of the hit and subsequent ball path is very important when the game is used for professional batting practice. The skills of the participant, gained within the game, must be directly translated to the real event, i.e., learning how to hit pitched balls better.

Normally a game will have elements of both accuracy and realism. However, a professional game or training simulator will likely have levels of accuracy a factor of 10 or more above those present in a

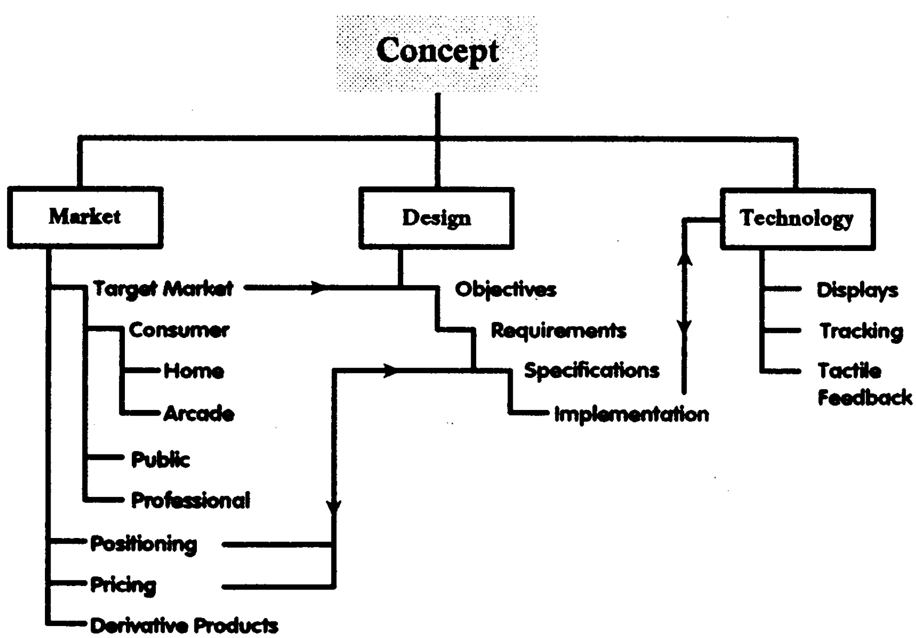


FIGURE 2 - Product Concept

casual entertainment game. These same considerations apply to Virtual Baseball.

Figure 2 is also a representation of the three elements factored into this design: market; design process and technology. The design process began with objectives and from this requirements were developed. This, in turn, led to the formulation of specifications and implementation concepts. Our intent is not to create a final design but illustrate a process. The various linkages, shown as lines between the elements, illustrate how the three were related. No design can be isolated from practical cost, technology and market considerations and this study included these considerations.

As with any product there must be a linkage between the target market and the objective of the design. A fundamental premise (Latta92) is that the level of expectation of the participant will be based on the individuals' experience and perceptions. Thus, for a batting game to match the skills of an individual, who would practice batting on an actual playing field or play against a pitching machine, Virtual Baseball must be similar to those competitive activities. This premise was a key driver in the development of the design objectives. We will review the objectives below while at the same time develop some of the requirements. These are shown in Figure 3.

Objective	Ranking*	Requirements
Affordable	A - 5 P - 1	• < $10 for 10 Minutes of Play • System Cost < $100,000
Realistic	A - 5 P - 3	• Visual Resolution Matches Visual Perception • Full Field-of-View (Complete Environment) • Illusion of Hitting Actual Ball • Realistic Sounds • Synchronization of All Events
Accurate	A - 5 P - 3	• Bat-Ball Relative Positions Accurately Measured at Impact ± .1" • Ball's Direction after Impact ± 2° • Calculated Time of Impact ± .5ms
Selectable Scenarios	A - 4 P - 4	• Variable Model Parmeters including Pitcher, Ballpark, Type of Pitch, Game Situation, and Environmental Parameters
Swing Analysis	A - 3 P - 5	• Precise Record of Bat and Body Motion • Concept of Ideal Swing for Comparison • Replay Display of Batter from External Viewpoint

* Ranking Key:
1 = Low; 5 = High
A = Arcade; P = Pro.

Figure 3 - Virtual Baseball Objectives and Requirements Analysis

Objectives and Requirements Analysis

The first objective is that the system be affordable. This is essential for the arcade game, since sales will only come from discretionary income. It is estimated that a participant should not pay more than $10 for 10 minutes of play. This implies system cost less than $100,000. For the professional application, however, affordability is relatively unimportant since other costs, such as the players salaries and playing stadium, dwarf the cost of the machine.

The second objective requires that the virtual environment be realistic. This, along with affordability, is the most important objective for the arcade game, because these are the key discriminates from other forms of baseball entertainment games. High levels of reality will be achieved by synchronizing inputs to all modalities, but vision will be the primary modality. The entire playing environment must be visible, with resolution equivalent to human capabilities, and have no perceptible lag during head motion. Selectable ballpark sounds, such as crowd noise, umpire calls, and the crack of the bat must all be audible at the proper times. The final modality is the haptic one. The bat must contain effectors providing the illusion of contact with the ball. Most importantly, all sensors and effectors must be time synchronized with no discernible lags.

For the professional system, realism is less important than accuracy. A professional system is driven by the need to develop precise repeatable swing performance against Major League pitches. For example, the accuracy of the bat location, ball movement, impact analysis and swing motion are more important than the impression of being in a ballpark. Participants in the arcade game will probably be less susceptible to differences in the accuracy of the game than the overall environment which conveys the feel of the game. Sounds will be more important in the arcade game than the professional version.

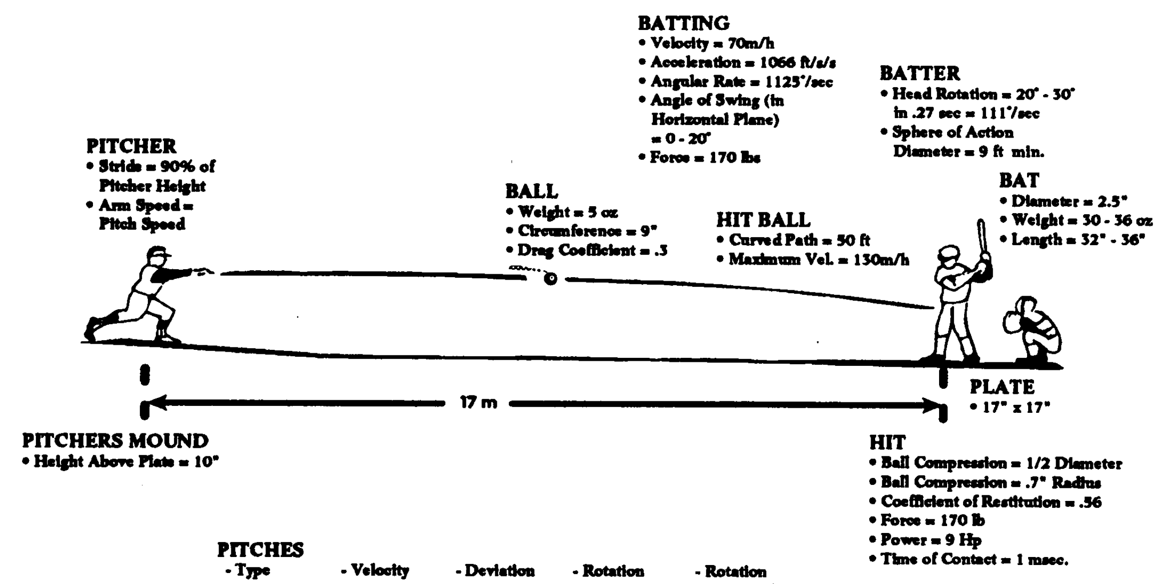
The ability to select scenarios is an important objective in both applications. In the arcade game, the participant must be able to select which ballpark to play in, which pitcher to face, and what game situation he is facing. Selection of physical parameters such as reducing gravity, varying windspeed and changing ballspeed will also be available. These alternatives will allow the player to create the fantasy scenario of their choice.

For the professional system, the selection of options plays a different role. The participant, or the batting coach, will be able to select a particular pitcher, with all of his personal pitch types, to practice against. This will provide a batter with experience against a pitcher he has never faced. The large assortment of pitches will also provide the batter with the chance to face pitches of unknown speed and spin, giving him practice at reading pitches. This capability is currently not possible other than in batting practice against the actual pitchers.

The final objective is for the system to provide swing analysis. For the arcade player, it is only moderately important that the batter be able to see a replay of the swing. Note that this conclusion is from a training perspective, however, if a replay of the swing enhances the participants quality of play such a display could be an important addition to the arcade game. For the professional player, however, it is vitally important to receive a practice assessment because swing improvement is the ultimate purpose of the system. The ability to see a replay of the swing from various perspectives will allow the player to see what they did wrong. Further, Virtual Baseball will allow the batter to get information on the parameters of the ball, pitch, bat and swing along with an assessment of what parts of the swing need improvement.

These objectives culminate with a high quality of play, i.e., the batter has the feel of a real at bat, swing and hit. The first step to meeting this goal is in the physical feel of the interface equipment: the bat must feel like a real bat, any head mounted display must feel no more cumbersome than a batting helmet and the sphere of activity must allow full freedom to swing the bat. The second, and probably more difficult step is to ensure that I/O interface performance is consistent with the characteristics of the batting process. The impacts of this requirement on the display, tracking sensors and tactile feedback implementations will be discussed below.

Description of Batting



PITCHES

- Type	- Velocity	- Deviation	- Rotation	- Rotation Axis Angle
Fast Ball	80 - 100 m/h	8"H + 30"V	1500 r/m	131°
Curve	65 - 80 m/h	15"H - 20"V	1800 r/m	141°
Slider	80 - 90 m/h	10"H - 20"V	1680 r/m	125°
Knuckle Ball	60 - 70 m/h	30"H - 20"V	300 r/m	n/a
Change Up	60 - 70 m/h	15"H - 25"V		

FIGURE 4 - Virtual Baseball Parameters

Ted Williams has often called hitting a baseball the "single most difficult thing to do in sport." An at bat in baseball is a true battle of wits and talent, as the pitcher tries to use power and deception to throw the ball past the batter, while the batter uses all of his senses in an attempt to hit the ball. Although the batter must try to focus attention on the pitch, the environment includes the crowd cheering and booing; the call of the umpire; the movement and chattering of the players; and the elements of the weather. Virtual Baseball encompasses the same factors as a major league at bat. A summary of the key pitching and batting parameters are shown in Figure 4. In order to best understand the goals of Virtual Baseball we must review the specifics of the actual game.

Deception is as crucial to the pitcher as power. The grip on the ball is hid in the glove so that the batter cannot foresee what type of pitch to expect. The free arm is used to block the view of the hand with the ball until the moment of release. All successful major league pitchers have at least three pitches, with varying speeds and curvature. The pitcher chooses his pitch, and its location, attempting to maximize the use of his talents while keeping the batter off guard.

Baseballs are very uniform, weighing 5 ounces with a circumference of 9", but the flights of the pitch may vary dramatically. The ball, as a whole, has a drag coefficient of about .3, but this varies widely with the relative airspeed and the roughness of the surface. It is this differential drag that results in curveballs and rising fastballs. Pitches rotating at 1500 - 1800 rpm have different relative airspeeds on opposite sides of the spin axis, leading to a net force and curves in the flight path of 15" or more. The knuckleball uses the other extreme of no spin. When the ball is not spinning, a slight variation in surface roughness (even scratches barely visible) may lead to asymmetric forces and movement in directions even the pitcher cannot predict. All told, a major league pitch may range in speeds from 60 - 100 miles per hour, and may curve by more than 15" in any direction.

The batter has very little time to watch the pitch and make up his mind; a fastball will cross the plate in less than half a second. This leaves about two tenths of a second for the batter to watch the trajectory and the spin, estimate the location and curve, and decide whether to swing. Sometimes a poor pitcher will provide tips to a clever batter through differences in motion and release, but the batter must usually rely solely on the flight of the ball. Rod Carew has said that reading the spin of the ball is imperative, and claims that he judged it after 15 - 20' of flight.

Coaches have always said "keep your eye on the ball", but the human capability to do this is debatable. Ted Williams claimed that he watched the ball all of the way, but he has also admitted that he probably never saw the actual collision between ball and bat. The human eye cannot track objects moving faster than 200°/s, and this speed is reached 5' - 10' before the ball crosses the plate. Tests on ball tracking ability have not found any players who can track the ball after it gets within 5' of the plate. However, one possible method is through saccadic motions, in which the eye jumps ahead of the ball and waits for the ball to catch up. This can be done without perception of the jump and could be used to see the ball as it crosses the plate. Unfortunately, the benefit is not obvious since it is too late for the batter to react once the ball gets that close.

The swing of the bat is a work of art that must be performed repeatably in identical fashion. The batter steps into the pitch, actually stepping before the pitcher throws the ball. By transferring his weight forward, the batter generates 9 horsepower and puts about 170 lbs. of force into the bat. The bat rotates at 1125°/s, reaching a velocity of 70 mph with an acceleration of $1066'/s^2$.

The ideal bat weight has been argued for decades. Babe Ruth used bats weighing about 50 ounces, but today's players use bats weighing 30 - 36 ounces. A heavier bat transfers more power, but a lighter bat may be swung with higher batspeeds. Most players opt for lighter bats, and in fact are limited by the strength of the wood. Major League bats must be made of a solid piece of wood, and the typical bat is 32" - 36" with a diameter of 2.5". To make a bat less than 30 ounces would require the reduction of the diameter to unacceptably narrow widths.

The actual impact between bat and ball lasts only one one thousandth of a second. The ball has 22% of the angular momentum that the bat does. When the hit takes place this transfer of momentum will be felt as a torque and only during the msec of the impact. During that period, the ball may compress to one half its original diameter. The coefficient of restitution, which determines how fast the ball springs off the bat, is .56. The theories of "live ball" and "dead ball" eras assume that this coefficient of restitution has changed over the years. The coefficient of restitution can also change with temperature, and some teams have been accused of heating or icing the balls in the past.

As the ball leaves the bat, it may achieve velocities up to 130 mph. The ideal hit, with an angle of trajectory of about 35°, may travel up to 500'. The flight of a hit ball is affected by the ball's spin in the same manner as the pitch. A home run ball is hit a little below the center, giving the ball backspin. The

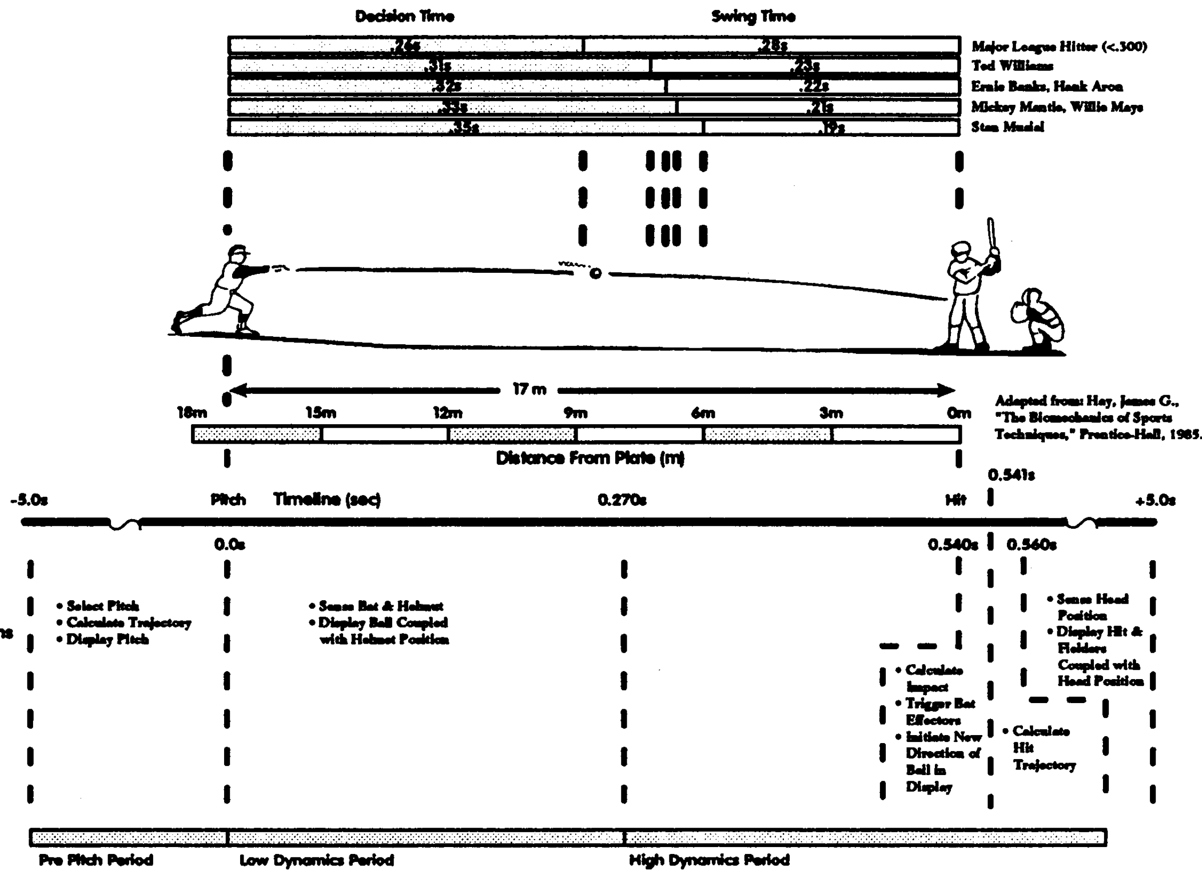


FIGURE 5 - Virtual Baseball Dynamics

spin, like a rising fastball, gives the ball more loft and can add 10% to the distance. Likewise, a ball spinning about a vertical axis will curve sideways, often up to 50'.

Virtual Baseball Dynamics

The pitching and batting environment just described will be timed for Virtual Baseball operations and this is shown in Figure 5. The upper right portion of the chart shows decision and swing time intervals for Hall-Of-Fame baseball players. The timing parameters for this game are based on matching the pitching and hitting profiles of professional players.

The virtual operations are shown in the lower section of Figure 5. Two scales are shown here: distance and time. From the system perspective the time scale is the most important and these have been divided into: pre-pitch; low dynamics and high dynamics periods.

Game events take place most rapidly during the high dynamics period. This includes the time of impact and ball departure. A driving design point is the period of ball contact, which lasts for only 1ms. During this period the system must calculate the ball impact, trigger the bat effectors and begin the ball movement away from the bat. During the next 20ms the actual ball trajectory is computed.

We have now established a baseball "baseline" for design. The next task is to translate that information and the game requirements into a set of trades which will lead to a design.

Implementation Design Space

We will begin this process using the VR model described by Latta (Latta92) and shown in Figure 6 as it applies to Virtual Baseball. It is clear that a basic design decision centers around the trade between a conjugate or an immersive design. This is highlighted in the lower portion of the drawing: conjugate and immersive; and the associated notes.

The immersive approach assumes that the participant wears a personal appliance which blocks out other visual stimulation. In this case, the appliance would resemble a batting helmet which includes both the display and head tracking equipment. In order to meet the requirements, this display would have to provide sufficient visual field-of-view for the play. A major consideration in this implementation is the computational bandwidth required to compute the scene for each display, i.e., each eye. The batting situation is visually a fairly simple one because the batter is in a relatively fixed position. The prominent moving objects are the ball and pitcher while the majority of the image is stable with respect to the batter. The key to a immersive design is to provide both this image of the playing area, while providing an very realistic image of the fast moving baseball, where all the attention of the batter is focused. During the design process it was clear that these two components of the visual field could be separated and a simpler design result.

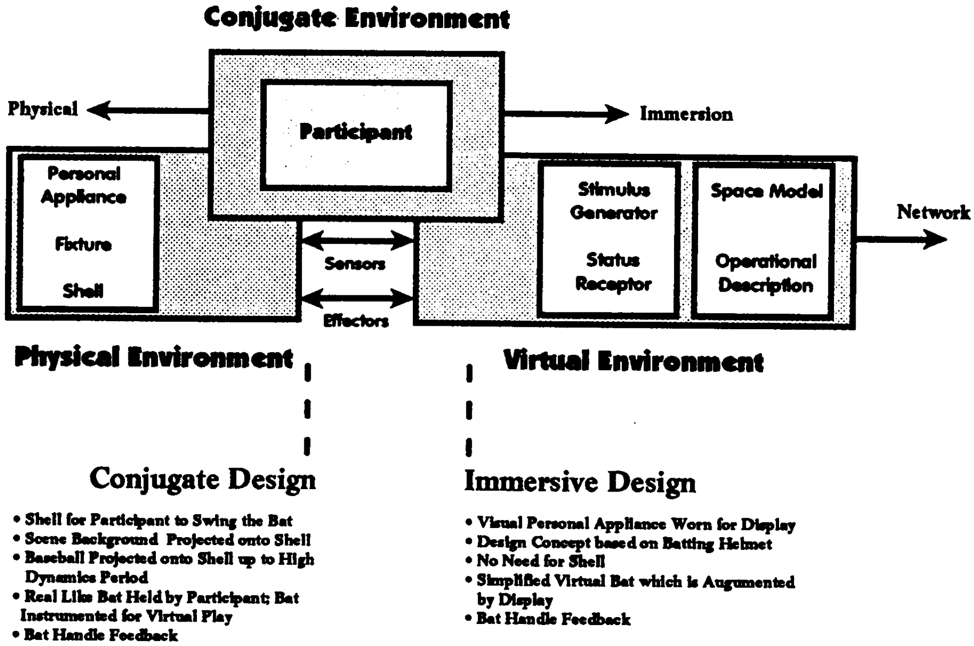


FIGURE 6 - Virtual Reality Model - Virtual Baseball

The next major design issue is the implementation of the bat. It is virtually impossible to realistically create the feel of the bat without using a bat like object. The hand and the rest of the muscular system, up to the shoulders, are far too sensitive to be fooled with designs which are at substantial variance from a bat like object. It is a simpler design to use a bat like object tailored to this system because anything less would significantly compromise the participation qualities of the game. The bat used is shaped like a regular bat but is built internally to generate the necessary impulses to match the hit. The use of an actual bat like object is also consistent with the thrust towards a visual system which is conjugáte. The bat and its design will be described in more detail later.

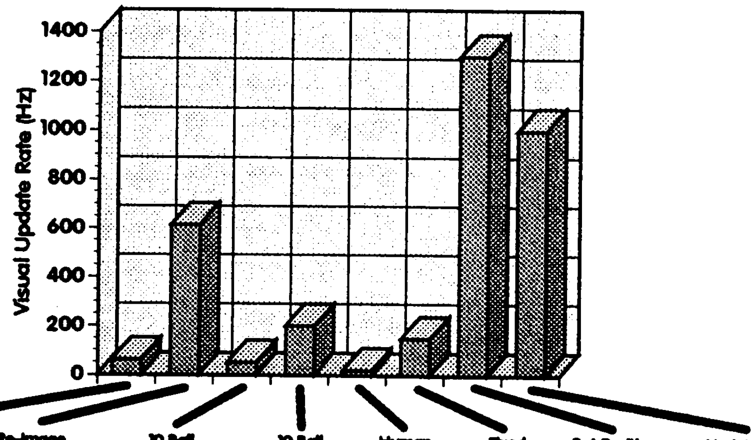
These factors now require a conjugate implementation. In this case, part of the image is implemented in the physical world, i.e., the playing field and the image of the bat, while the ball is done in the virtual environment. We examined if the ball, during the course of the pitch, would transition between the physical and virtual environment. The decision was made to keep the ball image all within the batting image space of the display of the helmet, i.e., the ball is always virtual.

There are a number of methods of generating and displaying the scene imagery. In fact, there is no reason that the image need move or appreciably change during the game. Two components which appear to the batter to change are the pitcher and the ball. As a result, an image of an actual ball park would provide the most realistic setting for the game. Video or multimedia techniques could then be used to superimpose the image of the pitcher and other elements which change in the scene. The helmet display would utilize a combiner and thus the remaining field-of-view of the rest of the shell would also be visible to the player. The helmet and bat are each instrumented for tracking.

The implementation of the physical environment was based on using a shell in which the participant stands to swing the bat. This is a sphere whose diameter enables free swings and normal batter movement. This sphere need not be complex and the initial design was based on an inflatable sphere with an entrance way for the batter. The imagery is shown on the internal surface of the shell, using multiple projectors centered underneath home plate. Such an approach permits a wide field-of-view with high quality imagery and low computational bandwidth. Superimposed on this background image is the image of the batter. This is accomplished through multimedia techniques from a library of pitchers and pitcher throwing conditions. Once a pitch is selected it is combined in the video with the background image to show a pitcher on the mound.

Design Specifications - Effectors

The initial form of the design is now taking form. Yet to be developed are the details of the visual system and the bat design. To accomplish the former we will examine the visual update requirements shown in Figure 7. This drawing also includes some elements of the immersive and conjugate trade just discussed. Central to the understanding of the visual update requirements are a range of update frequencies based on the actual game. Each corresponds to the "update rate application" shown in the center of the figure. One would like to select the lowest update rate for the whole period of the pitch. This is not possible because of the changes in the visibility of the ball and the actions of the pitcher during the periods of the pitch described in the bottom of Figure 5.



Update Rate Application	Non-Flicker Refresh Rate	Re-Image Ball 1/Diameter of Movement	10 Ball Images Prior to Start of Swing	10 Ball Images Per Ball Rotation	Human Reaction Rate	Fixed Scene to Participant (Image/.5° Head Rotation)	Bat Position Accurate to 1"	Update Ball Position During Impact (Ball not Behind Bat)
Conjugate	Pitch	Pitch	Low-Dynamic Period	Pitch	Pitch	N/A	N/A	1 ms Contact
Immersive	Whole Scene	Pitch	Low-Dynamic Period	Pitch	Pitch	Pitch	High-Dynamic Period	1 ms Contact

FIGURE 7 - VISUAL UPDATE RATE ANALYSIS

The actual display quality is driven by two requirements: 1) the resolution and response times must be sufficient for the scene to seem real, and 2) the scene must be accurate enough that a batter's success is determined by his physical ability and not the display performance. The realism requirement points to a scene covering the entire field-of-view with a resolution of one arc-minute and an update rates of 60 Hz. This is shown in Whole Scene requirement in the lower left of the table for the immersive design. Even though it might be argued that the field-of-view requirements can be less in an immersive design, the angular rate of the head during the pitch makes the simultaneous display of the background scene and the fast moving ball very difficult. This drives the computational bandwidth because of the large field-of-view and is the key reason the simpler conjugate design was selected.

Several criteria for update rate are illustrated, but one which is most reasonable for this game is based on the rotation of the ball. Since the best batters read the spin of the ball before making their swing decision, it is logical to require 10 updates per ball revolution, allowing the player to plan his swing the same way as in an actual game. This leads to a required update rate of 200 Hz for the ball.

One of the highest update rates is the last one, i.e., during the impact of the bat and ball. However, this is a short impulse requirement driven by the need to not have the ball out of position with the bat. A number of implementation strategies are possible to avoid this display inconsistency and thus the attendant high impulse rate requirement. In a practical sense, this requirement is not being driven by the ability of the batter to see the ball shortly before the impact, thus, is should not be considered as a valid display requirement. This is an example where the realities of actual play, discussed earlier, temper the complexity of the design.

Given that the design now displays just the ball in the batting helmet it is necessary to compute the total image update rate. To determine the number of pixels which must be computed during the pitch an analysis was performed to determine the number of pixels which define the ball during batting. One criteria used is that a batter expects to see the ball seams as it proceeds to the plate. This helps define the resolution requirements. Shown on the left side of Figure 8 is a plot of the number of pixels. Note that the number of pixels decreases from 70 as the ball approaches the batter to 16 when it passes into the high dynamics period.

This data is now combined with the update rate analysis from Figure 7, based on the timing of the pitch, to realize the pixel rate on the right of the chart. The numbers are quite low and peak at the start of the pitch at 45,000 pixels/sec and go as low as 12,000 pixels/sec.

The sensation of hitting the ball will be provided through a combination of the visual image of the ball leaving the bat, an audio representation of the crack of the bat, and tactile feedback. The bat - ball impact lasts only a millisecond and this is a driving requirement for synchronization of feedback.

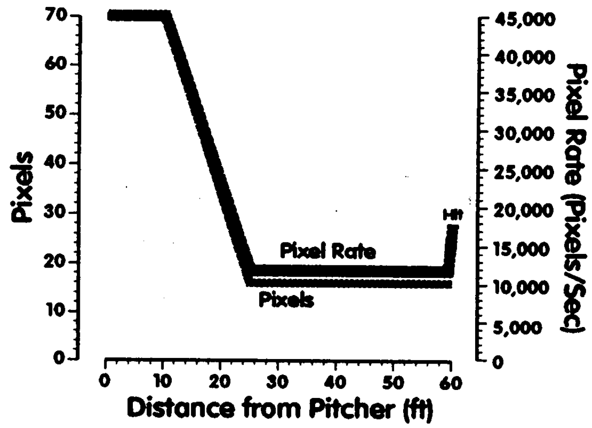


FIGURE 8 - Conjugate Design Pixel Rate

The vibration in the bat depends on where the ball hits the bat. The frequency ranges from 200 to 500 Hz and the amplitude ranges from 0 to .5". A vibrator is used to generate these vibrations and simulate contact, but the bat only vibrates when the sweet spot is missed and would not provide the sensations of a good hit.

Our studies indicate that the most feasible means of providing tactile feedback is with inflatable devices which are triggered during the bat-ball impulse. These would not accurately simulate the total forces on the bat but would give the batter sudden force sensations in his hands. Our review of the batting process and literature shows that the force direction, event synchronization and feedback of the hit are more important than the magnitude of the forces felt in the hands and wrists of the batter. This then allowed us to design an approach which emphasized these elements.

The design uses eight 1" X 1" pads, with four spread evenly under each hand. During contact appropriate pads are inflated to simulate the torque in the bat resulting from ball contact. Inflation of the pads to 1/4" with 30 psi pressure would produce the desired effect. CO_2 cartridges, similar to those used to fire BB guns, would be used to inflate the pads. The cartridges used in the guns are pressurized to 900 psi and are small and light enough to easily fit in the bat. The 12 grams of CO_2 would allow several uses before replacement.

Bat and Ball Collision Transducer

The ball-bat collision process is illustrated in Figure 9 as a transfer process where the ball bat collision is a transducer function. A complete solution to this collision could involve the use of finite element models which take into account the deformation of the bat and ball during impact. Such an approach would again use significant levels of computational power. It is our estimation that such rigor is not required. The key output parameters required are the ball speed, spin and direction, as shown on the right of the transfer function. When straightforward approximations are use this can be determined by equations which use the variables shown here. The key point to note is that our end result is a reasonable approximation of the hitting process against a pitched ball and not the rigor of the calculations of the hitting process.

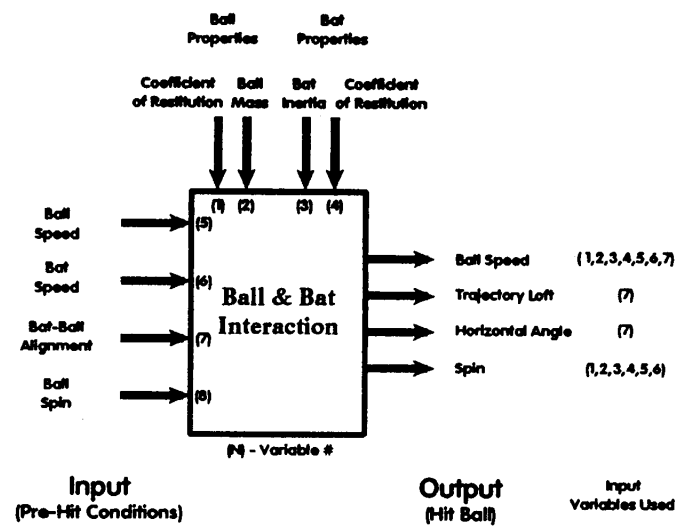


FIGURE 9 - Bat - Ball Collision Transducer

Design Specifications - Sensors

The tracking sensors serve two roles, they sense the head position to enable proper scene orientation and they sense the bat position to enable impact calculations. Two potential implementations are envisioned; external trackers or internal inertial sensors. External trackers directly measure position, velocity and angle with respect to a fixed environmental reference. Inertial sensors may be used to measure acceleration and rotation rate with respect to some starting point and then these measurements may then be integrated to calculate position, angle and velocity.

The tracking requirements discussed below are for a game that feels realistic to the participant but are not necessarily sufficient to provide useful instruction for a professional.

The requirements for sensing of the head are reduced somewhat by the fact that our visual perception drops dramatically while the head is in motion. During the low dynamics period the requirements are .01° and .1" and .5° and .5" during high dynamics. These can be satisfied with external sensors measuring position ±.05", velocity ±1'/second, and angle ±.001° with sampling rates of 200 Hz.

The requirements for bat sensing are very strict and, in fact, increase with higher speeds. For this design they have been set at .1", 3'/second and 2°. These are determined by the dynamics of the swing and the ball bat impact calculations and are not associated with the batter's perceptions. Inertial sensors measuring angular rate ±.001°/second and acceleration ±.3"/ second^2 at rates of 20 Hz would meet the requirements. Due to the high dynamics, inertial sensors are preferable because they can measure the derivatives of the desired states, and keep up with the system dynamics. Currently available inertial sensors provide more than enough precision and are probably small enough to fit in the bat. The drawbacks to an inertial implementation are the cost and the requirement to provide a fixed starting point as a reference.

Objectives and Requirements Satisfaction

We have done an initial assessment of this concept design to meet the objectives and requirements shown in Figure 3. One of the most difficult requirements to assess is cost. At this stage in the design it is too early to estimate if this has been met. We feel that the design has met all of the realism requirements. However, the accuracy requirements are only partially met. One reason is that these requirements were stated for the professional game and the initial design target was the arcade game. The design has also met the variability requirements. Because of the level of instrumentation in the bat and the head this design provides excellent information on the batting dynamics. Although this provides numerical feedback, visual feedback would require that the batting sphere be equipped with a video camera. Thus, the video could be annotated with the numerical information from the pitched ball, the swing and the hit ball. This level of information is not available in any other type of batting system. Virtual Baseball meets the swing analysis needs, however, for complete feedback a video recording system would be desirable. Again, this is a component specifically needed by the professional version.

Product Market

Products do not stand alone in a competitive market and the positioning of Virtual Baseball is shown in Figure 10. This comparison includes three other batting practice systems. The first two use conventional batting machines. However, these machines provide for limited variability in the pitched ball. A key advantage is the actual contact with the ball. However, most systems use special balls which hold up well under the continuous pitching situation of a batting cage. A third system is a batting

	Real Bat-Ball Impact	Real Pitches or Simulation	Pitch Known to Batter	See Pitcher Delivery	Swing Diagnostics	Environment	Cost
VR Baseball	No	Yes	No	Yes	Yes	Like Baseball Game	TBD
Public Batting Cages	Yes	No	Yes	No(1)	No	Consumer Game Atmosphere	Inexpensive(2)
Pro Batting Cage	Yes	Yes	Yes	No	No	? - Based on Location and Setting	Moderate
Batting Simulator	No	Yes	No	Yes	Yes	Like Baseball Game	Expensive(3)

(1) - Lever Action To Pitch Ball on Several Pitching Machines
(2) - $2,000 - $3,000/Machine; $50,000 - $100,00 Full Installation
(3) - Design Concept Only

FIGURE 10 - Baseball/Batting Practice Comparsions

simulator developed at the Institute of Sports Vision. It has many of the features of Virtual Baseball. However, it is also a conceptual design and limited details are available.

From this table we believe that Virtual Baseball has shown that such a design can provide market discrimination for realistic game play. However, its positioning is not one of dominance over other forms of play. We will examine this in more detail in the next section.

Given a Virtual Baseball batting game, how does it compare as a consumer might view the offering? To answer this question we will use a scatter plot to examine product positioning as shown in Figure 11. There are five primary factors which compare these two products. It is expected that Virtual Baseball would be more expensive. The game, however, would have greater control over the delivery of the ball and consequently represent a higher challenge to the batters. Through input, it would be possible to control and select a wide variation of pitch types and speeds to tax the skills of the batter. In quality of practice, a pitching machine scores higher because it allows the batter to physically hit a real ball with a real bat. This one factor is clearly subjective and would be best evaluated through the use of focus groups actually testing the Virtual Baseball game in comparison with a batting game. A factor which supports Virtual Baseball is practice constraints. For example, it can be set up in any indoor location and is unaffected by weather. A significant advantage of Virtual Baseball is its ability to measure the swing and head movement. This could be a very valuable in improving the performance of batters, in much the same way that monitoring a golfers swing is a good diagnostic tool. Thus, as a learning tool, Virtual Baseball scores higher than a pitching machine.

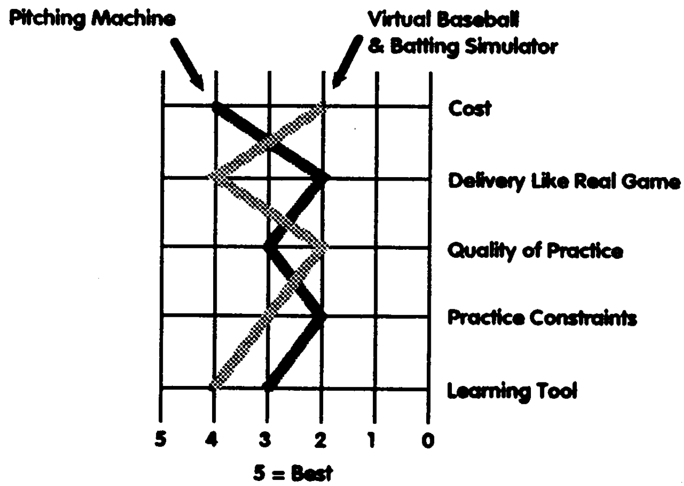


FIGURE 11 - Virtual Baseball Product Positioning

Summary

The task of building Virtual Baseball remains a significant challenge, however, based on this conceptual design it is clear that such a game could represent a viable market alternative to a pitching machine. As described at the beginning of this paper, the implementation of a full multi-player game is the ultimate objective of Virtual Baseball. This also has considerable potential, however, the design challenges represent another system engineering task along with support from the necessary technology.

We have taken a top down design approach to a Virtual Reality product. Most applications for VR originate from a bottom up approach where existing technology is applied to implement what is possible. If such an approach was followed with this example the likely product comparison would be with a Nintendo baseball game. Yet, VR will not develop as a market when its full potential is limited to narrow market segments or when it is only implemented using existing technology. Only by the integration of the design process, with the understanding of markets along with the technology, will VR enter the mainstream.

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