US006304665B1

(12) **United States Patent**
Cavallaro et al.

(10) **Patent No.: US 6,304,665 B1**
(45) **Date of Patent: Oct. 16, 2001**

(54) **SYSTEM FOR DETERMINING THE END OF A PATH FOR A MOVING OBJECT**

(75) Inventors: **Richard H. Cavallaro**, Mountain View; **James R. Gloudemans**, San Mateo; **Stanley K. Honey**, Palo Alto; **Terence J. O'Brien**, San Jose; **Alan C. Phillips**, Los Altos, all of CA (US); **William F. Squadron**, Scarsdale, NY (US); **Marvin S. White**, San Carlos, CA (US)

(73) Assignee: **Sportvision, Inc.**, New York, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/283,729**

(22) Filed: **Apr. 1, 1999**

Related U.S. Application Data

(60) Provisional application No. 60/080,612, filed on Apr. 3, 1998.

(51) **Int. Cl.**[7] **G06K 9/00**
(52) **U.S. Cl.** **382/106**
(58) **Field of Search** 382/100, 103, 382/106, 154, 181, 276, 285, 286, 291; 348/135, 139, 140, 142; 396/89, 94, 104, 121; 356/3, 4.01, 4.06, 919; 473/198, 199; 701/200, 201, 202, 204, 207, 211, 300

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,545,576	10/1985	Harris	473/468
4,858,922	8/1989	Santavaci	473/192
5,092,602	3/1992	Witler et al.	473/199
5,138,322	8/1992	Nuttall	342/126
5,363,297 *	11/1994	Larson et al.	700/91
5,401,026	3/1995	Eccher et al.	473/199
5,413,345	5/1995	Nauck	473/156
5,446,701 *	8/1995	Utke et al.	367/118
5,486,002 *	1/1996	Witler et al.	473/194
5,513,854 *	5/1996	Daver	700/91
5,605,326	2/1997	Spear, Jr.	473/422
5,609,534	3/1997	Gebhardt et al.	473/409
5,768,151 *	6/1998	Lowy et al.	463/2
5,868,578	2/1999	Baum	434/247
5,912,700 *	6/1999	Honey et al.	348/157
5,926,780	7/1999	Fox et al.	702/142
6,042,492	3/2000	Baum	473/453
6,084,979 *	7/2000	Kanade et al.	382/154
6,093,923 *	7/2000	Vock et al.	250/206.1

OTHER PUBLICATIONS

Glen Dickson, "ESPN Checks Swings With Bat Track", magazine (Broadcasting & Cable) article, Jun. 22, 1998, pp. 46–47.

* cited by examiner

Primary Examiner—Andrew W. Johns
Assistant Examiner—Shervin Nakhjavan
(74) *Attorney, Agent, or Firm*—Vierra Magen Marcus Harmon & DeNiro LLP

(57) **ABSTRACT**

A system is disclosed that can determine the distance a baseball would have traveled after being hit if its path was not interrupted. Thus, when a player hits a home run and the ball collides with an obstruction such as the seating area of a stadium or a wall, the present invention can determine how far the ball would have traveled had the ball not hit the stadium or the wall. The present invention can also be used to determine information about the path of objects other than a baseball.

36 Claims, 6 Drawing Sheets

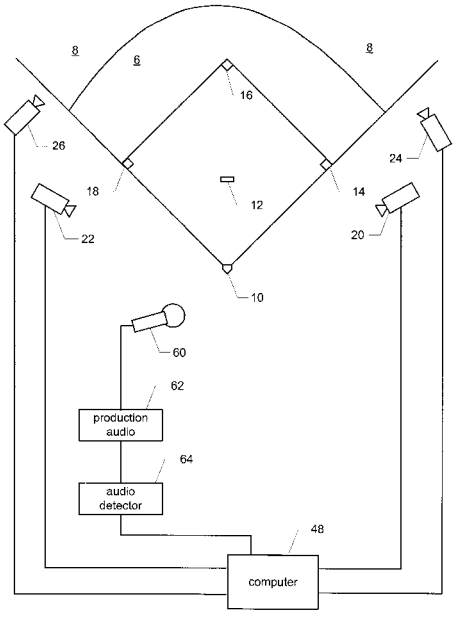
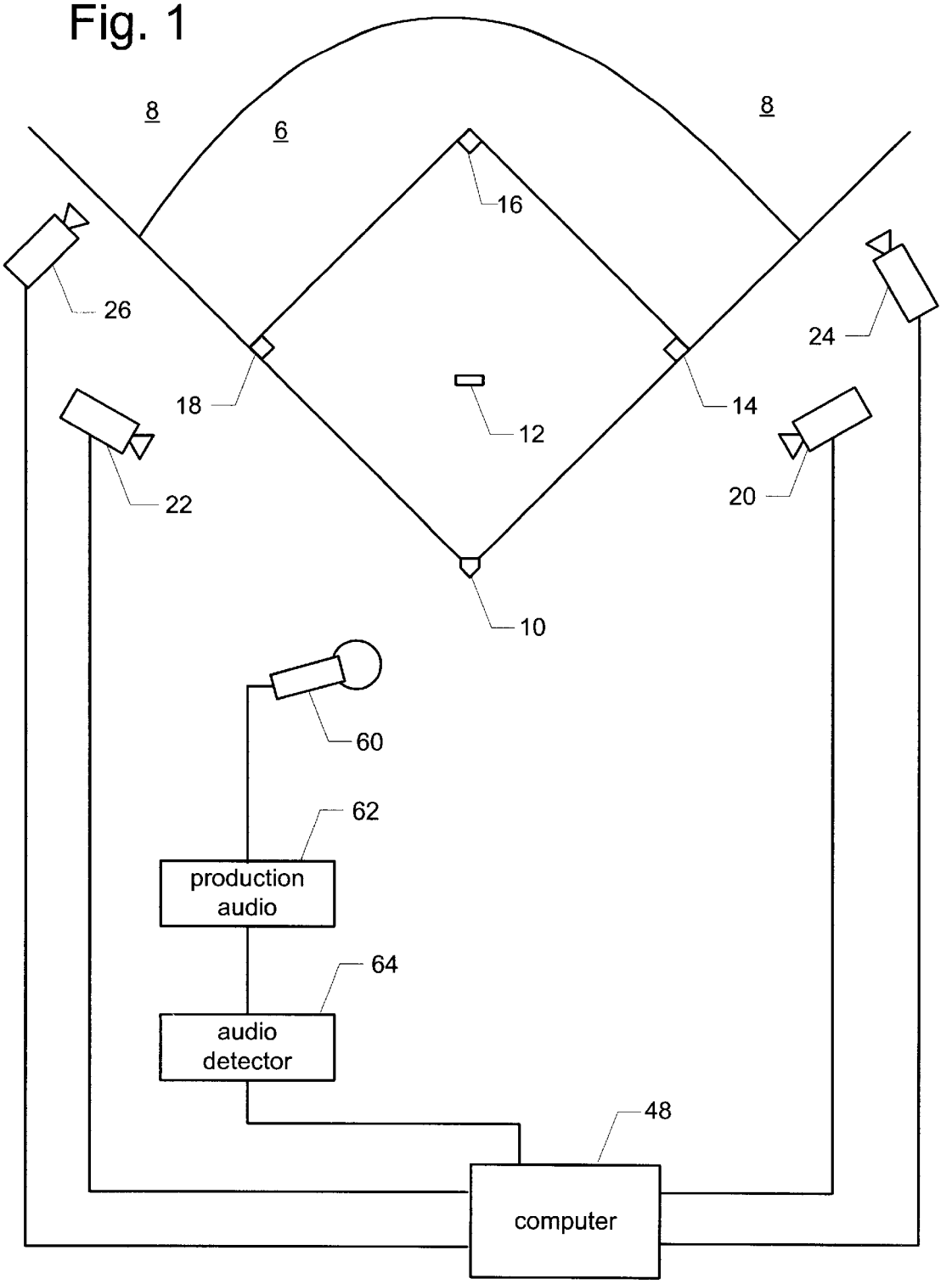


Fig. 1


8
6
8
16
26
24
18
14
12
22
20
10
60
62
production audio
64
audio detector
48
computer

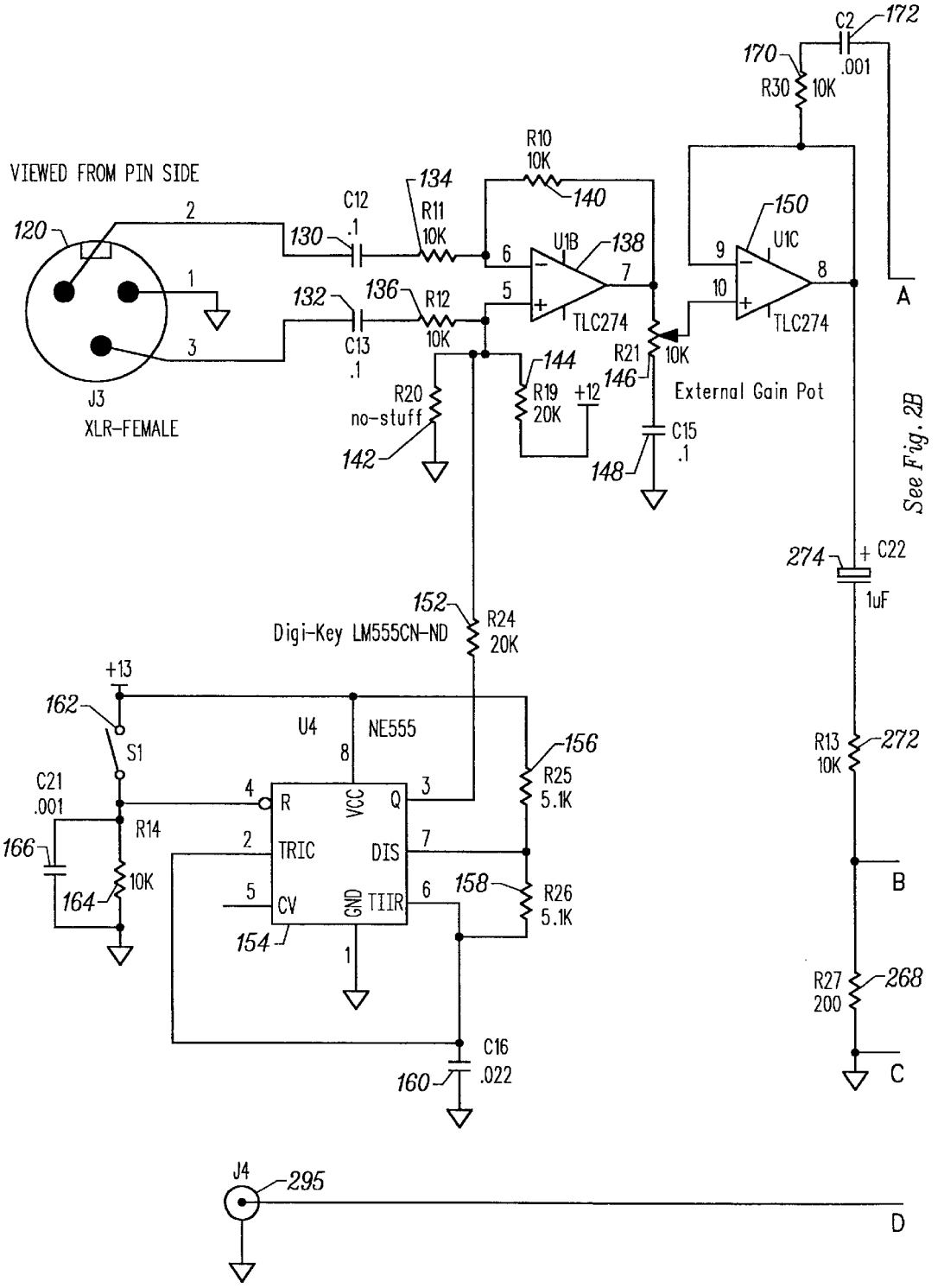

VIEWED FROM PIN SIDE
120
J3
XLR-FEMALE
C12
.1
130
134
R11
10K
R10
10K
140
U1B
138
TLC274
132
C13
.1
136
R12
10K
R20
no-stuff
142
R19
20K
144
+12
R21
10K
146
External Gain Pot
C15
.1
148
150
U1C
TLC274
C2
.001
172
170
R30
10K
A
See Fig. 2B
274
+ C22
1uF
152
Digi-Key LM555CN-ND
R24
20K
+13
162
S1
U4
NE555
156
R25
5.1K
C21
.001
R14
166
10K
164
R
VCC
Q
TRIC
DIS
CV
GND
TIIR
158
R26
5.1K
154
C16
.022
160
R13
10K
272
B
R27
200
268
C
J4
295
D

FIG. 2A

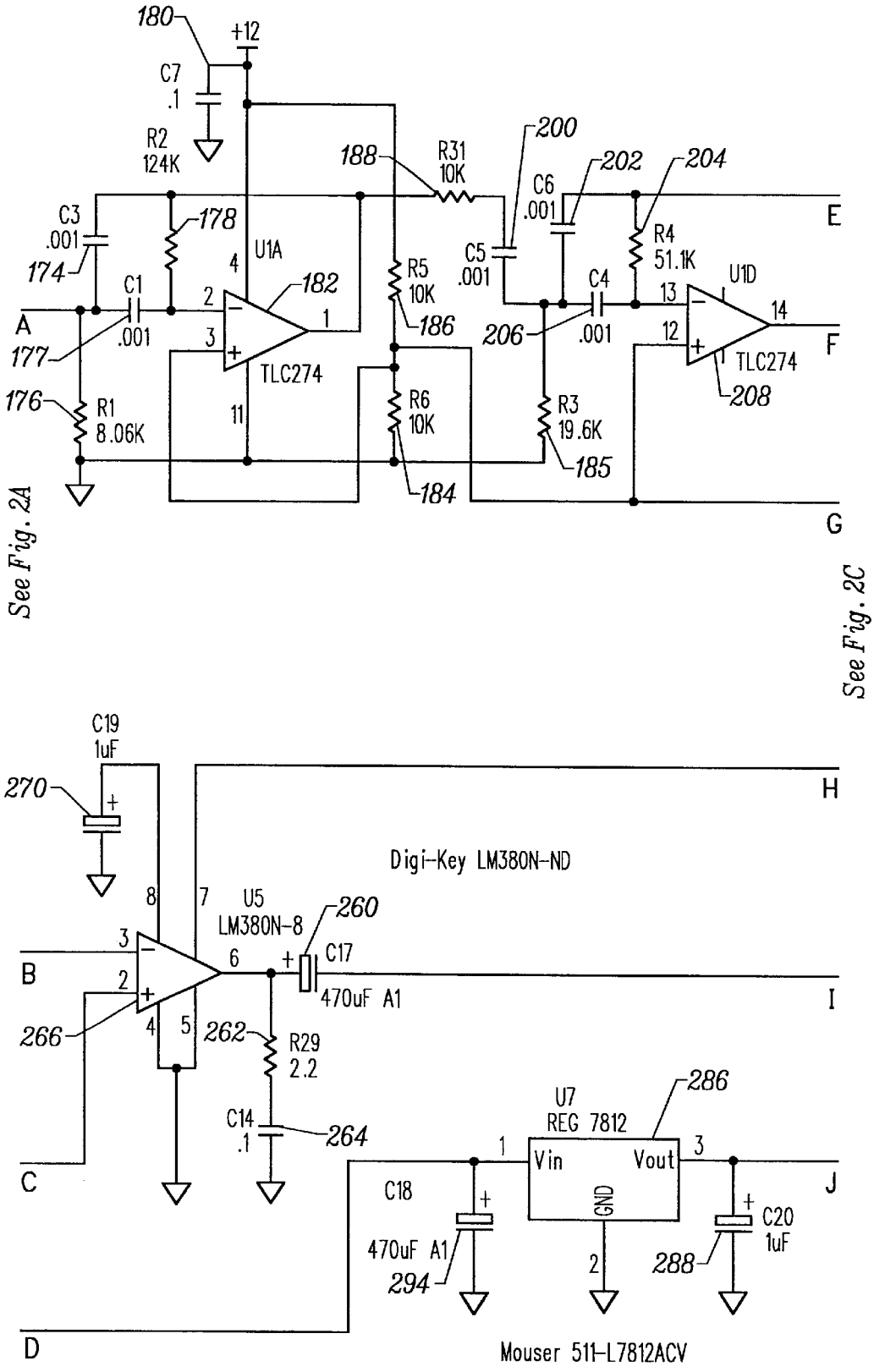

180
+12
C7
.1
R2
124K
188
R31
10K
200
202
204
C6
.001
C3
.001
178
174
U1A
4
182
R5
10K
C5
.001
R4
51.1K
U1D
E
C1
2
1
186
C4
13
14
A
.001
3
206
.001
12
F
177
TLC274
TLC274
208
176
R1
8.06K
11
R6
10K
R3
19.6K
185
184
G
See Fig. 2A
See Fig. 2C
C19
1uF
270
H
Digi-Key LM380N-ND
8
7
U5
LM380N-8
260
3
6
C17
B
2
470uF A1
I
266
4
5
262
R29
2.2
286
U7
REG 7812
C14
.1
264
1
Vin
Vout
3
C
C18
GND
J
470uF A1
C20
1uF
294
2
288
D
Mouser 511-L7812ACV

FIG. 2B

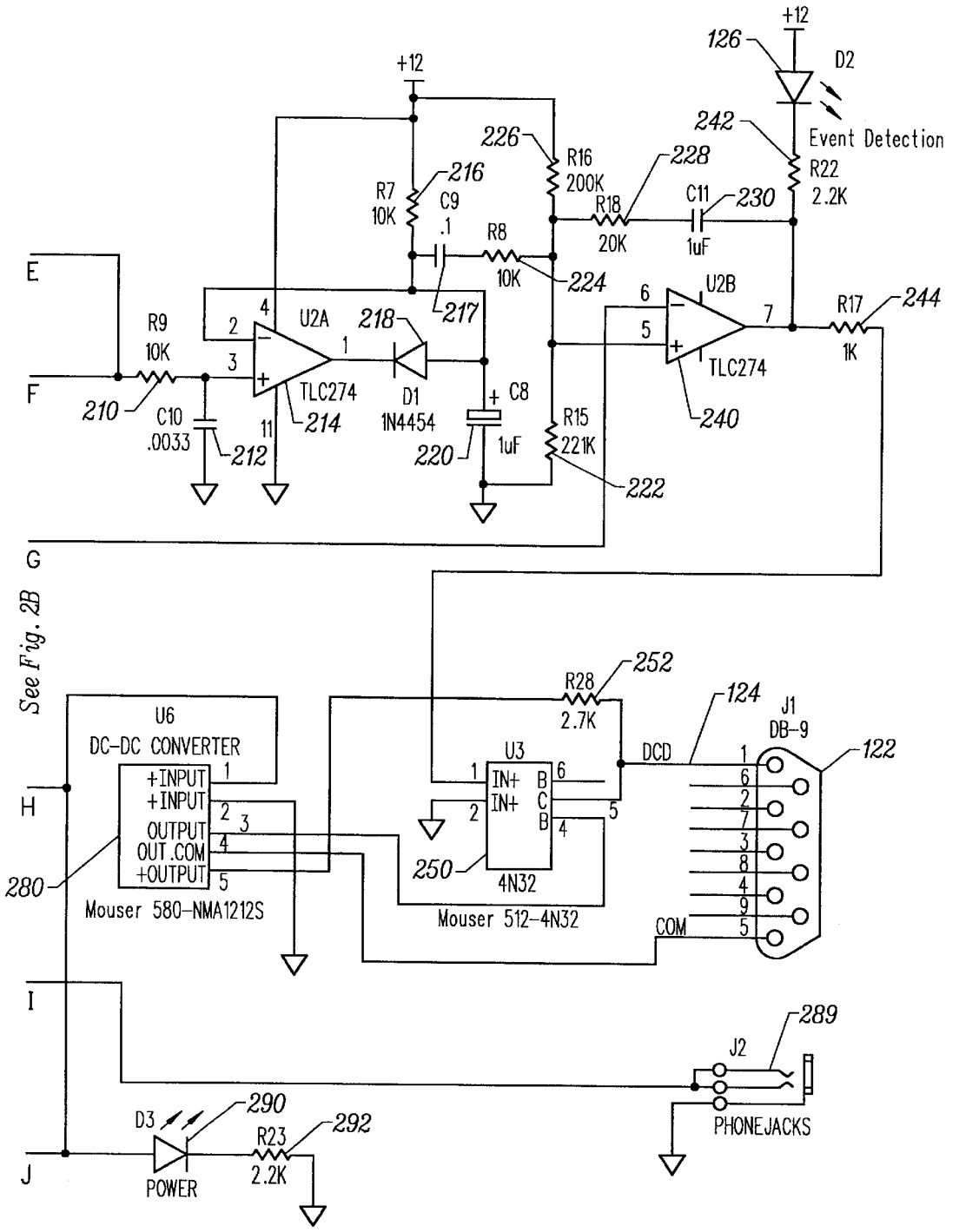

+12
126
D2
Event Detection
242
R22
2.2K
226
R16
200K
228
R18
20K
C11
1uF
230
R7
10K
216
C9
.1
R8
10K
224
E
F
R9
10K
210
C10
.0033
212
U2A
218
217
TLC274
214
D1
1N4454
C8
1uF
220
R15
221K
222
U2B
TLC274
240
R17
1K
244
G
See Fig. 2B
U6
DC-DC CONVERTER
+INPUT
+INPUT
OUTPUT
OUT.COM
+OUTPUT
Mouser 580-NMA1212S
280
H
I
J
U3
IN+
IN+
B
C
E
4N32
250
Mouser 512-4N32
R28
2.7K
252
DCD
124
J1
DB-9
122
COM
J2
289
PHONEJACKS
D3
290
R23
2.2K
292
POWER

FIG. 2C

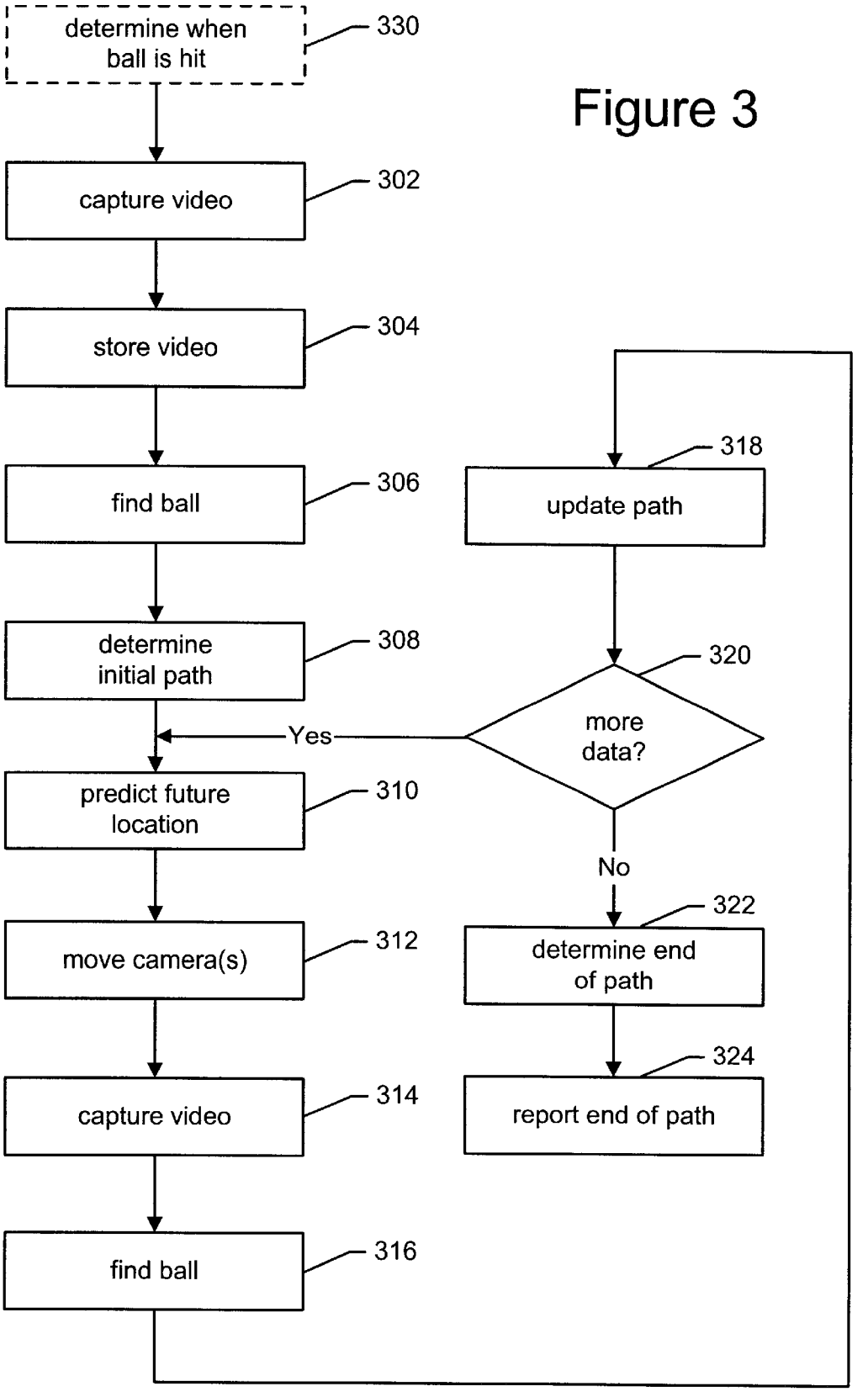
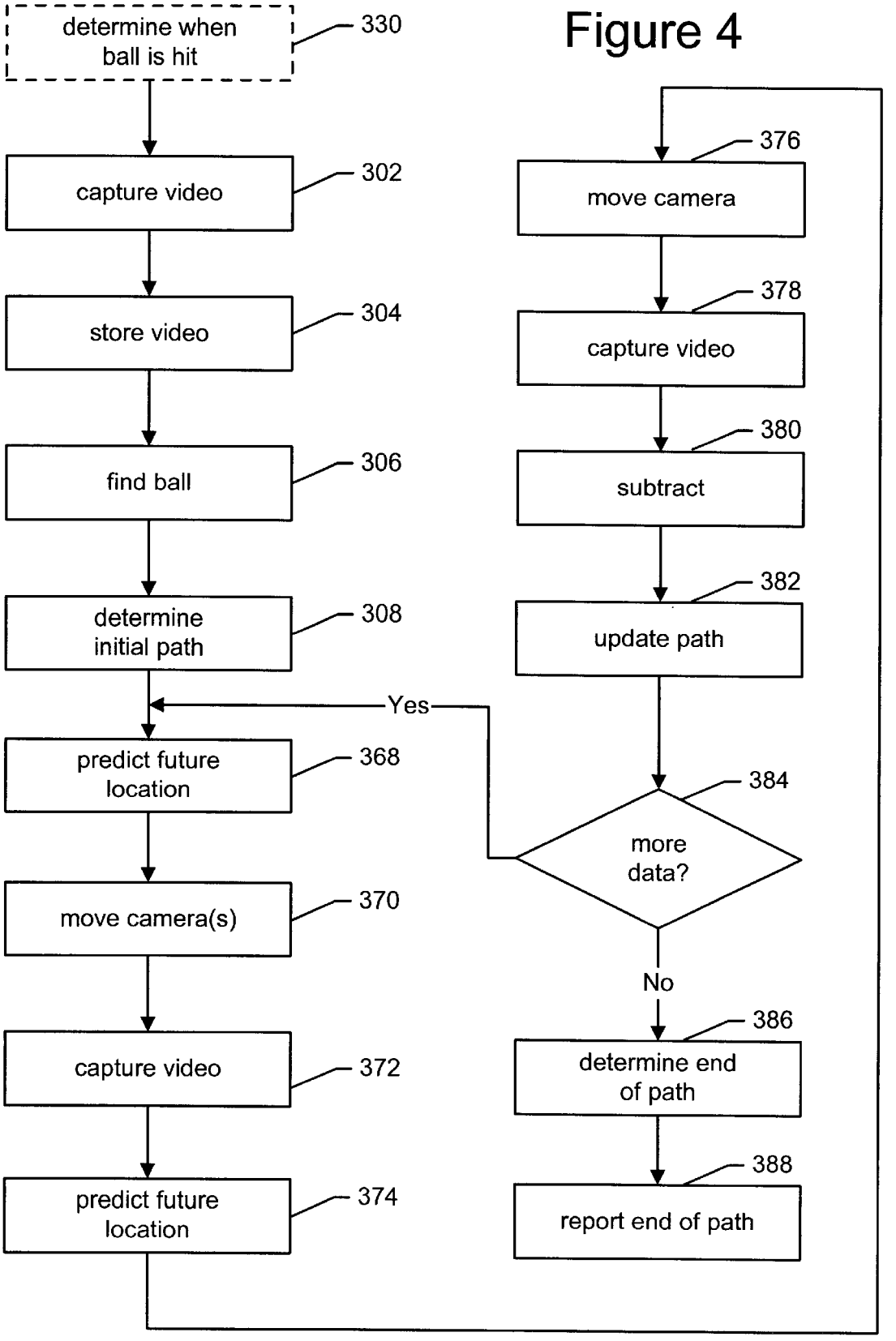

determine when ball is hit
330
capture video
302
store video
304
find ball
306
determine initial path
308
predict future location
310
move camera(s)
312
capture video
314
find ball
316
update path
318
more data?
320
Yes
No
determine end of path
322
report end of path
324

Figure 3

Figure 4


determine when ball is hit
330
capture video
302
store video
304
find ball
306
determine initial path
308
predict future location
368
move camera(s)
370
capture video
372
predict future location
374
Yes
move camera
376
capture video
378
subtract
380
update path
382
more data?
384
No
determine end of path
386
report end of path
388

SYSTEM FOR DETERMINING THE END OF A PATH FOR A MOVING OBJECT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/080,612, entitled, "System For Determining Information About Moving Objects," filed on Apr. 3, 1998, incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed to a system for determining information about the path of travel of a moving object.

2. Description of the Related Art

The remarkable, often astonishing, physical skills and feats of great athletes draw millions of people every day to follow sports that range from the power of football to the grace of figure skating, from the speed of ice hockey to the precision of golf. Sports fans are captivated by the abilities of a basketball players to soar to the rafters, of a baseball player to hit home runs, of a runner to explode down the track, etc. In televising these events, broadcasters have deployed a varied repertoire of technologies—ranging from slow-motion replay to lipstick-sized cameras mounted on helmets—to highlight for viewers these extraordinary talents. Fans are intrigued and excited by the efforts of athletes and the comparative abilities of athletes become topics of endless debate at water coolers, in sports bars, on the Internet, etc.

One piece of information that has never been available to fans of sports like baseball is the distance a baseball would have traveled when a home run is hit. In most cases a home run consists of a batter hitting the baseball over the home run fence. After the ball travels over the fence, it usually lands in the seating area. Because the ball's path of travel from the bat to a natural impact on the ground is interrupted by the ball hitting the stands, it is not known how far the ball would have traveled. Such information will not only create a statistic that reflects a critical athletic skill—batting power—but will also provide announcers with information that will enhance their analysis of the game. This information will be of tremendous interest to baseball fans, and to date there have been no successful attempts to reliably provide such information during the telecast of a game.

Therefore, a system is needed that can determine information about the path of a moving object, for example, the distance a baseball would travel if its path is not interrupted.

SUMMARY OF THE INVENTION

The present invention includes a system that can determine the distance a baseball will travel after being hit if its path is not interrupted. Thus, when a player hits a home run and the ball hits the stadium, the present invention can determine how far the ball would have traveled had the ball not collided with the stadium. The present invention can also be used to determine the path of a ball as well as the end of the path of the ball. In addition to baseball, the present invention can be used to determine similar information for moving objects at other events including sporting and non-sporting events.

In one embodiment of the present invention, the system determines one or more locations of the object or ball after the ball has been hit by a bat. The determined locations do not include the end of the ball's uninterrupted path, which is the location the ball would have landed if the ball's path was not interrupted (or obstructed) and the ball was allowed to land at the end of its natural path. After determining the one or more locations of the ball, the system uses the determined locations to determine the distance the ball would have traveled after being hit if the ball's path was not interrupted.

Another embodiment of the present invention includes capturing video images of an object and determining an end of a hypothetical uninterrupted path of the object based on the video images. The term uninterrupted path means the natural path an object would take without being obstructed (e.g. by a stadium or a pole). The term "hypothetical" is used to indicate that the ball did not or will not take the natural path; therefore, the path is not the actual path it is only a hypothetical path.

In another embodiment, the system initially determines a hypothetical uninterrupted path. The system subsequently determines a set of three dimensional locations of the object during its flight and updates the hypothetical uninterrupted path based on the set of three dimensional locations. Finally, the system determines the end of the hypothetical uninterrupted path. The determination of a path does not require that the coordinates of every point along the path be known. Rather, the determination of the path includes a determination of the mathematical relationship that can be used to find a point along the path. For example, knowing location and velocity data for a moving object, one or more equations can be created to describe the path of the moving object.

One implementation of the present invention includes a processor and a set of cameras in communication with the processor. The processor is also in communication with a storage element that stores program code for programming the processor to perform the methods disclosed herein.

These and other objects and advantages of the invention will appear more clearly from the following detailed description in which the preferred embodiment of the invention has been set forth in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a drawing of a baseball field and the present invention.

FIG. **2** is a schematic of a circuit used to detect the sound of a bat hitting a baseball.

FIG. **3** is a flow chart describing the steps of a first embodiment of the present invention.

FIG. **4** is a flow chart describing the steps of a second embodiment of the present invention.

DETAILED DESCRIPTION

The present invention can be used in conjunction with many different events and situations, including sporting events and events other than sporting events. For illustrative purposes, the embodiment described below is used in conjunction with the broadcast of a baseball game.

FIG. **1** shows the hardware for one embodiment of the present invention in conjunction with a baseball field. Specifically, baseball field **6** is depicted having outfield **8**, home plate **10**, pitcher's mound **12**, first base **14**, second base **16** and third base **18**. Typically, a pitcher would stand on pitcher's mound **12** and throw the ball to a catcher behind home plate **10**. A batter would attempt to hit the ball while standing next to home plate **10**. The far perimeter of outfield **8** is bordered by a home run fence (not shown). Typically, the baseball stadium includes seating for fans behind the home run fence.

FIG. **1** also shows four cameras **20**, **22**, **24** and **26**. In one embodiment, cameras **20** and **22** are high quality instrumentation cameras that have a faster shutter speed and frame rate than a typical video camera. In another embodiment, cameras **20** and **22** will have a faster shutter speed, but the frame rate will be the normal NTSC 30 frames per second. Other cameras can also be used. Cameras **20** and **22** are located to the side of field **6**, and are pointed at home plate **10** such that each camera has a field of view that includes home plate **10** and 20–30 feet in front of home plate **10**. Cameras **20** and **22** are connected to computer **48**. Cameras **20** and **22** are rigidly mounted with fixed pan, tilt, focus and zoom. In another embodiment, either camera **20** or **22** can be located behind or above home plate **10**.

Cameras **24** and **26** are mounted on tripods (or other suitable fixtures) having servo motors that allow computer control of the pan and tilt of the two cameras. In one embodiment, the shutters of the cameras **24** and **26** are synchronized and the shutters of the cameras **20** and **22** are synchronized. Cameras **24** and **26** are connected to computer **48**. Computer **48** can be an O2 workstation from Silicon Graphics. Other computers can also be used. Computer **48** includes a processor, memory, a hard disk, a floppy disk, a monitor, a printer, a keyboard, a pointing device, a CD-ROM drive, a modem and/or a network interface.

In one alternative, cameras **24** and **26** have a fixed zoom level. In another alternative, cameras **24** and **26** have servo motors to control the zoom of each camera. Cameras **24** and **26** can be standard interlaced video cameras. Computer **48** sends signals to the servo motors controlling the pan and tilt of cameras **24** and **26**, thus, allowing cameras **24** and **26** to view the moving object. If cameras **24** and **26** had rapidly moving pan and tilt motors, fixed cameras **20** and **22** would not be necessary since cameras **24** and **26** could first be pointed at the batter and then rapidly be moved to point to outfield **8**.

Located near home plate **10** is a microphone **60**. In one alternative, instead of locating the microphone near home plate **10**, microphone **60** can be designed to be located elsewhere but to pick up sounds from near home plate **10**. Currently, most television broadcasters will bring many microphones to the game in order to pick up sounds from the playing field. It is customary for a broadcaster to locate one microphone near home plate **10**. If the broadcaster is already locating a microphone near home plate **10**, an additional microphone may not be necessary. That is, the system of the present invention can use a microphone already used by the broadcaster at the game. Even if a broadcaster has a microphone at the game, the system can still use a separate microphone. A broadcaster's microphone will typically be in communication with production audio **62**. Production audio **62** is the production equipment used by the broadcaster at the game to produce the audio portion of the broadcast. The output of production audio **62**, which is a signal received from microphone **60** with some modifications (e.g. amplification, filtering, etc.) is sent to audio detector **64**. It is possible, in some embodiments, to bypass production audio **62**. That is, microphone **60** can communicate directly to audio detector **64**, which could include any necessary amplification and filtering circuits. Audio detector **64** is an electronic device that can detect one or more predetermined sounds. For example, in the system shown in FIG. **1** audio detector **64** can be designed to detect the sound of a bat hitting a baseball. Other sounds can also be detected. When audio detector **64** detects the sound of the bat hitting the ball, it will send a signal indicating that detection to computer **48**. As will be described below, microphone **60** and the associated electronics are optional. That is, many embodiments of the present invention do not use any audio detection. For example, one embodiment relies on video and another embodiment uses radar technology.

FIG. **2** is a schematic drawing of one embodiment of audio detector **64**. The embodiment shown in FIG. **2** can detect the sound of a bat hitting a baseball. The input to the circuit of FIG. **2** is female connector **120**, which would receive a signal from microphone **60**. The output of the circuit of FIG. **2** is connector **122** which outputs a signal **124** (labeled as DCD) that indicates whether the circuit of FIG. **2** has detected the sound of a ball hitting a bat. The circuit of FIG. **2** also includes a light emitting diode (LED) **126** which also indicates whether the circuit of FIG. **2** detected the sound of the bat hitting the ball.

Connector **120** is connected to ground, capacitor **130** and capacitor **132**. Capacitor **130** is also connected to resistor **134**, and capacitor **132** is connected to resistor **136**. Resistor **134** is connected to resistor **140** and an input of amplifier **138**. Resistor **136** is connected to another input of amplifier **138**, resistor **142** and resistor **144**. Resistor **142** is also connected to ground, and resistor **144** is also connected to a 12 volt source. Resistor **140** is also connected to the output of amplifier **138** and potentiometer **146**. Potentiometer **146** is connected to capacitor **148** and an input to amplifier **150**.

Resistor **136** is also connected to the top of resistor **152**. The other side of resistor **152** is connected to the Q output of pulse generator **154**. The R input of pulse generator **154** is connected to switch **162**, resistor **164** and capacitor **166**. The other side of switch **162** is connected to the vcc input of pulse generator **154** and resistor **156**. Switch **162** is used to test the circuit of FIG. **2** by generating a simulated bat crack sound signal. Resistor **164** and capacitor **166** are both connected to ground. The trigger input of pulse generator **154** is connected to capacitor **160** and resistor **158**. Capacitor **160** is also connected to ground. Both resistors **156** and **158** are also connected to the DIS pin of pulse generator **154**. The purpose of pulse generator **154** (and its accompanying components) is to create a signal representing the sound of a bat hitting the ball which can be used to test the circuit of FIG. **2** and the components of FIG. **1**.

One of the inputs of amplifier **150** is connected to resistor **170** and capacitor **274**. Resistor **170** is also connected to capacitor **172**. Capacitor **172** is connected to capacitor **174**, resistor **176** and capacitor **177**. Capacitor **177** is connected to resistor **178** and one of the inputs of amplifier of **182**. Resistor **178** is also connected to the output of amplifier **182** and resistor **188**. Capacitor **180** is connected to ground, the vcc input of amplifier **182** and resistor **186**. The other side of resistor **186** is connected to resistor **184**, an input of amplifier **182**, an input of amplifier **208** and an input of amplifier **240**. Resistor **184** is also connected to ground, resistor **176**, amplifier **182** and resistor **185**. The other end of resistor **185** is connected to capacitor **200**, capacitor **202** and capacitor **206**. Capacitor **206** is also connected to resistor **204** and an input to amplifier **208**. Resistor **204** is also connected to capacitor **202**, the output of amplifier **208** and resistor **210**. Resistor **210** is also connected to capacitor **212**, which is connected to ground, and an input to amplifier **214**. The other input of amplifier **214** is connected to diode **218**, resistor **216**, capacitor **217** and capacitor **220**. The vcc input of amplifier **214** is connected to the top of resistor **216**, resistor **226** and a 12 volt source. The other side of capacitor **217** is connected to resistor **224**. Resistor **224** is also connected to resistor **222**, resistor **228**, resistor **226** and an input to amplifier **240**. Resistor **222** is also connected to capacitor **220** and ground. Resistor **228** is connected to

capacitor **230**, which is connected to resistor **242**, resistor **244** and the output of amplifier **240**. The other side of resistor **242** is connected to LED **126**, which is also connected to a 12 volt source.

Resistor **244** is connected to the output of amplifier **240** and the IN+input of opto-isolator **250**. The IN−input of opto-isolator **250** is connected to ground. The B output of opto-isolator **250** is connected to resistor **252** and provides the DCD signal **124**. The Eoutput of opto-isolator **250** is connected to the −OUTPUT of DC-DC converter **280**. The OUTPUT common of DC-DC converter **280** is connected to the common pin of the output connector **122**. The +OUTPUT from DC-DC converter **280** is connected to resistor **252**. The −INPUT is connected to ground and the +INPUT of DC-DC converter **280** is connected to amplifier **266**, LED **290** (indicates power is on), capacitor **288** and Vout regulator **286**. LED **290** is also connected to resistor **292**, which is also connected to ground. One example of a suitable opto-isolator device is a Mouser 512-4N32. A suitable DC-DC converter is the Mouser 580-NMA1212S. The ground pin for voltage regulator **286** is tied to ground. The Vin pin for voltage regulator **286** is connected to capacitor **294** (which is connected to ground) and to power supply input **295** (which connects to a DC power supply).

The output of amplifier **266** is connected to resistor **262** and capacitor **260**. Resistor **262** is also connected to capacitor **264**, which is connected to ground. Capacitor **260** is connected to phone jacks **289** which allows the operator to listen to the sound being processed by the circuit of FIG. **2**. One terminal of capacitor **270** is connected to amplifier **266** and the other terminal is connected to ground. One end of resistor **268** is connected to an input of amplifier **266** and resistor **272**. The other end of resistor **268** is connected to ground and to another input of amplifier **266**. Resistor **272** is also connected to capacitor **274**. Capacitor **274** is also connected to resistor **170**, an input of amplifier **150** and an output of amplifier **150**.

FIG. **3** shows the steps of a first embodiment for determining how far a ball will travel if its path is unimpeded. In step **302**, cameras **20** and **22** capture video of the home plate area. Each of the frames of data captured by cameras **20** and **22** are sent to computer **48**. In step **304**, the captured video is stored in computer **48**. In one embodiment, steps **302** and **304** are continuously performed throughout the event. In one alternative, step **304** stores the video in a circular buffer. In another embodiment, step **302** is performed continuously, but step **304** stops storing data within a small time (e.g. .5 seconds, 3 seconds, etc.) after it is determined that a bat hit a ball (optional step **322** discussed below).

In step **306**, computer **48** finds the baseball inside the video frames received from cameras **20** and **22** and stored in step **304**. Since the steps of FIG. **3** may have started before a bat hit a ball, step **306** may continue to search through the video as (or after) it is stored until it finds the ball traveling away from home plate **10**. One embodiment of step **306** is accomplished using pattern recognition to find the ball in successive video frames moving in a direction away from home plate. In another embodiment, the pattern recognition is enhanced using subtraction techniques. In some cases, it may be possible to find the ball using subtraction without traditional pattern recognition techniques. One example of a suitable subtraction technique is to consider multiple video frames from one camera and subtract the data for successive video frames (or successive even and/or odd fields). The only objects that should be moving in the video are the player, the bat and the ball. Thus, only three groups of data will remain after subtracting two video frames. If subtraction is done from multiple sets of frames, the computer can identify one of the three groups of data that is moving away from the other two sets of data. That identified group of data is the baseball. The color, size and shape of the images can also be used as clues to identify the baseball. This process can be done for the video received from both cameras **20** and **22**.

After computer **48** finds the ball in the videos, it determines the initial path of the ball in step **308**. The initial path of the ball is the path the ball would take if there is no wind, spin or obstructions. By knowing the location, pan, tilt and zoom of cameras **20** and **22**, the pixel positions of the ball in the video frames (from step **306**) and timing of the video frames, computer **48** can determine the speed of the ball leaving the bat and a line of position for the ball in each frame. A line of position is a line (or vector) from the camera to the ball. The point of closest approach between a line of position for a video frame from camera **20** and a line of position for a corresponding in time video frame from camera **22** is the best estimate of the three dimensional location of the ball. Based on a set of three dimensional location values, computer **48** can determine an initial direction vector and a trajectory can be computed. The initial trajectory can be used to predict a path of the ball. More information about lines of position and determining three dimensional locations can be found in U.S. patent application Ser. No. 09/041,238, filed on Mar. 11, 1998, Cavallaro, et al., "System For Determining The Position Of An Object," and U.S. patent application Ser. No. 08/585,145, filed Jan. 10, 1996, Honey, et al., "System for Enhancing the Television Presentation of an Object at a Sporting Event," both applications are incorporated herein by reference.

The ball's path can change as it travels along the trajectory. Thus, cameras **24** and **26** are used to update the path as the ball travels. In one embodiment, cameras **24** and **26** are located on opposite sides of the field, approximately halfway between home plate and the home run fence. In step **310**, computer **48** uses the previously determined trajectory to predict when the future path of the ball will be within the view of cameras **24** and **26**. Computer **48** can predict a time and corresponding location along the ball's path and send signals to the servo motors for cameras **24** and **26** to point exactly at that predicted location at the appropriate time (step **312**).

In one embodiment, cameras **24** and **26** would be manually panned and tilted (rather than using motors) to follow the ball or point to a future location of the ball. In this embodiment, cameras **24** and **26** would have pan and tilt sensors. Knowing the location of the cameras, the pan angle and the tilt angle, computer **48** can predict the time that the ball will be within the field of view of the camera and the pixel position. More information about pan and tilt sensors can be found in U.S. patent application Ser. No. 08/585,145, cited and incorporated above.

At the calculated time for the ball to be within the field of view of camera **24** and/or **26**, computer **48** receives video images of the ball from cameras **24** and **26** in step **314**. In step **316** computer **48** finds the ball in the video images received in step **314**. In one embodiment computer **48** divides the images into successive pairs and subtracts the pairs of video images. Since cameras **24** and **26** were not moving when it captured the images in step **314**, the video images should only differ by the position of the ball. Thus, subtracting two successive video images will remove the background data and leave two locations of the ball (or four in the case of interlaced images). Computer **48** determines lines of position, as discussed above, and the three dimen-

sional location of the ball at multiple times. Computer **48** then determines whether the ball was where it was expected it to be. If so, the path is not updated. If the ball was not in the predicted location at the predicted time, the path is updated in step **318**. In one alternative, step **316** also uses pattern recognition in conjunction with subtraction to find the ball. In another alternative, step **316** is performed using pattern recognition without subtraction. In one embodiment, an operator of the system would be able to choose whether to use the subtraction techniques.

In step **320**, the system determines whether more data can be captured. That is, knowing the location of cameras **24** and **26**, can the cameras be moved to view the ball at a future point in the ball's path. If so, the system loops back to step **310**. If cameras **24** and **26** cannot be moved to view the ball, then computer **48** performs step **322** which includes determining the end of the ball's path.

In previous steps, computer **48** determined the ball's path. Step **322** includes determining the location at which the ball's path would intersect the ground (field level), assuming that the ball's path would not be interrupted by a fence, a person, a wall, stadium seating or any other obstruction. The location at which the ball's path would intersect the ground is compared to the location of home plate **10** to determine the distance that the ball would have traveled if the path was not interrupted. In step **324**, the distance determined in step **322** is reported. The step of reporting includes displaying the information on a monitor, printing the information, using pre-stored audio files to report the information, passing the information to another function or process, transmitting the information to another computer or adding a graphic which indicates the determined distance (using a keyer) to a video of the baseball game. In a simple embodiment, reporting includes providing the information to a television announcer for the game.

In one embodiment, the steps of FIG. **3** are performed in real time. In another embodiment, steps **316**, **318**, **322** and **324** are performed slower than in real time but quick enough to report results within 30 seconds of the ball's path being terminated. To be most useful, the system should provide results before the next pitch. In some cases, results before the next batter is sufficient.

In one embodiment, step **320** can be eliminated and steps **310–318** are only performed once. In another embodiment, the system includes additional cameras and steps **310–318** are performed for the additional cameras. In one embodiment, the steps can also be performed using a manual digitizing technique.

In an alternative embodiment, cameras **24** and **26** (and/or their servo motors) are directly connected to a local computer, for example, a PC using an Intel Pentium processor. Each of the local computers are connected to computer **48**. In another embodiment, computer **48** can include multiple processors or multiple computers.

In another alternative embodiment, cameras **24** and **26** are replaced with a set of cameras having fixed pan, tilt and zoom. The set of cameras includes enough cameras to have sufficient coverage of the outfield such that each part of the outfield is within the field of view of at least two separately located cameras. Rather than move servos motors to point cameras at the predicted location of the ball, the system would use the predicted location of the ball to select the appropriate subset of cameras. Alternatively, many cameras can be simultaneously selected if there is sufficient bandwidth and computing power. In another alternative, steps **310**, **314**, **316** and **318** can be performed for multiple subsets of cameras.

FIG. **3** shows step **330** in dotted lines because this step is optional. Step **330** is used to conserve resources on computer **48**. In step **330**, the system determines the moment when the ball is hit by the bat. In the embodiment of FIG. **1**, the sound of the bat hitting the ball is detected by audio detection circuit **64**. Audio detection circuit **64** sends a signal to computer **48** that the ball has been hit. By knowing the moment that the bat hit the ball, the process of finding the ball (step **306**) can be restricted to frames of video within a time window of the bat hitting the ball. This free up processor resources on computer **48**.

FIG. **4** is a flow chart describing the steps of a second embodiment for determining the distance a ball will travel. The first four steps of FIG. **4** are the same as the first four steps in FIG. **3**. In step **368**, the system predicts the future location of the ball, similar to step **310** of FIG. **3**. In step **370**, cameras **24** and **26** are moved so that the ball will soon appear in the center of each of the camera's field of view. In step **372**, the cameras capture a first set of video frames. In step **374**, the computer **48** determines a future location of the ball and moves (step **376**) the cameras so that the ball will be in the center of the cameras' field of view. In one embodiment, step **374** includes finding the ball in the video captured in step **372** and using that pixel location to predict the future location. In another embodiment, the future location is determined using the data from steps **306** and **308**. In step **378**, the cameras capture a second set of video frames. In step **380**, the frames of video for each camera captured in step **372** are subtracted from the frames of video captured by the same camera in step **378**. Step **380** includes shifting the pixels of the video frames prior to subtraction. That is, computer **48** knows how cameras **24** and **26** were moved between video frames. Thus, computer **48** can calculate an offset and shift, rotate or scale the pixels of the video frames captured in step **378** so that the background of the two video frames align with minimal error. When subtracting two frames, the background should subtract out and only the locations of the ball will remain. Based on the pixel locations of the ball and the time the video frames were captured, computer **48** determines the three dimensional location of the ball at multiple times and updates the path of the ball in step **382**. Step **384** is similar to step **320** of FIG. **3**. If more data can be captured using any of the cameras, the system loops back to step **368**. Otherwise, the system predicts the end of the ball's path in step **386** and reports that information in step **388**. Note that in the steps of FIG. **4**, the zoom setting of each camera is constant. While it is possible to operate the system if the zoom settings for each camera is not constant, the task would be significantly more difficult. If the steps of subtraction create too large of an error due to camera jiggle or other external factors, computer **48** can offset one of the video frames to compensate accordingly.

In one alternative embodiment, a Doppler radar system can be used to determine the moment a ball hit a bat. In that embodiment three or more radar units can be placed behind home plate, pointing at home plate. For example, five radar units can be placed behind home plate with a first radar unit directly behind home plate, two radar units separated from the first radar unit by twelve degrees and two more radar units separated from the first radar unit by twenty two degrees. A computer performs a Fourier Transform or Fast Fourier Transform on the data from the radar units. The transformed data indicates velocity information, which includes data about speed and direction. The computer can be programmed to find the data representing the ball and to identify when the direction of the ball changes. The point when the direction of the ball changes is the moment that the

bat hit the ball. In some instances, the data representing the ball may have a gap at the point the direction of the ball changes. To compensate, the system can interpolate or use other known mathematics (e.g. Rate×Time=Distance) to calculate the time the bat hit the ball. The computer can also be programmed to identify the time the bat hit the ball by looking for velocity information about the bat in order to identify when the bat speed abruptly changes due to contact with a ball.

In one embodiment of the radar system, the radar units can be used to determine a set of three dimensional velocity vectors representing the velocity of the ball. A set of velocity vectors can be used to determine the path of the ball. In such an embodiment, an "out of plane" radar could be used that looks downward toward home plate **10** to capture the vertical velocity component of the ball.

Various radar units can be used with the present invention. One example of a suitable radar unit is sold as part of the Stalker Dual DSR Moving Radar from Applied Concepts, Inc., 730 F Avenue, Suite 200, Plano, Tex. 75074. The Stalker radar system is typically sold as a complete radar system for measuring the speed of objects. The present invention will only utilize what is called the antenna unit portion of the Stalker radar system. The antenna unit is basically a radar transmitter/receiver. Other Doppler radar units can also be used.

Another use of the present invention is to predict and display the path of a moving object. For example, after the present invention determines the initial path of a baseball, the path can be displayed. In one alternative, the system can add a target graphic to the video image of a baseball field to show the location where the ball will land (e.g. the end of the path). As the system updates the path of the ball, the displayed path and the displayed graphic at the end of the path can also be updated. For example, if a batter hits a fly ball to the outfield, while the outfielder is attempting to catch the ball the television display can show the path of the ball and the location in the outfield where the ball will land. That way, the viewer of the game on television will see if the outfielder is in the correct position. The graphic and the path can be created by a computer and added to the video of the baseball game using a keyer. More information about adding images to a video can be found in U.S. patent application Ser. No. 08/585,145, filed Jan. 10, 1996, Honey, et al., "System for Enhancing the Television Presentation of an Object at a Sporting Event," incorporated herein by reference.

The present invention has been described in relation to determining how far a baseball would have traveled. However, the present invention can be used to determine the distance or path of travel (or predicted travel) of other moving objects. For example, the system can be used to measure the distance of travel for a golf ball, football, soccer ball, javelin, shot put, frisbee, or other moving object (including objects not related to sporting events).

The above description discusses the use of video frames and assumes an NTSC video format. However, the present invention will work with other video formats (e.g. PAL, SECAM, HDTV, etc.). Although the above discussion specifically mentions frames of video, it is known that NTSC frames include odd and even fields. One skilled in the art will understand that the methods disclosed herein can be discussed or practiced in regard to fields or frames.

The foregoing detailed description of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously many modifications and variations are possible in light of the above teaching. The described embodiments were chosen in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.

We claim:

1. A method for determining information about a hypothetical uninterrupted path of a ball after said ball is hit by a bat, comprising the steps of:

sensing camera orientation data for a set of one or more cameras pointing at said ball while said ball is traveling along said hypothetical uninterrupted path, said step of sensing uses one or more camera orientation sensors;

capturing video images of said ball while said ball is traveling along said hypothetical uninterrupted path, said video images are captured using said set of one or more cameras; and

determining an end of said hypothetical uninterrupted path based on said captured video images and said camera orientation data.

2. A method according to claim **1**, wherein:

said one or more camera orientation sensors includes a pan sensor.

3. A method according to claim **1**, further including the step of:

determining a distance from a beginning of said hypothetical uninterrupted path to said end of said hypothetical uninterrupted path.

4. A method according to claim **3**, further including the step of:

reporting said distance.

5. A method according to claim **1**, further including the step of:

displaying said end of said hypothetical uninterrupted path.

6. A method according to claim **1** ,wherein said step of determining said end of said hypothetical uninterrupted path includes the steps of:

finding said ball in said video images;

initially determining said hypothetical uninterrupted path; and

updating said hypothetical uninterrupted path.

7. A method according to claim **6**, wherein said step of initially determining said hypothetical uninterrupted path includes the steps of:

determining a set of three dimensional locations of said ball; and

using said three dimensional locations to determine an initial trajectory.

8. A method according to claim **6**, wherein said step of updating said hypothetical uninterrupted path includes the steps of:

predicting a future location of said ball;

moving two cameras to point at said predicted future location after said step of predicting and prior to said ball reaching said future location;

finding said ball in video images from said two cameras pointed at said predicted future location; and

updating said hypothetical uninterrupted path based on said step of finding said ball in video images from said two cameras.

9. A method according to claim 6, wherein said step of updating said hypothetical uninterrupted path includes the steps of:

predicting a future location of said ball;

selecting two cameras that are pointing at said future location;

finding said ball in video images from said two cameras; and

updating said hypothetical uninterrupted path based on said step of finding said ball in video images from said two cameras.

10. A method according to claim 6, wherein said step of updating said hypothetical uninterrupted path includes the steps of:

predicting a first future location of said ball;

moving a camera to point at said first future location;

capturing a first set of one or more video images from said camera pointed at said first future location;

predicting a second future location of said ball;

moving said camera to point at said second future location;

capturing a second set of one or more video images from said camera pointed at said second future location;

subtracting one or more video images of said first set of video images from one or more video images of said second set of video images in order to find said ball; and

updating said hypothetical uninterrupted path based on said step of subtracting.

11. A method according to claim 6, wherein:

said step of finding said ball in said video images includes performing pattern recognition.

12. A method according to claim 6, wherein:

said step of finding said ball in said video images includes subtracting video images.

13. A method according to claim 1, further including the step of:

reporting information based on said step of determining an end of said hypothetical uninterrupted path.

14. A method according to claim 1, wherein said step of determining an end of said hypothetical uninterrupted path comprises the steps of:

determining positions of said ball in said captured video images;

using said positions of said ball in said captured video images and said camera orientation data to determine two or more three dimensional locations of said ball; and

using said more three dimensional locations of said ball to determine said end of said hypothetical uninterrupted path.

15. A method for determining a distance a ball would have traveled after being hit by a bat, comprising the steps of:

determining one or more locations of said ball after said ball has been hit by said bat, said step of determining is performed during a game, said determined locations do not include an end of said ball's uninterrupted path; and

using said determined locations to determine said distance said ball would have traveled after being hit if said ball's path was not interrupted, said step of using said determined locations comprises the steps of:

determining path information using a first set of location data,

using said path information to predict a future location,

capturing video from a set of cameras looking at said future location, and

using said captured video to determine said distance.

16. A method according to claim 15, wherein:

said step of using said determined locations is performed in real time.

17. A method according to claim 15, wherein:

said step of using said determined locations is performed within thirty seconds of said bat hitting said ball.

18. A method according to claim 15, wherein:

said step of using said determined locations is commenced while said ball is airborne.

19. A method according to claim 15, wherein:

said step of determining one or more locations is performed using pattern recognition on a set of video images.

20. A method according to claim 15, further including the step of:

identifying a sound of said bat hitting said ball, said step of determining one or more locations is triggered by said said step of identifying.

21. A method according to claim 15, wherein:

said step of determining one or more locations is performed using subtraction and pattern recognition on a set of video images.

22. A method according to claim 15, wherein said step of using said determined locations further includes the step of:

pointing said set of cameras toward said future location in response to said step of using said path information to predict said future location.

23. A method according to claim 15, wherein said step of using said determined locations further includes the step of:

selecting said set of cameras from a group of cameras because said set of cameras are pointing toward said future location, said step of selecting is performed in response to said step of using said path information to predict said future location.

24. An apparatus for determining information about a ball's travel along a hypothetical uninterrupted path, comprising:

a first video camera capable of being oriented;

a first set of one or more camera orientation sensors, said first set of camera orientation sensors sense camera orientation data for said first camera;

a second video camera capable of being oriented;

a second set of one or more camera orientation sensors, said second set of camera orientation sensors sense camera orientation data for said second camera;

a storage element capable of storing program code; and

a processor in communication with said first video camera and said second video camera and said storage element, said processor programmed by said program code to perform a method comprising the steps of:

receiving video images from said first and second video cameras captured while said first and second cameras are pointed at said ball traveling on said uninterrupted path;

receiving a first set of camera orientation data from said first set of camera orientation sensors, said first set of camera orientation data pertains to an orientation of said first camera while said first camera is pointed at said ball traveling on said uninterrupted path;

receiving a second set of camera orientation data from said second set of camera orientation sensors, said

second set of camera orientation data pertains to an orientation of said second camera while said second camera is pointed at said ball traveling on said uninterrupted path; and

determining an end of said hypothetical uninterrupted path of said object based on said video images received from said first and second video cameras, said first set of camera orientation data and said second set of camera orientation data.

25. An apparatus according to claim **24**, further including:

an output device for reporting information about said end of said uninterrupted path of said ball.

26. An apparatus according to clam **25**, wherein:

said information includes a distance said ball would have traveled, but did not travel, had the ball's path not been interrupted.

27. An apparatus according to claim **24**, further including:

a third camera in communication with said processor, said third camera is rigidly mounted to point toward a location where said ball is likely to be hit by a bat; and

a fourth camera in communication with said processor, said fourth camera is rigidly mounted to point toward said location where said ball is likely to be hit by said bat, said processor uses video from said third camera and said fourth camera to perform said step of determining an end of said hypothetical uninterrupted path.

28. An apparatus according to claim **27**, further including:

a first set of one or more motors in communication with said processor, said first set of one or more motors capable of changing an orientation of said first camera based on instructions from said processor; and

a second set of one or more motors in communication with said processor, said second set of one or more motors capable of changing an orientation of said second camera based on instructions from said processor, said processor predicts a future location of said ball and instructs a changing of orientation of said first camera and said second camera so that said first camera and said second camera point toward said predicted future location prior to said ball reaching said predicted future location.

29. An apparatus according to claim **24**, further including:

a microphone; and

audio detection electronics in communication with said microphone and said processor, said audio detection electronics sends a signal to said processor when a sound of a bat hitting said ball is detected, said processor uses said signal to start said step of finding said ball in said video images.

30. An apparatus according to claim **24**, wherein said step of determining an end of said hypothetical uninterrupted path comprises the steps of:

storing positions of said ball in said video images received from said first and second video cameras;

using said positions of said ball in said video images and said camera orientation data to determine two or more three dimensional locations of said ball; and

using said more three dimensional locations of said ball to determine said end of said hypothetical uninterrupted path.

31. A method for determining information about a hypothetical uninterrupted path of a ball after being hit by a bat, comprising the steps of:

detecting a sound of said bat hitting said ball;

capturing video images of said ball; and

determining an end of said hypothetical uninterrupted path of said ball based on said captured video images, said step of determining is performed in response to said step of detecting.

32. A method according to claim **31**, further comprising the steps of:

determining a distance from a beginning of said hypothetical uninterrupted path to said end of said hypothetical uninterrupted path; and

reporting said distance.

33. A method according to claim **32**, wherein said step of determining an end includes the step of:

determining path information for said ball;

using said path information to predict a future location of said ball;

pointing a set of cameras toward said future location in response to said step of using said path information to predict said future location;

capturing first video from said set of cameras looking at said future location; and

using said captured first video to determine said end of said hypothetical path.

34. A method according to claim **32**, further comprising the step of:

displaying, in a video of a baseball game, said hypothetical uninterrupted path and said end of said hypothetical uninterrupted path while said ball is traveling along said hypothetical uninterrupted path.

35. A method according to claim **32**, wherein:

said captured video images includes a first video image and a second video image; and

said step of determining an end includes subtracting said first video image from said second video image.

36. A method according to claim **32**, further comprising the steps of:

manually pointing a camera at said ball; and

sensing camera orientation sensor data about said camera pointing at said ball, said step of determining an end is at least partially based on said camera orientation sensor data.

* * * * *