EXHIBIT F
(PART 1 OF 2)

US006384871B1

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

(10) **Patent No.:** **US 6,384,871 B1**
(45) **Date of Patent:** **May 7, 2002**

(54) **METHOD AND APPARATUS FOR AUTOMATIC ELECTRONIC REPLACEMENT OF BILLBOARDS IN A VIDEO IMAGE**

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

(21) Appl. No.: **09/703,442**

(22) Filed: **Nov. 1, 2000**

Related U.S. Application Data

(63) Continuation of application No. 08/776,038, filed as application No. PCT/GB96/02226 on Sep. 9, 1996, now Pat. No. 6,208,386.

(30) **Foreign Application Priority Data**

Sep. 8, 1995 (GB) 9518439
Jan. 19, 1996 (GB) 9601101

(51) **Int. Cl.**[7] **H04N 5/262**; H04N 5/225

(52) **U.S. Cl.** **348/578**; 348/157; 348/135; 348/140; 348/580

(58) **Field of Search** 348/578, 744, 348/157, 143, 135, 137, 140, 580, 586, 587, 592, 39; 386/107, 117; 358/906; H04N 5/262, 5/225

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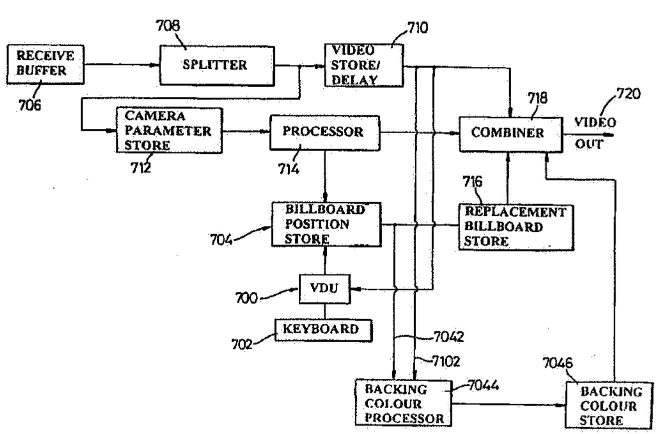
(57) **ABSTRACT**

Apparatus for automatic electronic replacement of a billboard in a video image including an automatic camera orientation measurement apparatus including motion measurement means operative to measure the Field of View (FOV) of the TV camera relative to a known reference position.

25 Claims, 16 Drawing Sheets



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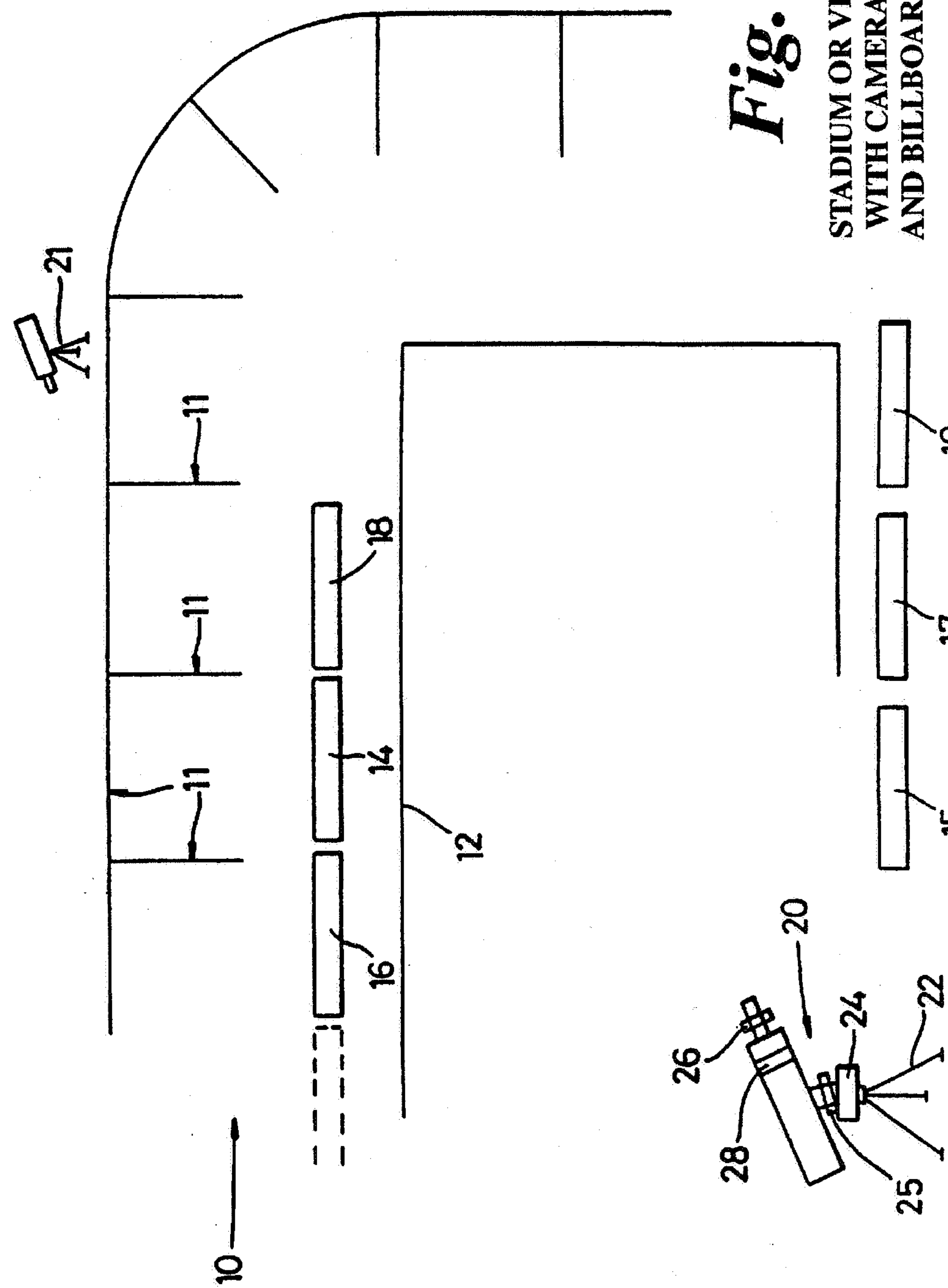


Fig. 1

STADIUM OR VENUE 10
WITH CAMERAS 20, 21
AND BILLBOARDS 14-19

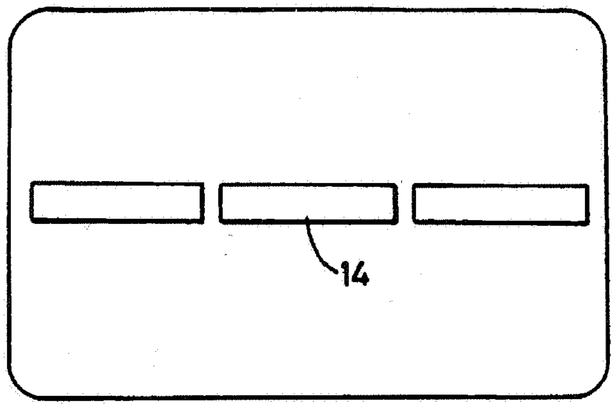


Fig. 2

VIDEO IMAGE OF THE STADIUM WITH BILLBOARD 14 CENTERED IN THE FIELD OF VIEW

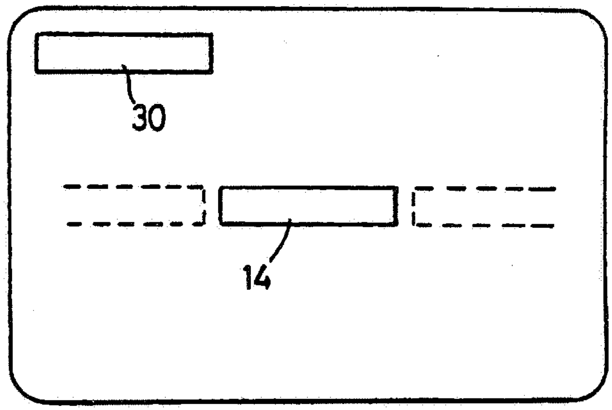


Fig. 3

VIDEO IMAGE OF THE STADIUM WITH BILLBOARDS AT DIFFERENT HEIGHTS

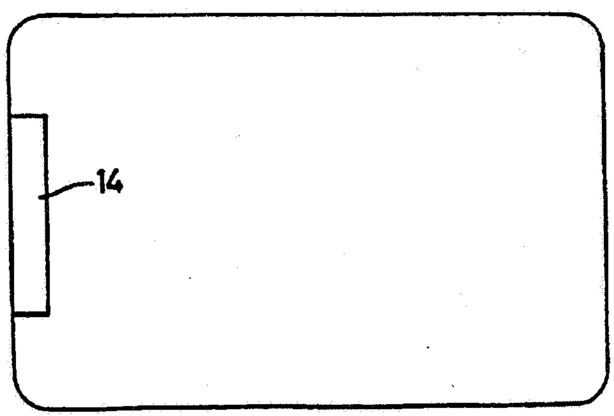


Fig. 4

BILLBOARD ENTERING THE CAMERA'S FIELD OF VIEW AS THE CAMERA PANS

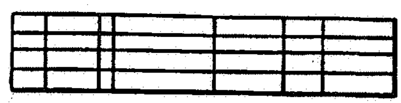


Fig. 5

PATTERNED CHROMA-KEY BILLBOARD

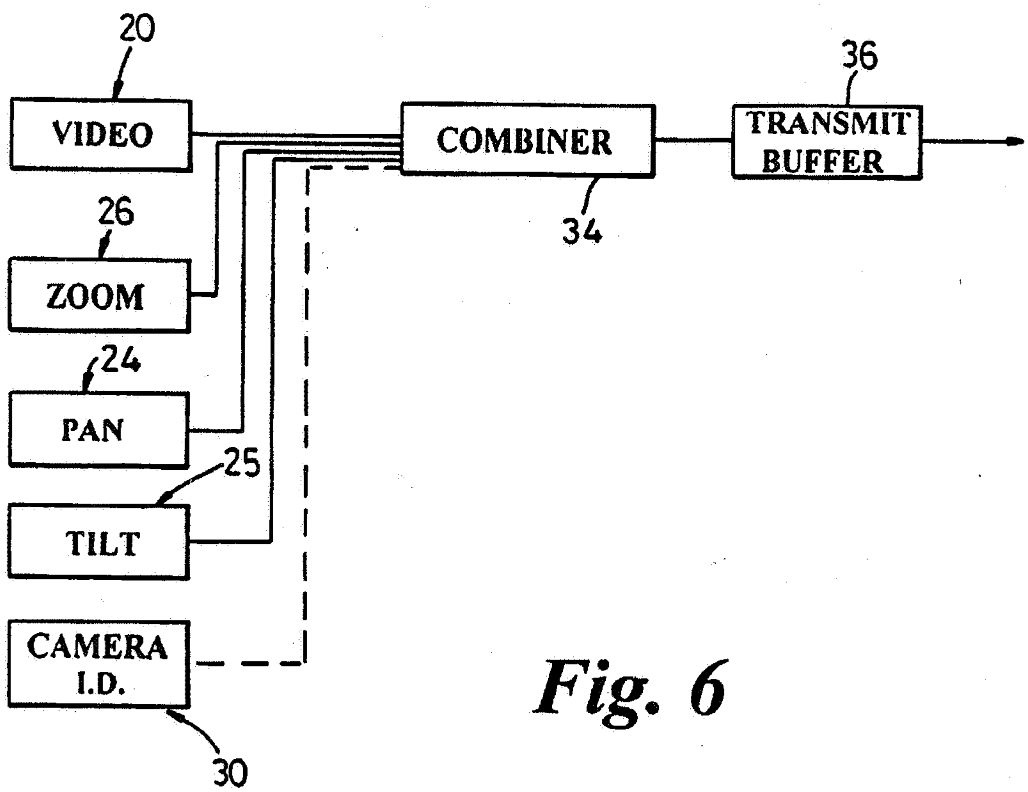
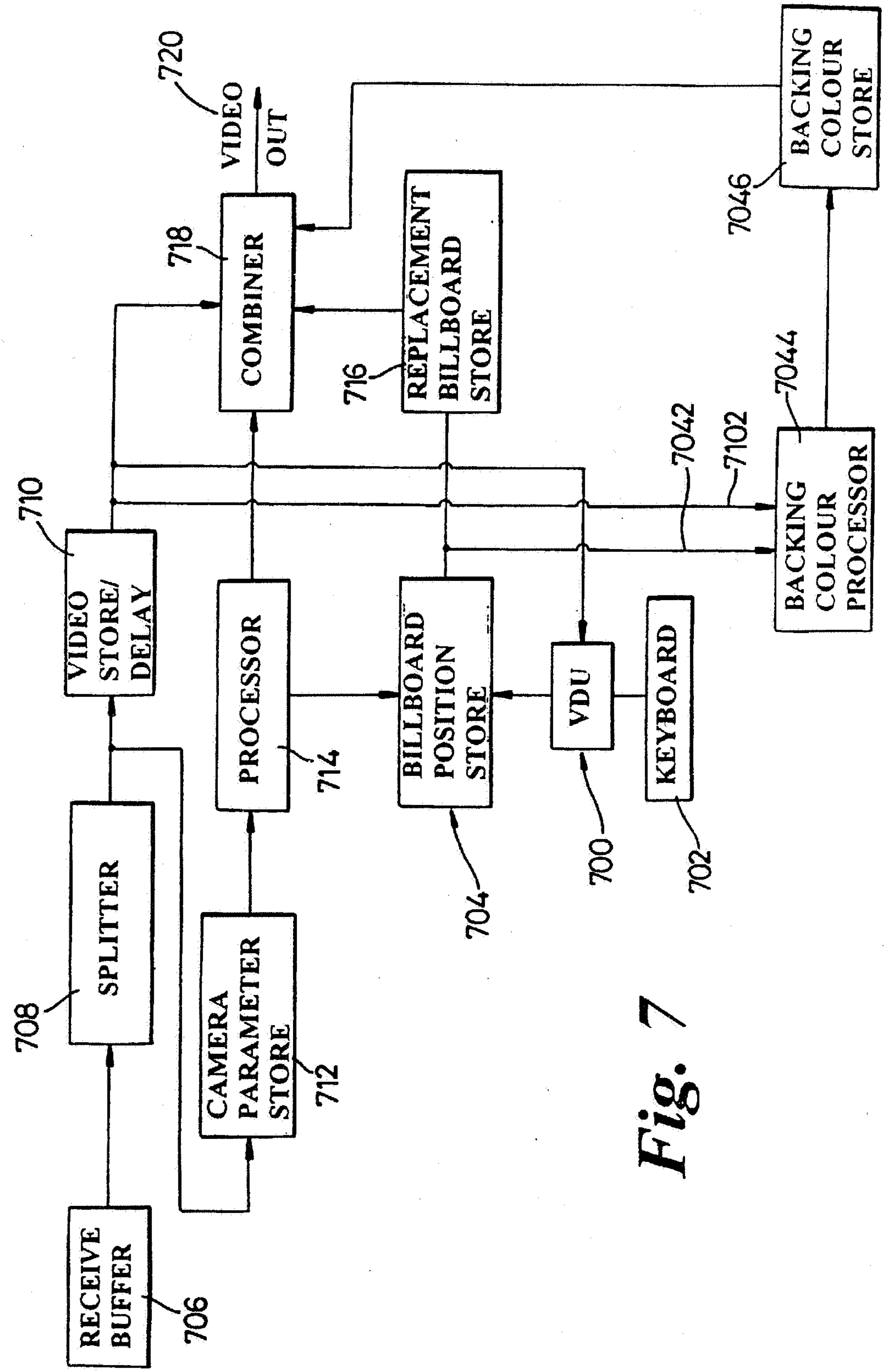


Fig. 6



RECEIVE BUFFER
706
SPLITTER
708
VIDEO STORE/ DELAY
710
CAMERA PARAMETER STORE
712
PROCESSOR
714
BILLBOARD POSITION STORE
704
VDU
700
KEYBOARD
702
COMBINER
718
REPLACEMENT BILLBOARD STORE
716
VIDEO OUT
720
BACKING COLOUR PROCESSOR
7044
7042
7102
BACKING COLOUR STORE
7046

Fig. 7

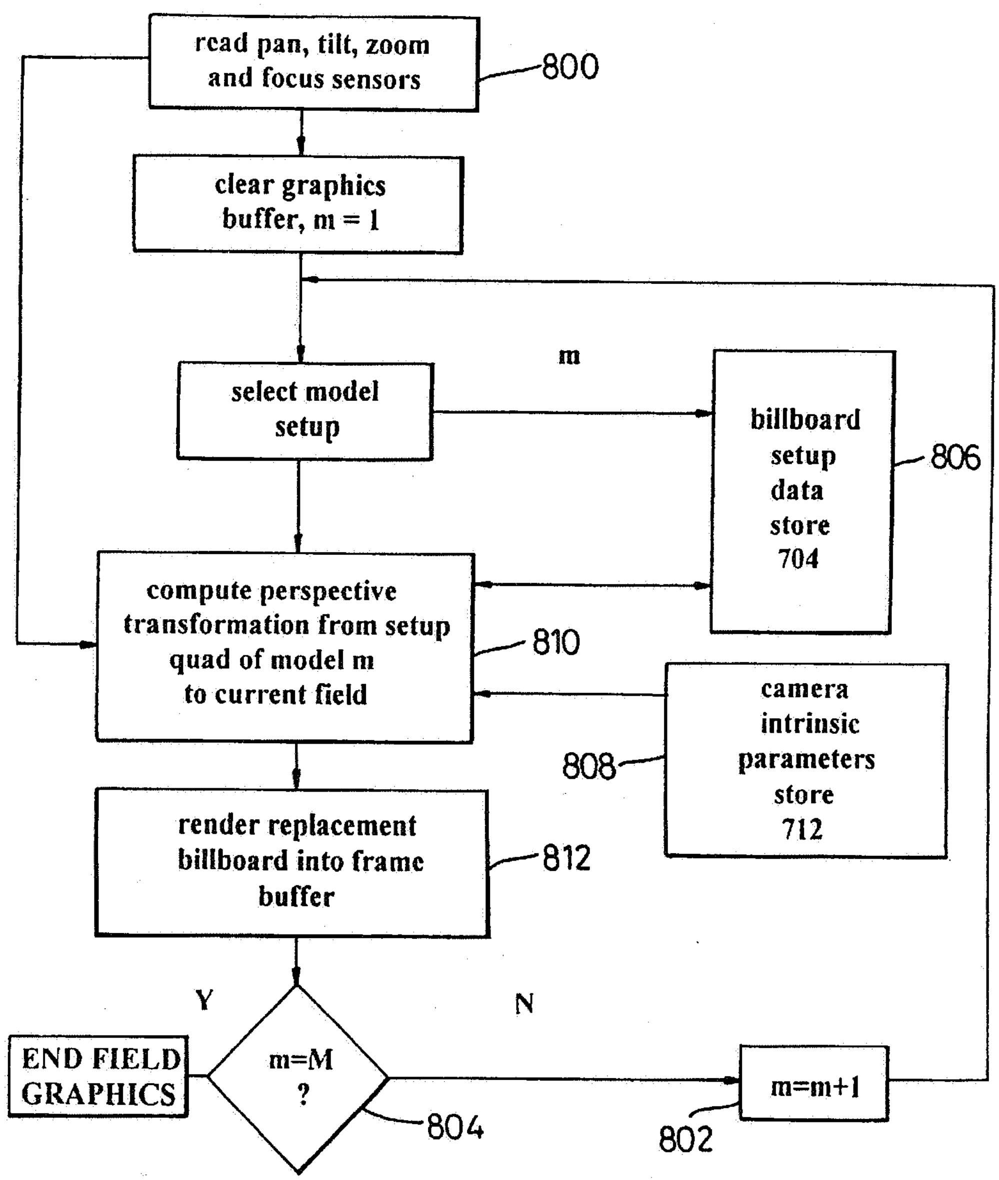

read pan, tilt, zoom and focus sensors
800
clear graphics buffer, m = 1
m
select model setup
billboard setup data store 704
806
compute perspective transformation from setup quad of model m to current field
810
camera intrinsic parameters store 712
808
render replacement billboard into frame buffer
812
Y
N
END FIELD GRAPHICS
m=M ?
804
m=m+1
802

Fig. 8

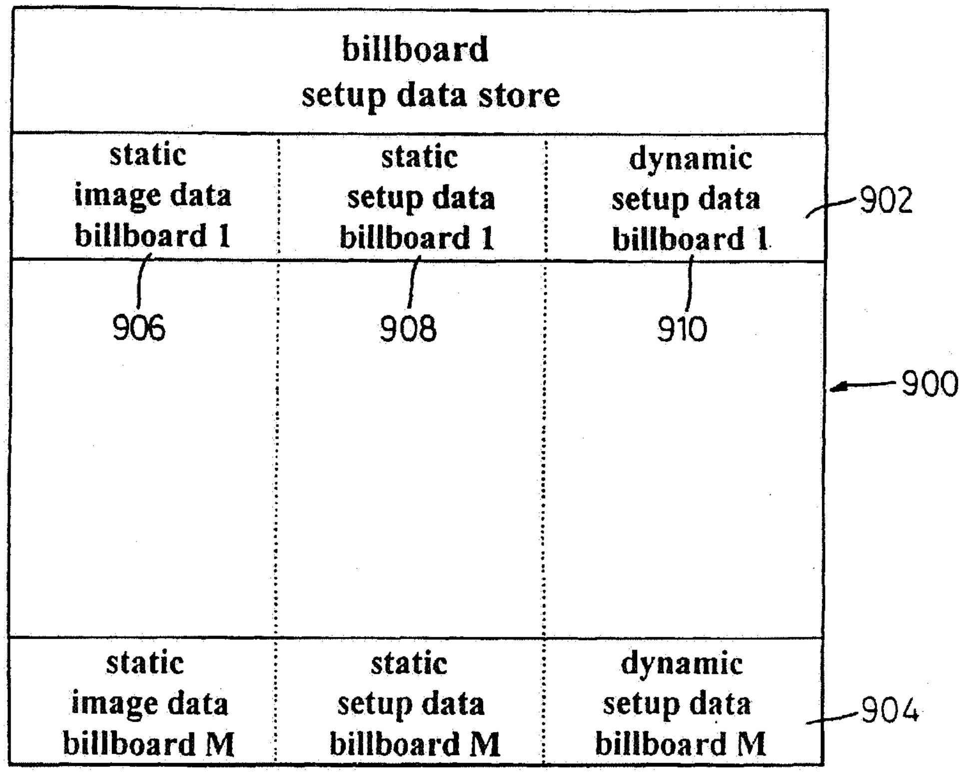

billboard
setup data store
static
image data
billboard 1
static
setup data
billboard 1
dynamic
setup data
billboard 1
902
906
908
910
900
static
image data
billboard M
static
setup data
billboard M
dynamic
setup data
billboard M
904

Fig. 9

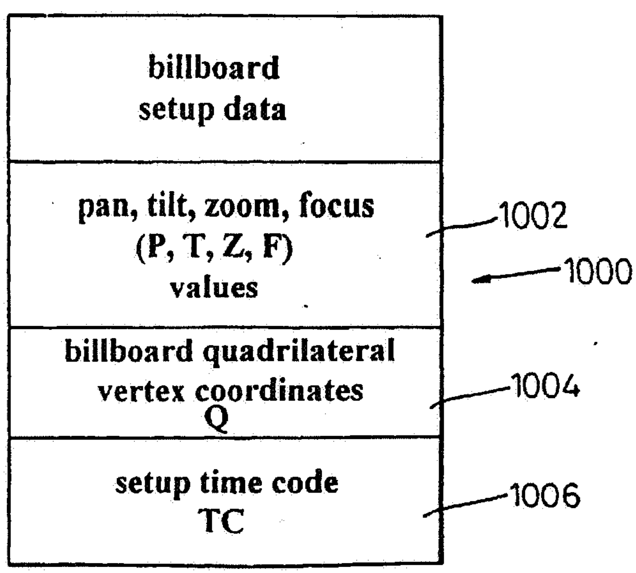

billboard
setup data
pan, tilt, zoom, focus
(P, T, Z, F)
values
1002
1000
billboard quadrilateral
vertex coordinates
Q
1004
setup time code
TC
1006

Fig. 10

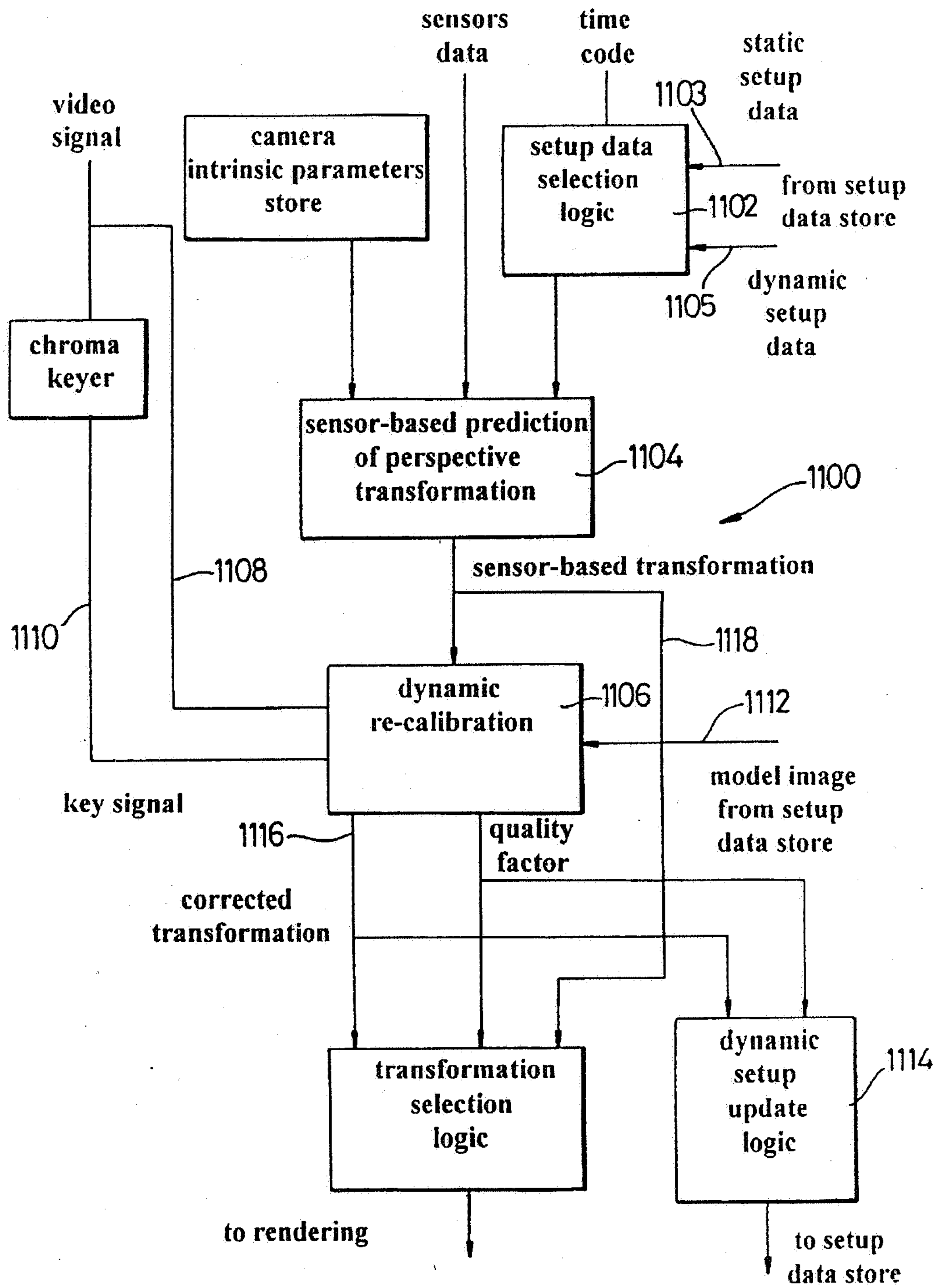

sensors data
time code
static setup data
1103
video signal
camera intrinsic parameters store
setup data selection logic
1102
from setup data store
1105
dynamic setup data
chroma keyer
sensor-based prediction of perspective transformation
1104
1100
1108
sensor-based transformation
1110
1118
dynamic re-calibration
1106
1112
model image from setup data store
key signal
1116
quality factor
corrected transformation
transformation selection logic
dynamic setup update logic
1114
to rendering
to setup data store

Fig. 11

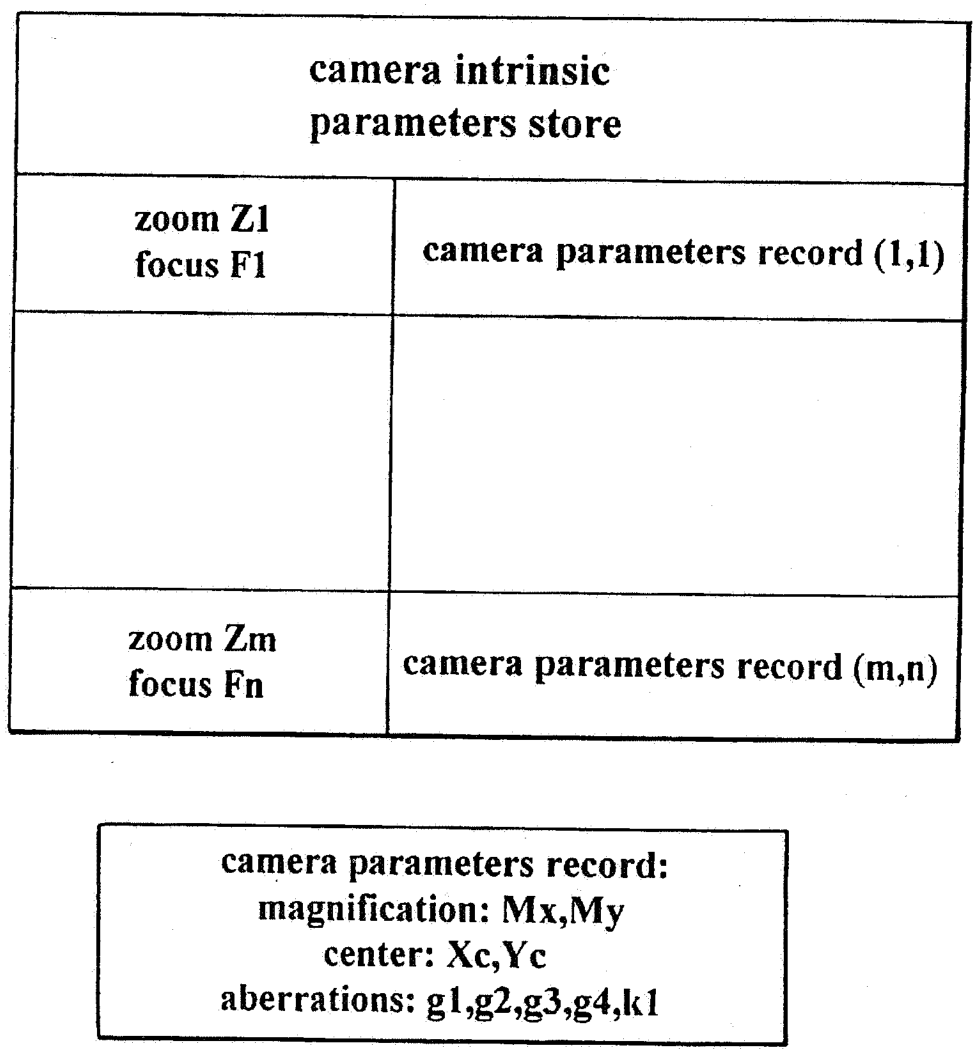

camera intrinsic parameters store
zoom Z1
focus F1
camera parameters record (1,1)
zoom Zm
focus Fn
camera parameters record (m,n)
camera parameters record:
magnification: Mx,My
center: Xc,Yc
aberrations: g1,g2,g3,g4,k1

Fig. 12

1. setup rotation matrix (600)

$$R_s = \begin{bmatrix} \cos(P_s) & 0 & -\sin(P_s) \\ 0 & 1 & 0 \\ \sin(P_s) & 0 & \cos(P_s) \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(T_s) & \sin(T_s) \\ 0 & -\sin(T_s) & \cos(T_s) \end{bmatrix}$$

2. prediction rotation matrix (602)

$$R_p = \begin{bmatrix} \cos(P_p) & 0 & -\sin(P_p) \\ 0 & 1 & 0 \\ \sin(P_p) & 0 & \cos(P_p) \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(T_p) & \sin(T_p) \\ 0 & -\sin(T_p) & \cos(T_p) \end{bmatrix}$$

3. setup to prediction perspective transformation (604)

$$R_{sp} = R_s^{-1} R_p$$

4. setup to prediction point transformation (606)

$$u_p = \frac{R_{sp}[0][0]u_s + R_{sp}[1][0]v_s + R_{sp}[2][0]}{R_{sp}[0][2]u_s + R_{sp}[1][2]v_s + R_{sp}[2][2]}$$

$$v_p = \frac{R_{sp}[0][1]u_s + R_{sp}[1][1]v_s + R_{sp}[2][1]}{R_{sp}[0][2]u_s + R_{sp}[1][2]v_s + R_{sp}[2][2]}$$

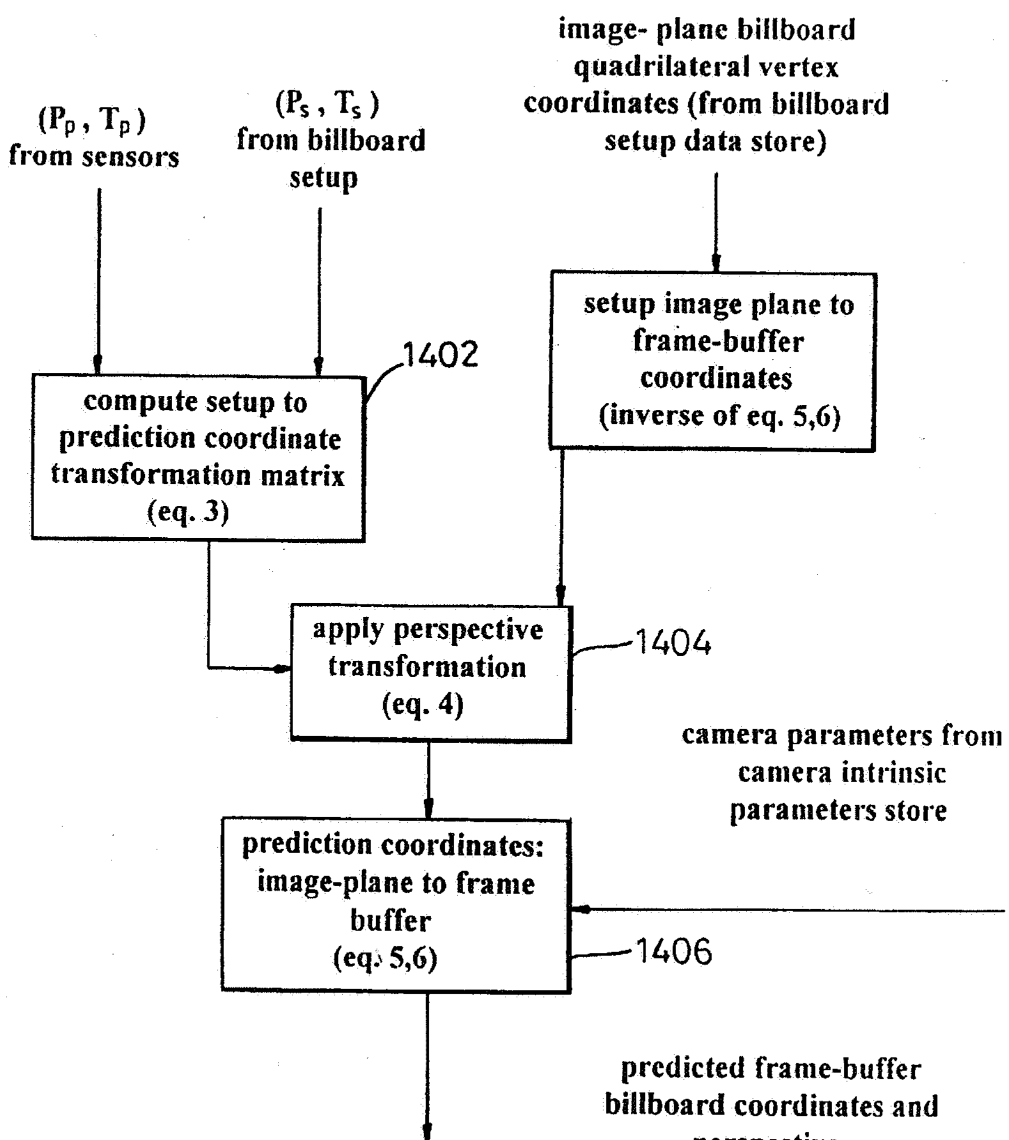
5. image plane to frame-buffer (608)

$$x = (u - A_u(u,v))\,M_X + X_C$$
$$y = (v - A_v(u,v))\,M_Y + Y_C$$

Fig. 13

6. aberrations (610)

$$A_u(u,v) = (g_1 + g_3)u^2 + g_4 uv + g_1 v^2 + k_1 u(u^2 + v^2)$$
$$A_v(u,v) = g_2 u^2 + g_3 uv + (g_2 + g_4)v^2 + k_1 v(u^2 + v^2)$$



(P_p, T_p) from sensors
(P_s, T_s) from billboard setup
image- plane billboard quadrilateral vertex coordinates (from billboard setup data store)
compute setup to prediction coordinate transformation matrix (eq. 3)
1402
setup image plane to frame-buffer coordinates (inverse of eq. 5,6)
apply perspective transformation (eq. 4)
1404
camera parameters from camera intrinsic parameters store
prediction coordinates: image-plane to frame buffer (eq. 5,6)
1406
predicted frame-buffer billboard coordinates and perspective transformation

Fig. 14

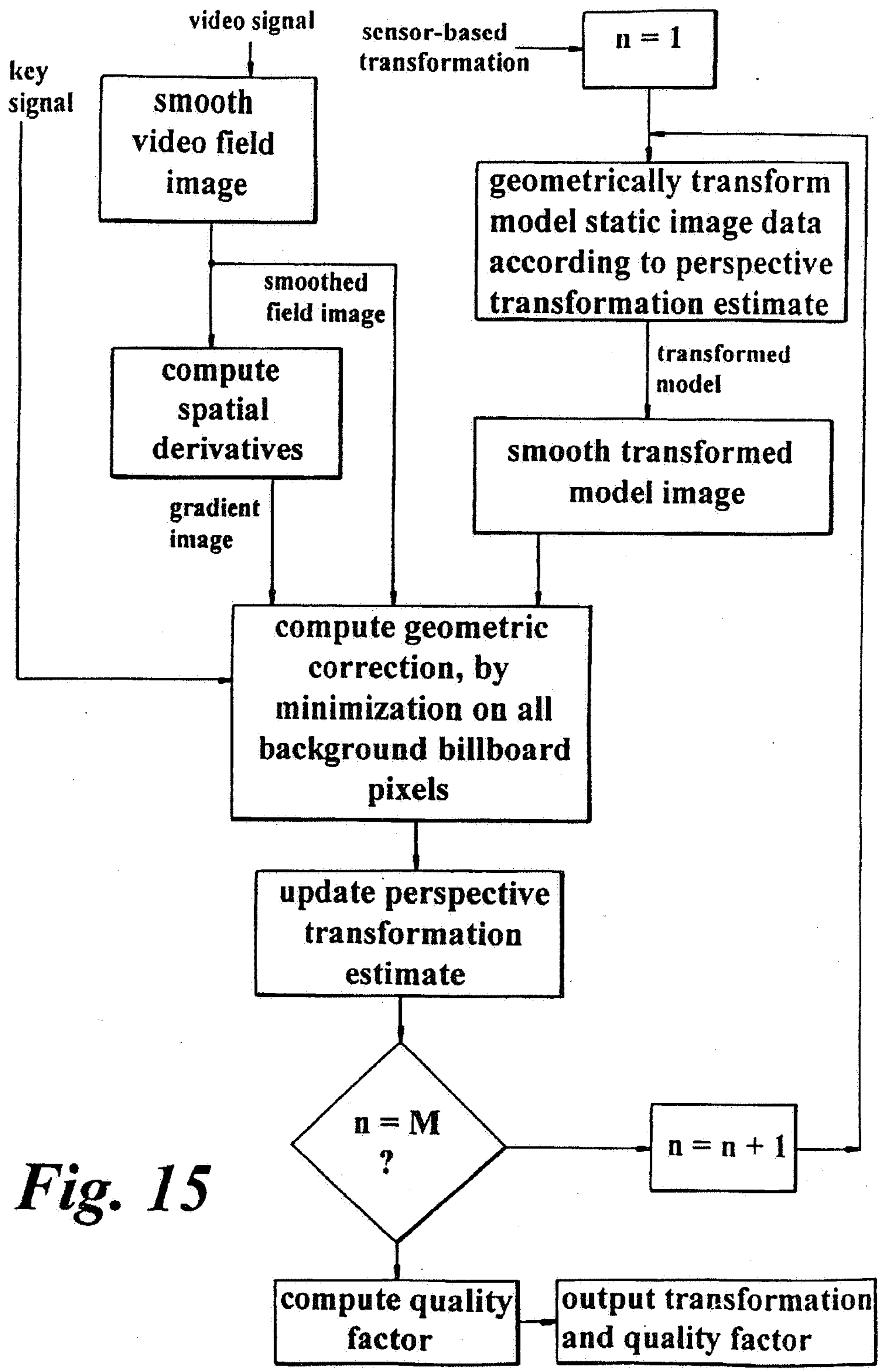

video signal
sensor-based transformation
n = 1
key signal
smooth video field image
smoothed field image
geometrically transform model static image data according to perspective transformation estimate
transformed model
compute spatial derivatives
smooth transformed model image
gradient image
compute geometric correction, by minimization on all background billboard pixels
update perspective transformation estimate
n = M ?
n = n + 1
compute quality factor
output transformation and quality factor

Fig. 15

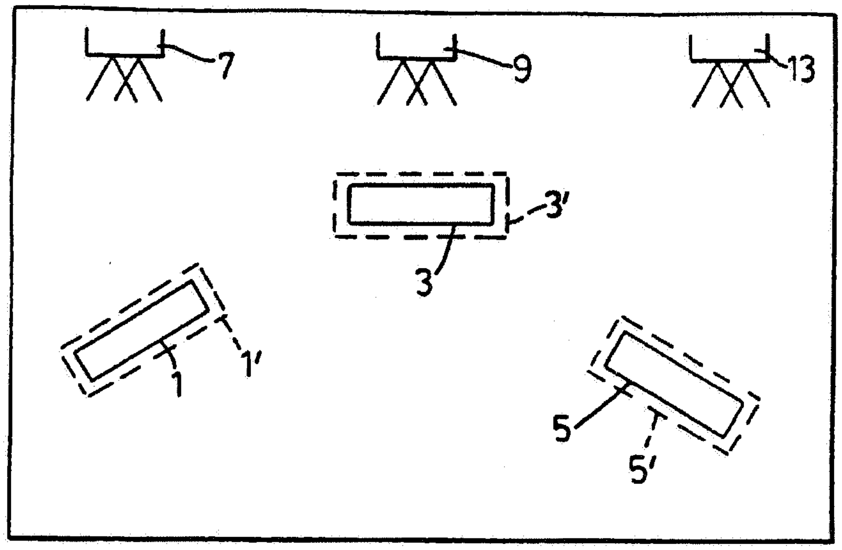


Fig. 16

BILLBOARDS 1, 3, 5 AT DIFFERENT LIGHTING CONDITIONS DUE TO LIGHTS 7, 9, 13 AND WITH VIRTUAL BOXES 1', 3' AND 5' WHICH IDENTIFY THEIR LOCATIONS

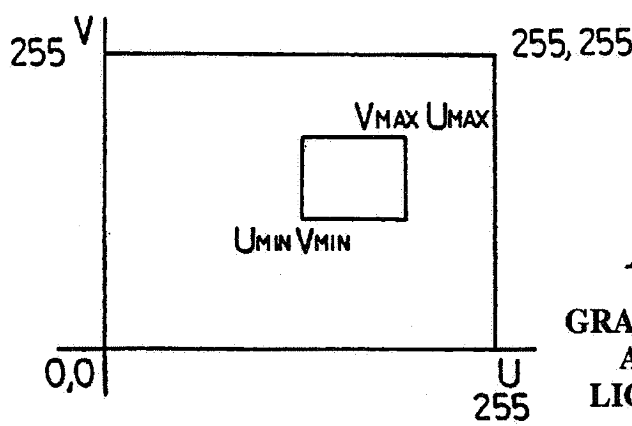


Fig. 17

GRAPH OF MAXIMUM AND MINIMUM LIGHTING VALUES

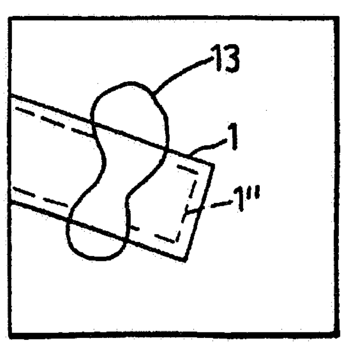


Fig. 18

VIEW OF BILLBOARD 1 BEING OCCLUDED BY OBJECT 13

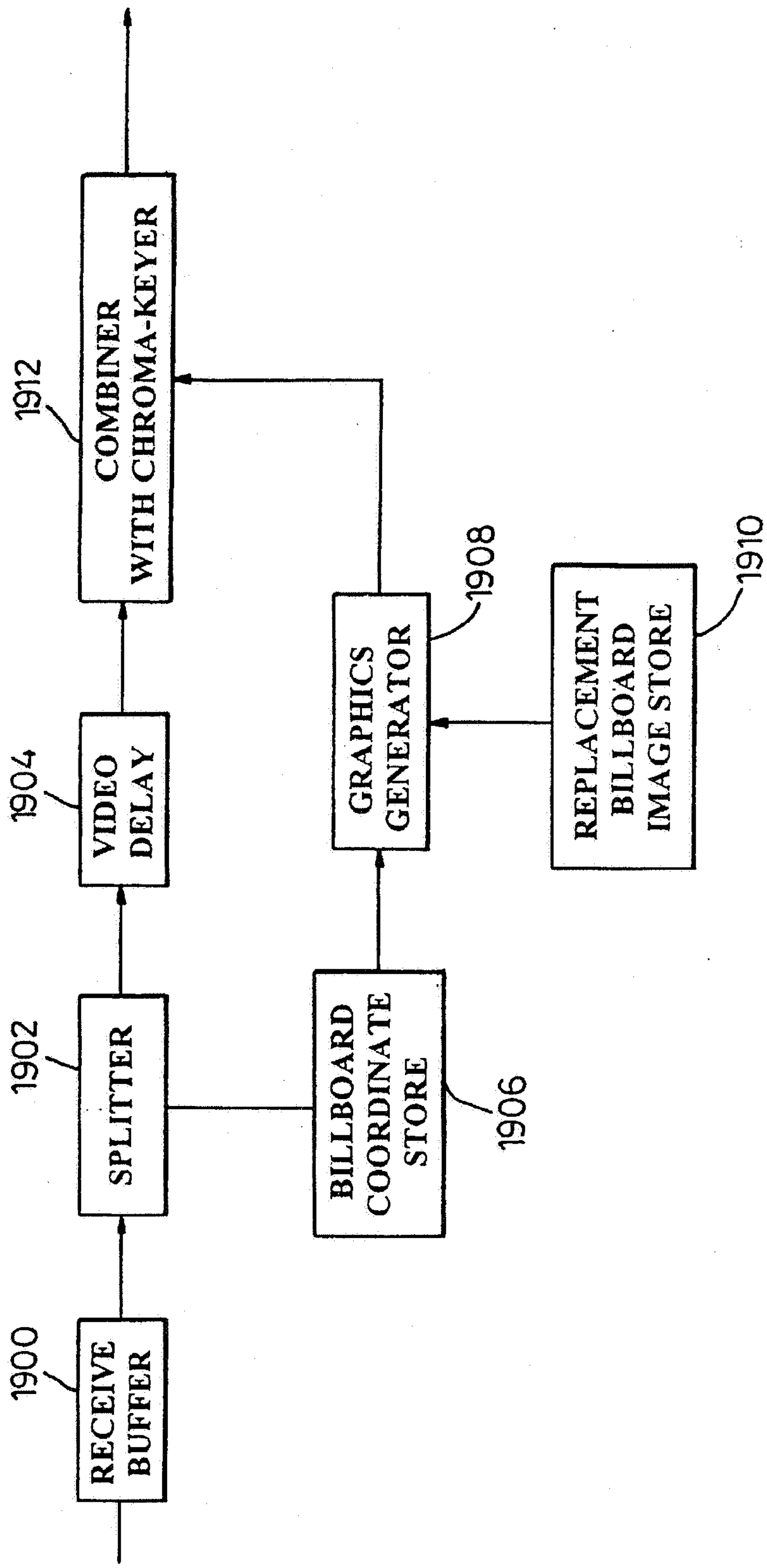
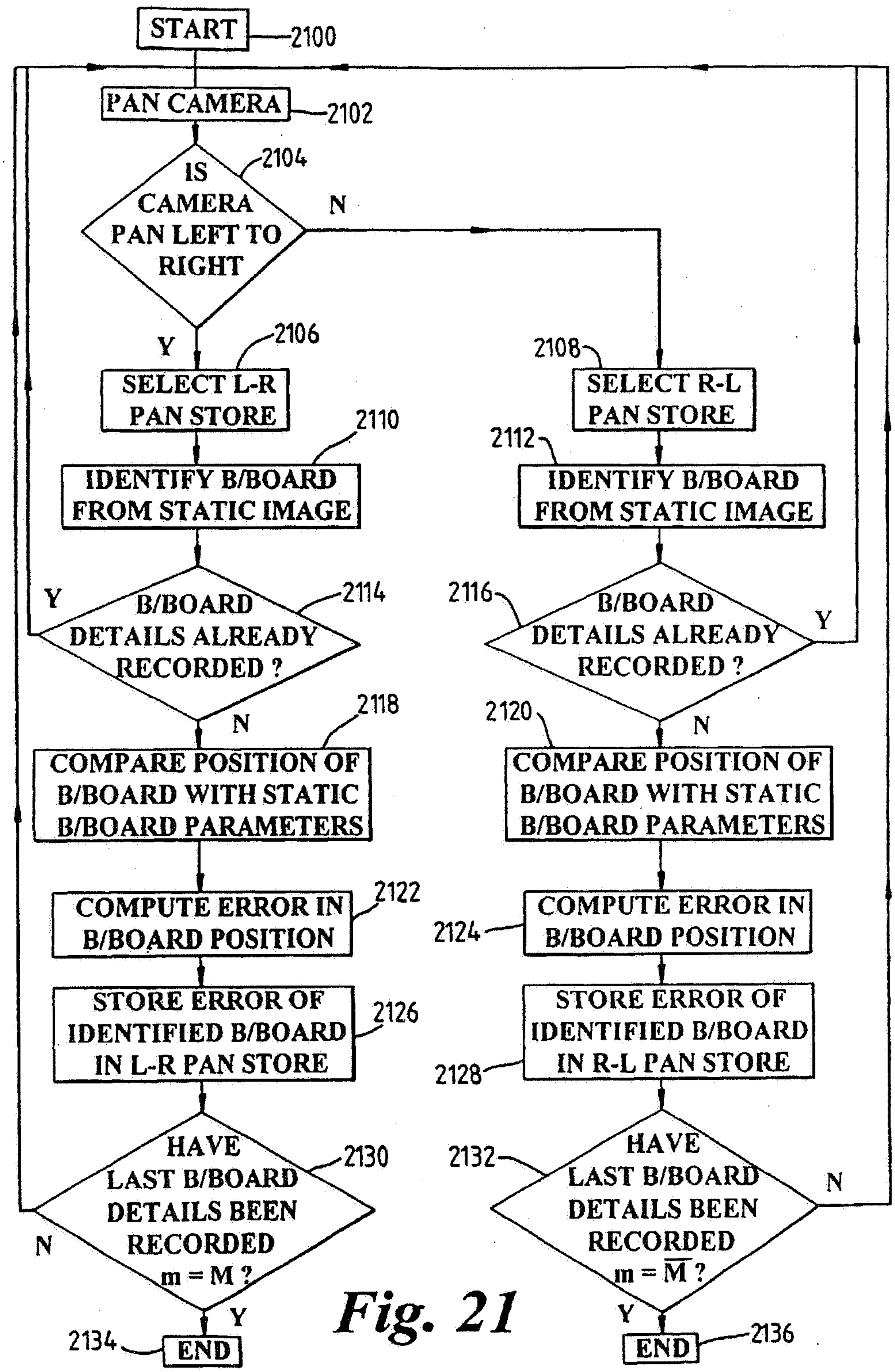

RECEIVE BUFFER
1900
SPLITTER
1902
VIDEO DELAY
1904
BILLBOARD COORDINATE STORE
1906
GRAPHICS GENERATOR
1908
REPLACEMENT BILLBOARD IMAGE STORE
1910
COMBINER WITH CHROMA-KEYER
1912

Fig. 19

BILLBOARD STATIC AND DYNAMIC SET UP DATA STORE					
STATIC IMAGE DATA	STATIC SET UP DATA	DYNAMIC CALIBRATION DATA			
		PAN L-R	PAN R+L	TILT UP	TILT DOWN
B/BOARD 1	B/BOARD 1	B/B 1	B/B 1	B/B 1	B/B 1
906	908	2002	2004	2006	2008
B/BOARD M	B/BOARD M	B/B M	B/B M	B/B M	B/B M

Fig. 20


START
2100
PAN CAMERA
2102
IS CAMERA PAN LEFT TO RIGHT
2104
N
Y
SELECT L-R PAN STORE
2106
2108
SELECT R-L PAN STORE
2110
IDENTIFY B/BOARD FROM STATIC IMAGE
2112
IDENTIFY B/BOARD FROM STATIC IMAGE
Y
B/BOARD DETAILS ALREADY RECORDED ?
2114
2116
B/BOARD DETAILS ALREADY RECORDED ?
Y
N
2118
2120
N
COMPARE POSITION OF B/BOARD WITH STATIC B/BOARD PARAMETERS
COMPARE POSITION OF B/BOARD WITH STATIC B/BOARD PARAMETERS
COMPUTE ERROR IN B/BOARD POSITION
2122
2124
COMPUTE ERROR IN B/BOARD POSITION
STORE ERROR OF IDENTIFIED B/BOARD IN L-R PAN STORE
2126
2128
STORE ERROR OF IDENTIFIED B/BOARD IN R-L PAN STORE
HAVE LAST B/BOARD DETAILS BEEN RECORDED m = M ?
2130
2132
HAVE LAST B/BOARD DETAILS BEEN RECORDED m = M̄ ?
N
N
Y
Y
2134
END
END
2136
Fig. 21

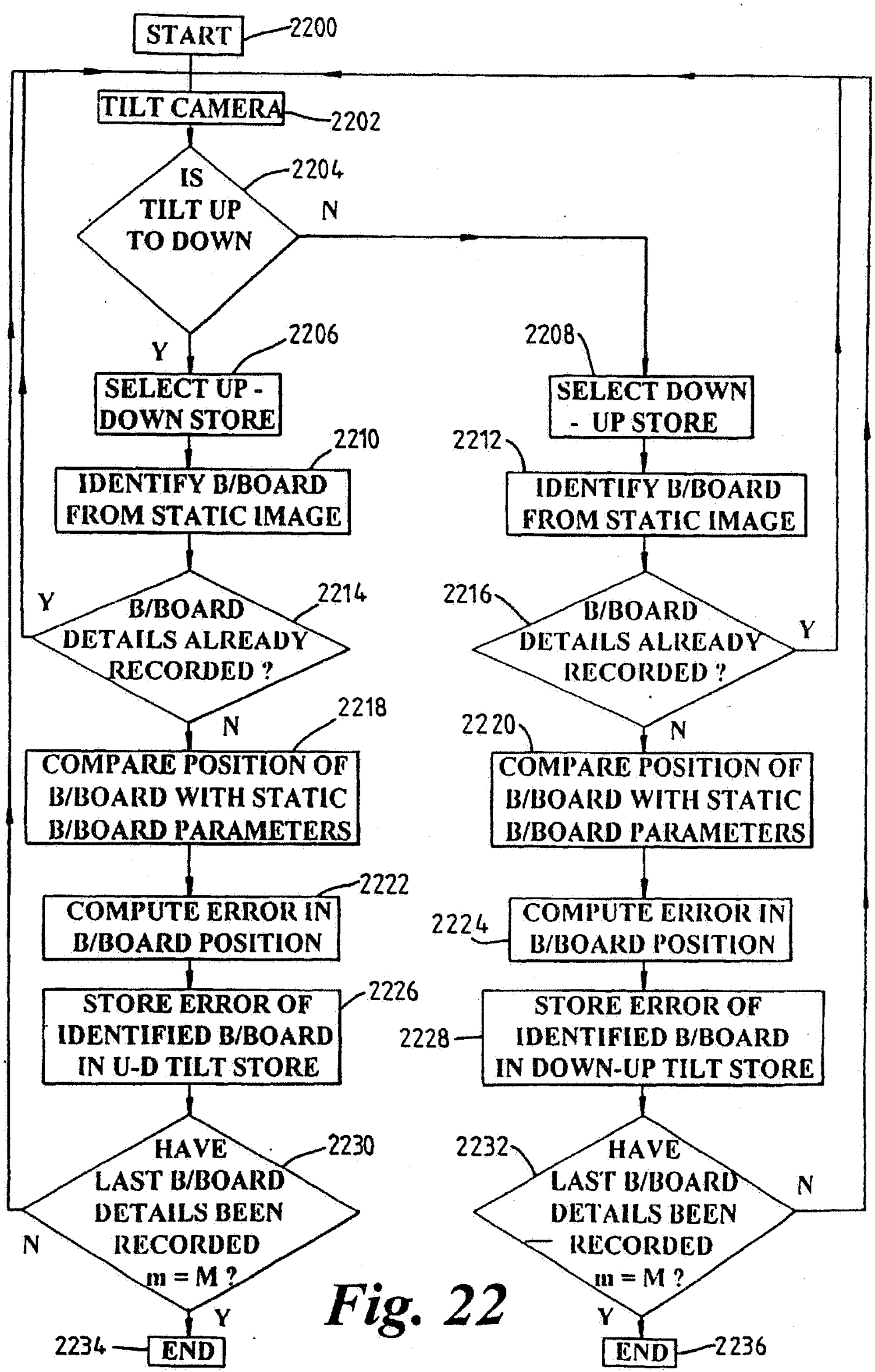

START
2200
TILT CAMERA
2202
IS TILT UP TO DOWN
2204
N
Y
SELECT UP - DOWN STORE
2206
2208
SELECT DOWN - UP STORE
2210
IDENTIFY B/BOARD FROM STATIC IMAGE
2212
IDENTIFY B/BOARD FROM STATIC IMAGE
Y
B/BOARD DETAILS ALREADY RECORDED ?
2214
2216
B/BOARD DETAILS ALREADY RECORDED ?
Y
N
2218
2220
N
COMPARE POSITION OF B/BOARD WITH STATIC B/BOARD PARAMETERS
COMPARE POSITION OF B/BOARD WITH STATIC B/BOARD PARAMETERS
2222
COMPUTE ERROR IN B/BOARD POSITION
2224
COMPUTE ERROR IN B/BOARD POSITION
STORE ERROR OF IDENTIFIED B/BOARD IN U-D TILT STORE
2226
2228
STORE ERROR OF IDENTIFIED B/BOARD IN DOWN-UP TILT STORE
HAVE LAST B/BOARD DETAILS BEEN RECORDED m = M ?
2230
2232
HAVE LAST B/BOARD DETAILS BEEN RECORDED m = M ?
N
N
Y
Y
2234
END
END
2236

Fig. 22