US005912700A

United States Patent [19]

Honey et al.

[11] **Patent Number: 5,912,700**

[45] **Date of Patent: Jun. 15, 1999**

[54] **SYSTEM FOR ENHANCING THE TELEVISION PRESENTATION OF AN OBJECT AT A SPORTING EVENT**

[75] Inventors: **Stanley K. Honey**, Palo Alto; **Richard H. Cavallaro**, Mountain View; **David Blyth Hill**, Los Angeles; **Andrew G. Setos**, Pacific Palisades, all of Calif.; **Jerry Neil Gepner**, Langhorn, Pa.; **Timothy Paul Heidmann**, Los Altos, Calif.; **Patrick Wade Olsen**, Sunnyvale, Calif.; **Fred Judson Heinzmann**, Los Altos, Calif.; **Alan C. Phillips**, Los Altos, Calif.; **Harold Guthart**, Los Altos, Calif.; **Alan Alexander Burns**, Portola Valley, Calif.; **Charles Lawrence Rino**, Menlo Park, Calif.; **Philip Calvin Evans**, Portola Valley, Calif.

[73] Assignee: **Fox Sports Productions, Inc.**, Los Angeles, Calif.

[21] Appl. No.: **08/585,145**

[22] Filed: **Jan. 10, 1996**

[51] **Int. Cl.**[6] **H04N 7/18**; H04N 5/225; H04N 9/74

[52] **U.S. Cl.** **348/157**; 348/61; 348/169; 348/578; 348/589; 473/199; 473/200

[58] **Field of Search** 348/169, 170, 348/171, 172, 157, 61, 571, 578, 584, 585, 586, 589, 598, 599, 600; 473/131, 198, 199, 200, 351, 353, 516, 517, 569, 570; H04N 7/18

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,351,347	11/1967	Smith et al.	473/199
3,580,993	5/1971	Sandorf et al.	348/584
3,840,699	10/1974	Bowerman	348/169
3,851,303	11/1974	Muller	340/27
3,944,738	3/1976	Johnson	348/157
3,945,716	3/1976	Kinder	350/174
3,949,490	4/1976	Derderian et al.	35/12
3,973,239	8/1976	Kakumoto et al.	382/275
4,057,782	11/1977	Muller	340/27
4,064,528	12/1977	Bowerman	348/578
4,067,015	1/1978	Mogavero et al.	343/225
4,084,184	4/1978	Crain	358/93
4,179,704	12/1979	Moore et al.	348/579
4,183,536	1/1980	Platt	473/570

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

2106336	3/1994	Canada .
41 01 156 A1	1/1991	Germany .
1659078 A1	6/1991	U.S.S.R. .
WO 95/10915	4/1995	WIPO .
WO 95/10919	4/1995	WIPO .

OTHER PUBLICATIONS

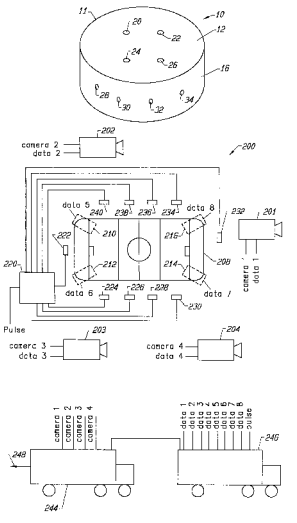
"For Hockey Fans The Puck Starts Here," by J. Mason, Sports Illustrated, Oct. 8, 1990.
Replay 2000—The Ultimate Workstation for Sport Commentators and Producers, Orad Hi–Tech Systems, Apr. 1995.
SailTrack, GPS Tracking System for Animated Graphics Broadcast Coverage of the America's Cup Races, 1992.
Sail Track Technical Overview, 1992.
Sail Viz Software Documentation, 1992.

Primary Examiner—Bryan Tung
Attorney, Agent, or Firm—Fliesler, Dubb, Meyer & Lovejoy LLP

[57] **ABSTRACT**

A system for enhancing the television presentation of an object at a sporting event includes one or more sensors which are used to determine the location of the object. Based on the location of the object and the field of view of a broadcast camera, a processor determines the position of the object in a video frame of the broadcast camera. Once knowing where the object is positioned within the video frame, the television signal can be edited or augmented to enhance the presentation of the object.

95 Claims, 19 Drawing Sheets



U.S. PATENT DOCUMENTS

4,261,647	4/1981	Ellis	350/174
4,319,266	3/1982	Bannister	358/22
4,380,024	4/1983	Olofsson	358/93
4,386,363	5/1983	Morrison	358/22
4,390,950	6/1983	Muller	364/434
4,407,564	10/1983	Ellis	350/174
4,490,741	12/1984	Hornback	348/550
4,521,196	6/1985	Briard et al.	434/20
4,541,013	9/1985	Alpert	348/601
4,582,389	4/1986	Wood et al.	350/3.69
4,612,666	9/1986	King	382/214
4,613,200	9/1986	Hartman	350/3.7
4,647,969	3/1987	Graham, Sr.	348/601
4,669,810	6/1987	Wood	350/3.7
4,674,125	6/1987	Carlson et al.	382/303
4,700,306	10/1987	Wallmander	701/207
4,739,406	4/1988	Morton et al.	348/578
4,763,990	8/1988	Wood	350/320
4,775,218	10/1988	Wood et al.	350/174
4,811,084	3/1989	Belmares-Sarabia et al.	358/22
4,817,171	3/1989	Stentiford	382/195
4,846,475	7/1989	Newcomb et al.	473/570
4,847,603	7/1989	Blanchard	340/705
4,878,054	10/1989	Reynaud	340/975
4,892,386	1/1990	Suzuki et al.	350/174
4,897,726	1/1990	Morton et al.	348/578
4,924,507	5/1990	Chao et al.	382/211
4,950,050	8/1990	Pernick et al.	359/20
4,957,297	9/1990	Newcomb et al.	473/409
4,968,036	11/1990	Von Der Mark	473/570
4,970,666	11/1990	Welsh et al.	345/423
4,975,770	12/1990	Troxell	348/26
4,995,090	2/1991	Singh et al.	382/213
4,999,709	3/1991	Yamazaki et al.	348/589
5,034,732	7/1991	Iino	340/705
5,060,282	10/1991	Molley	382/211
5,082,263	1/1992	Berger	473/467
5,142,590	8/1992	Carpenter et al.	382/157
5,149,096	9/1992	Keating et al.	473/588
5,150,895	9/1992	Berger	473/467
5,179,421	1/1993	Parker et al.	356/139.06
5,184,820	2/1993	Keating et al.	473/588
5,207,720	5/1993	Shepherd	473/446
5,241,616	8/1993	Garcia	385/126
5,245,432	9/1993	Jaffray et al.	358/160
5,249,039	9/1993	Chaplin	358/22
5,264,933	11/1993	Rosser et al.	348/578
5,268,734	12/1993	Parker et al.	356/139.06
5,270,820	12/1993	Fellinger	348/169
5,274,716	12/1993	Mitsuoka et al.	382/210
5,305,107	4/1994	Gale et al.	348/590
5,313,304	5/1994	Chaplin	348/587
5,340,108	8/1994	Gerpheide et al.	473/156
5,346,210	9/1994	Utke et al.	473/415
5,353,392	10/1994	Luquet et al.	395/135
5,388,825	2/1995	Myers et al.	473/570
5,392,088	2/1995	Abe et al.	396/79
5,394,203	2/1995	Murphy et al.	353/13
5,398,075	3/1995	Freytag et al.	348/590
5,413,345	5/1995	Nauck	473/156
5,414,439	5/1995	Groves et al.	345/7
5,419,562	5/1995	Cromarty	473/269
5,419,565	5/1995	Gordon et al.	473/455
5,423,549	6/1995	Englmeier	473/353
5,436,672	7/1995	Medioni et al.	348/591
5,459,793	10/1995	Naoi et al.	382/165
5,465,144	11/1995	Parker et al.	356/139.06
5,465,308	11/1995	Hutcheson et al.	382/159
5,469,512	11/1995	Fujita et al.	382/118
5,469,536	11/1995	Blank	345/431
5,491,517	2/1996	Kreitman et al.	348/581
5,498,000	3/1996	Cuneo	273/354
5,508,737	4/1996	Lang	348/159
5,513,854	5/1996	Daver	273/454
5,523,783	6/1996	Cho	348/169
5,524,065	6/1996	Yagasaki	382/226
5,543,856	8/1996	Rosser et al.	348/578
5,549,259	8/1996	Herlik	244/136
5,563,620	10/1996	Terai	345/7
5,564,698	10/1996	Honey et al.	273/128 R
5,566,251	10/1996	Hanna et al.	382/284
5,592,236	1/1997	Rosenbaum et al.	348/586
5,627,915	5/1997	Rosser et al.	382/219
5,668,629	9/1997	Parker et al.	356/139.05
5,699,442	12/1997	Fellinger	348/169
5,808,695	9/1998	Rosser et al.	348/584

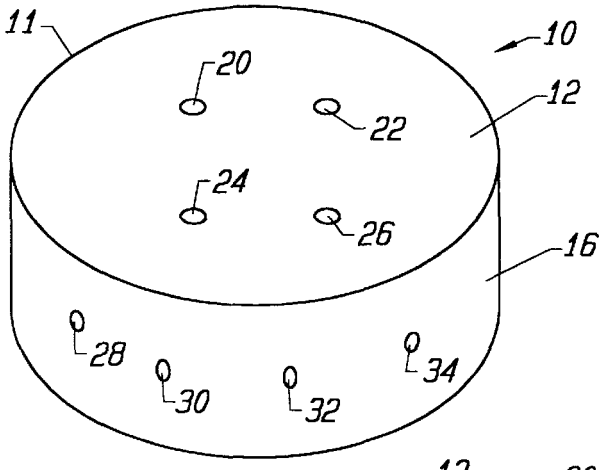


FIG. 1

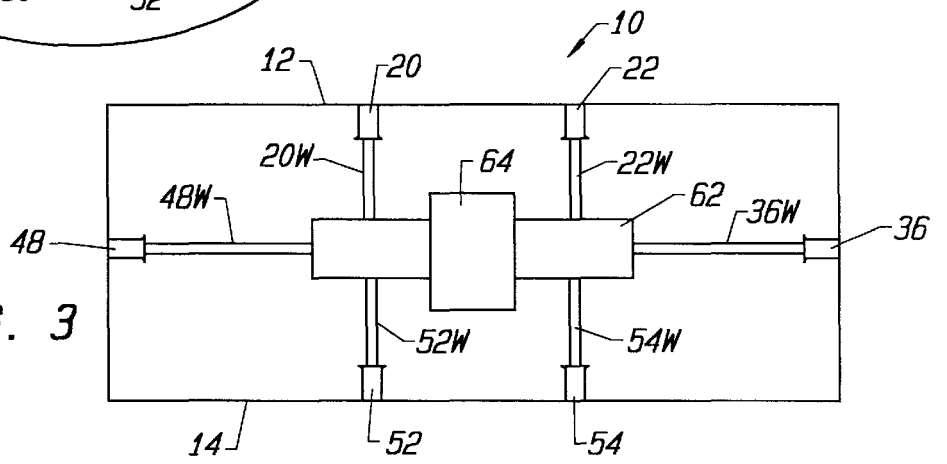


FIG. 3

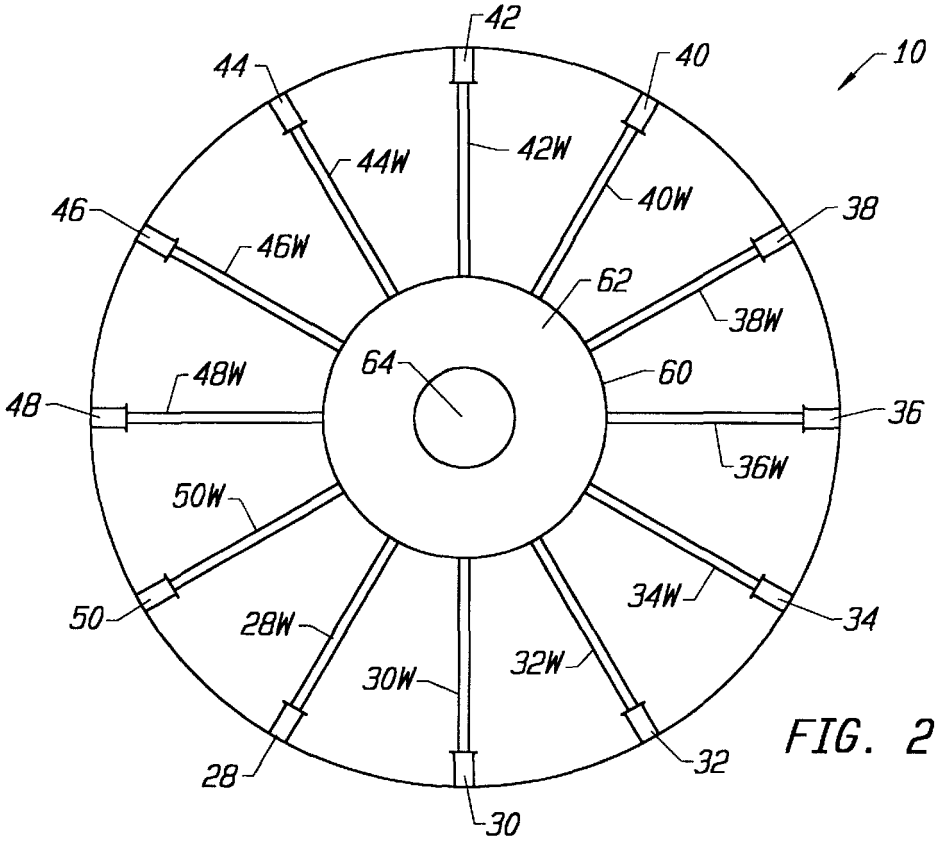


FIG. 2

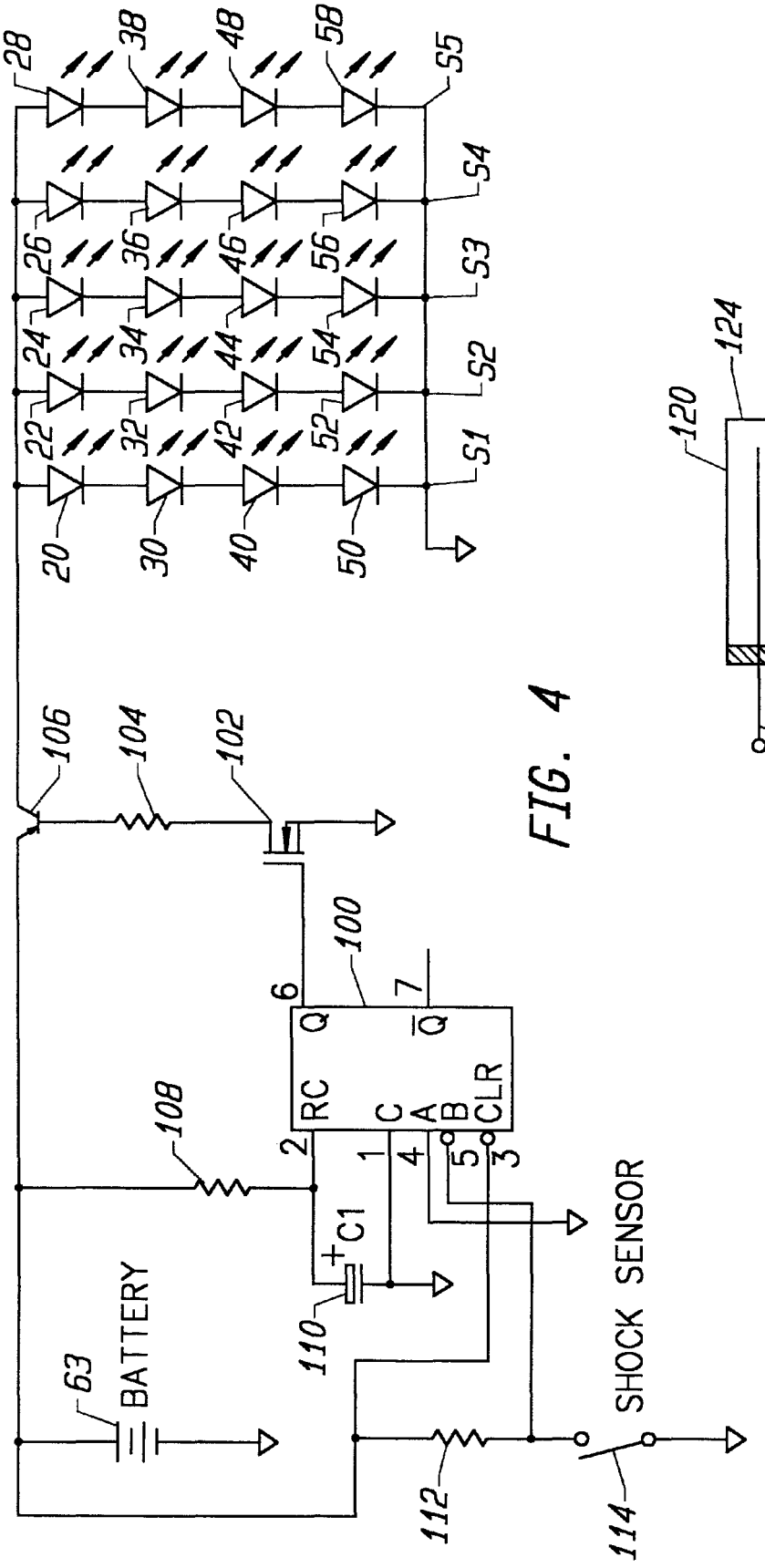

28
38
48
58
55
54
26
36
46
56
53
24
34
44
54
52
22
32
42
52
51
20
30
40
50
106
104
102
100
6
7
Q
$\overline{Q}$
RC
C
A
B
CLR
2
1
4
5
3
108
C1
110
63
BATTERY
112
SHOCK SENSOR
114

FIG. 4

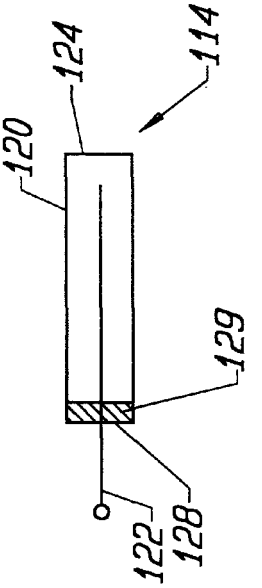

120
124
114
129
122
128

FIG. 5

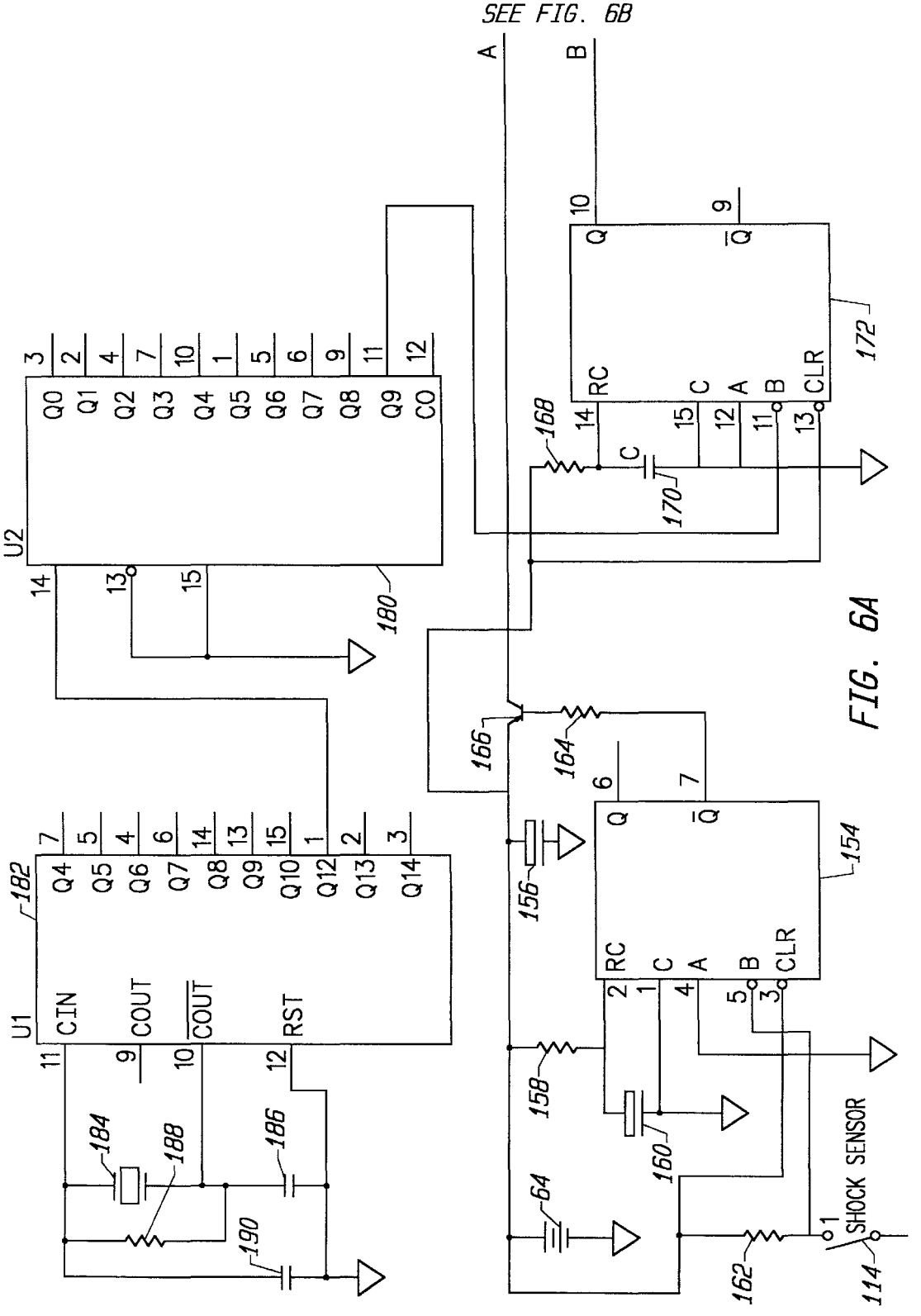

SEE FIG. 6B
A
B
U1
U2
CIN
COUT
RST
Q0
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
Q12
Q13
Q14
CO
RC
C
A
B
CLR
Q
SHOCK SENSOR
64
114
154
156
158
160
162
164
166
168
170
172
180
182
184
186
188
190

FIG. 6A

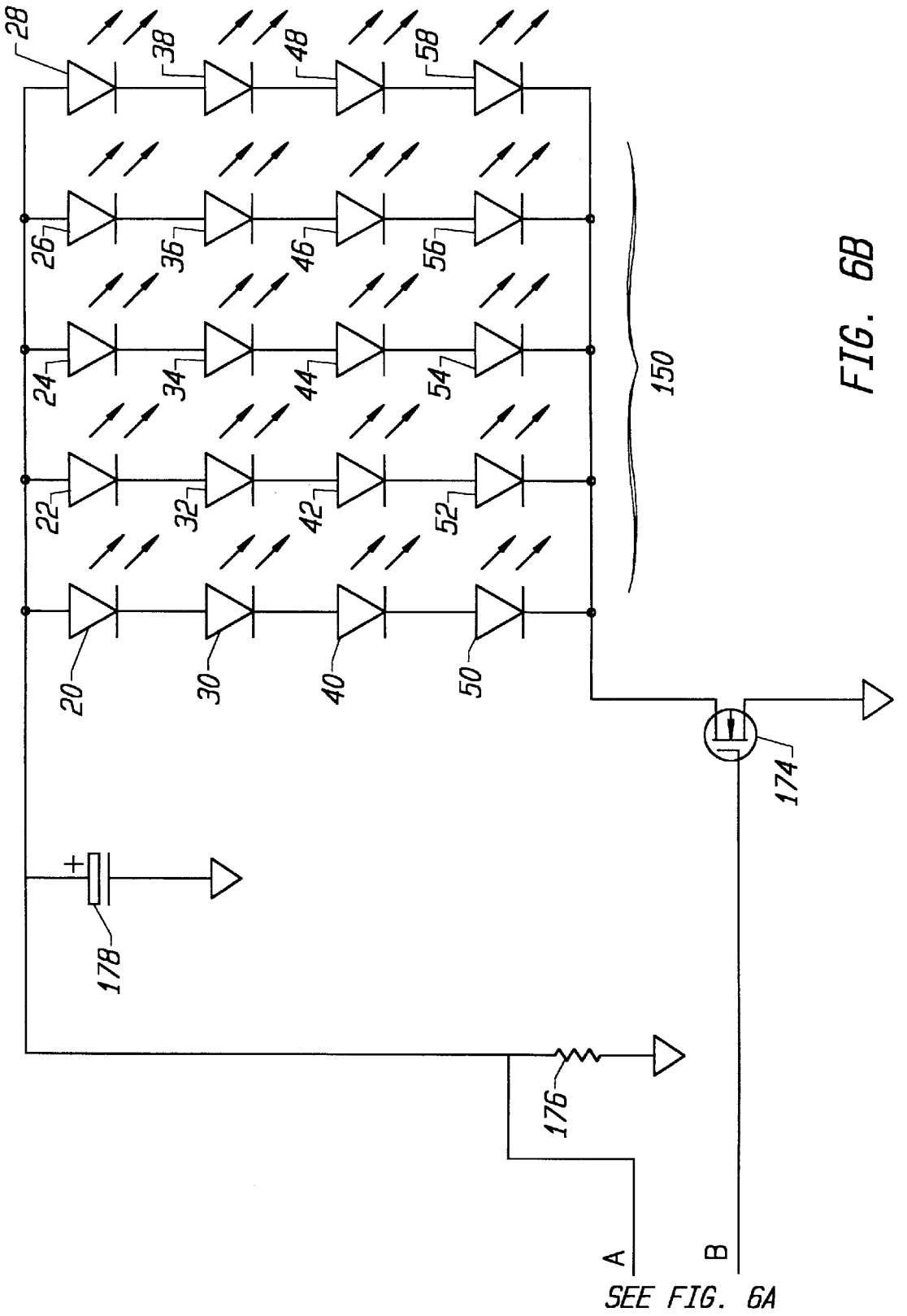
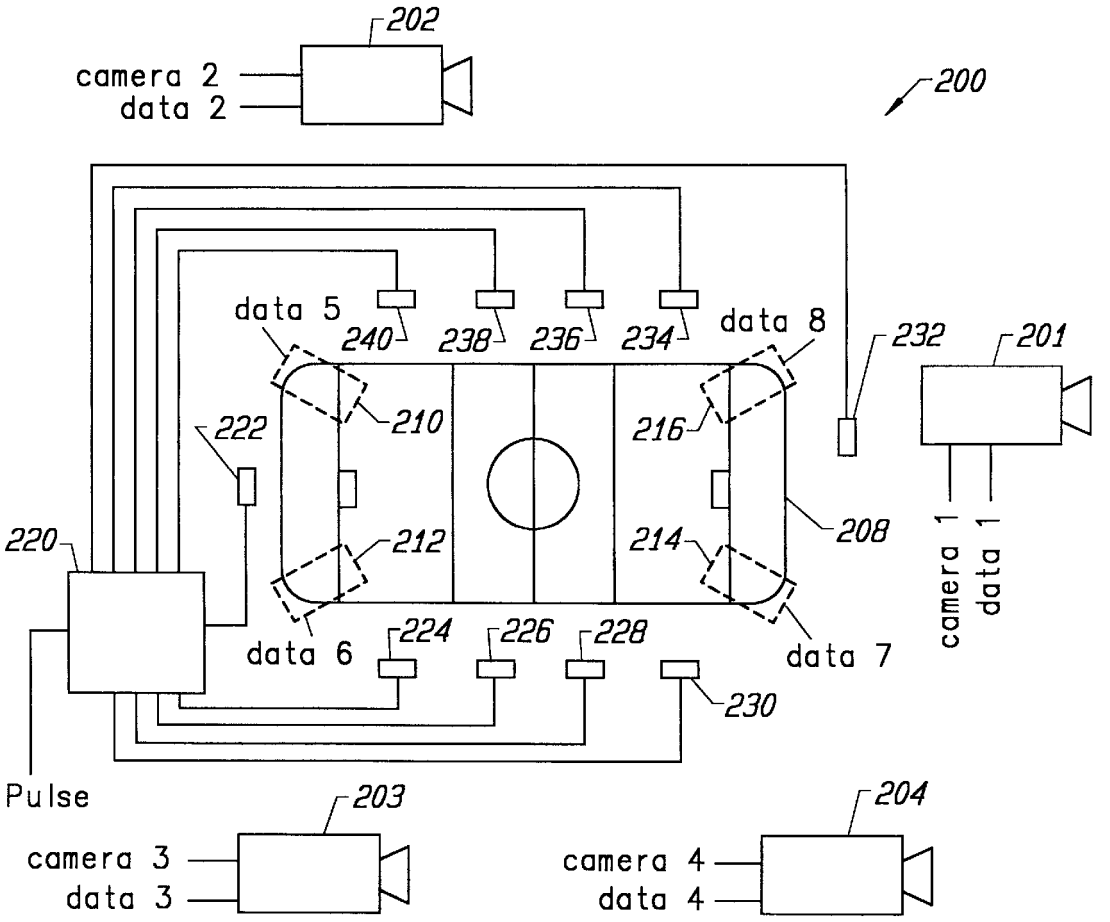

28
38
48
58
26
36
46
56
24
34
44
54
22
32
42
52
20
30
40
50
150
174
178
176
A
B
SEE FIG. 6A

FIG. 6B


202
camera 2
data 2
200
data 5
240
238
236
234
data 8
232
201
222
210
216
220
212
214
208
camera 1
data 1
data 6
224
226
228
data 7
230
Pulse
203
camera 3
data 3
204
camera 4
data 4

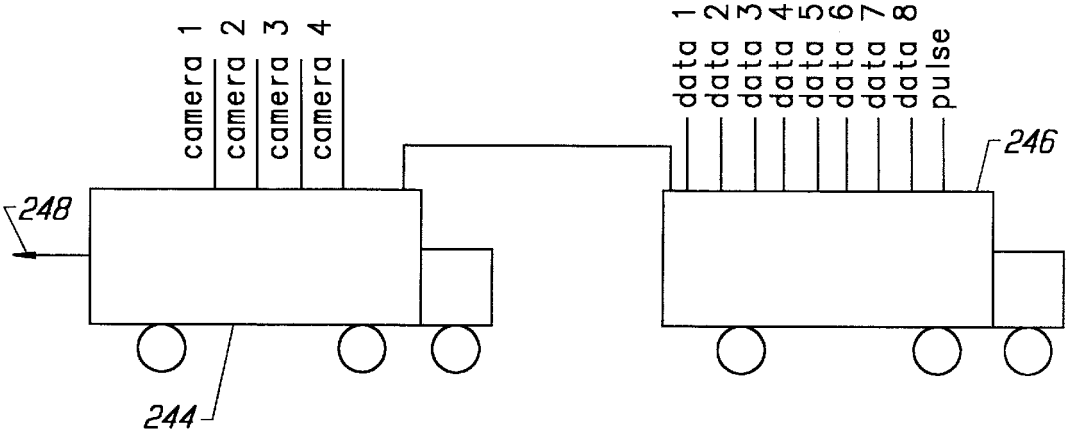

camera 1
camera 2
camera 3
camera 4
data 1
data 2
data 3
data 4
data 5
data 6
data 7
data 8
pulse
246
248
244

FIG. 7

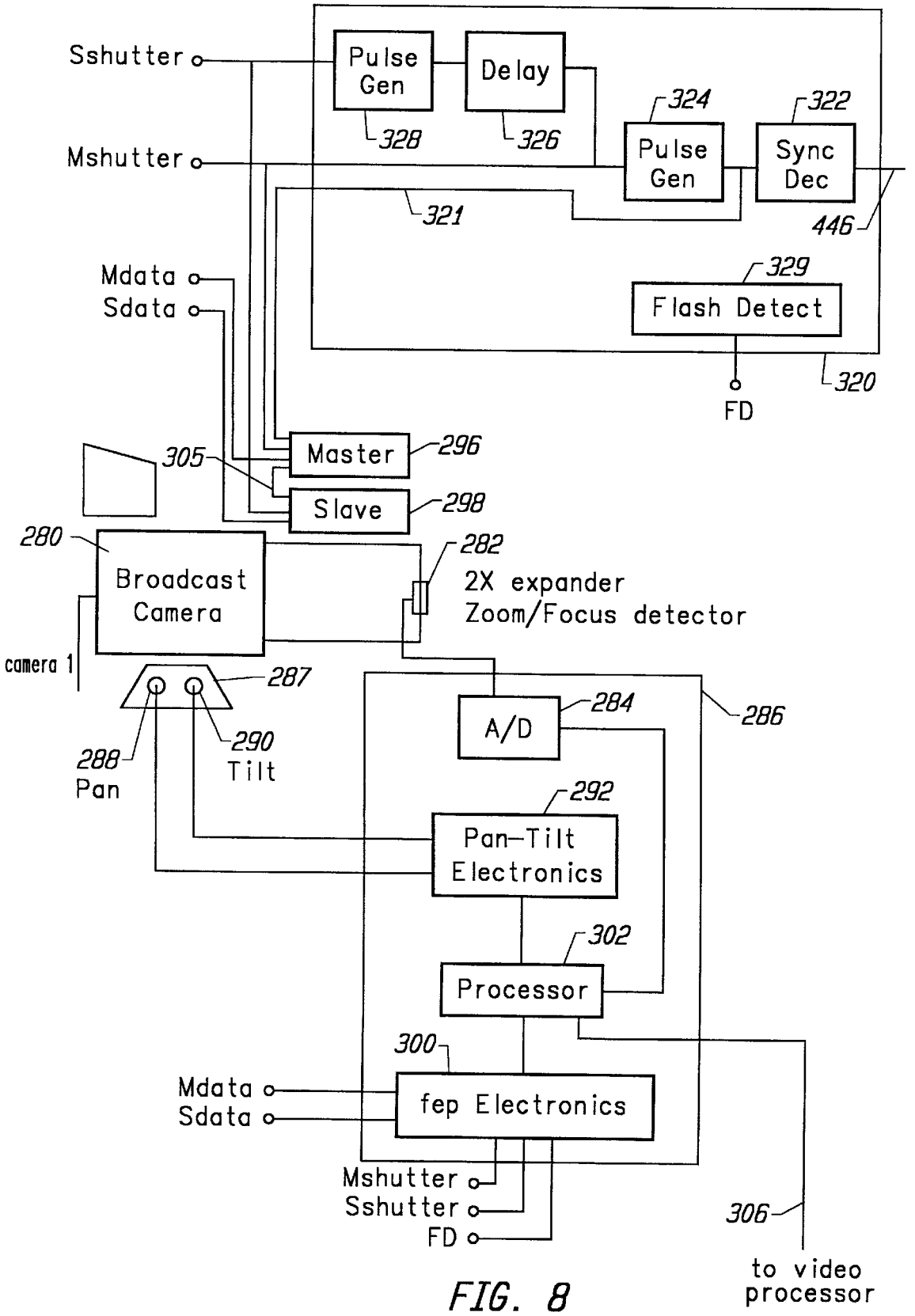

Sshutter
Mshutter
Mdata
Sdata
Pulse Gen
Delay
328
326
324
322
Pulse Gen
Sync Dec
321
446
329
Flash Detect
320
FD
305
Master
296
Slave
298
280
Broadcast Camera
282
2X expander
Zoom/Focus detector
camera 1
287
288
Pan
290
Tilt
A/D
284
286
292
Pan–Tilt Electronics
302
Processor
300
Mdata
Sdata
fep Electronics
Mshutter
Sshutter
FD
306
to video processor

FIG. 8

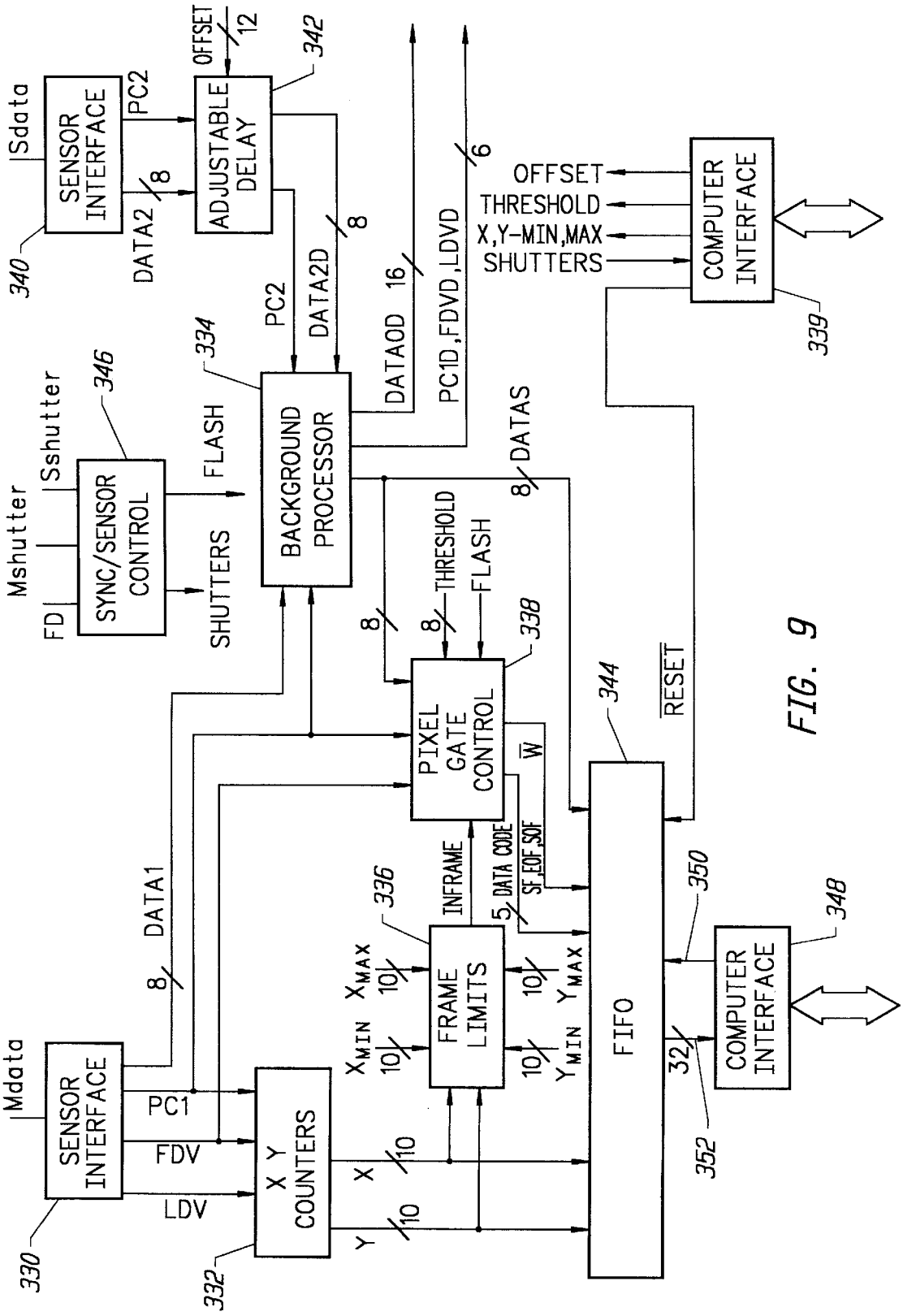

Sdata
SENSOR INTERFACE
340
PC2
8
DATA2
OFFSET
12
ADJUSTABLE DELAY
342
8
DATA2D
PC2
334
BACKGROUND PROCESSOR
16
DATAOD
6
PC1D,FDVD,LDVD
OFFSET
THRESHOLD
X,Y-MIN,MAX
SHUTTERS
COMPUTER INTERFACE
339
Mshutter
Sshutter
346
FD
SYNC/SENSOR CONTROL
FLASH
SHUTTERS
8
DATAS
8
THRESHOLD
FLASH
338
PIXEL GATE CONTROL
W
RESET
344
INFRAME
5
DATA CODE
SF,EOF,SOF
336
DATA1
8
Mdata
SENSOR INTERFACE
330
PC1
FDV
LDV
X Y COUNTERS
332
X
Y
10
10
XMIN
XMAX
YMIN
YMAX
10
10
10
10
FRAME LIMITS
FIFO
350
32
352
COMPUTER INTERFACE
348

FIG. 9

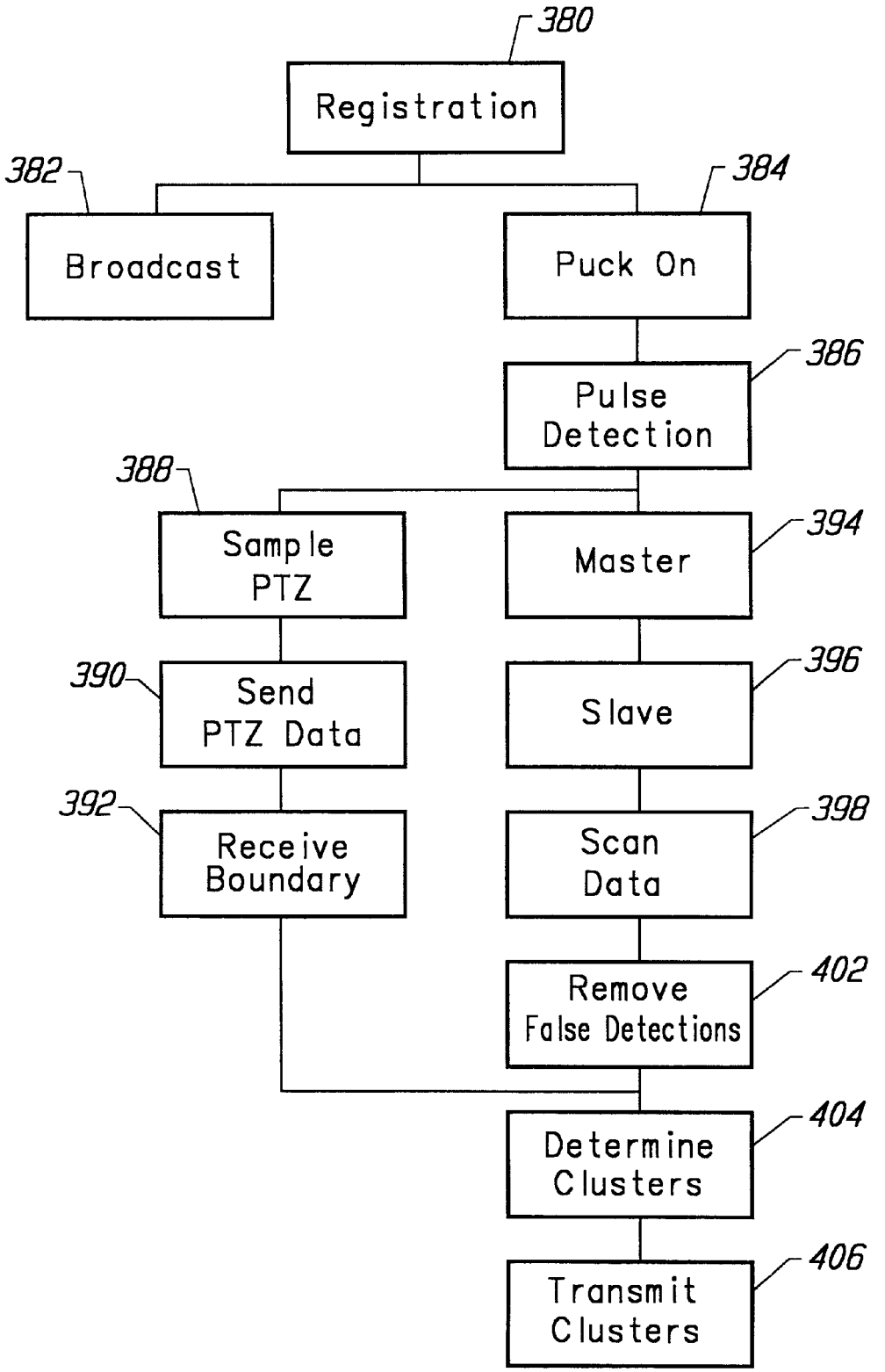

380
Registration
382
384
Broadcast
Puck On
386
Pulse Detection
388
Sample PTZ
394
Master
390
Send PTZ Data
396
Slave
392
Receive Boundary
398
Scan Data
402
Remove False Detections
404
Determine Clusters
406
Transmit Clusters

FIG. 10

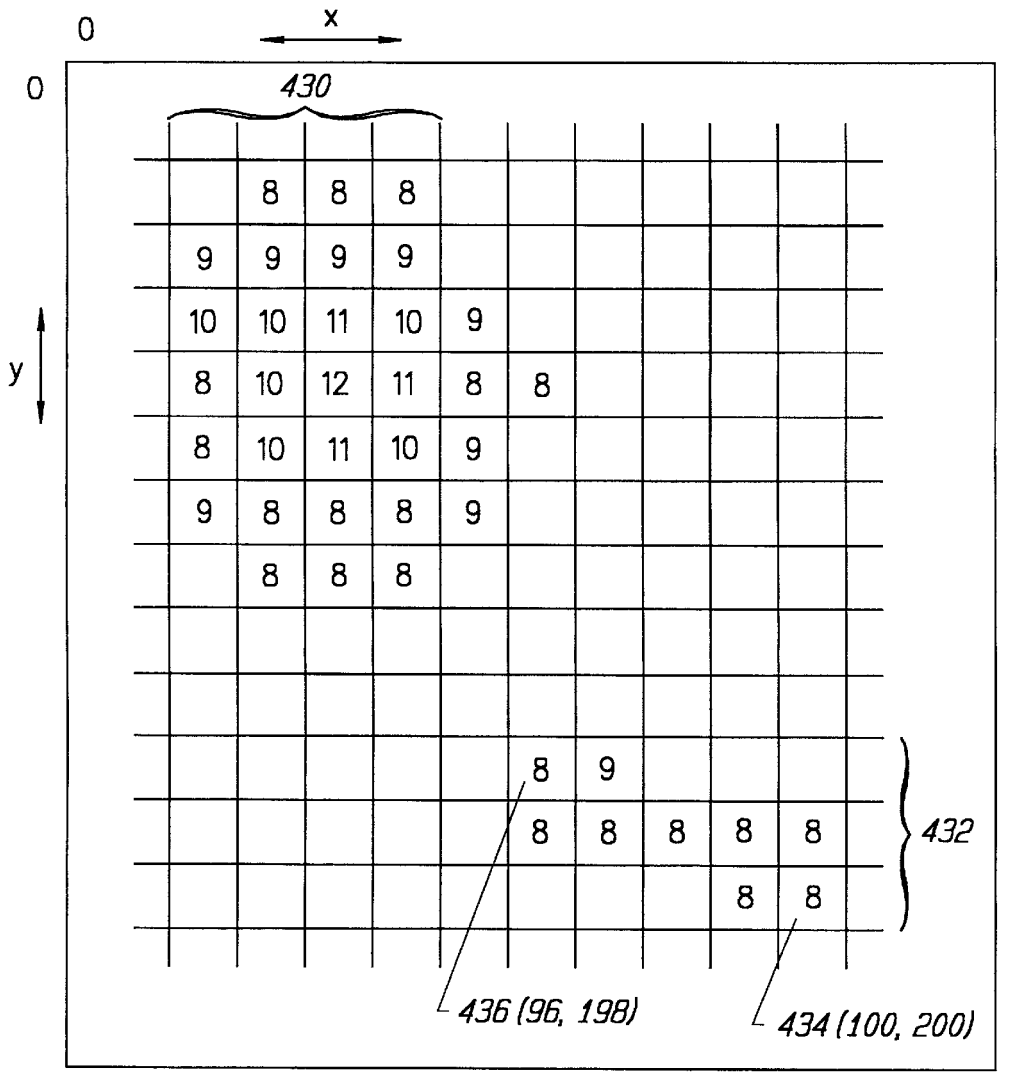

0
x
0
430
y
8 8 8
9 9 9 9
10 10 11 10 9
8 10 12 11 8 8
8 10 11 10 9
9 8 8 8 9
8 8 8
8 9
8 8 8 8 8
8 8
432
436 (96, 198)
434 (100, 200)

FIG. 11

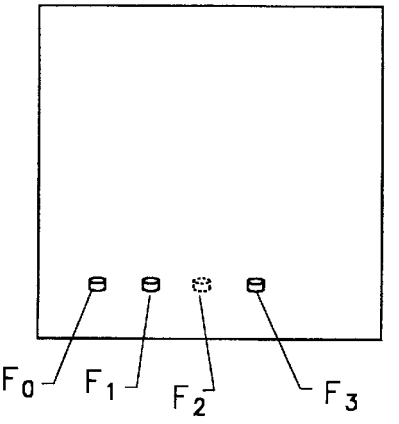

F0
F1
F2
F3

FIG. 19

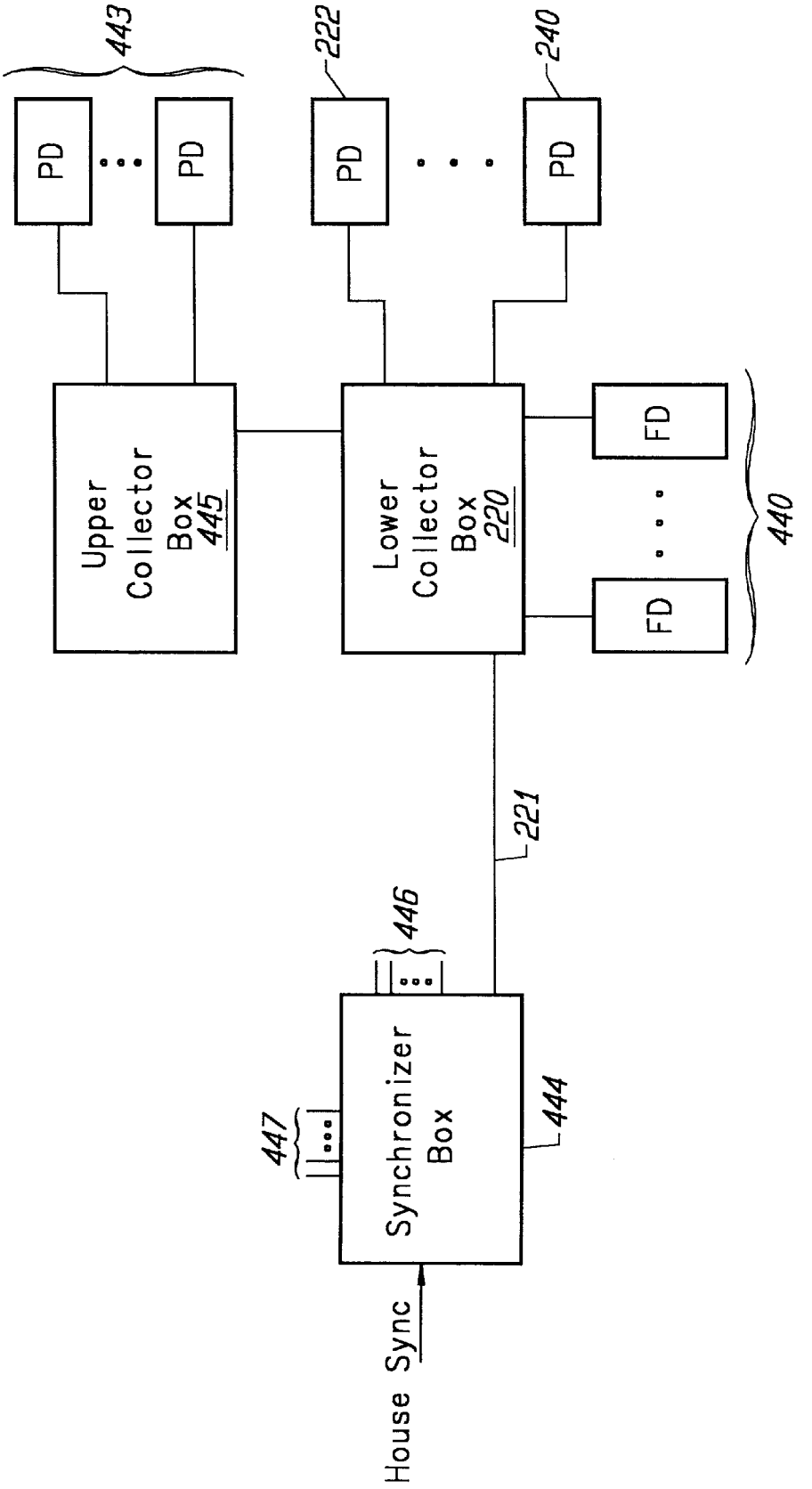

443
222
240
PD
PD
PD
PD
Upper Collector Box 445
Lower Collector Box 220
FD
FD
440
221
446
447
Synchronizer Box
444
House Sync

FIG. 12

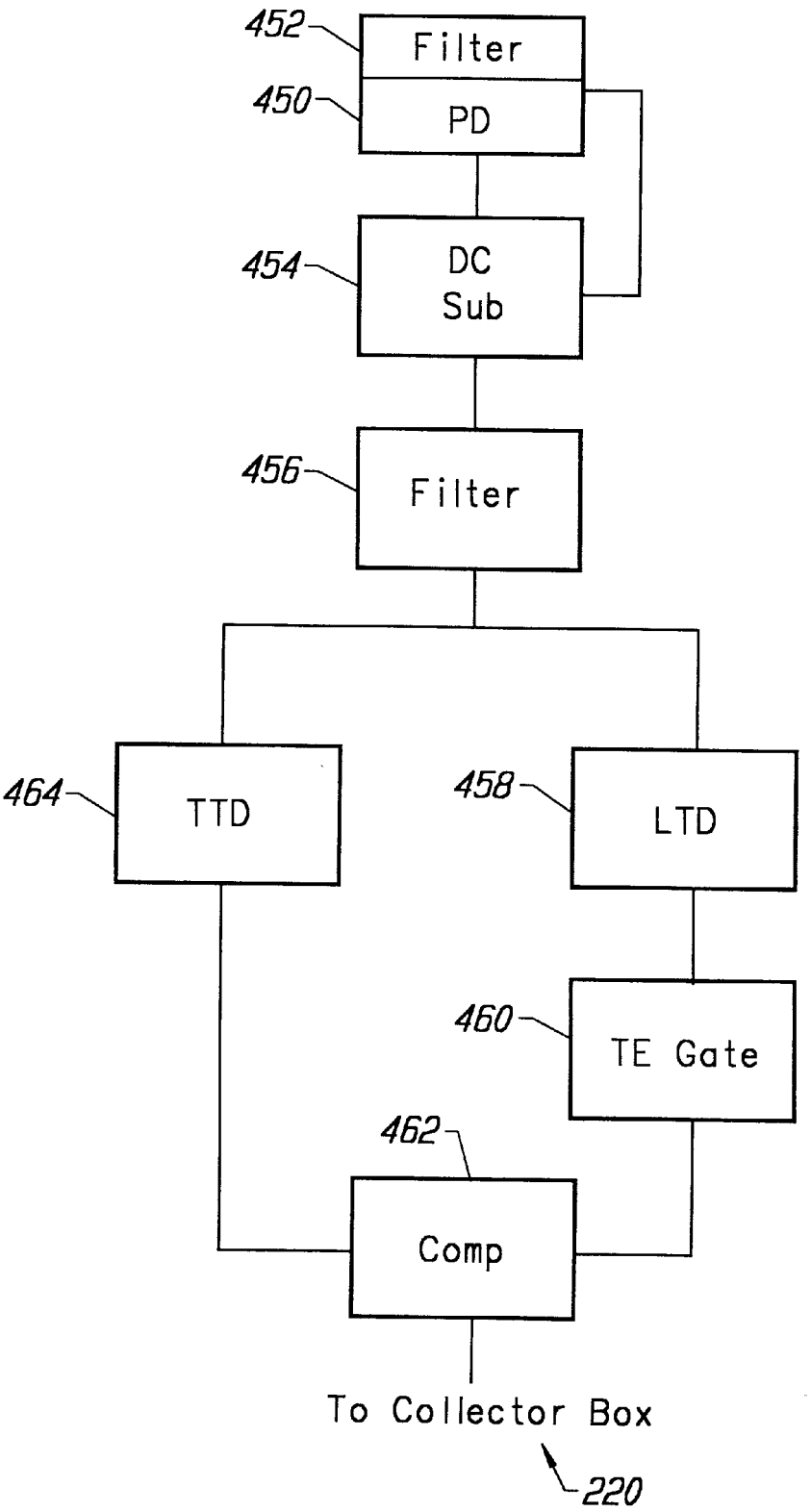
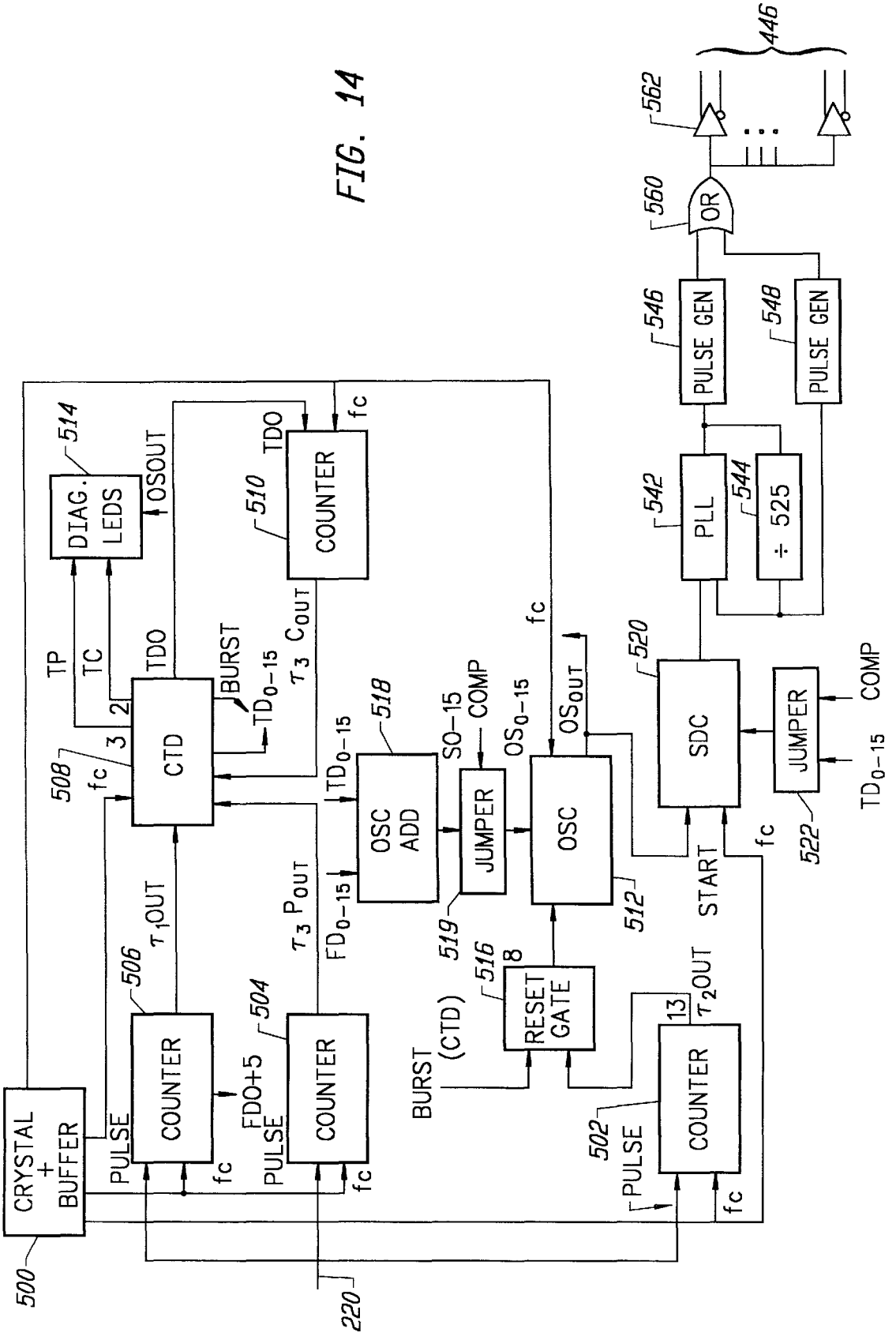

452
Filter
450
PD
454
DC
Sub
456
Filter
464
TTD
458
LTD
460
TE Gate
462
Comp
To Collector Box
220

FIG. 13

FIG. 14


CRYSTAL + BUFFER
500
PULSE
COUNTER
506
fc
FDO+5
PULSE
COUNTER
504
fc
220
τ_1OUT
τ_3 POUT
FD_{0-15}
OSC ADD
518
TD_{0-15}
SO-15
COMP
JUMPER
519
OS_{0-15}
OSC
512
OS_{OUT}
fc
RESET GATE
516
8
BURST (CTD)
13
τ_2OUT
COUNTER
502
PULSE
fc
START
SDC
520
JUMPER
522
TD_{0-15}
COMP
CTD
508
fc
3
2
TP
TC
TDO
BURST
TD_{0-15}
τ_3 C_{OUT}
DIAG. LEDS
514
OSOUT
COUNTER
510
TDO
fc
PLL
542
÷ 525
544
PULSE GEN
546
PULSE GEN
548
OR
560
562
446

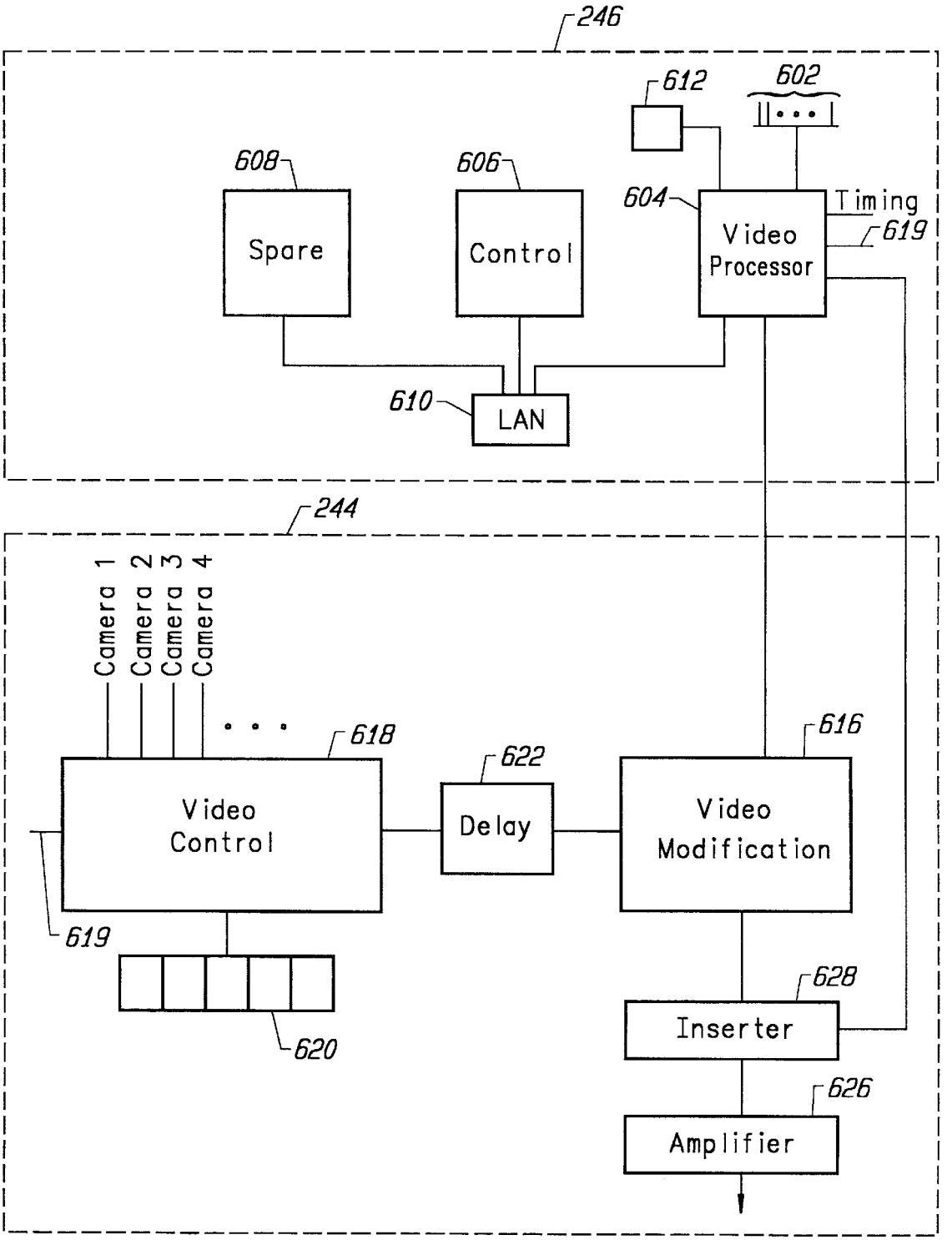

246
612
602
608
606
604
Timing
619
Spare
Control
Video Processor
610
LAN
244
Camera 1
Camera 2
Camera 3
Camera 4
618
622
616
Video Control
Delay
Video Modification
619
628
620
Inserter
626
Amplifier

FIG. 15

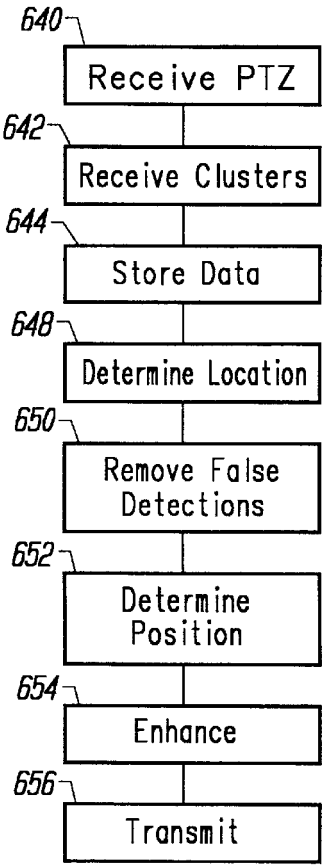


FIG. 16

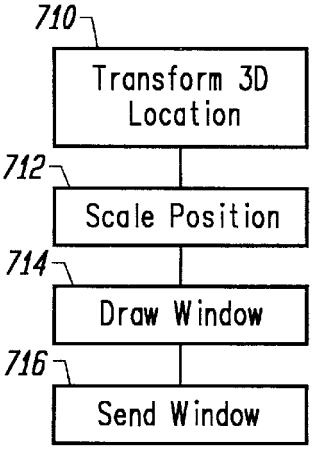


FIG. 18

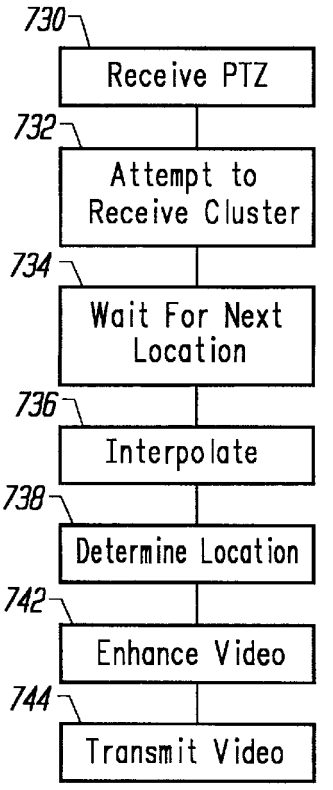


FIG. 20

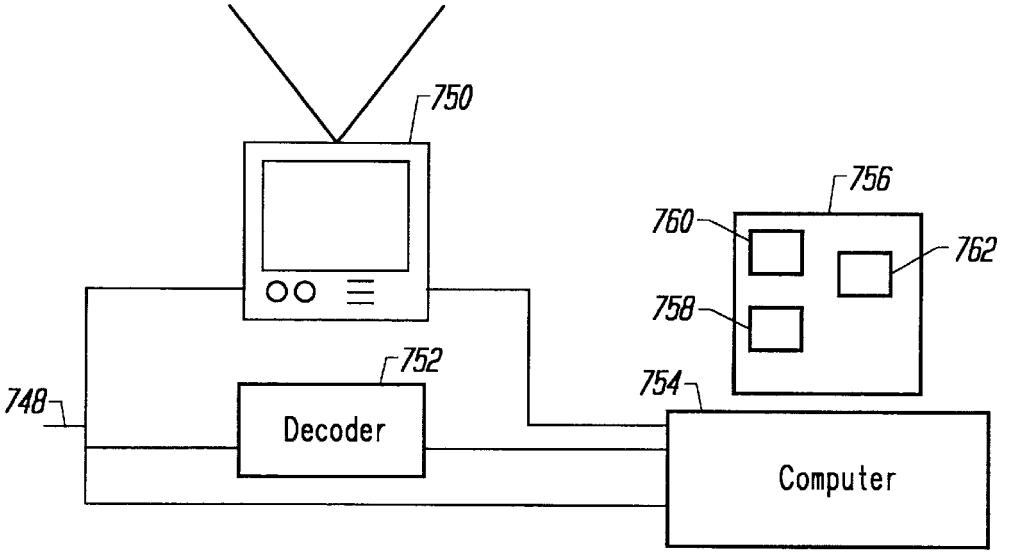


FIG. 21

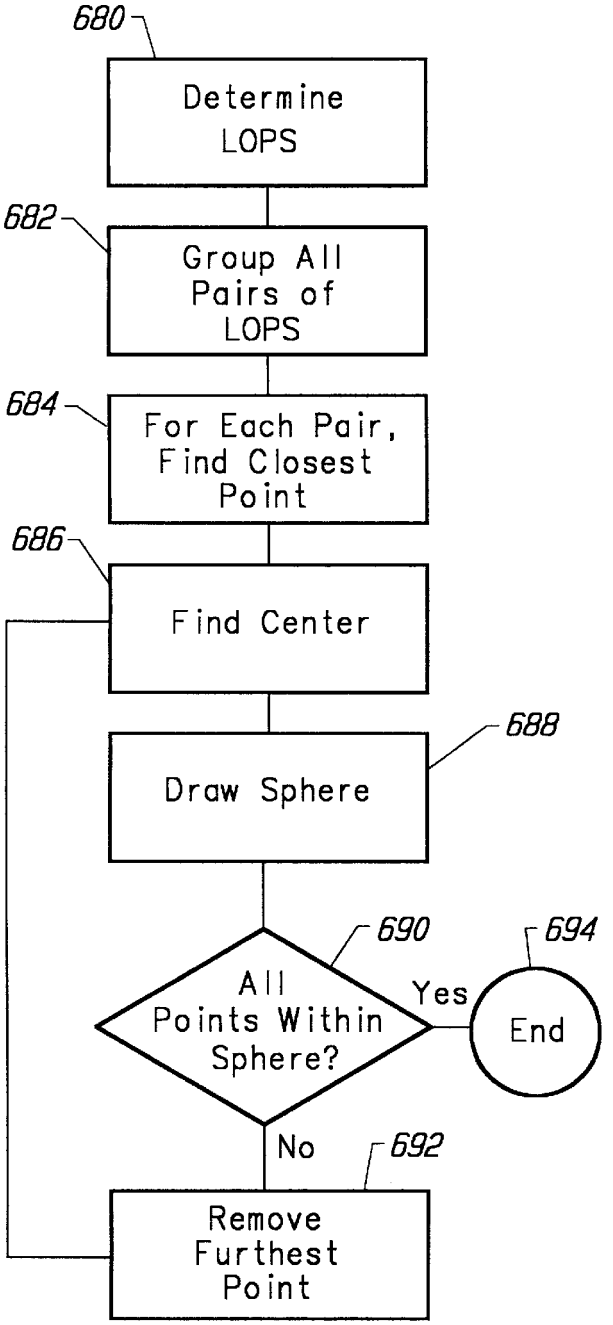


FIG. 17A

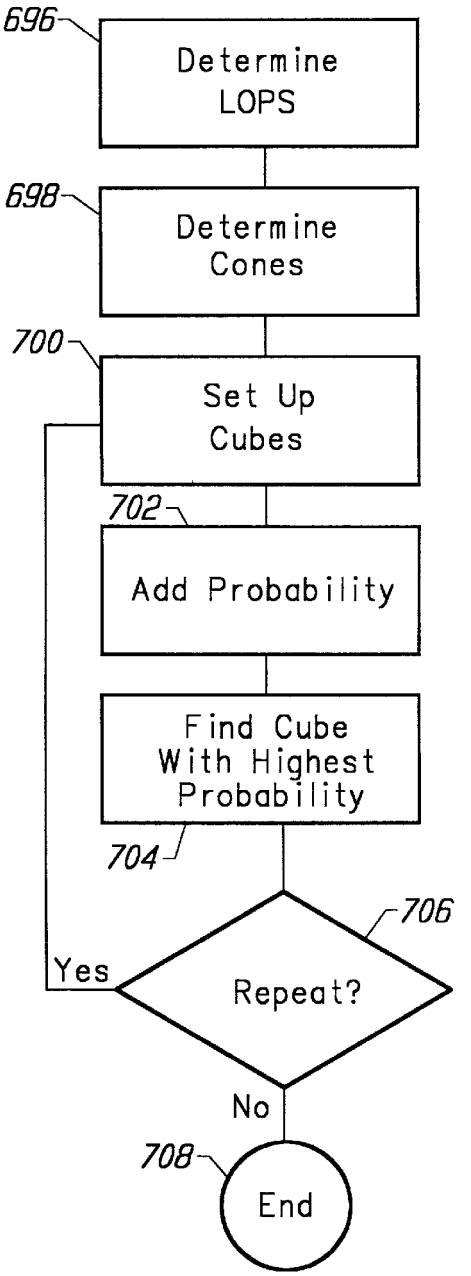


FIG. 17B

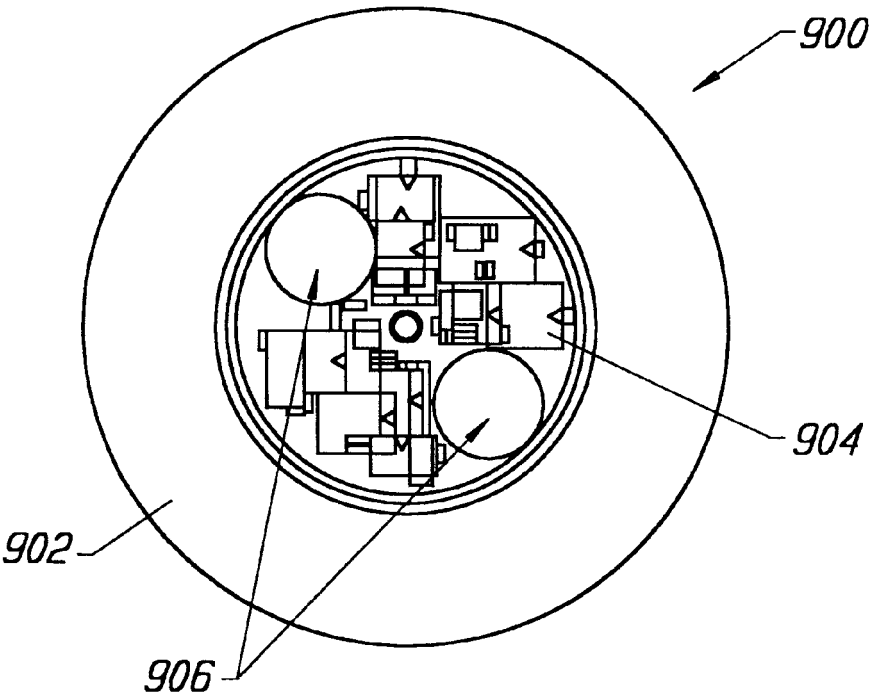


FIG. 22

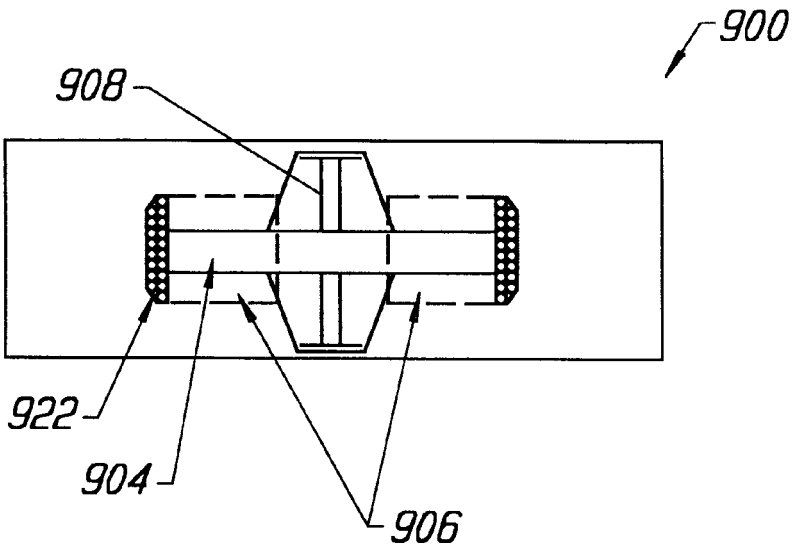


FIG. 23

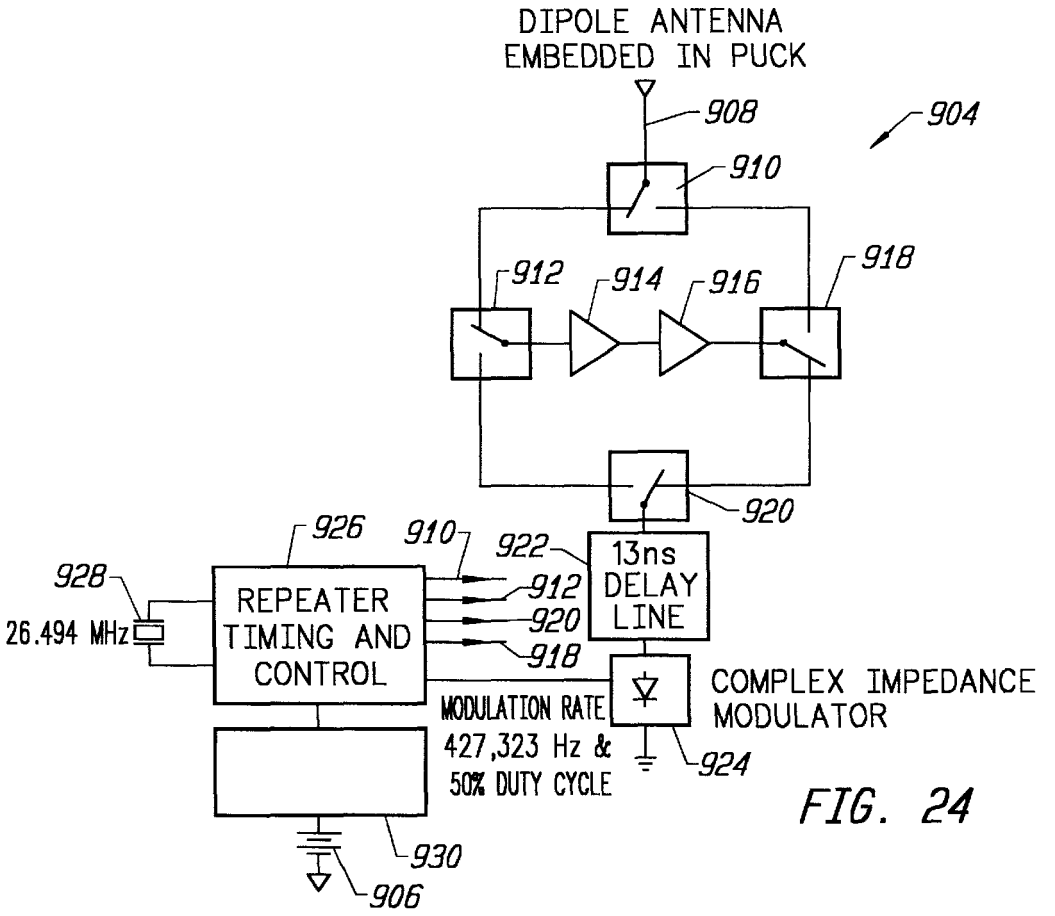


FIG. 24

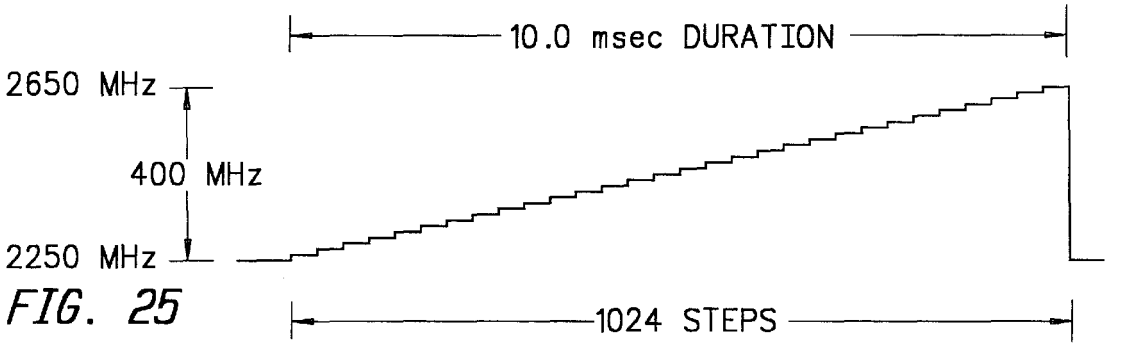


FIG. 25

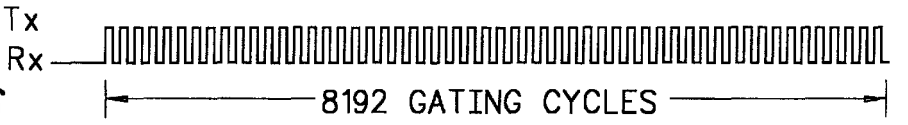


FIG. 26

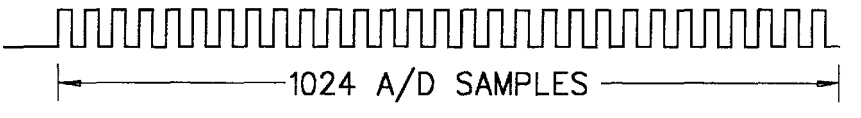


FIG. 27

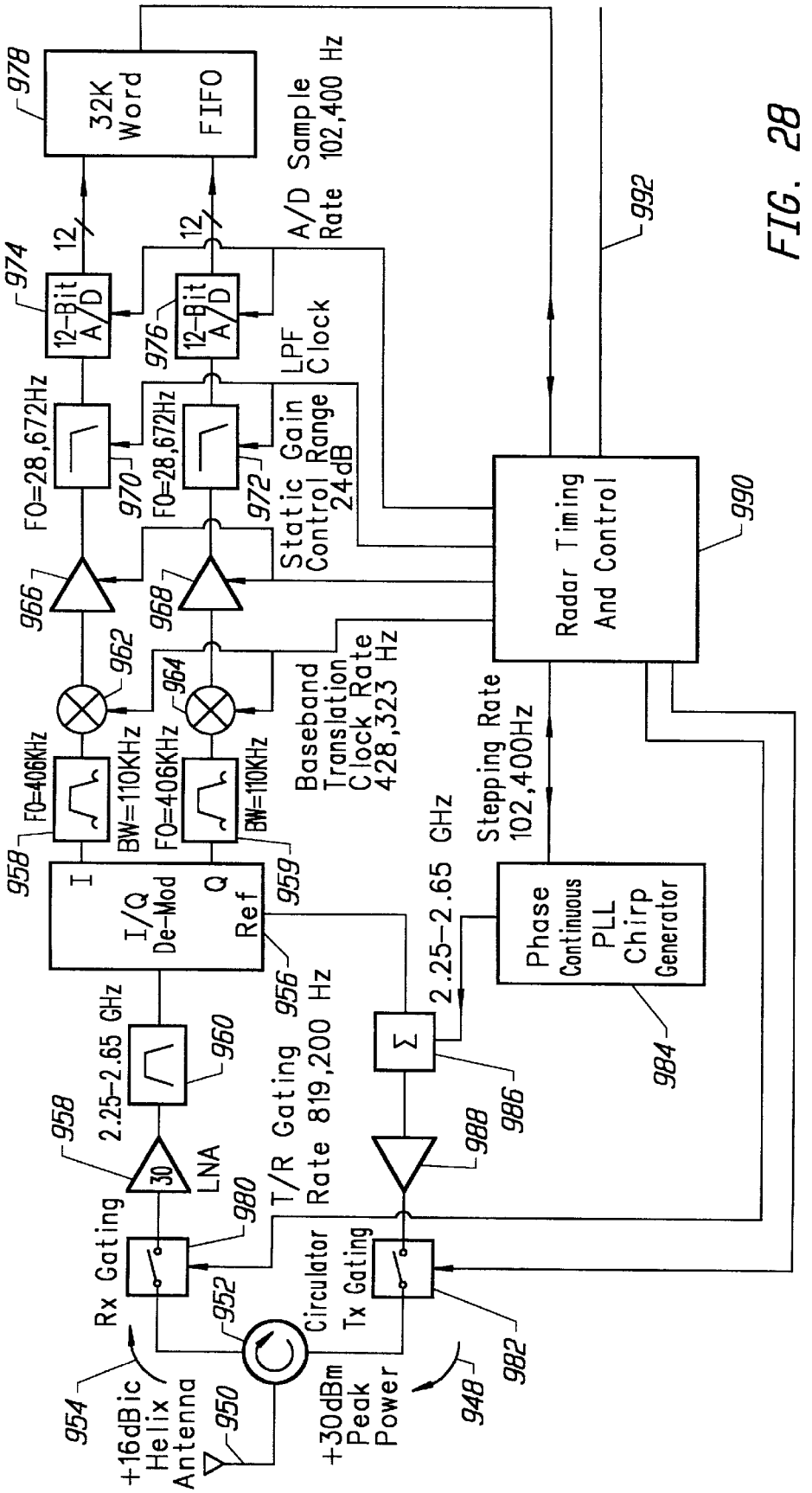
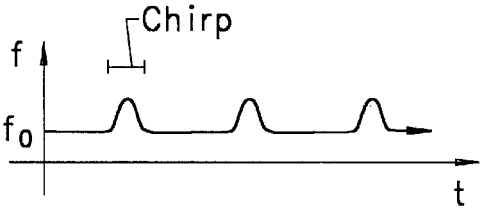

978
32K Word FIFO
A/D Sample Rate 102,400 Hz
974
12-Bit A/D
12
976
12-Bit A/D
12
992
LPF Clock
FO=28,672Hz
970
FO=28,672Hz
972
Static Gain Control Range 24dB
966
968
990
Radar Timing And Control
962
964
Baseband Translation Clock Rate 428,323 Hz
FO=406KHz
BW=110KHz
FO=406KHz
BW=110KHz
Stepping Rate 102,400Hz
958
I
I/Q De-Mod
Q
Ref
959
2.25-2.65 GHz
Phase Continuous PLL Chirp Generator
956
T/R Gating Rate 819,200 Hz
2.25-2.65 GHz
960
Σ
984
958
30
LNA
988
986
Rx Gating
980
Circulator
Tx Gating
952
982
954
+16dBic Helix Antenna
950
+30dBm Peak Power
948

FIG. 28

FIG. 29



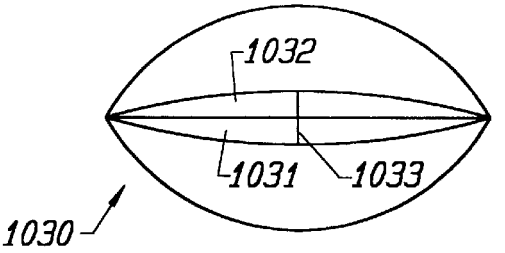
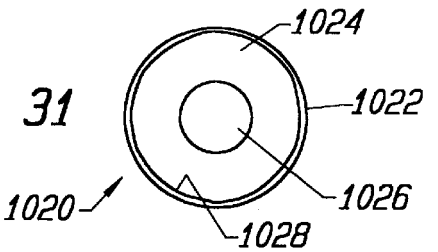


FIG. 30

FIG. 31



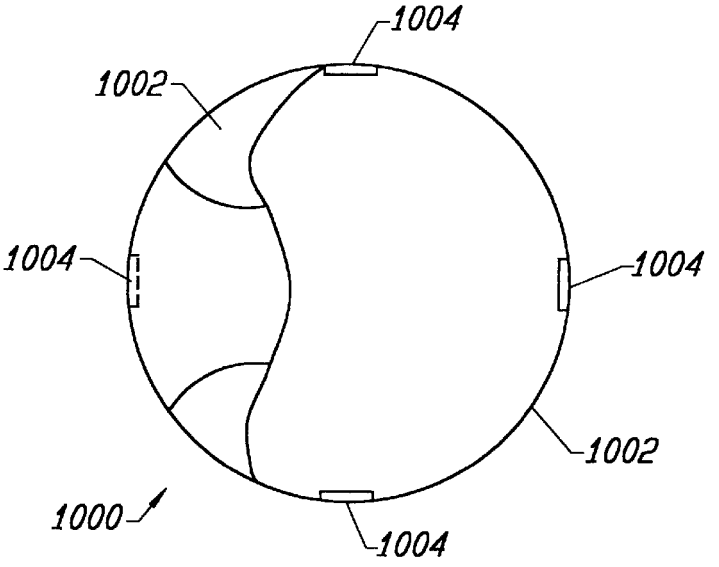


FIG. 32

SYSTEM FOR ENHANCING THE TELEVISION PRESENTATION OF AN OBJECT AT A SPORTING EVENT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed to a system for enhancing the television presentation of an object at a sporting event.

2. Description of the Related Art

The television presentation of sporting events needs to be improved. Because of the size and speed of some objects and the distance of the television camera from the playing field, some objects at a sporting event are hard to see on a television screen. One example of an object at a sporting event is the game object, which is defined as the article or thing which is the focus of the game, for example, a hockey puck, baseball, football, soccer ball, shotput, basketball, tennis ball, etc. To compensate for objects that are hard to see on television, broadcasters will use zoom lenses. However, the limited field of view of a zoomed camera prevents the object from being viewed in relation to the playing field and prevents the viewer from seeing other objects that are part of the sporting event. Additionally, even with zoom lenses some objects remain difficult to see on television.

For example, television viewing of a hockey game is hampered by poor visibility and distortion of the hockey puck. The puck is small, and is passed, shot and deflected at high speeds. A standard hockey puck is three inches in diameter and one inch high. A television viewer sees only a limited portion of the ice and the scene being viewed changes rapidly as the camera moves to follow the action. In order to be able to view all areas of the hockey rink, cameras must be located far from the playing surface. Thus, on a standard television screen a hockey puck tends to appear as a small dot or a smear, and sometimes the puck is not perceptible by a viewer. As a result, it is difficult to follow the puck from player to player, and it is especially difficult to follow the puck as it is shot toward the goal. For most viewers, recognizing that a goal has been scored probably comes after the fact when a signal light is turned on or the announcer informs the viewer that a goal has been scored. Because viewers cannot follow the puck, they do not sustain interest in the game. Although hockey is a popular sport, telecasts of hockey games would have wider appeal and be more fully enjoyed if the movement of the puck could be more closely followed.

In golf and baseball it is hard to see the ball when the ball is hit in the air for a long distance (e.g. a home run in baseball or a tee shot in golf). To compensate, cameras will zoom in on the baseball or golf ball which allows the viewers to see the ball against the sky. Such a view of the ball does not give the viewer a true perspective of the ball's path. That is, the viewer cannot determine how far the ball was hit or where the ball is in the relation to the playing field. At times a viewer of a baseball game cannot distinguish between a home run and a routine fly ball. One way to show a baseball or a golf ball in relation to the playing field is to zoom out and show the entire baseball field or golf course. However, such a zoom-out will make the ball difficult or impossible to see. Other sporting events present similar visibility problems.

Furthermore, television viewers do not have access to the same information that is available to spectators at the event (e.g. game programs, messages on the scoreboard, etc.).

Thus, broadcasters may be able to sustain greater viewer interested by presenting the viewers with additional desired information and provide for the use of that information in an exciting way.

Thus, there is a need for enhancing the television presentation of objects at sporting events. However, any solution to the problem should not significantly effect the players or fans who attend the sporting event.

SUMMARY OF THE INVENTION

The present invention is directed to overcome the disadvantages of the prior art. Thus, the present invention provides for a system for enhancing the television presentation of an object at a sporting event. The system, roughly described, determines an object's location, captures a video image which includes a field of view encompassing the location of the object, determines the position of the object in the field of view of the broadcast camera capturing the video image and enhances the television presentation of the object.

One embodiment includes one or more sensors and at least one processor. The sensors are used to detect the object. Many different types of sensors can be used; therefore, the invention is not limited to any particular sensor. One exemplar sensor is an infrared sensor which detects infrared signals from an object. One infrared sensor can be used to determine the object's position in a video image from the broadcast camera. Two or more infrared sensors can be used to determine the three dimensional location of the object. The processor communicates with the sensors and is programmed to determine the object's position in the video image from the broadcast camera. If the sensor or the broadcast camera can be moved, the system includes one or more field of view sensors which provide the processor with information about the broadcast camera's (and the sensor's) field of view. A field of view sensor can include one or more of the following: a pan sensor, tilt sensor, zoom sensor, beacon or anything else used to determine the field of view of a camera or sensor. If the processor knows the three dimensional location of the object, the processor can determine the position of the object in a video frame of any broadcast camera whose field of view is known.

Various means can be used to enhance the television presentation. For example, the system can add a graphic to the video image at the position of the object in the video frame, a graphic near the position of the object in the video frame, a graphic in a location logically related to the position of the object in the video frame, statistical information or announcements related to the object's location, audio data or non-video data. In one alternative, the processor manipulates the video image. In another alternative, the processor creates a second video image and combines the video image created by the processor and the video image from the broadcast camera. Other suitable methods of manipulating television data are also within the spirit of the present invention.

These and other objects and advantages of the invention will appear more clearly from the following 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** depicts a perspective view of a hockey puck according to the present invention.

FIG. **2** depicts a cut-away plan view of the hockey puck of FIG. **1**.

FIG. **3** depicts a cross-sectional view of the hockey puck of FIG. **1**.

FIG. **4** shows a first embodiment electronics package for the infrared transmitter of the hockey puck of FIG. **1**.

FIG. **5** depicts one exemplar shock sensor.

FIGS. **6**A and **6**B show a second embodiment electronics package for the hockey puck of FIG. **1**.

FIG. **7** is a block diagram of a system used for enhancing the television presentation of the hockey puck of FIG. **1**.

FIG. **8** is a block diagram of a camera location for the system of FIG. **7**.

FIG. **9** is a block diagram of the front end processor electronics of FIG. **8**.

FIG. **10** is a flow chart describing some of the operations in the camera location and related hardware.

FIG. **11** is a graphical representation of data from the infrared sensors.

FIG. **12** is a block diagram of the pulse detection system and strobe flash detection system.

FIG. **13** is a block diagram of a pulse detector.

FIG. **14** is a block diagram of the synchronizer box of FIG. **12**.

FIG. **15** is a partial block diagram of the graphics center and production center.

FIG. **16** is a flow chart describing some of the operations of the graphics center and production center.

FIGS. **17**A and **17**B are flow charts describing two exemplar methods for determining the puck's three dimensional location.

FIG. **18** is a flow chart describing the determination of the puck's position in a video frame and one alternative for enhancing the television presentation of the hockey puck.

FIG. **19** shows the hockey puck in a video frame at four moments in time.

FIG. **20** is a flow chart of the operation of the graphics center and production center when data is missing.

FIG. **21** is a block diagram of a remote system for interacting with a broadcast of a sporting event.

FIG. **22** is an elevational cut-away view of a second embodiment hockey puck with an active radar transponder.

FIG. **23** is a cross-sectional view of the hockey puck of FIG. **22**.

FIG. **24** is a block diagram of the electronics in the hockey puck of FIG. **22**.

FIGS. **25**–**27** describe a waveform used in conjunction with the hockey puck of FIG. **22**.

FIG. **28** is a block diagram of an exemplar radar base unit which can be used in conjunction with the hockey puck of FIG. **22**.

FIG. **29** depicts an exemplar waveform for a RF transmitting object.

FIG. **30** depicts a football used in a radar system.

FIG. **31** is a cross-sectional view of a golf ball used in a radar system.

FIG. **32** is a cut-away view of a tennis ball used in a radar system.

DETAILED DESCRIPTION

The present invention can be used with most video cameras known in the art. For example purposes only, the description below references a conventional broadcast television camera known in the art ("broadcast camera"). A broadcast camera captures video images in frames ("video frames"). In the United States, data is transmitted and presented on a standard television at a rate of thirty frames (60 fields) per second.

I. Infrared System

A. Infrared Transmitting Puck

Conventional hockey pucks are black, cylindrically shaped, 1" thick with a 3" inch diameter, 5½–6 ounces and made of vulcanized rubber. The preferred embodiment of the hockey puck according to the present invention is shown in FIG. **1** and designated generally by the reference numeral **10**. Hockey puck **10** is made in accord with conventional specifications and further includes an electromagnetic transmitter. In one embodiment, the electromagnetic transmitter includes infrared emitting diodes. Preferably (although not required), the tip of the diode is sliced off so that the diode can be flush up against the surface of the puck and the angular width of the infrared (IR) beam will be increased. As will be discussed below, alternatives to infrared emitters includes RF transmitters, radar repeaters and other devices which emit electromagnetic waves outside the visible light spectrum.

Electromagnetic waves include light, radio, X-rays, gamma rays, microwave, infrared, ultraviolet and others, all involving the propagation of electric and magnetic fields through space. The difference between the various types of electromagnetic waves are in their frequency or wavelength. The human eye is sensitive to electromagnetic radiation of wavelengths from approximately 400 to 700 nm, the range called light, visible light or the visible spectrum. Thus, the phrase "electromagnetic signal not visible to a human eye" means an electromagnetic signal outside of the visible spectrum. It is important that the signal transmitted by the hockey puck is not visible to the human eye so that the visual appearance of the puck will not be altered.

Puck **10** is comprised of a rubber body member **11** having a flat top surface **12**, a flat bottom surface **14** (shown in FIG. **3**) and a side surface or outer circumference **16**. At the top surface are shown four infrared emitting diodes **20**, **22**, **24** and **26**, which are fitted in bores in the puck. The bottom surface also has four infrared emitting diodes. Because of the point of view, FIG. **1** only shows four infrared emitting diodes **28**, **30**, **32** and **34** along outer circumference **16**. The preferred hockey puck includes twelve infrared emitting diodes along outer circumference **16**, spaced apart at 30° intervals. By the phrase "along an outer circumference" it is meant that the diodes are generally spaced at or near the outer circumference. For example, the diodes can be recessed (e.g. 1/16") from the circumference and still be "along the outer circumference." If the diodes are recessed from the circumference, then there may be an indent in the surface of the puck in front of the diode. As an option, the indent could be filled with an infrared transparent epoxy or other filling material which would not change the elasticity or color of the puck. Alternatively, a lens could be placed in front of the diode.

FIG. **2** shows a cutaway plan view of puck **10**. All twelve diodes (**28**, **30**, **32**, **34**, **36**, **38**, **40**, **42**, **44**, **46**, **48** and **50**) along outer circumference **16** can be seen. Each diode is housed in a bore approximately the size of the diode. Inside of the puck is a recess **60** which receives printed circuit board **62**. Mounted on printed circuit board **62** are electronics and a battery **64**. Wires **28***w*, **30***w*, **32***w*, **34***w*, **36***w*, **38***w*, **40***w*, **42***w*, **44***w*, **46***w*, **48***w* and **50***w* run from printed circuit board **62** to the diodes. Battery **64** can be more than one

battery vertically stacked in the center of printed circuit board **62**. The battery is a lithium battery which handles cold temperatures well and has high current capability. It is important that the electronics operate sufficiently under cold temperatures because hockey pucks are traditionally frozen prior to use during a hockey game. High current capability is also important so that the infrared emitting diodes can be driven with the high current to maximize the intensity of the infrared signal. Battery **64**, printed circuit board **62** and the infrared emitting diodes are held in place using a flexible epoxy, for example, DP190 by 3M. Additionally, any gaps in recess **60** not occupied by the electronics could be filled with epoxy to help secure the electronics and to maintain the pucks hardness and elasticity.

FIG. **3** is a side cut-away view of hockey puck **10** showing the bottom surface **14**, diodes **52** and **54** on the bottom surface and the wires (**20***w*, **22***w*, **52***w* and **54***w*). As discussed above, there are four diodes along the flat lower surface of the preferred embodiment hockey puck **10**. It is clear from FIGS. **2** and **3** that the components of the electromagnetic transmitter are completely disposed inside rubber body member **11**. Being "completely disposed inside the rubber body member" means that the electromagnetic transmitter does not protrude outside the puck's perimeter, this includes abutting or being flush with the perimeter of rubber body member **11**.

FIG. **4** is a schematic diagram of one alternative electronics package for hockey puck **10**. The infrared emitting diodes **20**–**58** are shown as five strings of diodes (S1–S5). Each string includes four diodes connected in series. The five strings are connected to each other in parallel. Thus, if one diode fails, all of the diodes on the particular string will turn off; however, the other four strings of diodes will remain functional. In accord with this arrangement, the diodes from the various strings are interleaved throughout the puck. That is, the diodes of one string are not located next to each other. Rather, the diodes are mixed. Looking at FIG. **2**, each diode is located next to a diode from another string. For example, diode **30** (which is on string S1) is between diode **28** (which is on string S5) and diode **32** (which is on string S2). This arrangement prevents the situation where one diode breaks and the entire side of the puck stops transmitting.

Timing and control circuit **100**, which includes an edge trigger and a timer, produces an output interval of a width determined by resistor **108** and capacitor **110**. Timing and control circuit **100** is a Motorola MC 4538 which is a dual precision re-triggerable/re-setable monostable multivibrator which may be triggered from either edge of an input pulse and produce an accurate output interval over a wide range of widths. In the circuit of FIG. **4**, battery **63** is made up of two 3 volt batteries in series.

The Q output of timing and control **100** is connected to the gate of FET **102**. The source of FET **102** is connected to ground and the drain of FET **102** is connected to the base of transistor **106** across resistor **104**. The emitter of transistor **106** is connected to battery **63** and to the RC PIN of timing and control **100** across resistor **108**. The RC input of control **100** is connected to capacitor **110** which is connected to the C input of timing and control circuit **100** and to ground. The A pin of timing and control circuit **100** is grounded, and the B pin is connected to shock sensor **114** and to resistor **112**. The clear pin of timing and control circuit **100** and resistor **112** are both connected to battery **63**.

Shock sensor **114** is used to turn on the circuit when it senses a shock. FIG. **5** is an example of a shock sensor. Shock sensor **114** includes a wire **122** suspended inside a brass or copper tube **120**. Wire **122** is attached to cap **128** with epoxy or other insulating material **129** which acts to suspend the wire inside tube **120** in a cantilevered fashion and insulates the wire. Tube **120** is mounted on board **62** and connected to the B pin of timing and control circuit **100**. When shock sensor **114** is shocked (e.g. puck is jolted or hit) wire **122** bends and touches tube **120** which, for a brief moment, completes the circuit. Timing and control circuit **100** includes an edge detector which senses an edge (the circuit being closed) and turns on the puck.

FIGS. **6**A and **6**B are schematics of a preferred electronics package for puck **10**. Diode bank **150** is the same five strings of infrared emitting diodes depicted in FIG. **4**. Although the electronics package uses twenty diodes, it is possible that the puck can be constructed and will function with more or fewer than twenty diodes. One diode by itself will produce a signal that can be detected; however, it is advantageous to have more than one diode so that the angle of the puck and location of the puck in regard to other objects will not significantly affect reception of the signal transmitted from the puck. Additional diodes also maximizes the output of the transmitters. The preferred embodiment diode is a GaAlAs infrared emitter SFH485-2, manufactured by Siemens. The SFH485-2 is an infrared emitting diode and emits radiation in the near infrared range (880 nm peak). Other infrared emitting diodes that can be used include an infrared laser diode or any other source which transmits an infrared signal. The infrared emitting diodes are used in the disclosed embodiment to emit an electromagnetic wave with a wavelength at or near 880 nm. Unlike the circuit of FIG. **4**, the circuit of FIG. **6** does not continuously transmit infrared energy. Rather, the diodes are pulsed. The advantage of pulsing the diodes is to extend battery life, to increase the infrared signal (e.g. run at one amp instead of one hundred milli-amps), to improve the signal to clutter ratio by matching the sensor shuttering to the diodes pulse and to allow for subtraction as is discussed below.

Battery **64** is made up of four 3 volt lithium batteries stacked near the center of PC board **62**. FIG. **6**A shows timing and control circuits **154** and **172** which are the same multi-vibrator as timing and control circuit **100** in FIG. **4**. Timing and control circuit **154** is used to detect a pulse from the shock sensor **114**, turn on the pulsing of the diodes and automatically turn off the pulsing of the diodes after a predetermined period of time before all available power has dissipated. That is, the pulsing of the diodes turns off after a preset period of time rather than waiting for the battery to dissipate. Preferably, the diodes are turned off after 45 seconds. This prolongs the life of the battery, allows testing and prevents pucks not in use from transmitting. Connected to the RC input of timing and control circuit **154** is resistor **158** and capacitor **160**, both used for timing purposes. The $\overline{Q}$ output of timing and control circuit **154** is connected, across resistor **164**, to the base of transistor **166**. The A input of timing and control circuit **154** is connected to ground. The B input is connected to shock sensor **114** and to the bottom of resistor **162**. The clear pin of timing and control circuit **154** is connected to the top of the resistor **162**, battery **64**, the top of resistor **158**, capacitor **156** and the emitter of transistor **166**. Capacitor **156** is also connected to ground.

The clear pin to timer control circuit **172** is connected to the emitter of transistor **166** and the top of resistor **168**. The RC input of a timer control **162** is connected to the bottom of resistor of **168** and to capacitor **170**. The C input of timing and control **172** is connected to capacitor **170**, the A input, and ground. The Q output of timing and control circuit **172**

is connected to FET **174**. The B input of timing and control circuit **172** is connected to the Q9 output of Divide by 10 circuit **180** (divides frequency by ten). The clock input to Divide by 10 circuit **180** is connected to the Q12 output of Divide by 16 circuit **182** (divides frequency by 16). The enable and reset pins of Divide by 10 circuit **180** are grounded. The reset pin of Divide by 16 circuit **182** is connected to capacitor **190**, capacitor **186** and ground. The $\overline{\text{COUT}}$ pin of Divide by 16 circuit **182** is connected to the bottom of resistor **188**, capacitor **186** and to resonator **184**. Resonator **184** is a CSB1228J ceramic resonator by Murata. Resonator **184** can be mounted on printed circuit board **62** or suspended, inside the puck, within an epoxy or other material to prevent damage to the resonator from shock. The CIN pin of Divide by 16 circuit **182** is connected to resonator **184**, the top of the resistor of **188** and to capacitor **190**.

FET **174** is connected to infrared emitting diodes **50**, **52**, **54**, **56** and **58**. The circuit will produce five amps of current to pass through diode bank **150**. Because the diodes are divided into five strings which are connected in parallel, each string receives approximately one amp. Because each string includes four diodes connected in series, each diode will receive approximately one amp of current. The collector of transistor **166** is connected to the top of resistor **176**, capacitor **178**, diode **20**, diode **22**, diode **24**, diode **26** and diode **28**. Capacitor **178** and the bottom of resistor **176** are connected to ground.

The circuit of FIGS. **6**A and **6**B provides for pulses of nominally 140 μsec at a nominal rate of 29.97 Hz. Those skilled in the art can modify the circuit to change the duration or frequency of the pulses. The pulses begin when the shock sensor is shocked. The pulses end 45 seconds after the last shock. If the shock sensor receives a shock while the puck is pulsing, the 45 second clock is reset. A shock sensor is only one of many alternatives to insure that the puck is on during play. It is anticipated that the shock to the puck when the referee drops the puck for a face off, a players hits the puck with a stick or the puck hits the boards will provide the shock necessary to trigger the circuit. While in play the puck should be hit by a player's stick or the boards at least once every 45 seconds. During the course of a game pucks are hit out of play. That is, a shot by a player goes over the boards and into the seating area. At that point it is desirable that the puck turn off. Thus, the timer is used to turn the puck off 45 seconds after the last shock. This prevents the arena from being filled with pucks continuously on.

There are at least four approaches to manufacturing a puck in accordance with the present invention. First, the electronics can be supported in an injection mold and vulcanized rubber can be injected around it. Second, the device can be in a pre-loaded package that is molded into a puck. Third, pucks can be molded into two halves with a recess in each half so that the is electronics can be fitted in the combined recess when the two halves are assembled together. Fourth, existing conventional pucks could be machined into separate pieces and reassembled with the electronics package (retrofitting). In one embodiment of the fourth approach, half of two pucks would be sliced away. A recess would be carved into the remaining two halves as well as bores for each of the diodes. There is also a need to carve a very thin passage to house the leads from the electronics to the diodes. The inventors envision various other manufacturing options that are compatible with the present invention.

B. System Overview

Puck **10** is used with a system that includes one or more sensors which can be used to detect the location of the puck in three dimensional space and/or the position of the puck in a video frame. An infrared sensor can determine the angle or direction of the puck from the sensor using techniques known in the art. Two or more infrared sensors can be used to determine the three dimensional location of the puck. The three dimensional location of the puck can be used, in conjunction with the broadcast camera's location and orientation to locate the puck in the video frame and enhance the television presentation of the puck.

FIG. **7** depicts system **200**, which is one embodiment of a system that can be used to enhance the television presentation of puck **10** with the electronics package depicted in FIGS. **6**A and **6**B. System **200** includes four camera locations **201**, **202**, **203** and **204**. It is possible for system **200** to function with only one camera location; however, to provide a viewer with multiple angles of view it is desired to have up to four or more camera locations. The various camera locations can be located anywhere in the arena suitable for capturing video images of puck **10** in hockey rink **208**. Each camera location includes a broadcast camera and communicates with graphics center **246**. As shown, signal data **1** transmits data between camera location **201** and graphics center **246**, signal data **2** transmits data between camera location **202** and graphics center **246**, signal data **3** transmits data between camera location **203** and graphics center **246** and signal data four transmits data between camera location **204** and graphics center **246**. In one embodiment, graphics center **246** includes computers and video equipment housed in a truck.

The camera locations also communicate with a television production center **244**. The signal camera **1** indicates communication between camera location **201** and production center **244**, camera **2** indicates communication between camera location **202** and production center **244**, camera **3** indicates communication between camera location **203** and production center **244**, and signal camera **4** indicates communication between camera location **204** and production center **244**. In one embodiment, the television production center is a truck including various video and audio equipment. Both the graphics center **246** and the video production center **244** can exist in various forms and can be located in various locations that can maintain the communications with the camera locations and sensors as described below.

System **200** includes one or more infrared sensors. To ease setup, wiring and maintenance, as well as increase the chance that the puck will be in the field of view of an infrared sensor, one or more infrared sensors are located at the camera locations. However, locating infrared sensors at the camera locations is optional. The sensors at the camera locations communicate with graphics center **246** via data **1**, data **2**, data **3** and data **4**. System **200** also includes additional sensor locations, **210**, **212**, **214** and **216**, which are not located at the camera locations. The signal data **5** indicates communication between infrared sensor location **210** and graphics center **246**. The signal data **6** indicates communication between infrared sensor location **212** and graphics center **246**. The signal data **7** indicates communication between infrared sensor location **214** and graphics center **246**. The signal data **8** indicates communication between infrared sensor location **216** and graphics center **246**.

System **200** also includes collector box **220** which is connected to pulse detectors **222**, **224**, **226**, **228**, **230**, **232**, **234**, **236**, **238** and **240**. The pulse detectors detect when puck **10** is pulsing on and transmit signals to the infrared sensors in order to open the shutter of the infrared sensors in synchronization with the puck's pulses. A system that uses a puck which continuously transmits an infrared signal

would not need pulse detectors. The pulse detectors shown in FIG. **7** are located at the top of the glass which surrounds the ice. Additional pulse detectors (optional) are mounted from the ceiling or other suitable locations in the arena. The components shown in FIG. **7** will be discussed in more detail below.

C. Camera Location

FIG. **8** shows one embodiment of the camera location. Broadcast camera **280** captures a video frame which is sent to a production center **244** as shown by the signal camera **1**. Broadcast camera **280** has a zoom lens including a 2× expander. Connected to broadcast camera **280** is a 2× expander/zoom/focus sensor **282** (collectively a "zoom sensor") which senses the zoom of the camera, the focal length of the camera, and whether the 2× expander is being used. The analog output of sensor **282** is sent to an analog to digital converter **284**, which converts the analog signal to a digital signal and transmits the digital signal to processor **302**. Broadcast camera **280** is mounted on tripod **287** which enables broadcast camera **280** to tilt and pan. Attached to tripod **287** are pan sensor **288** and tilt sensor **290**, both of which are connected to pan-tilt electronics **292**.

Remote processor unit **286** is a rack mounted system including analog to digital converter **284**, pan-tilt electronics **292**, processor **302** and front end processor electronics **300**. Processor **302** is an Intel **486** microprocessor with supporting electronics; however, various other processors can be substituted. Processor **302** includes memory and disks to store data and the software described below. In addition to being connected to the other boards in front end processor **286**, processor **302** is in communication with graphics center **246**, as indicated by signal **306**. In one embodiment, pan sensor **288** and tilt sensor **290** are optical encoders that output a signal, measured as a number of clicks, indicating the rotation of a shaft. Forty thousand clicks represent a full 360 degree rotation. Thus, a computer can divide the number of measured clicks by forty thousand and multiply by 360 to determine the pan or tilt angle. The pan and tile sensors use standard technology known in the art and can be replaced by other suitable pan and tilt sensors known by those skilled in the relevant art. Pan-tilt electronics **292** receives the output of pan sensor **288** and tilt sensor **290**, converts the outputs to a digital signal, representing pan and tilt, and transmits the digital signal to processor **302**. The pan, tilt and zoom sensors are used to determine the field of view of the broadcast camera and, in some cases, the field of view of an infrared sensor. Thus, one or more of the pan, tilt or zoom sensors can also be labelled as a field of view sensor. For example, if the camera cannot zoom or tilt, the field of view sensor would only include a pan sensor. One alternative field of view sensor includes placing marks in various locations on the hockey rink such that each mark looks different and at least one mark will always be visible to the camera while the camera is pointed at the hockey rink. A computer using optical recognition technology can find the mark in the video frame and, based on the mark's size and position in the video frame, determine the field of view and/or pan, tilt and zoom of the camera. Another alterative includes placing infrared emitters or beacons along the rink (e.g. on the glass). If each beacon has a unique appearance, then a computer can determine the infrared sensor's field of view based on the size of the received signal's size and location in the infrared sensor's frame of data. If an infrared sensor is mounted on a broadcast camera, determining the pan and tilt of one also determines the pan and tilt for the other (plus a known offset). Another alternative includes using pan and tilt sensors to get a rough estimate of field of view and using beacons to fine tune the field of view determination.

The camera location also includes two infrared sensors, master sensor **296** and slave sensor **298**, both of which are connected to front end processor electronics **300** and sensor interface box **320**. Although the system win function with only one sensor at each location, two sensors are used in master and slave configuration in order to perform substraction which will be discussed below. Master sensor **296** and slave sensor **298** are mounted near one another (e.g. next to each other) so that their optical axes are near each other. It is possible to mount the two sensors away from each other and correct for the misalignment of optical axis. Furthermore, both sensors are mounted on broadcast camera **280** so that they are pointed in the same direction as broadcast camera **280**. This is done because it is contemplated that a camera operator will be tilting and panning broadcast camera **280** to follow the puck, and mounting the sensors on broadcast camera **280** will increase the chance that the sensors will be pointed at the puck. Pan sensor **288** and tilt sensor **290** will indicate where the master and slave sensors are pointing. However, it is not necessary to mount the sensors on the broadcast camera. The internal clocks of the master sensor **296** and slave sensor **298** are synchronized as indicated by signal **305**.

The preferred infrared sensor is a progressive scan, full frame shutter camera, for example, the TM-9701 by Pulnix. The Pulnix sensor is a high resolution 768(H) by 484(V) black and white full frame shutter camera with asynchronous reset capability. The camera has an eight bit digital signal output and progressively scans 525 lines of video data. A narrow band infrared filter, which passes electromagnetic waves of approximately 880 nm +/−45 nm, is affixed in front of the lens of the Pulnix sensor. The purpose of the filter is to block electromagnetic signals that are outside the spectrum of the signal from the puck; thus, significantly reducing background clutter.

Each sensor captures a video frame which comprises a set of pixels. Each pixel is assigned a coordinate corresponding to an X axis and a Y axis. The sensor data includes an eight bit brightness value for each pixel. The eight bit brightness values are scanned out pixel by pixel to front end processor electronics **300** from master sensor **296** via the signal Mdata and from slave sensor **298** via the signal Sdata.

Sensor interface box **320** sends the shutter command and horizontal drive to the infrared sensors. Signal **446** from the pulse detection system (described below) is decoded by sync decoder **322** to extract horizontal drive signal **321** which is communicated to master sensor **296**. Horizontal drive signal **321** is used to phase lock the master sensor's internal clock to the puck. Signal **321** is also sent to pulse generator circuit **324** to produce a shutter control signal (Mshutter) at least 120 μsec wide, which is transmitted to master sensor **296**. The output of pulse generator **324** is also sent to delay circuit **326** to provide a signal delayed by approximately 60 μsec for pulse generator **328**. The output of pulse generator **328**, an approximately 120 μsec wide pulse used to control the shutter, is sent to slave sensor **298**. Both shutter control signals (Mshutter and Sshutter) are also sent to computer **286** for diagnostic purposes.

Many arenas do not allow photographers to use flashes on their cameras in order to prevent impairing the players' vision from random flashes. In lieu of individual camera flashes, many arenas install a set of strobe flashes at or near the ceiling of the arenas and provide for communication between each photographer's camera and the set of strobe flashes. When the photographer takes a picture, the strobe flashes emit a flash of light, which may include an electromagnetic wave in the infrared spectrum. In one embodiment,

the system avoids incorrect data due to a sensor detecting a flash by ignoring data sensed during a flash. One means for preventing the incorrect data is to use filters. A second embodiment connects a signal from the strobe flash to the sensors or a computer which causes the system to ignore data sensed during a flash. A third embodiment includes using flash detectors. The flash detectors can be located anywhere in the arena suitable for sensing a strobe flash. For manufacturing convenience, one alternative includes a flash detector **329** as part of the sensor interface box **320**. When flash detector **329** senses a flash a signal FD is sent to front end processor electronics **300**. In some environments, a flash detection system may not be necessary.

In addition to mounting sensors on broadcast cameras in the camera locations, additional sensors **210–216** are mounted throughout the arena to improve sensor coverage. Each sensor location, **210**, **212**, **214** and **216**, includes two sensors in master and slave configuration. Sensors **210–216** are preferably mounted above the rink so that the field of view of the sensors overlaps and each location on the ice is within the field of view of two sensors. Sensor locations **210**, **212**, **214** and **216** do not include broadcast cameras and pan/tilt/zoom detectors. Since the sensor at sensor locations **210–216** cannot pan, tilt or zoom, control system **606** (FIG. **15**) stores the location, pan and tilt of the sensors. Each sensor location also includes a processor **302** and front end processor electronics **300**.

FIG. **9** shows a block diagram of front end processor electronics **300**. Sensor interface **330** receives data (Mdata) from master sensor **296**, including the eight bit data for each pixel. Sensor interface **330** has four output signals: LDV, FDV, PC1 and DATA1. LDV (line data valid) is transmitted to XY counters **332** and indicates that a new line of valid data is being scanned out of master sensor **296**. FDV (frame data valid), which is transmitted to XY control **332** and pixel gate counter **338**, indicates that valid data for the next frame is being transmitted. PC1 (pixel clock **1**) is a 14.318 MHz clock from master sensor **296** and is sent to XY counters **332**, pixel gate control **338** and background processor **334**. DATA1 is transmitted to background processor **334**. XY counters **332** counts X and Y coordinates sequentially in order to keep track of the pixel of whose data is being scanned in at the current time. When LDV is asserted, the X counter is reset. When FDV is asserted, the Y counter is reset.

As XY counters **332** sequentially count the coordinates of the pixels, frame limits **336** determines whether the coordinate of the particular pixel being scanned in is within the valid frame limits. The valid frame limits includes pixels in a rectangular box within the frame of the sensor **296** which is determined by the values of X_{min}, X_{max} Y_{min}, and Y_{max}, all four of which are supplied from registers in processor **302** via computer interface **339**. The registers in processor **302** are set by software in computer **606**. (See FIG. **15**.) These values can be set based on the sensor location and orientation. For example, if half of the field of view of the sensor **296** is above the hockey rink or below the hockey rink, there is no need to consider data that is not within the hockey rink. This avoids sensing spurious sources. When frame limit **336** determines that the pixel is within the valid frame limits, the signal INFRAME is asserted and transmitted to pixel gate control **338**.

Sensor interface **340** receives data (Sdata) from slave sensor **298** and communicates the eight bit pixel data and PC2 (pixel clock two) to adjustable delay **342**. There is no need to send a version of the signal LDV and FDV for slave sensor **298** because master **296** and slave **298** are synchronized by signal **305** (FIG. **8**). Adjustable delay **342** is an adjustable shift register for aligning the optical data from the master and slave sensors. The amount of delay is determined by the variable OFFSET which is a twelve bit signal sent from processor **302** via computer interface **339**. OFFSET is set in processor **300** via a user interface residing on computer **606** or a local user interface. (See FIG. **15**.) The data from the two sensors are optically aligned because the two sensors will be mounted on top of each other or next to each other, therefore, having different optical axes. One alternative is to use one optical axis for both sensors, for example, using a prism to transmit one image to two sensors, which in turn are optically aligned. The delayed data (PC2 and DATA2D) is transmitted to background processor **334**.

Background processor **334** is an Arithmetic Logic Unit with a set of registers. Alternatively, background processor **334** could be a microprocessor. Background processor **334** aligns the data based on the pixel clocks and subtracts the two sets of data (DATA1 and DATA2). There are two types of subtraction that can be used; temporal subtraction and spectral subtraction, although either or both methods can be used, the preferred background processor **334** only performs temporal subtraction. The technique of temporal subtraction utilizes two sensors with similar field of views, opening their shutter at different times. The master sensor's shutter is open and captures data during an infrared pulse from puck **10**. The slave sensor's shutter is open and captures data between pulses from puck **10**. Therefore, master **296** and slave **298** sense substantially similar images except master sees the field of view with the puck on and slave sees almost the same field of view without the puck. If the two sets of data are subtracted, the difference should be the signal from the puck. Background processor **334** performs that subtraction. In the particular embodiment disclosed, master sensor **296** opens its shutter for 127 μsec. After master sensor **296** closes its shutter, both master and slave keep their shutters closed for 63 μsec. Subsequently, slave **298** opens its shutter for 127 μsec. followed by both shutters being closed for the remainder of the frame's 1/30 of one second. This process repeats itself approximately every 1/30 of a second based on the strobing of the puck which will be described below.

Spectral subtraction utilizes two sensors that have substantially similar field of views, but detect different spectrums. One spectrum includes the puck's pulse and the second spectrum does not. For example, master **296** would use the filter discussed above which passes wavelengths of 880+/−45 nm. However, slave **298** would use a filter that allows a bandwidth near but not including the bandwidth of master **296**. The shutters of both the master **296** and slave **298** would open and close at the same time, creating two sets of data. Theoretically, the two sets of data would differ in that one would include the puck and one would not. Subtracting the two sets of data causes most data to cancel out, except for the puck's signal.

The output of background processor **334** is eight bit DATAS which is sent to pixel gate control **338** and FIFO **344**. Pixel gate control **338** is used to determine whether data is valid and to store that data in FIFO **344**. Pixel gate control **338** uses three criteria to determine whether the data is valid. The first criteria is to determine whether the data is within the valid frame limits. The second criteria is to determine whether the data has met a certain brightness THRESHOLD. Certain pixels are so dim that they cannot be valid data. A variable THRESHOLD is used as a brightness threshold. All data with a brightness below the THRESHOLD value is discarded. Pixel gate control **338** receives THRESHOLD from register processor **302** via computer interface **338**.

THRESHOLD is set from a graphical interface in computer **606** (or a local interface) based on the environment surrounding the sensors and will usually be determined by trial and error or measurement at each sensor location.

The third criteria to determine whether the data is valid is to find out whether the data was captured during a flash. When a flash is detected sync/sensor control **346** receives a signal FD indicating a flash and forwards this signal to pixel gate control **338**. If pixel gate control **338** determines that the coordinates of the pixel are within the frame limit, DATAS is above the THRESHOLD and there is no flash during the frame, pixel gate control will assert $\overline{W}$ (write enable) to FIFO **334** to cause FIFO **334** to store the pixel coordinates (X,Y) from XY counters **332**, a data code and eight bit DATAS. The data code indicates whether FIFO **334** is storing valid data, a strobe flash indicator (SF), an end of frame indicator (EOF) or a start of frame indicator (SOF). If the data is not within the frame limits, or not above the THRESHOLD, pixel gate control **338** will not assert $\overline{W}$. If there is a flash during a frame, pixel gate control **338** will assert $\overline{W}$, and store SF in the data code field.

Background processor **334** also sends output signals DATA**0**D (16 bits), PC**1**D (2 bits), FDVD (2 bits), and LDVD (2 bits) to optional data monitors. DATA**0**D is DATAS sent as differential data. PC**1**D is pixel clock 1 sent as differential data. FDVD is frame data valid sent as differential data. LVDV is line data valid sent as differential data.

Computer interface **334** also transmits a reset signal to FIFO **344** to reset the FIFO when the system is being started up. Processor **302**, via computer interface **348**, sends a read control signal **350** to FIFO **344** in order to request data from FIFO **344**. The output of FIFO **344** is a 32 bit data signal **352** which is sent to computer interface **348** which aligns the data and presents the data to processor **302**.

FIG. **10** describes the operations in the camera location and related hardware. The first step depicted is registration and initialization **380**. This step, which will be discussed in more detail below, includes initializing and calibrating the hardware. Once normal operation begins during a television presentation, broadcast camera **280** begins selectively broadcasting the hockey game (step **382**) and, concurrently, steps **384–406** are performed. By selective broadcasting it is meant that the broadcast camera captures video images and sends those images to production center **244**. A manager in production center **248** may or may not use those particular video images.

In step **384**, puck **10** is turned on (e.g. starts pulsing). While puck **10** is transmitting pulses, one or more pulse detectors (discussed below) detect the puck's pulses and a shutter command is sent to the infrared sensors (step **386**). Although step **386** is drawn above step **388**, step **386** is continuous and occurs before, after and/or during step **388**. During normal operation, two sets of operations occur: steps **388–392** and steps **394–404**. In step **388** analog to digital converter **284** and pan-tilt electronics **292** sample the pan, tilt and zoom values. In step **390**, these values are sent to processor **302** which transmits the values to graphics center **246**. In step **392**, processor **302** receives the X and Y boundaries (X_{min}, X_{max}, Y_{min}, Y_{max}) from graphics center **246** and transmits those values to frame limits **336** via computer interface **338**. Alternatively, the X and Y boundaries can be determined by processor **302**. In step **394**, master sensor **296** opens its shutter for 127 μsec and captures (or creates) data representing a position of puck **10** in the field of view of master sensor **296**. In step **396**, slave sensor **298** opens its shutter for 127 μsec. and captures (or creates) data. In step **398**, data is serially scanned in for each pixel for both sensors. Step **398** could be divided into two separate steps. In step **402**, false detections (including noise) are removed, which includes subtraction, brightness threshold, frame limits, flash detection, region of play filters and exclusion zones. Region of play filters and exclusion zones are discussed below. The system also utilizes pulsing, infrared filters on the sensors and infrared reduction through filtering or polarization of spurious sources for assisting the detection of the puck's signal from noise and clutter. The infrared reduction is accomplished by placing filters that remove infrared signals in front of all or some of other electromagnetic emitting sources in the arena (e.g. scoreboard). Although the system uses the above listed methods to enhance performance, a system can be designed to function without any of the listed methods or with a subset of the listed methods. After false detections are removed, valid data is stored in FIFO **344**. In step **404**, clusters are determined, and in step **406** cluster information is transmitted to graphics center **246**.

The data that passes the tests of step **402** tends to be represented as clusters of pixels. Thus, the system can save time transferring sensor information from the camera location to the graphics processing center **246** by sending information which characterizes the clusters instead of individual pixel values. Characterizing these clusters is the tasks performed in step **404**. The advantage of clustering is that it saves bandwidth and distributes computer power. A cluster is defined as a group of valid pixels that border each other. FIG. **11** shows a portion of a frame of data. For example purposes only, the THRESHOLD value set for this particular frame of data is eight. Thus, only pixels that have the brightness of eight or greater are stored in FIFO **344**. Each square in FIG. **11** represents a pixel and the number in that square represents the brightness of the pixel. The pixels with no numbers have a brightness less than eight. The portion of the frame depicted includes two clusters **430** and **432**. The first row of cluster **430** includes three pixels having brightness of eight. The second row of cluster **430** includes four pixels having brightness of nine. The first row of cluster **432** includes two pixels, the first pixel having a brightness of eight and the second pixel having a brightness of nine.

For each cluster, a data structure is set up analogous to a structure in the C programming language. The fields of the structure include MINX, MAXX, MINY, MAXY, TOTAL ENERGY and MAX ENERGY. MINX is the minimum X value of any of the pixels in the cluster. MAXX is the maximum X value of any of the pixels in the cluster. MINY is the minimum Y value of any of the pixels in the cluster. MAXY is the maximum Y value of any of the pixels in the cluster. Note that the X and Y values are the coordinates of pixels in the frame. For example, point **436** has the coordinates 96, 198 and point **434** has the coordinates 100, 200. TOTAL ENERGY is the sum of the brightness of all of the pixels in the cluster, and MAX energy is the brightness of the brightest pixel in the cluster. Thus, for cluster **432** MINX equals 96, MAXX equals 100, MINY equals 198, MAXY equals 200, TOTAL ENERGY equals 73, and MAX energy equals 9.

D. Sync and Flash Detectors

FIG. **12** shows a pulse detection system, which is one type of a synchronization system that can be used to synchronize the sensors with the object being tracked. Lower collector box **220** sends power to pulse detectors (**440**) and flash detectors (**440–442**) and receives a signal from pulse detectors **222–240** indicating a puck pulse. Alternatively, pulse

detectors **222–240** can be self-powered. In addition to the pulse detectors arranged around the rink, the system can optionally include pulse detectors **443** above the rink (e.g. hanging from ceiling) or another location. Upper collector box **445** sends power to pulse detectors **443** and receives a signal from pulse detectors **443** indicating a pulse. Upper collector box **445** effectively wire-ORs the signals from pulse detectors **443** and sends the result to lower collector box **220**. Collector box **220** effectively wire-ORs the output signals from the pulse detectors **220–240** and upper collector box **245** and sends the result to synchronizer box **440** which resides in graphics center **246**. The system can include additional pulse detectors connected to additional upper collector boxes. Each upper collector box would have an output which is connected as an input to another collector box to be wire-OR'ed with the pulse detectors of the other collector box.

Lower collector box **220** receives a signal from each of the flash detectors **442** and effectively wire-ORs the signals. If any of the flash detectors **442** sense a flash, collector box **220** will ignore any pulses detected during the same time period as the flash. Thus, flash detectors **440** are a second (and optional) flash detect system in addition to the flash detectors at the camera locations.

Synchronizer box **444** receives the puck pulse signal on line **221** from lower collector box **220**. Based on the signal from the pulse detectors, synchronizer box **444** determines the period of the puck. Synchronizer box **444** sends to each infrared sensor location and camera location a signal **446** which is used to synchronize the shutter of the infrared sensors.

FIG. **13** shows a block diagram of a pulse detector. The heart of the pulse detector is a photodetector **450** which includes a photo diode and op-amp. In front of the photodetector is an infrared filter **452**. Photodetector **450** is also connected to DC subtraction circuit **454**. FIG. **13** shows two connections between photodetector **450** and DC subtraction circuit **454** to indicate that DC subtraction circuit **454** provides feedback to the op-amp in photodetector **450**. The output of DC subtraction circuit **454** is sent to filter **456** which reduces steady DC signals and low frequency AC signals such as 120 Hz power line modulation. The output of filter **456** is sent to leading edge threshold detector **458**, which detects the rising edge of the infrared pulse from puck **10**. Connected to leading edge threshold detector **458** is trailing edge gate **460** which outputs a pulse when leading edge threshold detector **458** detects a leading edge. The output of trailing edge gate **460** is transmitted to comparator **462**. Filter **456** also transmits its output to trailing edge threshold detector **464** which detects the falling edge of a pulse from puck **10**. The output of trailing edge threshold detector **464** is transmitted to comparator **462**. Comparator **462** determines whether a trailing edge was detected within the pulse created by trailing edge gate **460**. If so, comparator **462** outputs an indication that a puck pulse has just occurred. Flash detectors **440–442** are similar to the pulse detectors except that the narrow band infrared filter **452** is replaced with a filter that allows detection of signals in a wide spectrum that includes signals emitted by puck **10**.

FIG. **14** is a block diagram of synchronizer box **444**. Reference oscillator and buffer **500** includes an oscillator operating at 14.31818 MHz (70 nsec clock resolution) and a buffer. This circuit provides timing for circuits **502**, **504**, **506**, **508**, **510**, **512**, and **520**. Circuit **502** is an adjustable counter that nominally provides a delay of 4095 clock pulses (286 μsec). Circuits **504** and **510** are fixed counters that provide delays of 4092 clock pulses each (285.8 μsec). Circuit **506** is an adjustable delay counter that nominally provides a delay of 7675 clock pulses (536 μsec). Circuits **502**, **504**, and **506** are started by the pulse detect signal **221**. The difference in time delay between counter **506** and counter **502** is used to control the infrared sensor shutter timing in response to the pulse detect signal **221** so that the shutter opens just before a pulse from puck **10** occurs.

The delayed pulse from counter **506** starts counter timer **508**. The output of counter timer **508** starts counter **510**. The outputs of counters **504** and **510** are pulses with a width of 4092 clock pulses (285.8 μsec) each. In normal operation, the delays provided by the adjustable counter **506** and counter **508** are equal to the period of pulse **221** (approximately 30 Hz). The period of counter **508** counts an adjustable delay based on a user setable switch and an up/down counter/adder circuit inside counter timer **508** controlled by the output of counters **504** and **510**. The count of the up/down counter is determined by the relative overlap positions of the output pulses from counters **504** and **510**. If the output pulse from counter **504** leads the output pulse from counter **510**, the up/down counter will count down. If the output pulse from counter **504** lags the output pulse from counter **510**, the up/down counter will count up. If the pulses from counters **504** and **510** overlap, the up/down counter will not count up or down. Under this condition, the circuit is locked to input pulse stream **220** and the sum of the counter settings for counters **506** and **508** represent the number of clock pulses from circuit **500** occurring in the period of pulses **221**. The circuit will track the period of pulse stream **220** as the period varies over time or from puck to puck. Circuit **514** contains diagnostic LEDs to indicate the presence of pulse signals **221** and a "locked" condition on counter **508**.

The counter settings from counter **506** FD_{0-15} and counter **508** TD_{0-15} are added together in oscillator adder circuit **518**. The counter settings are also read into a computer (not shown) through a parallel port where they are added and averaged. Jumper **519** is used to select either the sum from circuit **518** or the computer averaged sum output. Since these sums represent the period for pulse signal **220**, they are used to control the period of oscillator counter **512**. This circuit will run continuously in the absence of pulses **220** and provides a "coasting" feature to control the shutter of the infrared sensors with or without the presence of the pulses from puck **10**. The oscillator phase is reset by the output of counter **502** passing through reset gate **516**. The gate is opened by the "burst" signal from counter **508**. This signal is present during valid pulse tracking intervals and represents the overlap of the pulses from counters **504** and **510**.

The output pulse from oscillator **512** starts shutter delay counter **520**. The output of this counter is sent to phase-locked loop **542**. The delay count for shutter delay counter **520** is selected by jumper **522** from the control values for counter **508** (TD_{0-15}) or from a computer average of the TD_{0-15} data. The output of counter **520** controls camera shuttering and occurs at a nominal rate of 30 Hz. This signal is used to control phase-locked loop **542** running at nominally 15,750 Hz. Divider **544** divides the output of phase-locked loop **542** by five hundred and twenty five to provide a 30 Hz reference signal that is compared to the output pulse from counter **520**, thus controlling the frequency of phase-locked loop **542**. Pulse generator **546** receives the output of phase-locked loop circuit **542** and generates approximately 10 μsec wide pulses. Pulse generator **548** generates a pulse approximately 30 μsec wide from the nominally 30 Hz rate out of divider **544**. The outputs of circuits **546** and **548** are combined in "OR" circuit **560** and buffered by circuits **562**

to provide a "composite sync" signal to the infrared sensors. The composite sync signal contains both a horizontal drive signal (the output of pulse generator **546**) and a camera shutter control (the output of pulse generator **548**). This composite sync signal is sent to the infrared sensors and decoded by sensor interface box **320**.

One alternative to using pulse detectors is to include a receiver (e.g. RF receiver) in the puck. A control transmitter (e.g. similar to that described below) can send a signal to the puck commanding the puck to pulse. The central transmitter would also send a synchronization signal to cause the infrared sensors to open their shutters.

E. Graphics Truck

FIG. **15** shows a partial block diagram of graphics center **246** and production center **244**. Graphics center **246** includes a video processor **604** which receives data **602** from processor **302** at each of the camera locations and infrared sensor locations. Video processor **604** performs the calculations to determine the location of the puck in the arena as well as the position of the puck in the video flame of a broadcast camera. The preferred video processor **604** is an Indigo Two Impact from Silicon Graphics. Video processor **604** receives cluster data for all of the infrared sensors and pan/tilt/zoom data for all of the broadcast cameras and saves that data in memory **612** along with timing information. The timing information is stored so that if the data is used at a later time, the processor can determine at what time the data was detected. Memory **612**, in conjunction with disk drives, also stores software used to program processor **604**.

Graphics center **246** also includes a control station **606** which is a second computer used as an operator interface. Control station **606** enables the operator of graphics center **246** to change variables (e.g. THRESHOLD), start the system and perform control functions. Graphics center **246** also includes a spare computer **608** which can be used in case either control station **606** or video processor **604** malfunction. Graphics center **600** can function with one computer. All three computers, **604**, **606** and **608**, communicate with each other over a local area network **610**, which is a 10 Base-T implementation of ethernet. Each computer is connected to a Starbase T-9, 10 Base-T hub with twisted pair wiring.

After video processor **604** determines the location of puck **10**, video processor **604** determines the position of the puck in the video frame of the broadcast camera. Video processor **604** then creates data which is sent to a video modification unit **616**.

Many cameras are used to televise a sporting event. The video signals from all of the cameras are sent to video control **618** which is used to select one broadcast camera for transmission to viewers. One embodiment of video control **618** includes a plurality of monitors, one monitor for each video signal, and a selection circuit. A director (or manager) would monitor the different video signals and choose which signal to broadcast. The choice will be communicated to the selection circuit which selects one camera signal to broadcast. The choice is also communicated to video processor **604**. The selected video signal is sent to delay **622**. The output of delay **622** is transmitted to video modification unit **616**. The purpose of delay **622** is to delay the broadcast video signal a fixed number of frames to allow time for video processor **604** to receive data and determine the position of the puck in the video frame. In the embodiment of FIGS. **7–19**, the video frame needs be delayed five frames. Additional delay can be added to allow for interpolation of missed data, as discussed below. Additionally, the hardware and the software can be modified to increase the speed of the video processing which would decrease the delay. Although the video is delayed a small number of frames, the television signal is still defined as live. The delay introduced by the system is a small delay (under one second) which does not accumulate. That is, successive frames are continuously enhanced with the same small delay. For example, a ten frame delay is equivalent to one third of a second, which is not considered a significant delay for television.

Video modification unit **616** modifies the video signal from delay **622** with the data/signal from video processor **604**. The type of modification can vary depending on the desired graphic. One exemplar implementation utilizes a linear keyer as video modification unit **616**. When using a keyer the signal from video processor **604** to the keyer includes two signals YUV and an external key (alpha). The YUV signal is called foreground and the signal from delay **622** is called background. Based on the level of the external key, the keyer determines how much of the foreground and background to mix to determine the output signal, from 100% foreground and 0% background to 0% foreground and 100% background, on a pixel by pixel basis.

As an option, the system can also include a data inserter **628** for inserting nonvideo data into a television signal. Nonvideo data is information other than the traditional data used by a television to draw the normal scan lines on a television display. An example of nonvideo data is data transmitted during the vertical blanking interval, which can be closed caption data, statistics regarding puck **10** (e.g. the puck's location, speed, acceleration etc.), interactive queries or internet addresses. In FIG. **15**, inserter **628** receives a television signal from video modification unit **616** and nonvideo data from video processor **604**, via signal **630**. Inserter **630** inserts the nonvideo data into the vertical blanking interval of the television signal and sends the resulting signal to amplifier **626**. Inserter **630** is a standard data inserter known in the art. One example of a suitable data inserter can be found in PCT International patent application Ser. No. PCT/US94/13484, which was published on Jun. 8, 1995 with International Publication Number WO 95/15654, which is incorporated herein by reference.

FIG. **16** describes some of the operations in graphics center **246** and processing center **248**. In step **640**, the pan, tilt and zoom data is received by video processor **604** from the various processors (e.g. processor **302**). In step **642**, cluster data is received from the processors (e.g. processor **302**). In step **644**, video processor **604** stores the pan/tilt/zoom information for all broadcast cameras and the cluster data in memory **612**. In step **648**, video processor **604** determines the three dimensional location of puck **10**. In step **650**, the system removes false detections. As discussed above, there are various means for removing false detections, some of which can be performed both by a processor at the graphics center. Preferably, region of the play filters and exclusion zones are accomplished at the graphics center, although the inventors do contemplate performing variations of these methods at sensor locations.

Exclusion zones are known areas of false data. For example, there may be a camera with a light near the arena, or any other light near the playing surface (e.g. light indicating a penalty, timeout, etc.). It is possible for these lights to emit an infrared signal. Since the existence and locations of these sources are known, they can be removed from the data considered by the video processor in determining the three-dimensional location. One method for ignoring an exclusion zone is after determining the three-dimensional

location of the puck, if that location is in an exclusion zone, then ignore that location data. For example, in some instances, the system determines one or more possible locations of the puck. If any of these locations are in the exclusion zone, that location is removed from consideration. Alternatively, the video processor can ignore all lines of position that pass (or substantially pass) through an exclusion zone. Another alternative includes the electronics at the sensor ignoring any cluster that would give rise to a line of position into an exclusion zone. Another alternative includes manually entering all exclusion zones for each sensor that is fixed (e.g. no pan or tilt) before the sporting event begins. This can be done at graphics center or the central location. If a sensor can pan or tilt, the processor at the sensor can be given the three-dimensional location. Exclusion zones can also be defined in two dimensions for a camera or sensor. The exclusion zone can be manually entered at one of the processors or an operator in the production center can identify the exclusion zone using an input device (e.g. mouse) in connection with a monitor (video or sensor data).

Field of play filters are software methods for ignoring data that indicate a location outside the field of play. For example, prior to the sporting event, the system can be programmed with the three dimensional coordinates of the hockey rink, for example, the X and Y coordinates of the hockey rink and a Z axis height limit (e.g. twenty feet). Any data indicating a location of the puck outside of these limits will be ignored.

In step **652**, video processor **604** determines the puck's position in the video frame of the selected broadcast camera. In step **654**, the television presentation of the selected broadcast camera is enhanced. In one embodiment, the enhancement includes video processor **604** creating a frame of data with a graphic at the position of the puck in the video frame of the broadcast camera. The frame of data created by video processor **604** is sent to video modification unit **616** which combines the frame of data sent from video processor **604** with the frame of data from the selected broadcast camera. In step **656**, the enhanced video frame is transmitted for broadcast or stored for later use.

The graphic could be a larger puck, a flashing puck, an icon, a trail of fire, an opaque cloud on top of the puck, any combination thereof, or any other graphic which highlights the video presentation of the puck. The graphic could also be logically near the position of the puck, for example, a trail of fire behind the puck, a trajectory of the puck's path, a target at the end of the pucks trajectory, an arrow pointing to the puck, etc. The enhancement could also include audio data, for example, a sound related to the speed or acceleration of the puck, or a sound indicating that the puck is at the certain location. Other examples of enhancements includes nonvideo data; statistics displayed on the television related to the puck's position, location, speed, acceleration, etc. The step of enhancing includes combining data (e.g. a keyer), editing data and creating data.

FIG. **17**A is a flow chart explaining the determination of the puck's three dimensional location (step **648** in FIG. **16**). There are many suitable ways for determining the three dimensional location of the puck using the available data described above. One alternative involves determining lines of position. Once lines of position are known, there are many suitable methods to determine three dimensional location. FIGS. **17**A and **17**B explain two exemplar methods.

In step **680** of FIG. **17**A, video processor **604** determines a line of position (LOP) for each cluster of each sensor. Thus, if there are twenty clusters transmitted to video processor **604**, twenty LOPs are determined. The LOP is first calculated in "camera space", the coordinate system where the infrared sensor is at the origin looking along the negative Y axis, with the X axis on the right and the Z axis up. The LOP is then transformed into the three dimensional coordinate system of the arena.

In order to calculate the LOP in camera space, the sensor focal length and aspect ratio are measured in advance on an optical bench. This measurement indicates that a target a meter away if moved one pixel to the side moves h meters in space, and if moved one scan line up or down, moves v meters in space. From these ratios, given that the cluster is x pixels and y scan lines from the center of the sensor field of view, a vector is constructed:

$$V=(x*h,y*v,1.0)$$

A line of position is represented as a point and a vector:

$$LOP=P,V$$

A point in three dimensional space is represented by a 4 element row vector: (x, y, z, 1.0). The 1.0 (sometimes called w) allows for translation. In camera space, point P is (0,0,0,1.0) since the sensor is at the origin. The LOP is a parametric representation of a line, since any point on the line can be represented as:

$p=P+k*V$, k is a scalar.

An LOP is transformed into the three dimensional coordinate system of the arena by a 4×4 matrix. The three element vector is multiplied by the inverse transform of the upper left 3×3 matrix of the 4×4 matrix. The four element point is multiplied by the 4×4 matrix.

For an infrared sensor rigidly mounted separate from a broadcast camera, the vector component of the LOP is transformed by the matrix (J):

$$J=TYPR,$$

where,

$$T=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -x & -y & -z & 1 \end{bmatrix}$$

$$Y=\begin{bmatrix} \cos yaw & -\sin yaw & 0 & 0 \\ \sin yaw & \cos yaw & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$P=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos pitch & -\sin pitch & 0 \\ 0 & \sin pitch & \cos pitch & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

-continued

$$R = \begin{bmatrix} \cos roll & 0 & \sin roll & 0 \\ 0 & 1 & 0 & 0 \\ -\sin roll & 0 & \cos roll & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Since the infrared sensor is in a fixed position, the yaw, pitch and roll can be measured during the registration process.

For infrared sensors mounted on a broadcast camera the transformation matrix (M) is:

M=XABCDO

X=TYPR

The matrix (X) models the fixed position and orientation of the broadcast camera. The matrices (ABCD) model the movement of the broadcast camera (e.g. pan, tilt, etc.). The matrix (O) has the same form as the matrix (X) and models the positional and rotational offset of the infrared sensor from the top surface of the camera head.

$$A = \begin{bmatrix} \cos pan & -\sin pan & 0 & 0 \\ \sin pan & \cos pan & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$B = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -forward & 0 & 1 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -tiltrise & 1 \end{bmatrix}$$

$$D = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos tilt & -\sin tilt & 0 \\ 0 & \sin tilt & \cos tilt & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$F = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -povdist & 0 & 1 \end{bmatrix}$$

$$E = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -axisheight & 1 \end{bmatrix}$$

Pan and tilt angles are measured with the pan and tilt sensors **288** and **290**. The forward offset distance (forward) is the distance that the tilt axis is positioned forward of the pan axis. The forward offset distance and optical axis height (axisheight) can be measured directly from the camera head with a ruler. The tilt rise, which is the distance from the nominal position that the camera plate rises, can also be measured with a ruler and a lookup table built as a function of tilt angle. The POV (povdist) (or First Principal Point, or Front Nodal Point) is the position of the camera's virtual point of view measured as a distance forward of the tilt axis when the camera is in the horizontal position. The POV can be measured on an optical bench and a lookup table built as a function of zoom position, focus, and 2× setting. The POV is measured by placing two targets in the field of view of the lens, off-center, one farther away than the other, so they appear in line through the viewfinder. Where a line extended through those targets intersects the optical axis of the camera is the position of the virtual POV. The effective horizontal and vertical focal length of the lens (f_h and f_v) are the half-width and -height of the camera's field of view at some distance divided into that distance. This is measured on the optical bench and a lookup table built as a function of zoom position, focus, and lens doubler. The aspect ratio is f_h/f_v and is constant, so usually f_v is modeled for given settings and f_h is equal to aspect multiplied by f_v.

After a line of position is determined for every cluster, video processor **604** groups all possible pairs of LOPs (step **682**). For each pair of LOPs, video processor **604** finds the closest point of contact of the two LOPs (step **684**). If the LOPs do not intersect the closest point of contact will be two points, one on each LOP. The line connecting the two points is perpendicular to both LOPs. To simplify the calculations, one embodiment contemplates using the midpoint of the line perpendicular to both LOPs as the closest point of intersection. However, both points can be used in the steps described below.

At the end of step **684**, video processor **604** now has a set of points of closest contact. In step **686**, video processor **604** finds a center of all of the points of closest contact. The center is the average of the coordinates of the points of closest contact. In step **688**, video processor figuratively draws a sphere around the center point. The radius of the sphere is predefined. The radius should be big enough to allow the system to function, but small enough so that improper data is thrown out. In one embodiment, the radius is set as one meter. Each time the system is set up, a user may need to use trial and error to determine the proper radius. In step **690**, video processor **604** determines whether all the points fit within the sphere. If not, video processor **604**, in step **692**, removes the furthest point and loops back to step **686**. If all the points do fit within the sphere, then the average or center of the sphere is a candidate for the three-dimensional location of puck **10**. One alternative is to reduce the radius for each iteration, keep iterating until the minimum radius is reached (e.g. 0.1 meter) and if there are a predefined number of points remaining (e.g. ≧2) then a valid three dimensional location candidate had been found. Another alternative includes reducing the radius for each iteration, removing all points outside the sphere for each iteration, continue iterating until the minimum radius is reached (e.g. 0.1 meter) and if there are a predefined number of points remaining (e.g. ≧2) then valid three dimensional location candidate has been found. The points of closest contact may form more than one separate groups of points, in which case the method of FIG. **17A** can be repeated for each group of points and more than one location candidate will be determined. The incorrect candidates should be removed when removing false detections in step **650** of FIG. **16**.

Another method for determining a three dimensional location based on lines of position is based on the probabili-

ties of finding the puck at certain locations along or near the lines of position. FIG. **17**B describes one exemplar method for using lines of position and probabilities to determine three-dimensional location. In step **696**, lines of position are determined for each cluster of each sensor. In step **698**, the system determines cones for each line of position. That is, each line of position can be thought of as a set of cones, one inside the other. Each cone represents a space with an assigned probability for the puck being within that space. The set of cones is projected onto the playing surface. In step **700**, a set of cubes are figuratively created. A first layer of cubes lie on the playing surface. A second layer of cubes are located above the first layer, and so on. Each cone is projected such that it passes through one or more cubes. For each line of position, each cube is assigned a probability equal to the probability of the cone passing through the cube. If more than one cone for a particular line of position passes through a cube, the cube is assigned the probability of the highest probability cone passing through it. If a cube lies within cones from more than one line of position, a cube will be assigned more than one probability. Each of the probabilities assigned to each cube are added and the sum is stored for each cube (step **702**). If a cube was assigned only one probability, then that one probability is the stored sum. The cube with the highest probability sum is assumed to be the cube where the puck is (step **704**). In one embodiment, the cubes are small enough so that the resolution of the cube is sufficient to find the puck in one iteration. In one alternative, the playing surface is divided into a small set of large cubes and step **704** determines which of the large cubes the puck lies in. Since the resolution of the cubes is not fine enough for the puck determination to be accurate, the process is repeated (in step **706**) by looking back to step **700**, dividing the one cube which contains the puck into smaller cubes, the probability is added up for the smaller cube and the system determines which of the smaller cubes contains the puck. If the resolution of the small cube is sufficient, the method ends; otherwise, the method performs another iteration. The inventors contemplate numerous other equivalent implementations that make use of the probability of the puck's location that are within the spirit of the present invention.

FIG. **18** is a flow diagram describing one exemplar embodiment of how video processor **604** determines the position of the puck in the video frame of the selected broadcast camera and creates data which is sent to video modification unit **616**. In step **710**, video processor **604** transforms the three dimensional location of the puck to a two dimensional position in the video frame of the selected broadcast camera. A broadcast camera is represented mathematically by a 4×4 matrix which includes details of position and orientation. The three dimensional point is transformed into a two dimensional normalized frame location by multiplying the point by the camera matrix (K). The camera matrix (K) in its simplest form is a combination of rotation, translation, and perspective elements, all of which are represented by 4×4 matrices. In reality, the motion of the camera point of view (POV) is much more complicated with offsets caused by the mounting of the camera on the tripod and the motion of the optical POV along the camera's optical axis due to lens characteristics. All these effects can be modeled as more complex linkages (additional matrices) between the fixed camera base and the resulting POV of the camera as the camera is moved through its range of controls. These techniques are well-known in the art.

In the disclosed embodiment, the broadcast camera is modeled as a 4×4 matrix which includes two parts—a fixed transformation (X) which represents the position of the camera in the arena and its orientation, and a variable transformation (V) which varies with changes in pan angle, tilt angle and the zoom:

$$K=XV$$

The fixed transformation matrix (X) models x, y, z position as well as fixed yaw, pitch and roll representing the camera's mount orientation:

$$X=TYPR$$

The variable transformation matrix (V) models not just the pan and tilt rotations, but also the complicated way the POV of the camera moves as it pans, tilts, and zooms. For a camera used with a Vinton Vector 70 camera head and a Canon J55 Super lense, the variable transformation is modeled in seven parts (matrices):

$$V = ABCDEFG$$

$$G = \begin{bmatrix} f_h & 0 & 0 & 0 \\ 0 & f_v & 0 & 0 \\ 0 & 0 & -(f+n)/(f-n) & -1 \\ 0 & 0 & -2fn/(f-n) & 0 \end{bmatrix}$$

The variable n and f are the distances to the mathematical near and far clipping planes; which are only important in assigning a useful range for z-buffered graphics drawing; therefore, nominal values are used of n=1 meter and f=100 meters.

The form of all seven matrices are defined above. Matrix (A) models the camera'pan on its fixed base. Matrix (B) models the tilt axis as a fixed distance forward of the pan axis. Matrix (C) models the tilt axis as a variable distance above the plane of the top of the tripod—the camera is raised as it tilts away from horizontal to counteract the tendency for it to flop forward or backward. The rise is a function of tilt. Matrix (D) models the camera's tilt angle. Matrix (E) models the optical axis of the lens as some fixed distance above the tilt axis. Matrix (F) models the lens moving forward and backward along the optical axis of the lens as a function of zoom. Matrix (G) models the effective focal length of the lens as a function of zoom, focus, and lens doubler (2×) settings.

In step **712** of FIG. **18**, the graphic (if any) is scaled for the field of view of the broadcast camera. The field of view of the broadcast camera, based on location, pan, tilt and zoom, determines how big the puck should be in the video frame. In step **714** video processor draws a black window and then places a graphic at or near the location of the puck. In step **716**, the window is sent to video modification unit **616**.

The present invention system is capable of performing look ahead processing. That is, due to frame delays, one embodiment of the present system can look at video frames and accompanying data for frames captured after the current frame being processed. This information can be used to enhance the processing at the current frame. One example of look ahead processing is interpolation.

During operation, video processor **604** may not receive data for a particular video frame of the broadcast camera. In such a situation, if only one or a small number of frames of

data are lost, it is possible that video processor **604** can interpolate the location or position of the puck so that the enhancement of the television presentation of puck **10** will be continuous. For example, FIG. **19** shows a symbolic video frame which includes four images of puck **10** superimposed on the same frame. F_0 signifies the location of the puck during frame **0**. F_1 signifies the location of the puck during frame **1**. F_2 represents the location of the puck during frame **2**, and F_3 represents the location of the puck during frame **3**. However, during frame **2**, video processor **604** did not receive any data and, thus, interpolates the position of puck **10** during frame **2**. Therefore, the puck is dotted for F_2.

FIG. **20** describes the process of interpolating the location of the puck. In step **730**, the pan/tilt/zoom data is received. In step **732**, video processor **604** attempts to receive cluster data, similar to step **642** in FIG. **16**. Since no useful cluster data is transmitted, video processor **604** waits for the next video frame of data. Step **734** includes steps **640–650** (or **640–652**) of FIG. **16**. After the location of the puck is determined for the next video frame, video processor **604** considers the location of the puck before and after the lost video frame in order to interpolate where the puck should have been during the lost video frame (step **736**). As discussed above, before a broadcast frame of data is sent to video modification unit **616** it is delayed five frames. In order to interpolate for one frame of lost data, video processor **604** needs to wait for an extra frame of data. This extra delay is added to the five frame delay discussed above. Thus, the total delay is six frames. If video processor **604** interpolates for five frames of data, then it needs five extra frames of data for a total delay of ten frames, and so on. Thus, under the current system, if video processor **604** can interpolate for N frames of lost data then the broadcast camera video frames must be delayed (e.g. at delay **622**) five plus N frames. After the system interpolates to find the position of the puck, the video is enhanced (step **742**) and transmitted (step **744**).

One embodiment of the present invention contemplates video processor **604** adding nonvideo data to the television signal. FIG. **21** depicts additional hardware at the viewer's home which allows for additional enhancement for the television presentation based on the nonvideo data. Television signal **748** is received by television **750** via cable, a conventional antenna or any other suitable means. The signal can also be sent to a decoder **752** or computer **754**. Computer **754** is in communication with decoder **752** and television **750**. Decoder **752** uses technology known in the art to remove data from the vertical blanking interval of a television signal. In one alternative, the function of decoder **752** is performed by computer **754**. Television **750** can also include a VCR or other videotape machine. Computer **754** includes a monitor **756** which displays windows (e.g. **758**, **760**, **762**). When television signal **748** is received in the viewer's home, decoder **752** strips out the nonvideo data from the vertical blanking interval. Decoder **752** sends the data to computer **754** which can display the data in window **762**. Video processor **604** can also be pre-programmed such that when certain events occur (e.g. relative to the location of the puck), video processor **604** inserts one or more addresses of web pages on the internet into the vertical blanking interval of the television signal. As decoder **752** strips out these addresses from the vertical blanking interval, computer **754** can display these addresses on window **762** and allow the user to click on the address with a mouse or use some other user input means which will cause software in the computer **754** (e.g. Mosaic or Netscape) to load the addressed web page.

In another alternative, a television signal is received at the viewer's home and is transmitted directly to computer **754**. Computer **754** will then display a window **760** which would show the televised sporting event. In yet another alternative, a viewer can be provided with remote control capabilities. Video processor **604** can determine the position of the puck in the broadcast video frame but not enhance the broadcast video. The puck's position is inserted into the vertical blanking interval of the broadcast signal and sent to the viewer's home. Decoder **752** strips out the location of the puck from the vertical blanking interval and sends the location to computer **754**. Computer **754** also receives the video signal and displays the sporting event in window **760**. Computer **754** includes software to add a graphic overlay at the position of the puck in window **760**. Window **758** could be used as a user interface to allow the viewer to turn on or off the enhancement of the puck or to choose what enhancements should be made. In a further alternative, instead of displaying the enhanced video in window **760**, computer **754** can send the enhanced video to television **750**. The software used to program computer **754**, and all of the software described above, can reside in memory, on a disk or any other computer readable medium.

F. Registration

The registration process includes initializing the system. As discussed above, at least one embodiment of the system determines the three dimensional location of the puck. Since location is relative, the system needs a reference point. Thus, the first step is to establish a coordinate system, which is accomplished by using X,Y,Z axes with the origin or center point (0,0,0) being at the center of the hockey rink. Three or more registration points (e.g. nine) are marked on the rink in addition to the center point. The distance from the center point can be measured for each registration point so that the coordinates of the registration points are known. The broadcast cameras and the sensors can be registered by solving for the unknown variables in the above described matrices.

Registering the broadcast camera involves the determination of the matrix (X). A broadcast camera is pointed at each registration mark in turn, centering the registration mark in the field of view using the center reference mark in the viewfinder. The pan and tilt angles are read and the variable part of the camera transform is calculated for each mark using an arbitrary constant zoom value. (Zoom is not a factor in these comparisons as each registration mark is centered in the field of view. Some constant value is used so errors of different registration marks can be directly compared.) An initial educated guess at the fixed transformation parameters (e.g. x, y, z, yaw, pitch, roll) is made and the fixed component matrix is calculated. For each registration point, the fixed matrix (X) is concatenated (multiplied) with the variable matrix (V) for each registration point to obtain the composite camera matrix. Then, the three dimensional location of the registration point is transformed by the composite camera matrix to a two dimensional position in the broadcast camera's video frame. An error is determined representing the distance from the calculated two dimensional position to the center of the video frame. The fixed transformation parameters are varied and the process is repeated until the error is minimized, at which point the camera is registered and the resulting fixed matrix (X) is used for subsequent calculations.

To register a stationary infrared sensor that is not mounted on a broadcast camera, infrared emitters are placed at the registration points. An initial educated guess is made at the parameter values for the transformation matrix (J) and the three dimensional locations of the registration marks are

determined using matrix (J). An error is determined between the calculated locations (via the matrix) and measured locations of the registration marks. The parameters are varied and the process is repeated until the error is minimized, at which time the sensor is registered and the resulting matrix is used for subsequent calculations.

Registering a camera-mounted infrared sensor is the process of determining the matrix (O). First the broadcast camera on which the infrared sensor is mounted is registered (the X matrix is determined). Infrared sources are placed at the registration marks and the broadcast camera is oriented to give the sensor a view of the infrared sources. The pan and tilt angles are read and the ABCD matrices are calculated. Matrix (G) is calculated using the measured focal length of the sensor. Matrix (O) is the only undetermined part of the equation. A first educated guess is made at the matrix (O) parameters and the composite transformation matrix is calculated. The three dimensional locations of the registration marks are calculated using the transformation matrix and an error is determined between calculated location and the measured location of the registration marks. The parameters are varied and the process is repeated until the error is minimized, at which time the sensor is registered and the determined matrix (O) is used for subsequent calculations. Alternatively, the x, y, z offsets of the infrared sensor relative to the camera plate can be measured directly rather than solving for them. Measuring directly is generally more accurate.

As an alternative, the location and orientation of the broadcast cameras and sensors can be measured relative to the center location. A tape measure can be used to determine the position of the cameras and sensors, or the cameras and sensors can be surveyed.

G. Single Sensor System

The above described system determines the three dimensional location of the puck in order to enhance the video and/or audio for any broadcast camera whose pan/tilt/zoom and location are known. The inventors also contemplate a system that does not determine the three-dimensional location of the puck. Such a system could include one infrared sensors (or master-slave configuration) attached to or fixed near the broadcast camera. The video processor receives clusters from one infrared sensor and creates a line of position for one clusters. Various criteria can be used to determine the one cluster, for example, the brightest cluster. Since there are no clusters from other infrared sensors, a three dimensional location of the puck cannot be determined. Video processor **604** transforms the line of position from camera space to the three dimensional coordinate system of the arena. A point is selected along the line of position at a fixed distance from the camera, and that point is assumed to be the three dimensional location of the puck. Although the point is not the actual location, it will be in line with the actual location. If the system misses a frame of data, the video processor can interpolate in a manner similar to that described above. However, rather than interpolate the puck's three dimensional location, the video processor interpolates the puck's position in the video frame.

H. Replay

As shown in FIG. **15**, the system includes replay decks **620** that can store video, with timing information, for short term use (instant replay) or long term use. Memory **612** stores the pan/tilt/zoom data for the broadcast cameras, data representing the location and/or position of the puck, and timing information. Alternatively, memory **612** can store the cluster information and the necessary parameters of the transformation matrices. Thus, the system stores all of the information necessary to enhance video subsequent to the live event. For example, between periods of a hockey game an announcer may wish to describe a particular play. The video for the play can be recalled from deck **620** and by matching the timing information, the corresponding data can be read from memory **612** and the system can perform all or part of the methods of FIGS. **16–20**.

I. Alternative Use of Infrared Technology

The infrared technology disclosed above can be used in conjunction with the television presentation of sporting events other than hockey. For example, the infrared transmitter can be located within any suitable object at a sporting event as long as the transmitter does not interfere with the proper use of that object.

II. Radar With Active Transponder

An alternative to using infrared technology is radar. A radar based detection system relies on energy scattered or reflected back to the radar from an object of interest. In the hockey application, the energy scattered from a conventional puck can be lost in all the undesired back scattered energy (clutter) from the players, the rink, the building, etc. In order to make the puck stand out among the clutter, the radar signal is amplified with an electronic repeater. The puck's emission is made stronger and given a unique signature which makes it more easily detected.

Using radar with an active repeater to track a hockey puck has several desirable qualities. First, in addition to having inherently high ranging accuracy of a few inches or better, RF in the low microwave band efficiently passes through dielectric materials, such as hockey sticks and partially defracts around optically opaque objects such as ice skates, blades and human bodies. Thus, the puck is visible to the radar a substantial percentage of the time. Second, the repeater electronics are entirely confined within the rubber of the puck. Third, puck modulation can be channelized so that errant pucks lost in the crowd cannot be turned on and interfere with the active game puck. Additionally, an active repeater is preferred over a passive reflecting hockey puck because it provides a much higher signal to noise ratio, provides false Doppler data (a motionless puck can be detected) and can be used to track more than one object.

A. Puck with Active Transponder

FIG. **22** shows hockey puck **900** to be used with a radar system. Completely embedded within rubber section **902** of puck **900** is radar repeater **904**, which uses a gated repeater architecture. Repeater **904** receives, amplifies, modulates and retransmits the instant radar signal. FIG. **23** is a side cut-away view of puck **900** showing repeater **904** with batteries **906** and antenna **908**. In the preferred embodiment of a hockey puck with an active transponder, batteries **906** includes two ⅓ N lithium ion primary cells.

FIG. **24** is a block diagram of radar repeater **904**. A signal is received by dipole antenna **908** (which is completely embedded in puck **900**) and then passes through a switch and amplifier network. First, the received signal passes through switch **910** to switch **912** and then to amplifiers **914** and **916**. After the amplifiers, the received signal passes through switch **918** followed by switch **920**. After leaving the switch and amplifier network, the received signal fills up a 13 ns delay line **922**, which, preferably, is a coaxial cable. Connected to delay line **922** is a complex impedance modulator **924** which modulates the radar signal by varying the reflection coefficient at the end of the cable at a rate of 427,323 Hz. Preferably, modulator **924** is a PIN diode which is turned

off and on (modulated open and closed) causing the phase of the received RF signal to be alternately shifted between 0° and 180°. Modulator **924** receives a modulation signal of 427,323 Hz from repeater and timing and control circuit **926**. Control circuit **926** also controls switches **910, 912, 918** and **920**. Connected to control circuit **926** is crystal **928** for creating a clock signal oscillating at 26.494 MHz.

The modulation performed by repeater **904** is biphase shift key modulation (BPSK), which creates two signals which have frequencies that vary from the incident signal by the modulation rate. The first signal has the same basic shape and amplitude as the incident signal, but with a frequency equal to the sum of the frequency of the incident signal and the modulation rate. In the preferred radar puck, the modulation rate is 427,323 Hz. The second signal has the same basic shape and amplitude as the incident signal, but with a frequency equal to the difference between the frequency of the incident signal and the modulation rate.

In the receive portion of the cycle, the switches are as drawn in FIG. **24**. When delay line **922** is full, the repeater switches to transmit mode where control **926** reverses switches **910, 912, 918** and **920**, and the signal flows out of the delay line, through switch **920** to switch **912**, through amplifier **914** followed by amplifier **916**, through switch **918** to switch **910** and finally to antenna **908**. Repeater **904** switches between receive and transmit at a rate of 26.494 MHz. One reason for the 13 ns delay in line **922** is to allow time to change the four switches.

The circuit of FIG. **24** has a shock activated switch and timer **930** which includes an RC decay timer which turns off the repeater after 45 seconds and a shock sensor which is used to turn on the circuit. Repeater **904** could have many (e.g. twenty) permanently programmed unique modulation channels. Thus, different pucks can modulate at different rates using control circuitry in timing and control circuit **926**. Alternatively, an RF signal could be sent to the puck to indicate which modulation rate to use. Thus, the base radar unit could determine the signature of each puck. Either way, a puck could be readily identifiable and differentiated from other pucks and other sources of RF transmission.

In theory, a radar base unit sends out a signal which is received by the repeater inside the puck. The repeater amplifies, modulates and retransmits the signal back to the radar base unit. The radar base unit uses a difference in frequency to determine how far the puck is from the unit. The location of the puck in three dimensional space can be determined by using three radar base units simultaneously because the location of the puck can be determined from knowing how far it is from three known points. Alternatively, a radar base unit can use other data related to time of travel of the signal to determine distance.

One method for using puck **900** is for the radar base unit to send out a frequency swept signal called a chirp which may, for example, be a sine wave with a constant amplitude and a frequency which is incrementally stepped over a given period of time. Preferably, a low power S-band radar is used to send signals to the puck in the microwave range. When the radar base unit receives the signal which has been sent by the puck, the radar base unit determines the difference between the frequency of the signal received from the puck and the frequency of the signal currently being sent as part of the chirp. The difference in frequencies can be used by techniques known in the art to determine the distance of the puck from the radar base unit.

Repeater **904** has the added feature that it modulates the radar signal, as described above, to create two signals which have frequencies that vary from the incident signal by the modulation rate. The modulated signal from the puck, when received by the radar base unit, would have the same frequency as a signal from an object much further than where the puck actually is. That is, a radar base unit would determine that the puck was at a phantom site five to ten times further than the actual location of the puck (e.g. that the puck was outside the arena). Since other objects actually at the phantom site would not be able to reflect a strong signal back to the radar base unit, the puck would stand out as the object giving the strongest return near the phantom location. A radar base unit could filter out signals received from objects not at the phantom location (e.g. most objects in the arena), allowing the puck to be located with minimal interference from any unwanted clutter.

FIGS. **25, 26** and **27** describe an exemplar radar waveform that can be used with puck **900**. The chirp, shown in FIG. **25**, includes 1024 steps from 2.25 GHz to 2.65 GHz with a ten millisecond period. As described above, the radar base unit alternates between transmit and receive mode during the chirp. FIG. **26** shows the-gating cycle between transmit and receive for the radar base unit which indicates that he radar base unit switches between transmit and receive modes at eight times the frequency stepping rate (819,200 Hz). As shown by FIG. **27**, 1024 12-bit in-phase and quadrature sample pairs are taken for each 10 msec chirp.

B. Radar System

Many systems can be designed to utilize the advantages of puck **900**. One exemplar radar base unit, shown in FIG. **28**, uses a homodyne conversion architecture with a gated Frequency Modulated Continuous Wave (FMCW) format. Waveform gating allows the use of a single antenna while the FMCW format allows maximal RF efficiency with minimal information bandwidth. The radar operates with a peak power of one watt, a center frequency of 2.45 GHz, and a FMCW bandwidth of 400 MHz.

The radar base unit of FIG. **28** includes two signal paths: a transmit path **948** and a receive path **954**. Gates **980** and **982** are used to open and close the transmission and reception paths which alternate, as discussed above with respect to FIG. **26**. The transmit path will be discussed first. Under the control of radar timing and control circuit **990**, a phase continuous phase locked loop chirp generator **984** creates the output waveform and counts in increments of frequency in 1024 steps from 2.25 GHz to 2.65 GHz. The waveform is sent to splitter **986** where substantially identical signals are sent to demodulator **956** (which is part of the receive path) and to amplifier **988** which amplifies the signal to one watt. After amplifier **988**, the signal is applied to the +16 dBic helical radar antenna **950** through circulator **952**.

A signal is received by antenna **950** and is passed through circulator **952** into a low noise preamplifier **958**. The signal is then passed through filter **960** to remove unwanted energies, for example, cellular phone and satellite signals. The filtered signal is transmitted to demodulator **956**, which creates in-phase (I) and quadrature (Q) outputs, both of which are filtered (**958** and **960**) to remove unwanted noise. The two signals are then sent to multipliers **962** and **964** which perform base band translation, at a clock rate of 428,323 Hz. The two signals are then transmitted to amplifiers **966** and **968**, and sent through filters **970** and **972**. The filtered signals are converted to digital signals in A/D converters **974** and **976**, and stored in FIFO **978** before being transmitted to a computer (not shown) via line **992** for processing.

The computer triggers the radar base unit to transmit one chirp via communication with control **990** over line **992**. After the chirp, the I/Q samples are read from the radar base unit and processed to extract the puck signal and then calculate its distance using techniques known in the art. In actual operation this process would happen at the video field rate of 60 Hz. Although the described radar repeater and radar base unit use a specific modulation scheme, the exact modulation scheme used is not critical to the inventive concept and many other suitable modulation schemes may be substituted.

The above described radar base unit is able to determine the distance from the base unit to the puck. Thus, a sphere can be drawn with the center of the sphere being the base unit and the radius of the sphere being the distance from the base unit to the puck. The puck's three-dimensional location can be determined using three base units. If spheres are drawn for each base unit, the three spheres will intersect at two points. One of these points is in the field of play and represents the three-dimensional position of the puck. The second point is an unrealistic location and is discarded. Once the puck's location is determined, a system can enhance the presentation of the puck in a manner similar to that described in FIGS. **15–21**.

The active radar system discussed above can be used with other objects in sporting events. For example, the radar repeater can be placed inside helmets, in various balls, in race cars, bicycles, etc.

C. Alternatives

One alternative utilizes a puck or other objects which includes an RF transmitter rather than a radar repeater; for example, a chirping puck. The chirping puck would send out a signal which includes periodic chirps. FIG. **29** is an example waveform with the Y axis representing frequency and the X axis representing time. A majority of time, the chirping puck is transmitting a signal with a frequency of f_0. Every period, the puck transmits a chirp which includes a signal whose frequency first increases from f_0 to a maximum frequency and then decreases back to f_0. The signal sent by the puck is received by a radar receiver which can determine relative distance. That is, two radar receivers can determine that one of the radar receivers is M meters closer to the puck than the other radar receiver. Four radar receivers are needed to determine the puck's three-dimensional location. The technology to utilize the chirping puck and accompanying radar receivers can be derived from the above discussed radar technology and from other technology known in the art. One alternative includes having multiple objects having RF transmitters, each transmitter sending a unique signal. Thus, a system can track more than one object and differentiate between the objects being tracked. Thus, when enhancing the television presentation each object separately being tracked can be enhanced distinctly.

Another alternative includes an object with an RF transmitter and a receiver. A base unit sends a signal to the object indicating when the object should transmit. The base unit can turn on one specific object at a unique frequency so that objects not in use will not transmit any signals and the base unit can determine which object the signal is coming from. Thus, objects can be enhanced distinctly.

III. Radar with a Passive Reflecting Target

Another embodiment of the present invention includes using the graphics enhancement system of the present invention with a radar base unit and a passive reflecting target. Similar to the radar with active transponder, three or more radar base units are needed to determine the three dimensional location of the object. A radar base unit sends a radar signal to the object which reflects the signal back to the base unit. The object being tracked does not include an active transponder (e.g. an unmodified baseball). Rather, the unmodified object itself passively reflects the radar signal or the object is modified to include a reflective element. One example of modifying an object includes adding a metal object or sputtering a film of metal throughout a surface. Another option includes adding a retro-reflector in the object. A retro-reflector returns energy directly back to the transmitter. One example of a retro-reflector is a trihedral, which is also known as a corner reflector. To use passive radar technology with the present invention, those skilled in the art could modify the system of FIG. **28** or use other systems known in the art. For example, U.S. Pat. No. 5,150,895 discloses a method of and a system for determining the position of a ball relative to a playing field using a signal reflecting off of a passive radar reflecting element.

FIG. **30** shows an outline of football **1030**. Inside football **1030** is a corner reflector which includes three walls **1031**, **1032** and **1033**. All three walls are perpendicular to each other. The corner reflector is made from metalized mylar or another suitable metal. Metalized mylar is particularly useful because it is lightweight and an excellent radar reflector.

FIG. **31** shows golf ball **1020** with core **1026**. Surrounding core **1026** is one or more wrapped rubber strands **1024**. Encasing the rubber strands is shell **1022**. Sputtered to the inside surface of shell **1022** are aluminum filings **1028** which are used as radar signal reflecting elements. Alternatives to the aluminum filings could be aluminum paint or any other good radar repeater. Additionally, the radar signal reflecting element can be dispersed within the wrapped rubber strand rather than attached to the inside of shell **1022**. Golf ball **1020** could also be used with a Doppler radar system.

FIG. **32** shows a tennis ball which includes radar signal reflecting elements. Tennis ball **1000** includes an outer ball body **1002** which is partially cut away to show radar signal reflecting elements **1004**. In one embodiment the radar reflective elements are metallic or metalized plastic foils that are attached to the inside surface of outer ball body **1002**. Alternatively, tennis ball **1000** can be constructed to include a plurality of metallic particles embedded in outer ball body **1002**. The radar system can be used to track other objects including soccer balls, helmets, bicycles, cars, etc.

IV. Optical Recognition

Another embodiment contemplates using a sensor employing optical recognition or pattern recognition. Such a system is uses video frames from cameras and relies on properly positioning the cameras. For example, for baseball a camera should be located behind the catcher, down the base paths, overlooking the infield and overlooking the outfield. In golf, cameras should be near the tee, in sight of the fairway and in proximity to the hole. The system operates best when the cameras are positioned such that the object to be tracked is always in the field of view of at least one or two cameras. Finding objects using optical or pattern recognition is known in the art. Examples of systems known in the art include U.S. Pat. No. 4,924,507, Real-Time Optical Multiple Object Recognition and Tracking System and Method; U.S. Pat. No. 4,950,050, Optical Target Recognition System; U.S. Pat. No. 5,060,282, Optical Pattern Recognition Architecture Implementing the Mean-Square Error Correlation Algorithm; U.S. Pat. No. 5,241,616, Opti-

cal Pattern Recognition System Utilizing Resonator Array; U.S. Pat. No. 5,274,716, Optical Pattern Recognition Apparatus; and *Digital Image Processing and Computer Vision,* Robert J. Schalkoff, John Wiley & Sons, Inc. (1989), all of which are incorporated by reference. An optical recognition system that determines the three dimensional location of an object can be used by a graphics center and production center in a manner similar to that described above to enhance a television presentation of the object.

V. Additional Graphical Enhancements

Additional enhancements particular to a system for enhancing a baseball game include graphically exaggerating a curve in the trajectory of a curve ball, providing statistics about a pitch, simulating the batter's point of view, graphically comparing a curve ball to a fast ball and other enhancements related to the location and movement of the ball.

The current invention can also be used to enhance live broadcast video based on past events. For example, ski races allow one racer to ski at a time. During television broadcast of ski competitions, television broadcasters divide the race course into four or five check points. When the racer crosses a particular check point, the broadcaster compares the current skier's time to the time of a previous skier. Using the current invention, the location of a first skier can be tracked (with timing information) along with the pan, tilt, zoom and location of various broadcast cameras. A video processor stores the data in memory. When a second skier races, the video processor uses the stored information about the first racer and the location, pan, tilt, and zoom of the broadcast camera viewing the second skier to create a graphic of the first skier. The graphic of the first skier would be overlaid or edited into the video frame with the second skier at the location where the first skier was at the particular relative time of the broadcast. Thus, during the race viewers would be able to see the second skier race against the first skier (phantom skier or phantom object). Similar enhancements can be made with different race events or other types of sporting competitions.

Another enhancement that can be accomplished using the disclosed system is future path display. Video processor **604** can determine the object's trajectory using techniques well known in the art and predict the path of the object. The predicted path can be displayed in the video frame. In one embodiment, a target can appear at the end of the predicted path, for example, a baseball glove. In one alternative, a system performing look ahead processing can delay the video data a given number of frames, thereby, allowing video processor **604** to verify the predicted path for the next given number of frames.

The present invention can be used with many different sporting events. 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 of the system for enhancing the television presentation of an object at a sporting event 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. For example, the inventors contemplate that the present invention can be used with many different suitable sensors and graphics processing systems. It is intended that the scope of the invention be defined by the claims appended hereto.

What is claimed is:

1. A method for enhancing a live video presentation of an object during a sporting event, comprising the steps of:

determining a three dimensional location of said object in real space, said step of determining said three dimensional location being performed during said sporting event;

determining a position of an image of said object in a first live video image using said determined three dimensional location of said object, said step of determining said position being performed during said sporting event; and

enhancing said first live video image based on said position.

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

said object is a game object used at a sporting event.

3. A method according to claim **2** wherein:

said game object is a hockey puck.

4. A method according to claim **2** wherein:

said game object is a football.

5. A method according to claim **2** wherein:

said game object is a golf ball.

6. A method according to claim **2** wherein:

said game object is a tennis ball.

7. A method according to claim **2** wherein:

said game object is a baseball.

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

said step of determining a three dimensional location uses infrared technology.

9. A method according to claim **1** wherein:

said step of determining a three dimensional location uses radar technology.

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

delaying said first live video image.

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

sensing flashes.

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

sensing pulses from said object.

13. A method according to claim **1** wherein:

said step of determining a three dimensional location includes:

sensing said object, including creating data representing said three dimensional location of said object; and

removing false detections from said data.

14. A method according to claim **13** wherein:

said step of removing false detections includes removing data outside of a defined set of boundaries.

15. A method according to claim **13** wherein:

said step of removing false detections includes subtracting data.

16. A method according to claim **13**, wherein:

said step of removing false detections includes temporal subtraction.

17. A method according to claim **13** wherein:

said step of removing false detections includes spectral subraction.

18. A method according to claim **13** wherein:

said step of removing false detections includes filtering data.

19. A method according to claim 13 wherein:

said step of removing false detections includes using a region of play filter.

20. A method according to claim 13 wherein:

said step of removing false detections includes removing data representing exclusion zones.

21. A method according to claim 13 wherein:

said step of removing false detections includes removing data if a flash occurred.

22. A method according to claim 13 wherein:

said step of removing false detections includes removing data below a predefined threshold.

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

determining a broadcast camera's pan, tilt and zoom, said broadcast camera being used to capture said first live video image, said pan, tilt and zoom being used in said step of determining a position.

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

registering a sensor and a camera, said sensor being used to determine said first three dimensional location, said camera being used to capture said first live video image.

25. A method according to claim 1 wherein:

said step of enhancing said first live video image includes:

creating a second video image; and

combining said second video image with said first live video image.

26. A method according to claim 1 wherein:

said step of enhancing includes adding a graphic to said first live video image.

27. A method according to claim 1 wherein:

said step of enhancing includes adding a graphic to said first live video image at said position.

28. A method according to claim 1 wherein:

said step of enhancing includes adding a graphic to said first live video image logically near said position.

29. A method according to claim 1 wherein:

said step of enhancing includes adding a trajectory to said first live video image.

30. A method according to claim 1 wherein:

said step of enhancing includes adding a trajectory and a target to said first live video image.

31. A method according to claim 1 wherein:

said step of enhancing includes adding audio data.

32. A method according to claim 1 wherein:

said step of enhancing includes adding data to a vertical blanking interval during a broadcast of said sporting event.

33. A method according to claim 1 wherein:

said step of enhancing includes providing a viewer with remote control capabilities.

34. A method according to claim 1 wherein:

said step of enhancing includes creating a video frame and combining said video frame with said first live video image.

35. A method according to claim 1 wherein:

said object is a game object, said game object includes an electromagnetic transmitter adapted to transmit an electromagnetic signal not visible to a human eye.

36. A method according to claim 1 wherein:

said step of determining a three dimensional location includes interpolating said object's three dimensional location if said object's three dimensional location cannot be determined directly.

37. A method according to claim 1 wherein:

said step of enhancing is finished within one second of said step of determining a three dimensional location.

38. A method according to claim 1 wherein:

said step of enhancing is finished within one third of a second of said step of determining a three dimensional location.

39. A method according to claim 1 wherein:

said step of determining said position includes:

transforming data representing said three dimensional location using a matrix.

40. A method according to claim 1 wherein:

said step of determining a three dimensional location includes determining lines of position.

41. A method according to claim 1 wherein:

said step of determining a three dimensional location includes:

determining lines of position;

grouping pairs of said lines of position;

determining one or more points of closest contact for at least a subset of said pairs of lines of position; and

determining a center of said points of closest contact.

42. A method according to claim 1 wherein:

said step of determining a three dimensional location includes:

determining lines of position;

determining probabilities for spaces near said lines of position; and

finding said location based on said probabilities.

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

inserting nonvideo data into a television signal, said nonvideo data relating to said position, said television signal including said first live video image.

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

inserting nonvideo data into a television signal, said data including an address on a network, said television signal including said first live video image.

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

inserting nonvideo data into a television signal, said data including said first location of said object, said television signal including said first live video image.

46. A method according to claim 1 further including the steps of:

calculating one or more statistics at least partially based on said location of said object.

47. A method according to claim 46 further including the steps of:

inserting said one or more statistics into said first video image.

48. A method according to claim 1 wherein:

said step of enhancing includes adding nonvideo data into a television signal, said television signal includes said first live video image.

49. A method according to claim 48, wherein:

said nonvideo data being used at a remote location to enhance said first video image.

50. A method according to claim 1 wherein said step of determining a three dimensional location includes:

receiving an infrared signal;

creating sensor data representing said reception of said infrared signal; and

removing a false detection from said sensor data, said sensor data being used to determine said three dimensional location of said object.

51. A method according to claim **50** wherein:

said step of removing false detections includes removing sensor data received during a flash.

52. A method according to claim **50** wherein:

said infrared signal is a series of pulses; and

said step of removing false detections includes subtraction.

53. A method according to claim **50** wherein:

the step of determining a three dimensional location of said object further includes the steps of:

determining lines of position;

grouping said lines of position into pairs of lines;

determining one or more closest points of intersection for one or more pairs of lines of position; and

determining a center of said points.

54. A method according to claim **50** further including the step of:

determining field of view data for a camera, said camera being used to capture said first live video image, said step of determining said position uses said field of view data.

55. A method according to claim **50** further including the step of:

creating clusters of said sensor data.

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

sensing field of view data, said step of determining said position uses said three dimensional location of said object and said field of view data.

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

capturing said first live video image.

58. A method according to claim **1** further including the steps of:

synchronizing a sensor to said object; and

sensing data using said synchronized sensor, said data being used by said step of determining a three dimensional location of said object.

59. A method according to claim **1** wherein:

said object is mobile.

60. A method for enhancing a live video presentation of an object during a sporting event, comprising the steps of:

sensing said object;

determining said object's three dimensional location in real space based on said step of sensing;

capturing a first live video image using a camera, said first live video image includes an image of said object;

determining field of view data for said camera while capturing said first live video image;

determining said object's position in said first live video image using said field of view data and said object's three dimensional location, said step of determining said object's position being performed during said sporting event; and

enhancing said live first video image using said determined position.

61. A method according to claim **60** wherein:

said step of enhancing includes creating a second video image, said second video image including a graphic at a position in said second video image corresponding to said object's position in said first live video image.

62. A method according to claim **60** wherein:

said step of enhancing includes creating a second video image, said second video image including a graphic logically near said object's position in said first live video image.

63. A method according to claim **60** wherein:

said step of determining said object's three dimensional location includes:

determining lines of position;

grouping pairs of said lines of position;

determining one or more points of closest contact for at least a subset of said pairs; and

determining a center of said points of closest contact.

64. A method according to claim **60** wherein:

said step of determining said object's three dimensional location includes:

determining lines of position; and

finding said object's location using probabilities.

65. A method for enhancing a live television presentation of an object during a sporting event, comprising the steps of:

receiving field of view data for a camera during said sporting event;

receiving sensor data pertaining to said object during said sporting event;

determining a three dimensional location of said object in real space using said sensor data during said sporting event;

determining a position of said object in a video frame of said camera using said field of view data and said three dimensional location, said step of determining a position being performed during said sporting event; and

enhancing said video frame based on said position, said enhanced video frame being part of said live television presentation.

66. A system for enhancing a television presentation of an object during a sporting event, comprising:

means for determining a three dimensional location of said object in real space during said sporting event;

means for capturing a live video image which includes an image of said object, said image of said object being at a particular position in said video image;

means for determining said particular position of the object in said video image during said sporting event using said three dimensional location; and

means for enhancing said live video image at said particular position.

67. A system for enhancing a live video presentation of an object during a sporting event, said system to be used in conjunction with a camera, said system comprising:

one or more object sensors;

a field of view sensor, said a field of view sensor senses field of view data for said camera; and

one or more processors in communication with said one or more object sensors and said field of view sensor; said one or more processors programmed to:

determine a three dimensional location of said object in real space during said sporting event,

determine a position of an image of said object in a live video image from said camera during said sporting event, based on said three dimensional location, and

cause the enhancement of said live video image based on said determined position.

68. A system according to claim **66** further including:

a video modification unit, said video modification receives data from said one or more processors and said camera in order to modify said live video image.

69. A system according to claim 68 further including:

a video delay unit coupled between said broadcast camera and said video modification unit.

70. A system according to claim 66 wherein:

said field of view sensor includes pan and tilt sensors.

71. A system according to claim 66 wherein:

said field of view sensor includes a zoom sensor.

72. A system according to claim 66 further including:

a flash detector in communication with said one or more processors.

73. A system according to claim 67 wherein:

said one or more object sensors include a radar unit.

74. A system according to claim 67 wherein:

said one or more object sensors include an optical sensor.

75. A system according to claim 67 further including:

a synchronization system in communication with said one or more object sensors.

76. A system according to claim 67 further including:

a video modification unit in communication with said camera and said one or more processors;

a video control unit in communication with said camera;

a replay deck in communication with said video control unit; and

a delay unit in communication with said video control unit and said video modification unit.

77. A system according to claim 67 wherein:

said one or more sensors include a master infrared detector and a slave infrared detector; and

said one or more processors subtract slave infrared detector data from master infrared detector data.

78. A system according to claim 67 wherein:

said one or more sensors include a radar transmitter and a radar receiver.

79. An apparatus according to claim 67 wherein:

said one or more processors further programmed to calculate one or more statistics regarding said object.

80. A system according to claim 67 further including an electromagnetic transmitter, completely disposed inside said object, said electromagnetic transmitter adapted to transmit an electromagnetic signal not visible to a human eye to said one or more object sensors.

81. A system for enhancing a live video presentation of an object at a sporting event, said system to be used in conjunction with a camera, comprising:

a field of view sensor coupled to said camera;

a first infrared pulse detector;

a first infrared sensor unit receiving data from said first infrared pulse detector and from said object; and

one or more processors receiving data from said field of view sensor and said first infrared sensor unit, said processors programmed to determine a three dimensional location of said object in real space during said sporting event, to determine a position of an image of said object in a live video frame from said camera during said sporting event and based on said three dimensional location, and to cause an enhancement of said live video frame based on said determined position.

82. A system according to claim 81 further including:

a flash detector, in communication with said one or more processors.

83. A system according to claim 81 wherein:

said first infrared sensor unit includes a master infrared sensor and a slave infrared sensor.

84. A system according to claim 83 wherein:

said one or more processors includes sensor electronics adapted to remove data outside of a defined boundary and below a defined brightness, said sensor electronics further adapted to subtract slave infrared sensor data from master infrared sensor data.

85. A system according to claim 84 further including:

a second infrared sensor unit.

86. A system according to claim 81 wherein:

said first infrared pulse detector includes:

a photodetector;

an infrared filter in front of said photodetector;

a leading edge threshold detector in communication with said photodetector; and

a trailing edge threshold detector in communication with said photodetector.

87. A system according to claim 81 further including:

a collector box; and

a plurality of infrared pulse detectors connected to said collector box.

88. A system according to claim 87 further including:

at least one flash detector in communication with said collector box.

89. A system according to claim 81 wherein:

said field of view sensor includes a pan sensor, a tilt sensor and a zoom sensor.

90. A system according to claim 81 wherein:

said one or more processors include:

means for performing brightness threshold analysis;

means for performing subtraction; and

means for boundary determinations.

91. A system according to claim 81 wherein:

said one or more processors include:

means for performing field of play filters; and

means for using exclusion zones.

92. A system according to claim 81 further including:

a second infrared sensor unit, said one or more processors receives data from said second infrared sensor unit, said one or more processors uses said data from said first infrared sensor unit and from said second infrared sensor unit to determine said three dimensional location of said object.

93. A system for enhancing a live video presentation of an object at a sporting event, comprising:

a camera, said camera includes a tripod for panning and tilting;

a pan sensor connected to said camera;

a tilt sensor connected to said camera;

a zoom sensor connected to said camera;

a first infrared sensor unit including a first master sensor and a first slave sensor;

a second infrared sensor unit including a second master sensor and a second slave sensor;

a first processor in communication with said first infrared sensor;

a second processor in communication with said second infrared sensor;

a third processor in communication with said first processor, said second processor, said pan sensor, said tilt sensor and said zoom sensor;

a flash detector in communication with said first processor; and

one or more pulse detectors in communication with said first and second infrared sensors.

94. A system according to claim **93** further including:

a memory in communication with said third processor;

a keyer in communication with said third processor;

a video control unit in communication with said camera; and

a delay unit in communication with said video control unit and said keyer.

95. A processor readable storage medium having processor readable code embodied on said processor readable storage medium, said processor readable code for programming one or more processors to perform a method comprising the steps of:

determining a three dimensional location of said object in real space, said step of determining a three dimensional position being performed during said sporting event;

receiving field of view data for a first live video image, said first live video image includes an image of said object, said image of said object being at a particular position in said first live video image;

determining said particular position of said image of said object in said first live video image using said determined location and said field of view data, said step of determining being performed during said sporting event; and

directing an enhancement of said first live video image based on said particular position.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,912,700
DATED : June 15, 1999
INVENTOR(S) : Honey et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 38,
Line 64, after "claim" and before "further" delete "66" and substitute therefor -- 67 --

Column 39,
Line 4, after "claim" and before "wherein:" delete "66" and substitute therefor -- 67 --
Line 6, after "claim" and before "wherein:" delete "66" and substitute therefor -- 67 --
Line 8, after "claim" and before "further" delete "66" and substitute therefor -- 67 --

Signed and Sealed this

Nineteenth Day of February, 2002

Attest:

Attesting Officer

JAMES E. ROGAN
Director of the United States Patent and Trademark Office