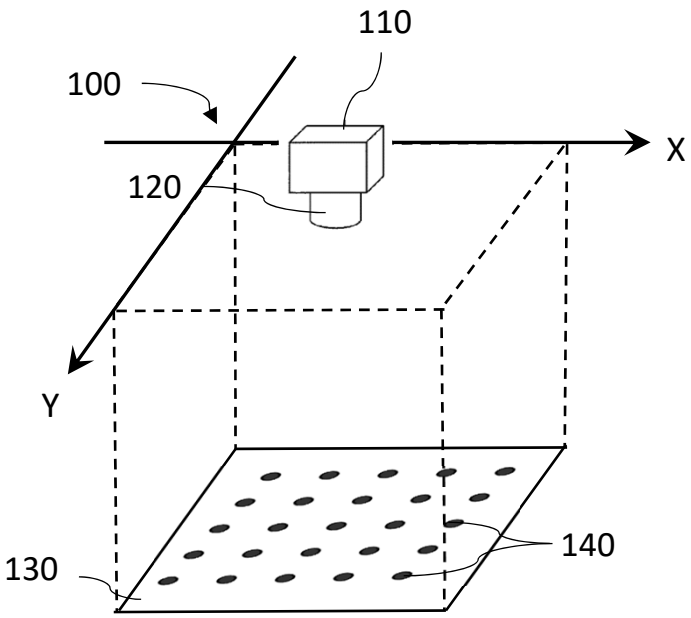


Figure 1

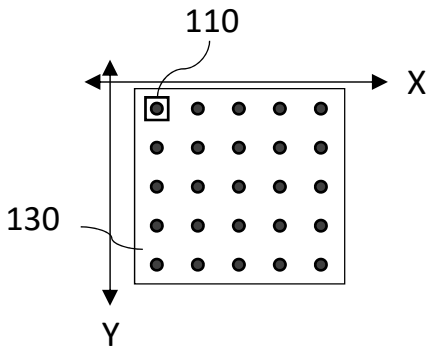


Figure 2A

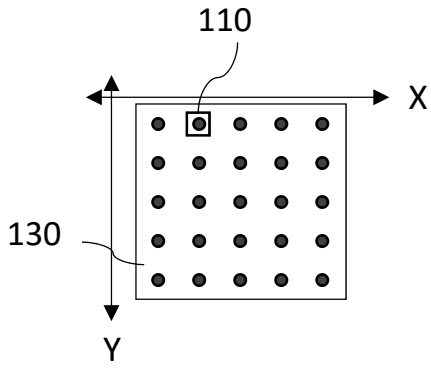


Figure 2B

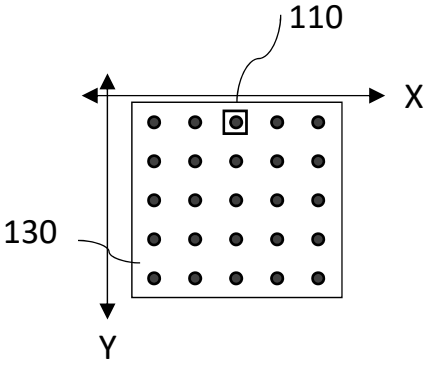


Figure 2C

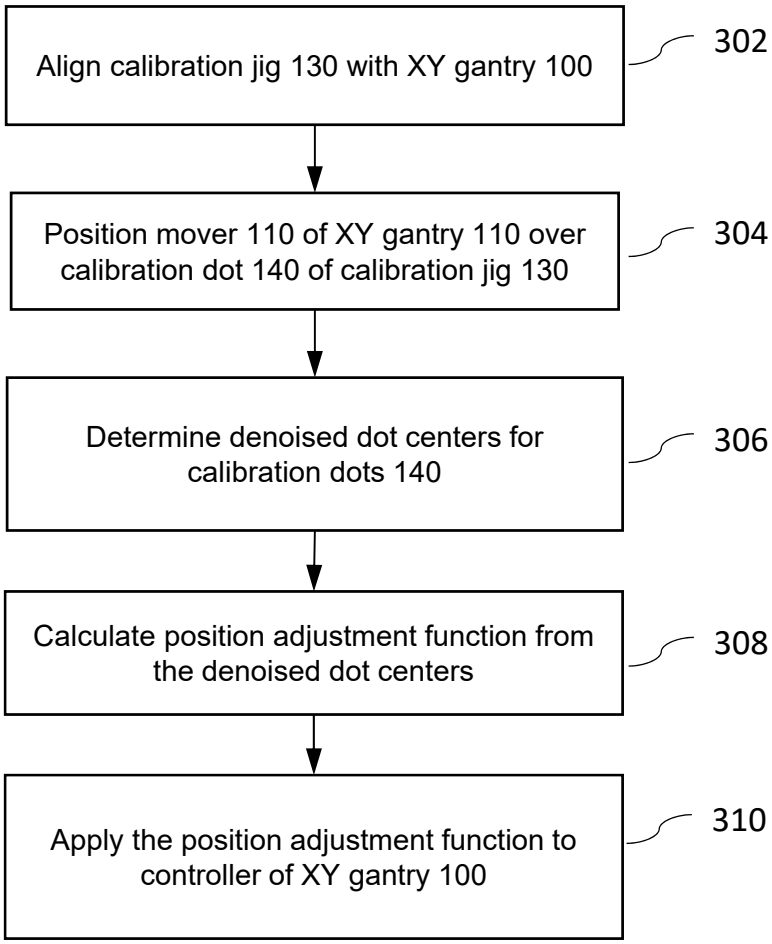

Align calibration jig 130 with XY gantry 100
302
Position mover 110 of XY gantry 110 over calibration dot 140 of calibration jig 130
304
Determine denoised dot centers for calibration dots 140
306
Calculate position adjustment function from the denoised dot centers
308
Apply the position adjustment function to controller of XY gantry 100
310

Figure 3

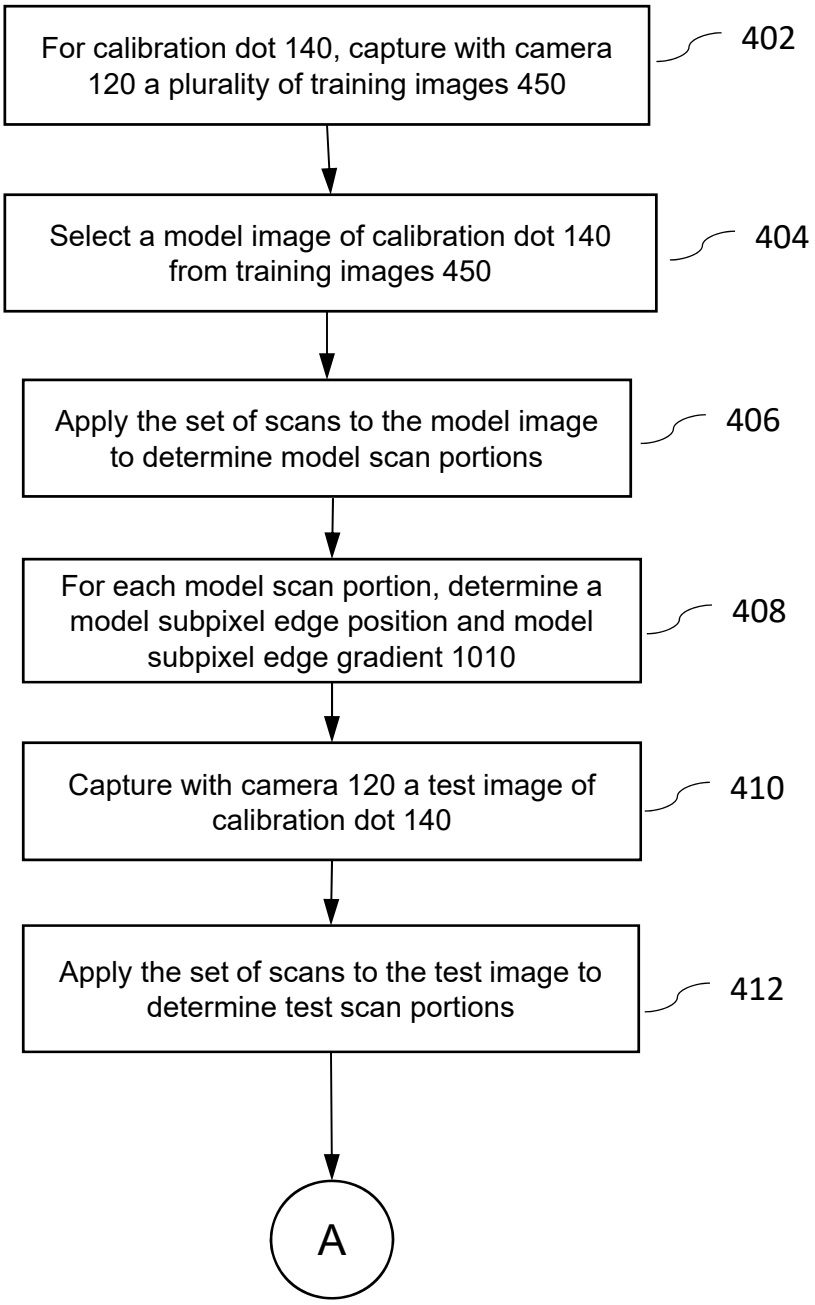

For calibration dot 140, capture with camera 120 a plurality of training images 450
402
Select a model image of calibration dot 140 from training images 450
404
Apply the set of scans to the model image to determine model scan portions
406
For each model scan portion, determine a model subpixel edge position and model subpixel edge gradient 1010
408
Capture with camera 120 a test image of calibration dot 140
410
Apply the set of scans to the test image to determine test scan portions
412
A

Figure 4

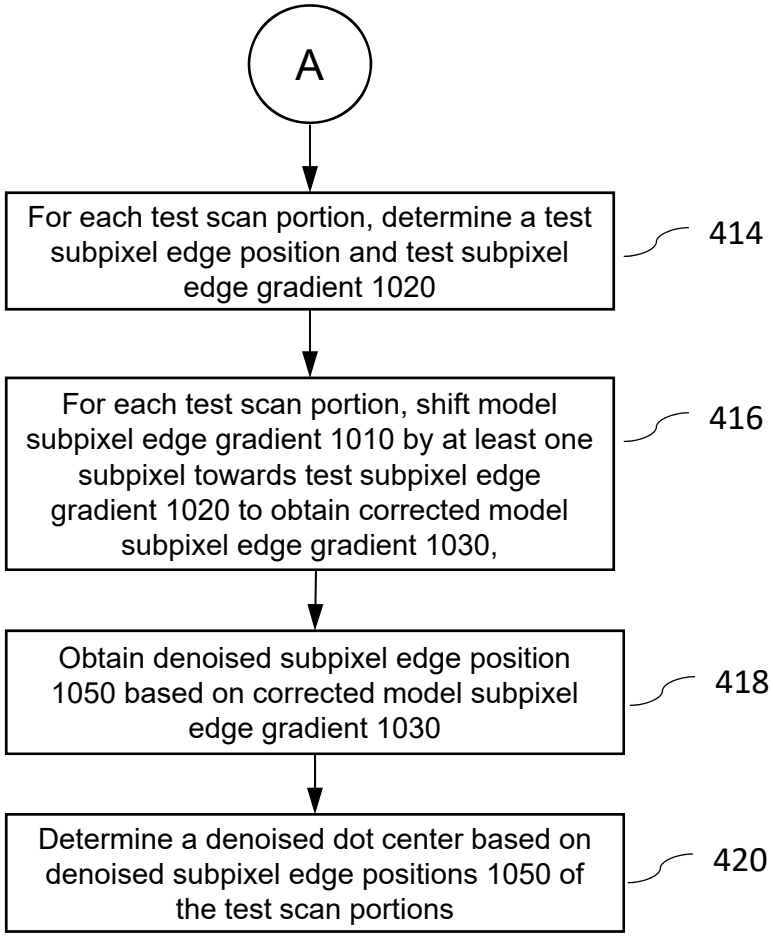


Figure 4 (continue)

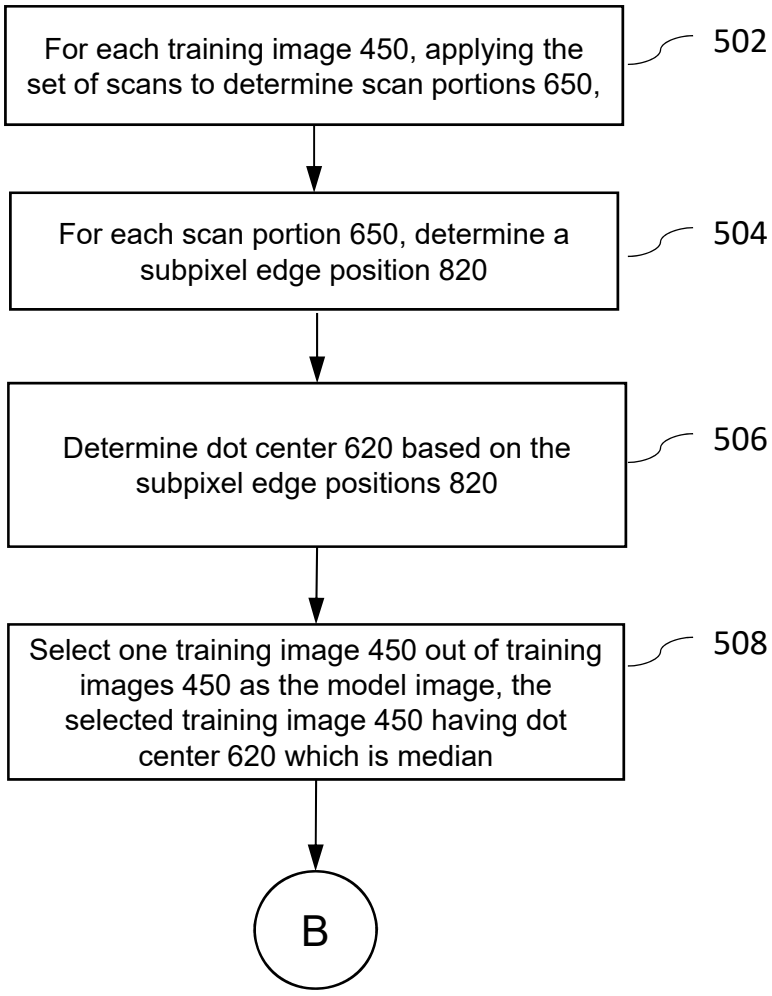

For each training image 450, applying the set of scans to determine scan portions 650,
502
For each scan portion 650, determine a subpixel edge position 820
504
Determine dot center 620 based on the subpixel edge positions 820
506
Select one training image 450 out of training images 450 as the model image, the selected training image 450 having dot center 620 which is median
508
B

Figure 5

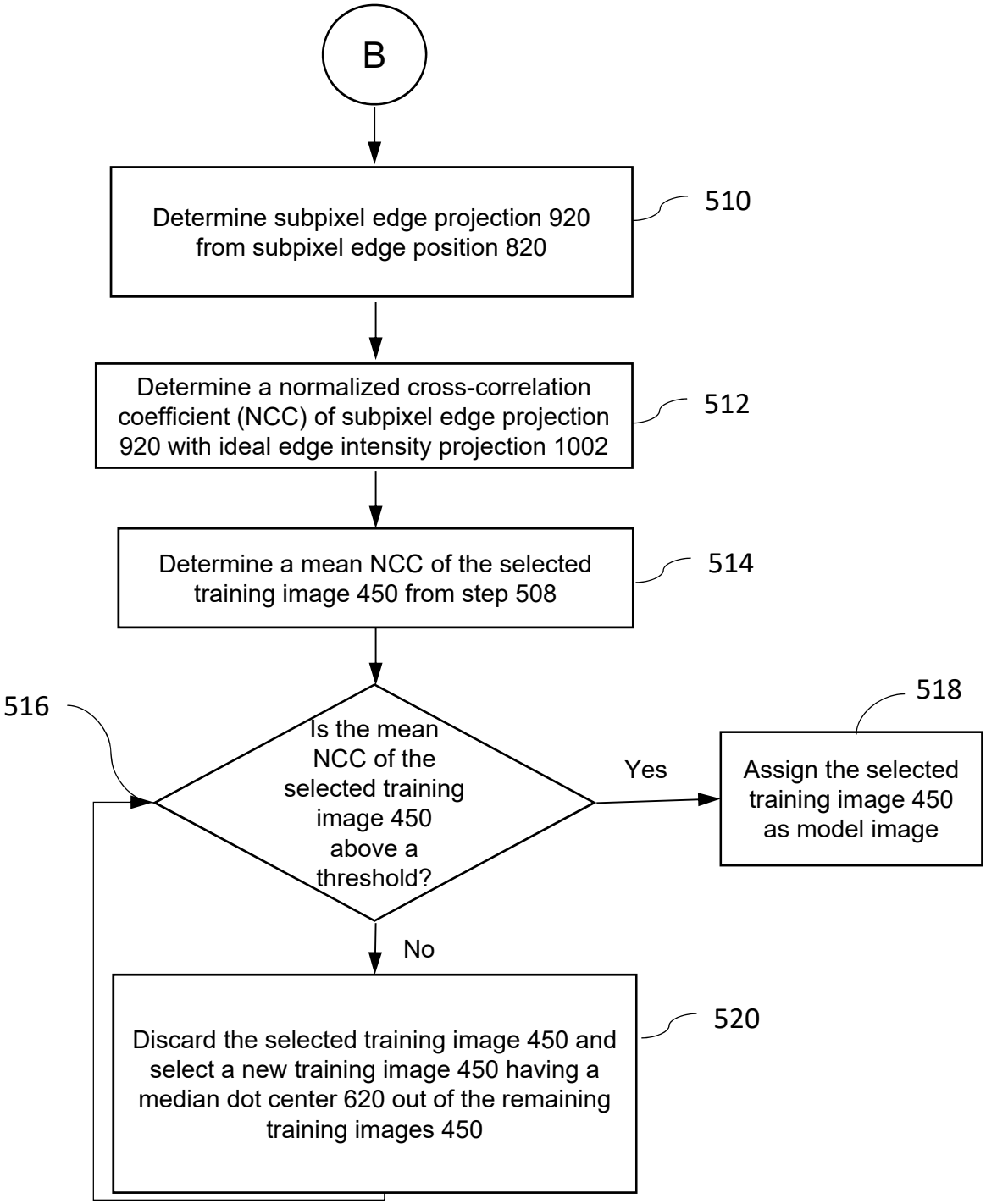


Figure 5 (continue)

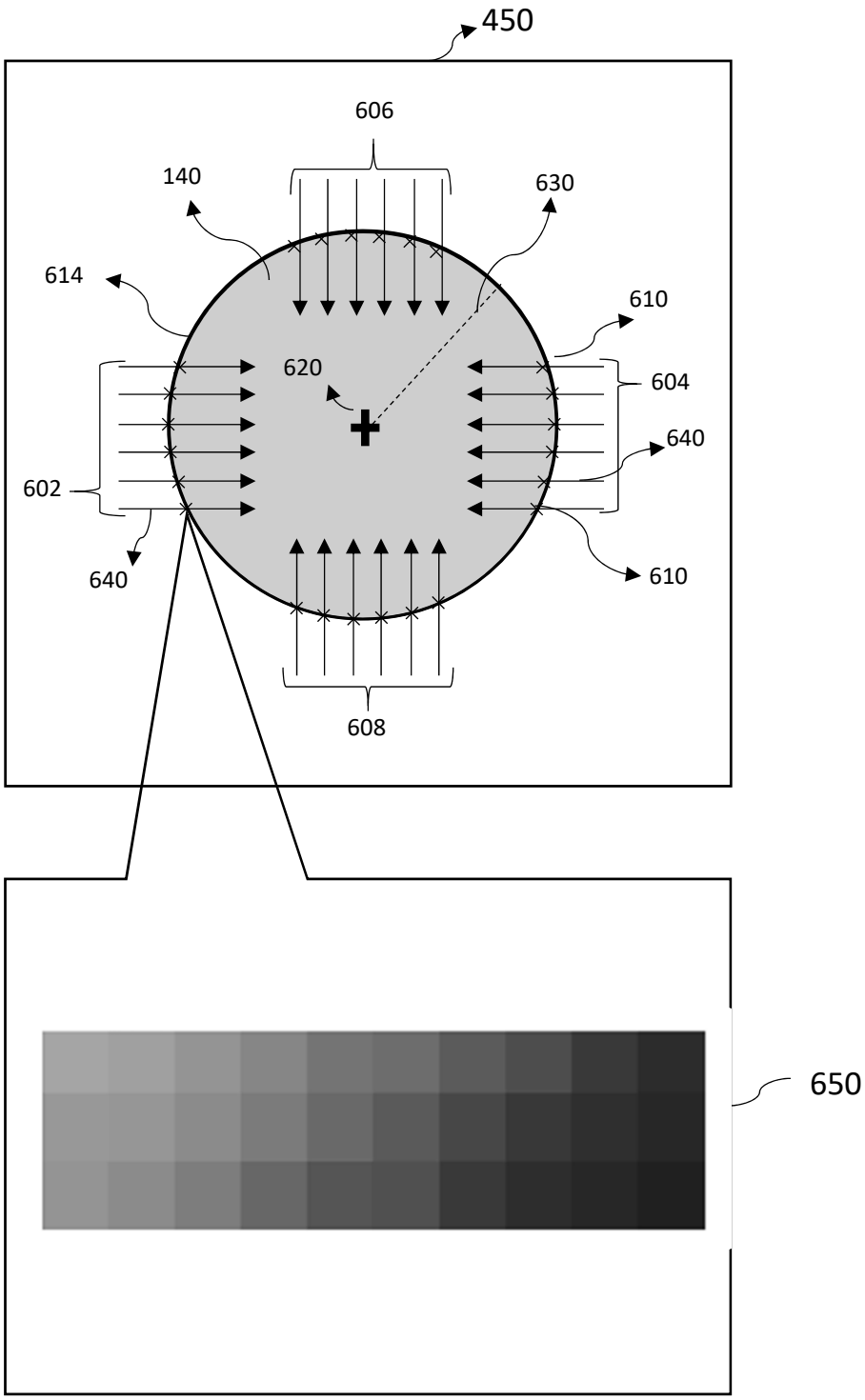


Figure 6

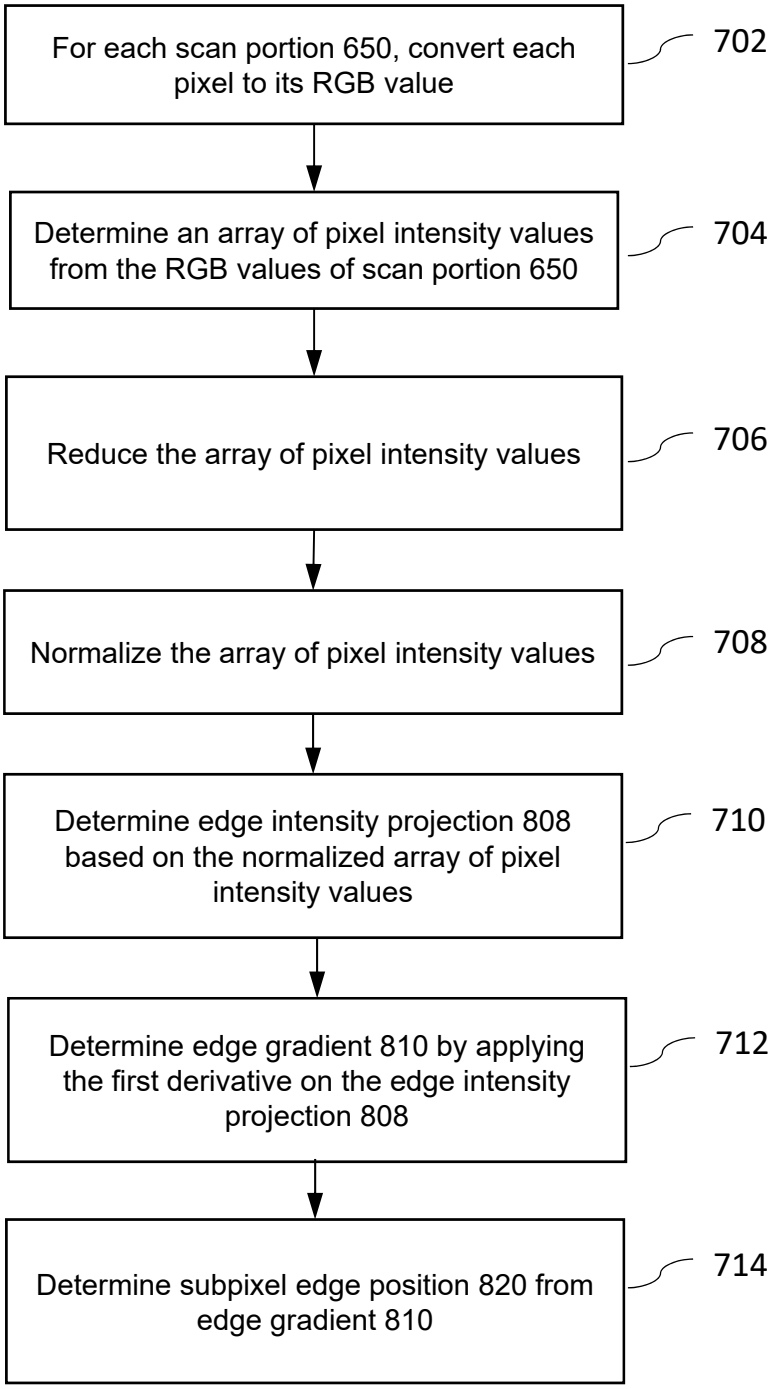

For each scan portion 650, convert each pixel to its RGB value
702
Determine an array of pixel intensity values from the RGB values of scan portion 650
704
Reduce the array of pixel intensity values
706
Normalize the array of pixel intensity values
708
Determine edge intensity projection 808 based on the normalized array of pixel intensity values
710
Determine edge gradient 810 by applying the first derivative on the edge intensity projection 808
712
Determine subpixel edge position 820 from edge gradient 810
714

Figure 7

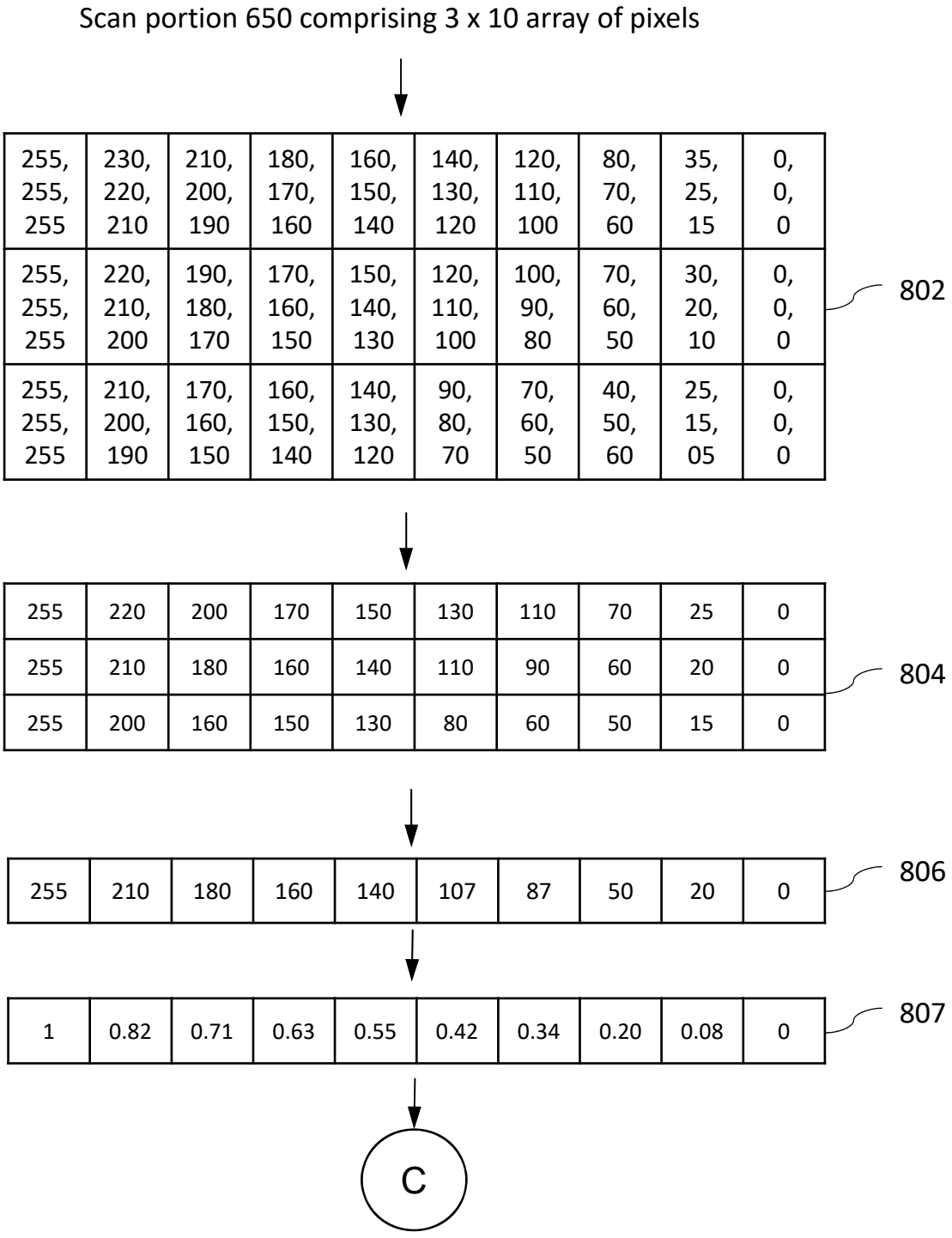

Scan portion 650 comprising 3 x 10 array of pixels
255, 255, 255
230, 220, 210
210, 200, 190
180, 170, 160
160, 150, 140
140, 130, 120
120, 110, 100
80, 70, 60
35, 25, 15
0, 0, 0
255, 255, 255
220, 210, 200
190, 180, 170
170, 160, 150
150, 140, 130
120, 110, 100
100, 90, 80
70, 60, 50
30, 20, 10
0, 0, 0
255, 255, 255
210, 200, 190
170, 160, 150
160, 150, 140
140, 130, 120
90, 80, 70
70, 60, 50
40, 50, 60
25, 15, 05
0, 0, 0
802
255 220 200 170 150 130 110 70 25 0
255 210 180 160 140 110 90 60 20 0
255 200 160 150 130 80 60 50 15 0
804
255 210 180 160 140 107 87 50 20 0
806
1 0.82 0.71 0.63 0.55 0.42 0.34 0.20 0.08 0
807
C

Figure 8

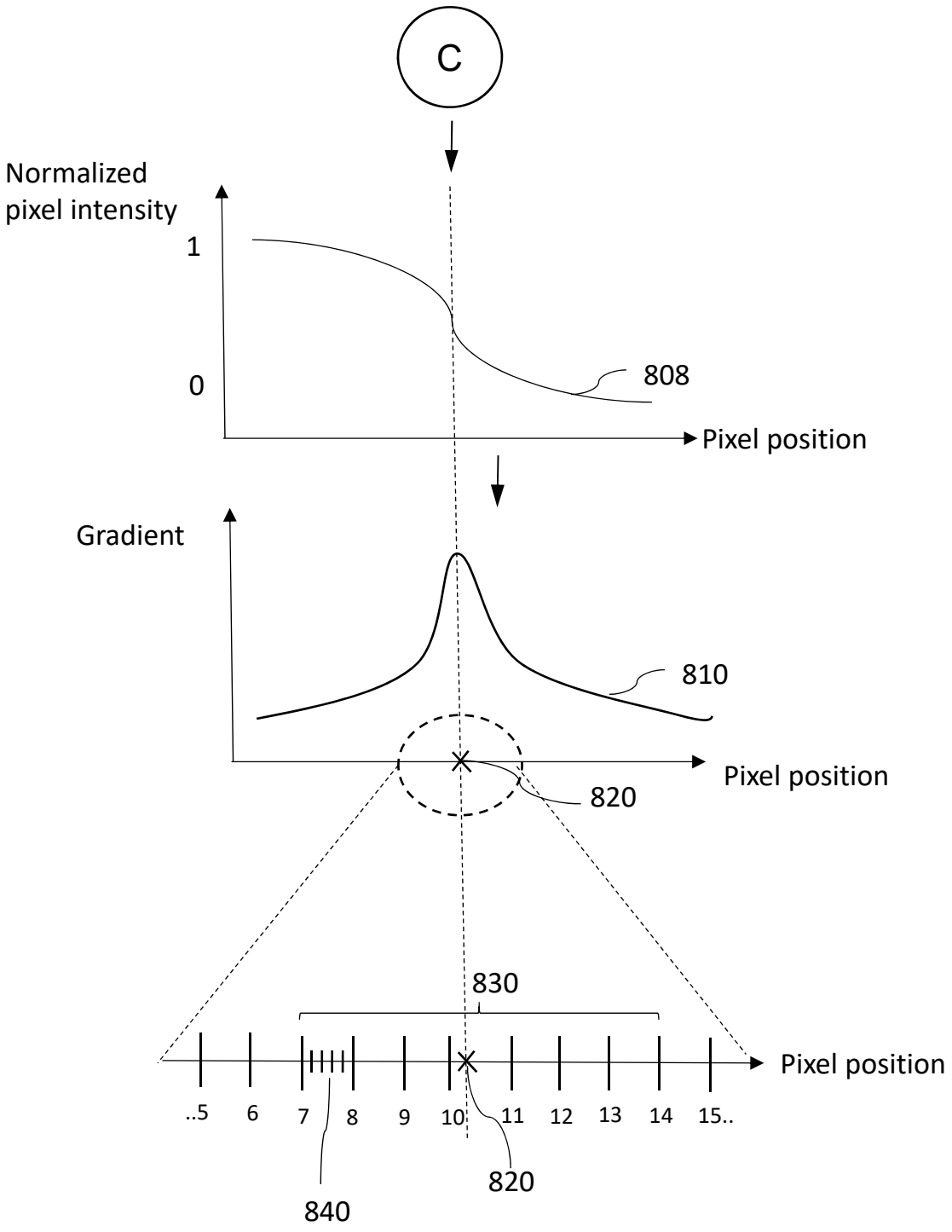


Figure 8 (continue)

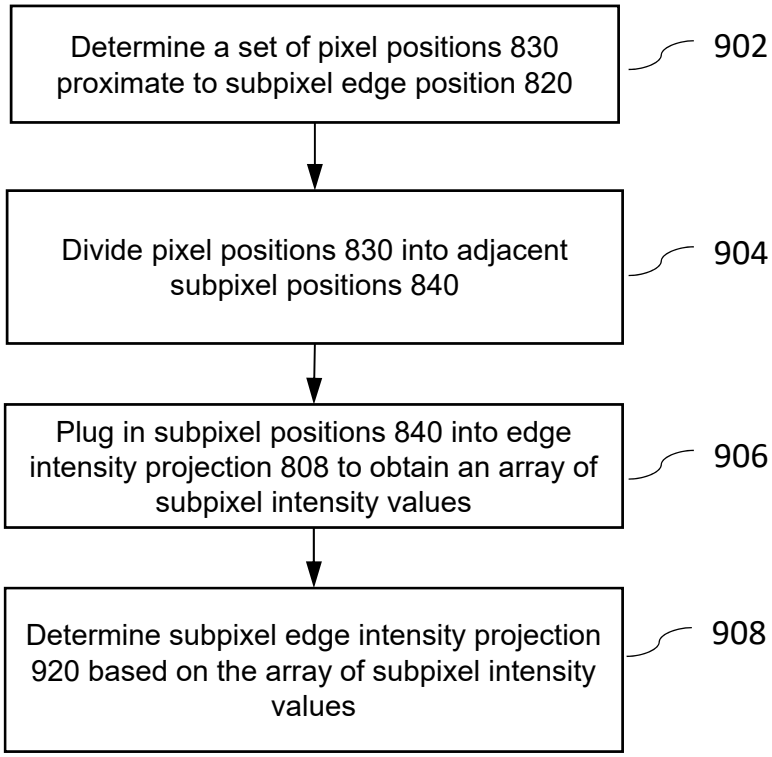

Determine a set of pixel positions 830 proximate to subpixel edge position 820
902
Divide pixel positions 830 into adjacent subpixel positions 840
904
Plug in subpixel positions 840 into edge intensity projection 808 to obtain an array of subpixel intensity values
906
Determine subpixel edge intensity projection 920 based on the array of subpixel intensity values
908

Figure 9

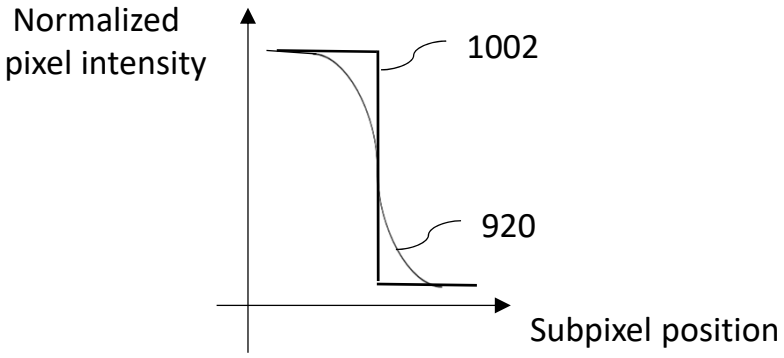


Figure 10A

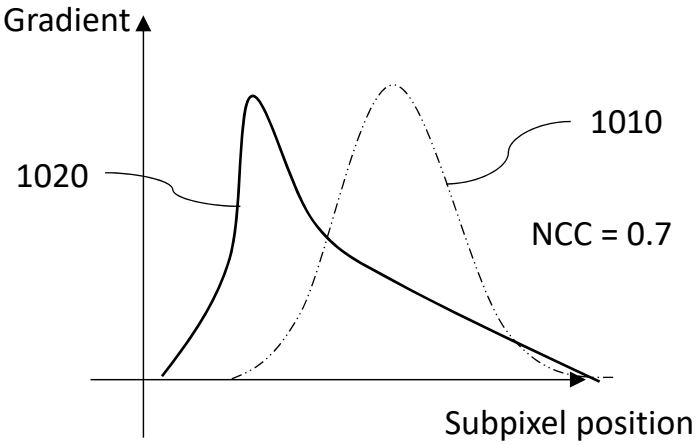


Figure 10B

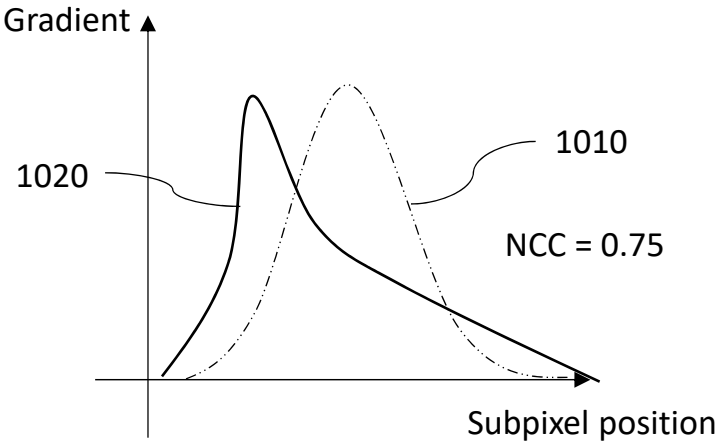


Figure 10C

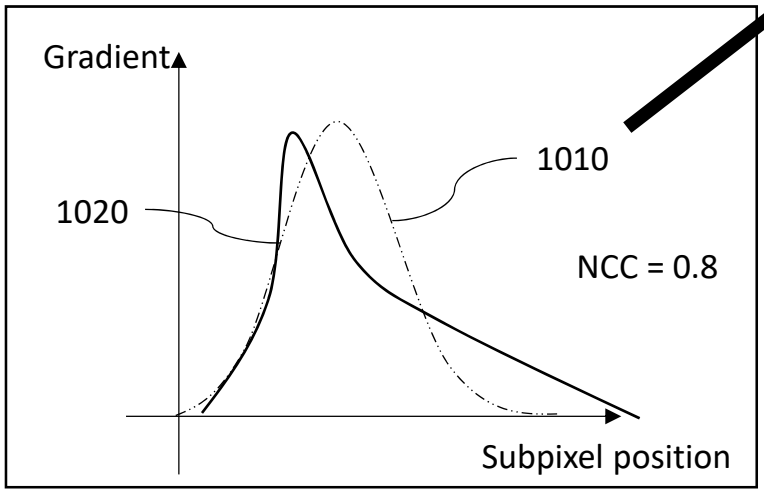


Figure 10D

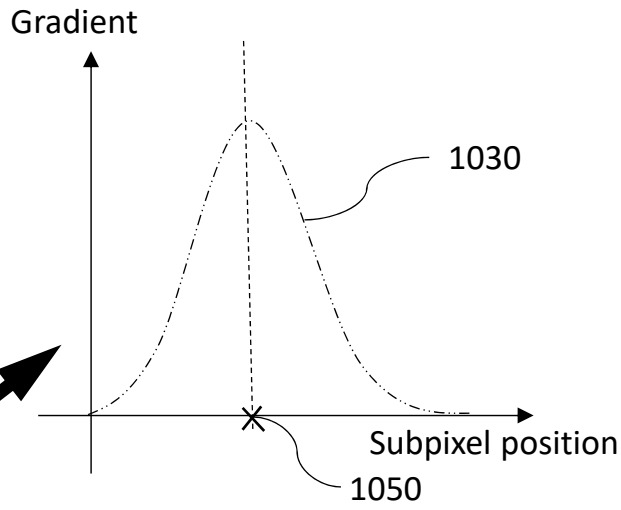


Figure 10E

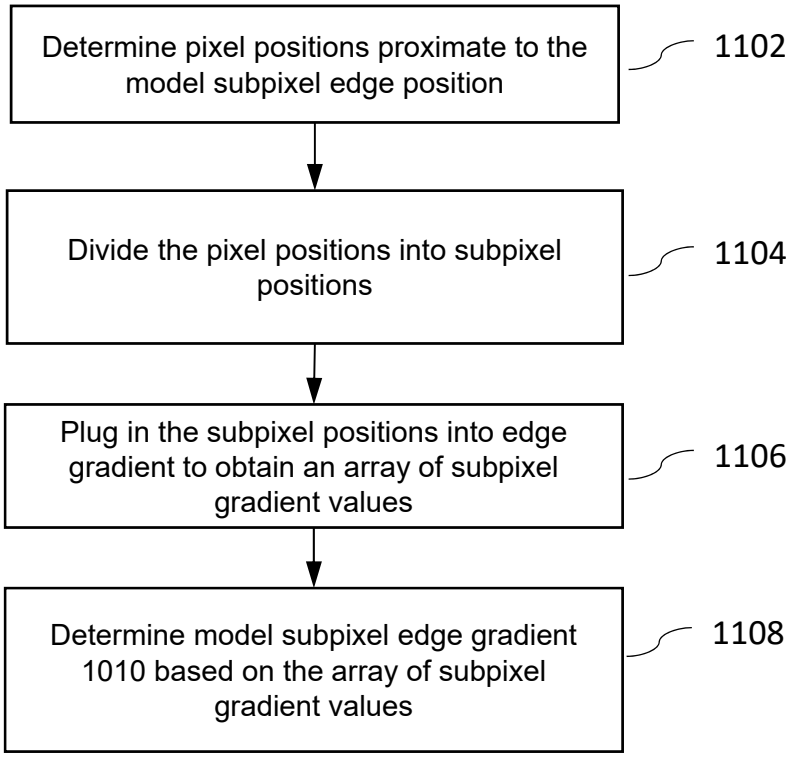

Determine pixel positions proximate to the model subpixel edge position
1102
Divide the pixel positions into subpixel positions
1104
Plug in the subpixel positions into edge gradient to obtain an array of subpixel gradient values
1106
Determine model subpixel edge gradient 1010 based on the array of subpixel gradient values
1108

Figure 11

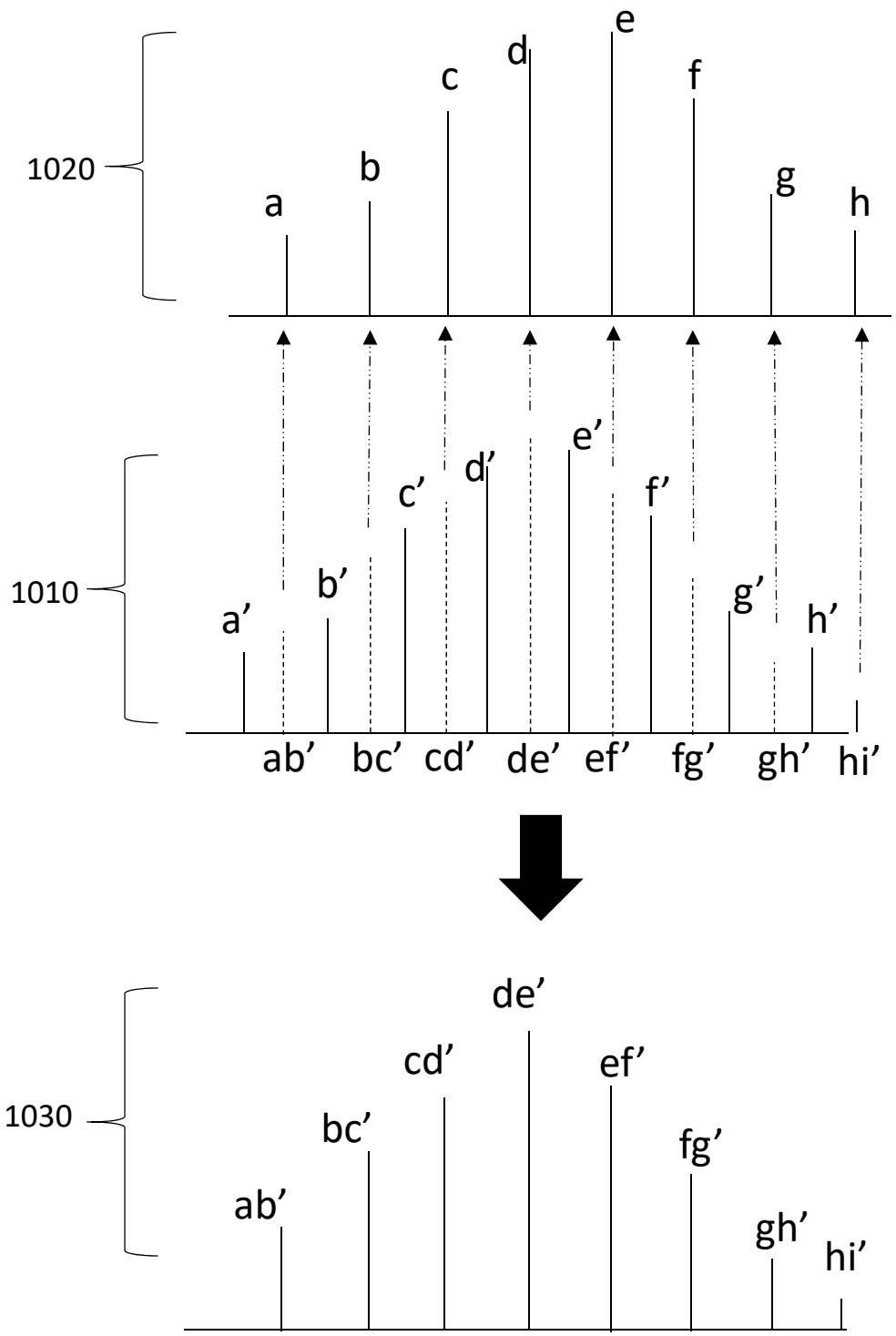

1020
a
b
c
d
e
f
g
h
1010
a’
b’
c’
d’
e’
f’
g’
h’
ab’
bc’
cd’
de’
ef’
fg’
gh’
hi’
1030
ab’
bc’
cd’
de’
ef’
fg’
gh’
hi’

Figure 12

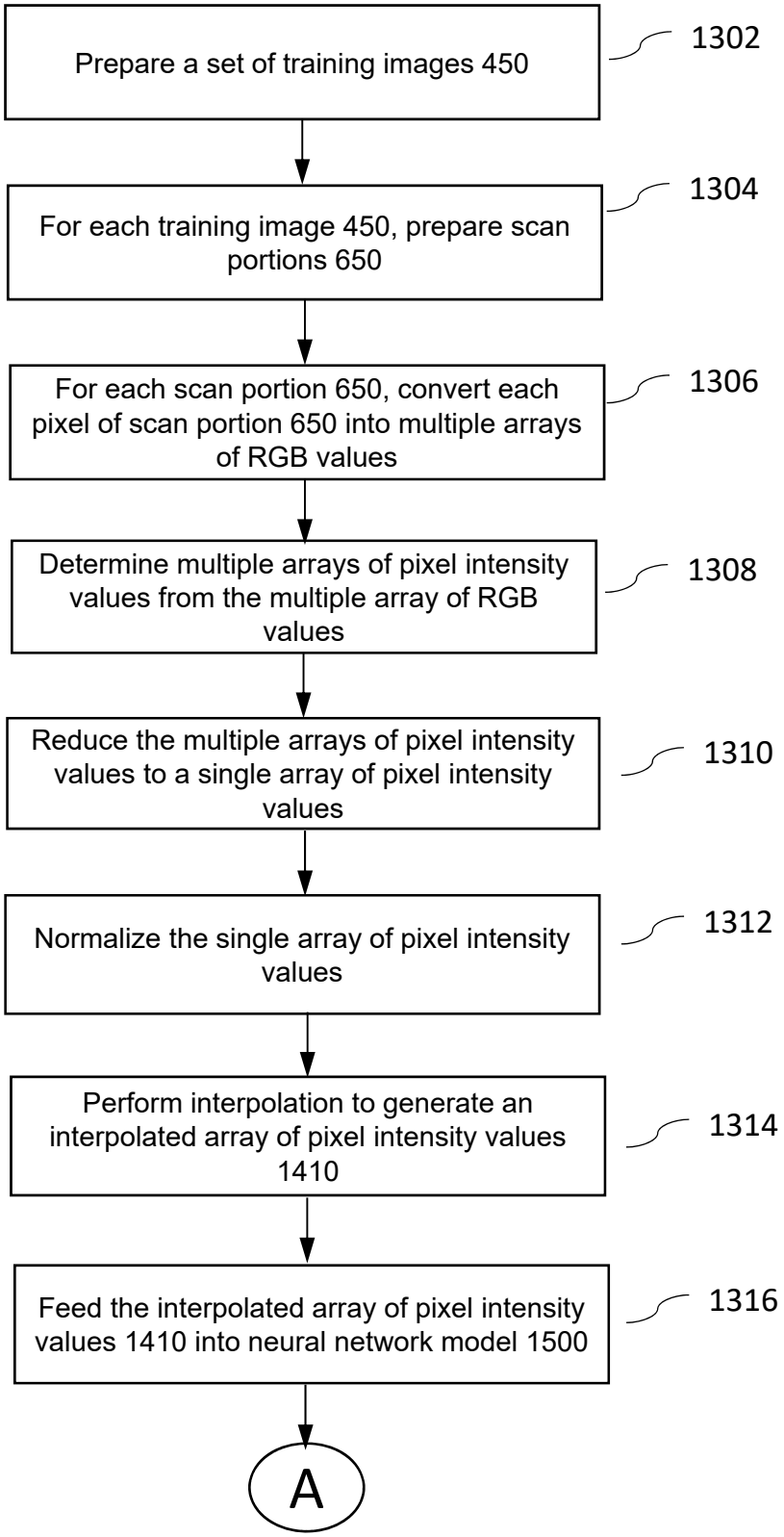

Prepare a set of training images 450
1302
For each training image 450, prepare scan portions 650
1304
For each scan portion 650, convert each pixel of scan portion 650 into multiple arrays of RGB values
1306
Determine multiple arrays of pixel intensity values from the multiple array of RGB values
1308
Reduce the multiple arrays of pixel intensity values to a single array of pixel intensity values
1310
Normalize the single array of pixel intensity values
1312
Perform interpolation to generate an interpolated array of pixel intensity values 1410
1314
Feed the interpolated array of pixel intensity values 1410 into neural network model 1500
1316
A

Figure 13

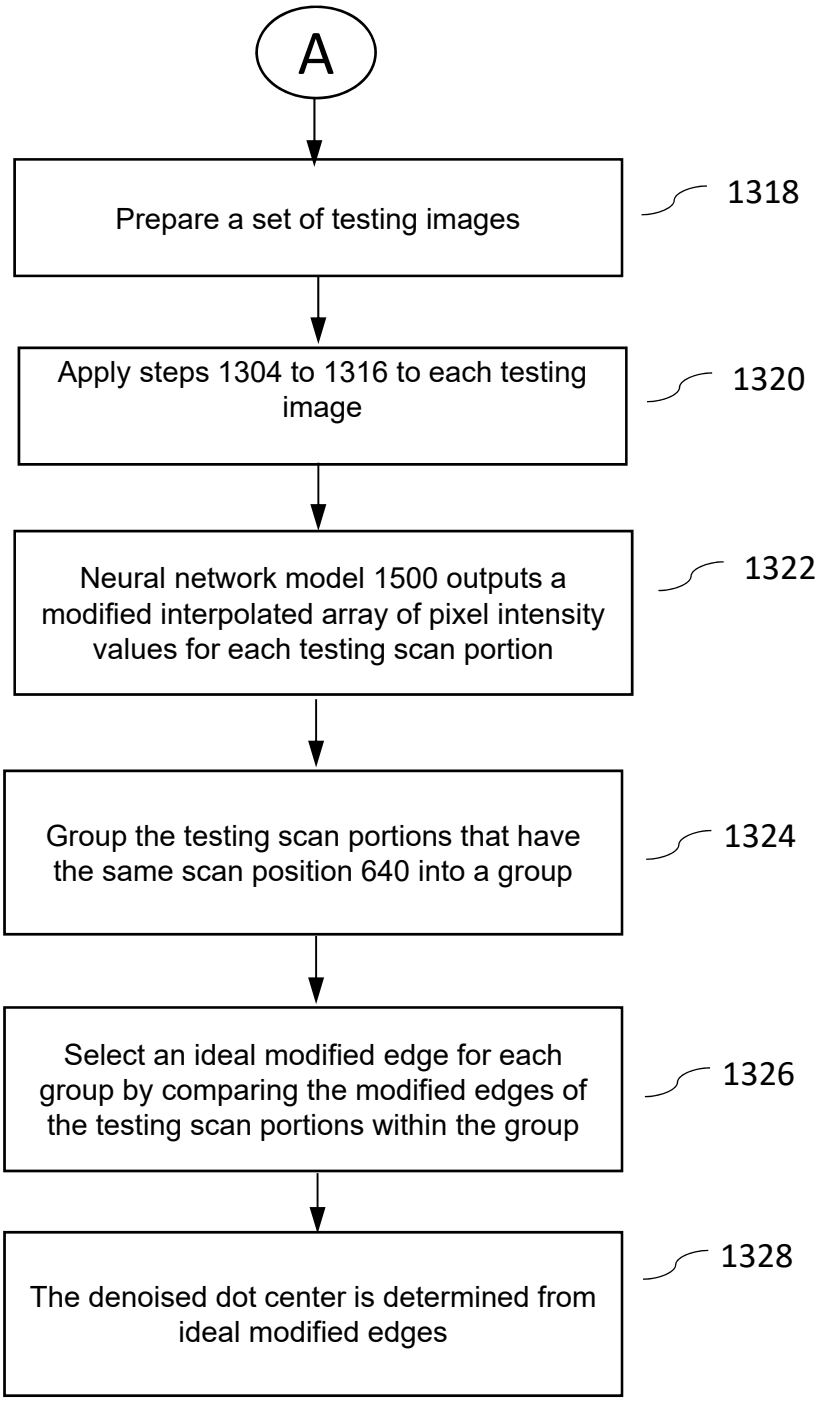


Figure 13
(continue)

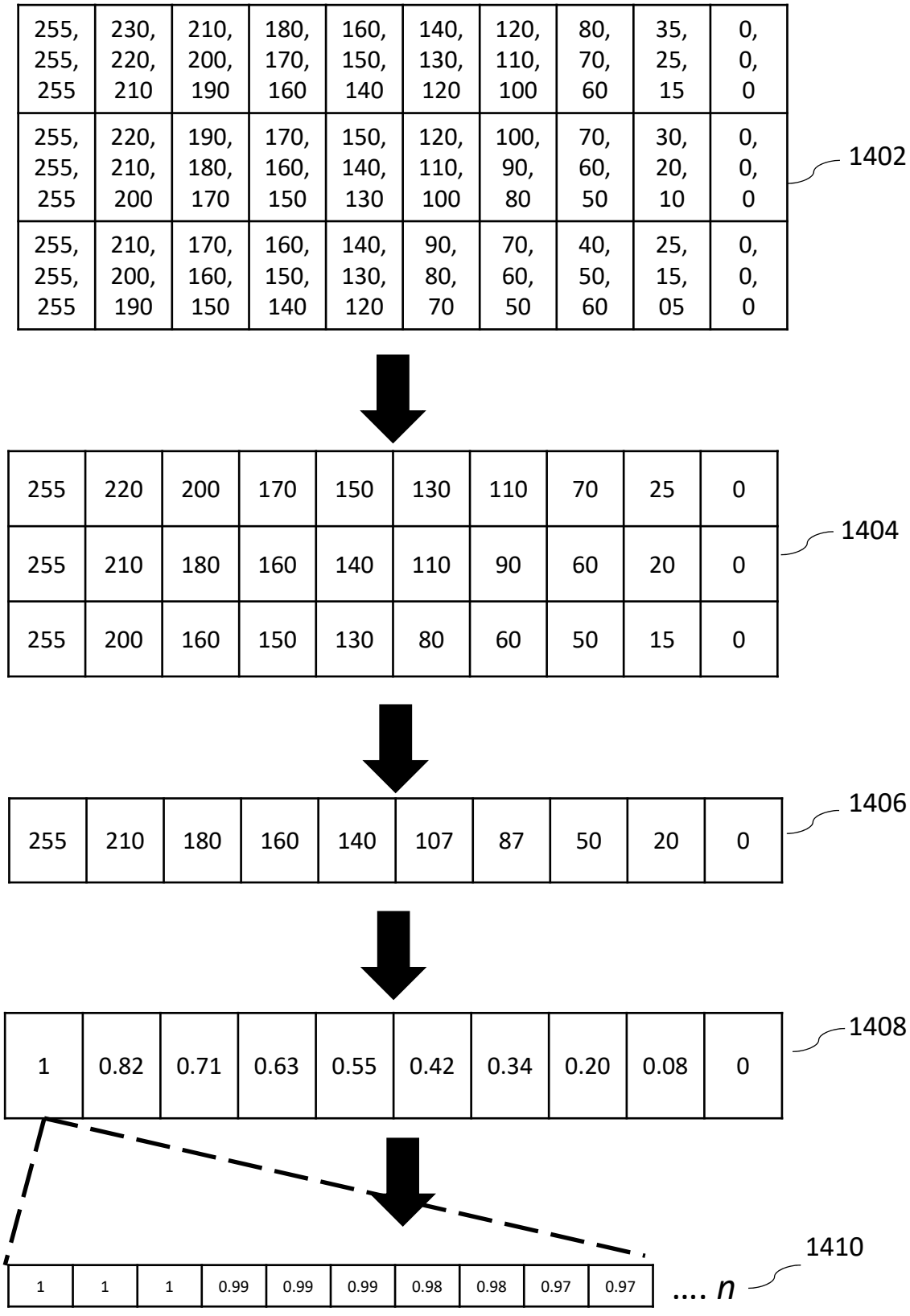

255, 255, 255
230, 220, 210
210, 200, 190
180, 170, 160
160, 150, 140
140, 130, 120
120, 110, 100
80, 70, 60
35, 25, 15
0, 0, 0
255, 255, 255
220, 210, 200
190, 180, 170
170, 160, 150
150, 140, 130
120, 110, 100
100, 90, 80
70, 60, 50
30, 20, 10
0, 0, 0
255, 255, 255
210, 200, 190
170, 160, 150
160, 150, 140
140, 130, 120
90, 80, 70
70, 60, 50
40, 50, 60
25, 15, 05
0, 0, 0
1402
255 220 200 170 150 130 110 70 25 0
255 210 180 160 140 110 90 60 20 0
255 200 160 150 130 80 60 50 15 0
1404
255 210 180 160 140 107 87 50 20 0
1406
1 0.82 0.71 0.63 0.55 0.42 0.34 0.20 0.08 0
1408
1 1 1 0.99 0.99 0.99 0.98 0.98 0.97 0.97
.... n
1410

Figure 14

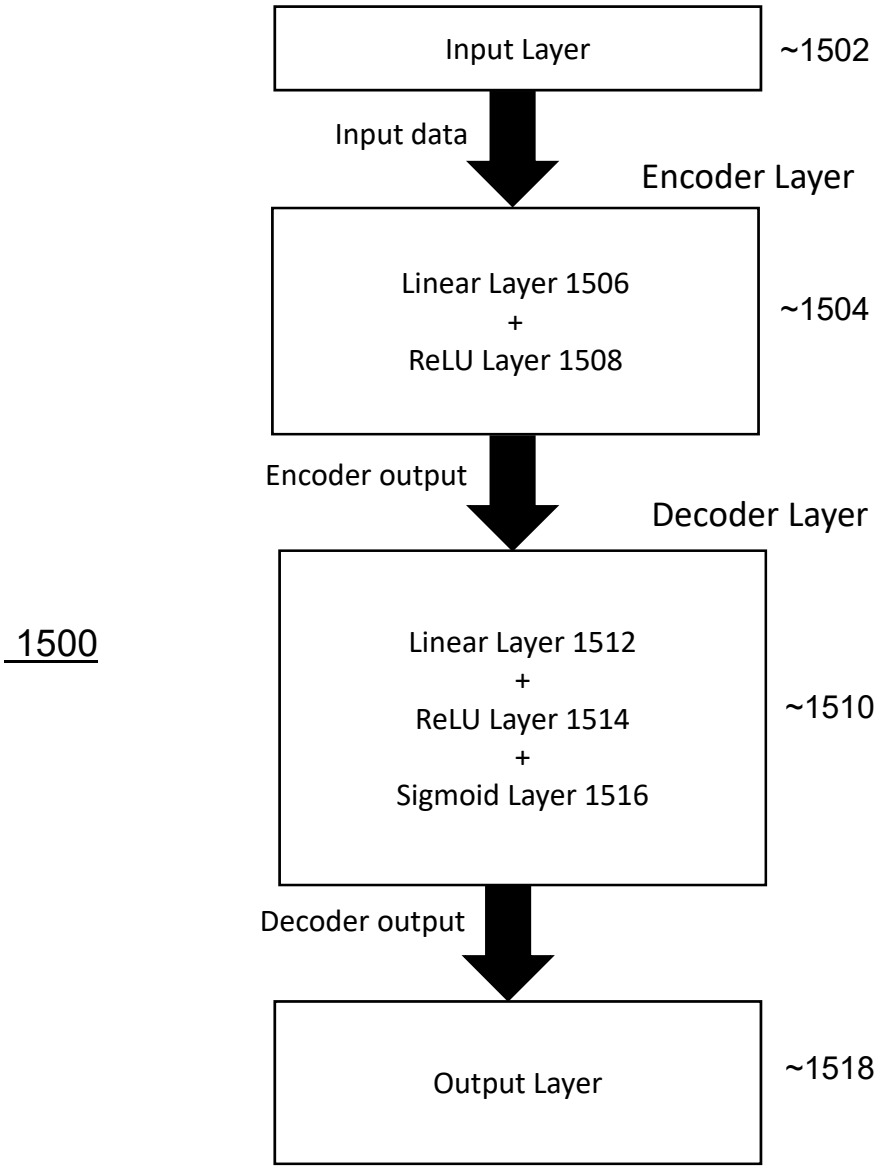

Input Layer
~1502
Input data
Encoder Layer
Linear Layer 1506
+
ReLU Layer 1508
~1504
Encoder output
Decoder Layer
1500
Linear Layer 1512
+
ReLU Layer 1514
+
Sigmoid Layer 1516
~1510
Decoder output
Output Layer
~1518

Figure 15

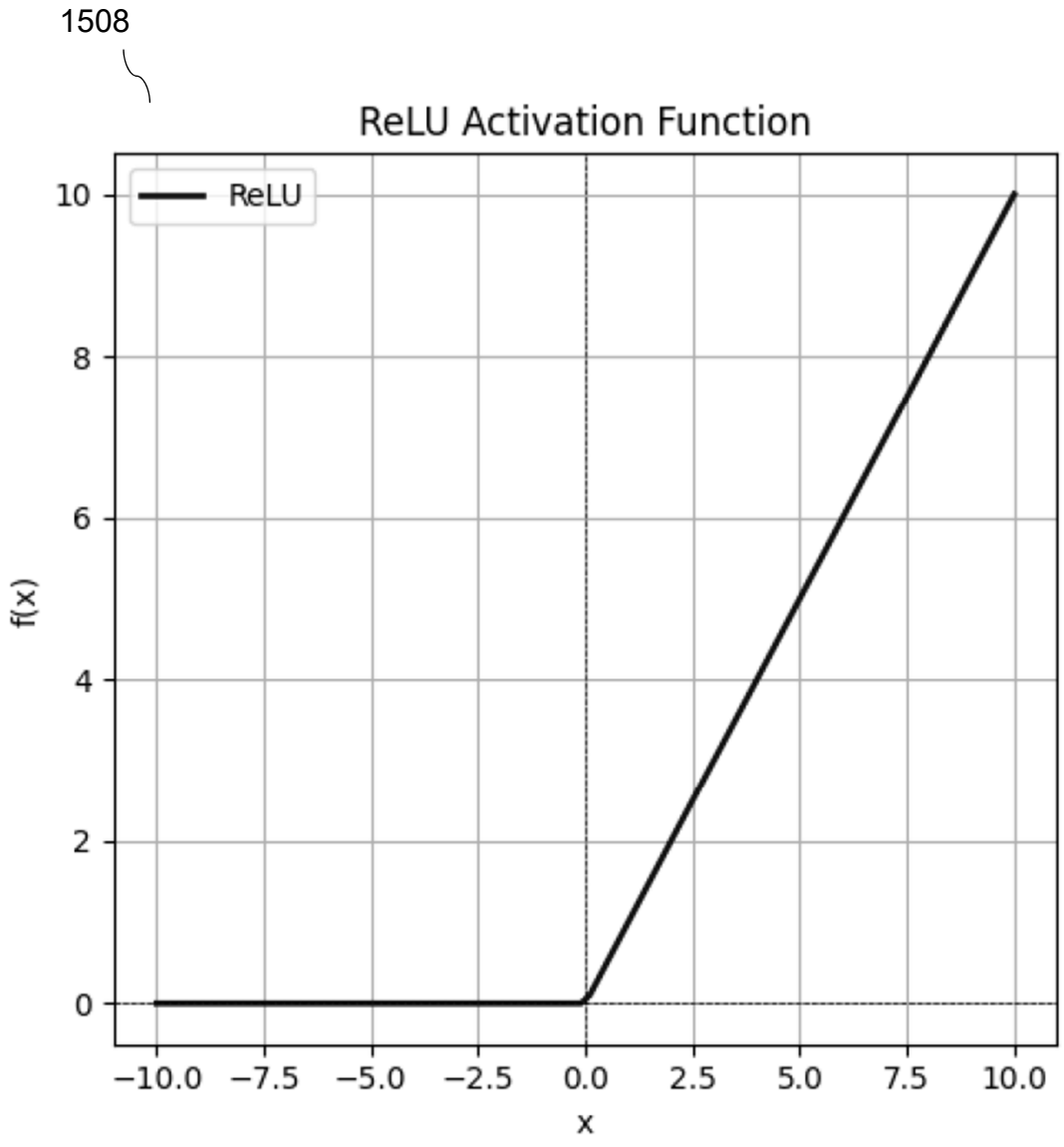

1508
ReLU Activation Function
ReLU
f(x)
10
8
6
4
2
0
−10.0
−7.5
−5.0
−2.5
0.0
2.5
5.0
7.5
10.0
x

Figure 16

1516

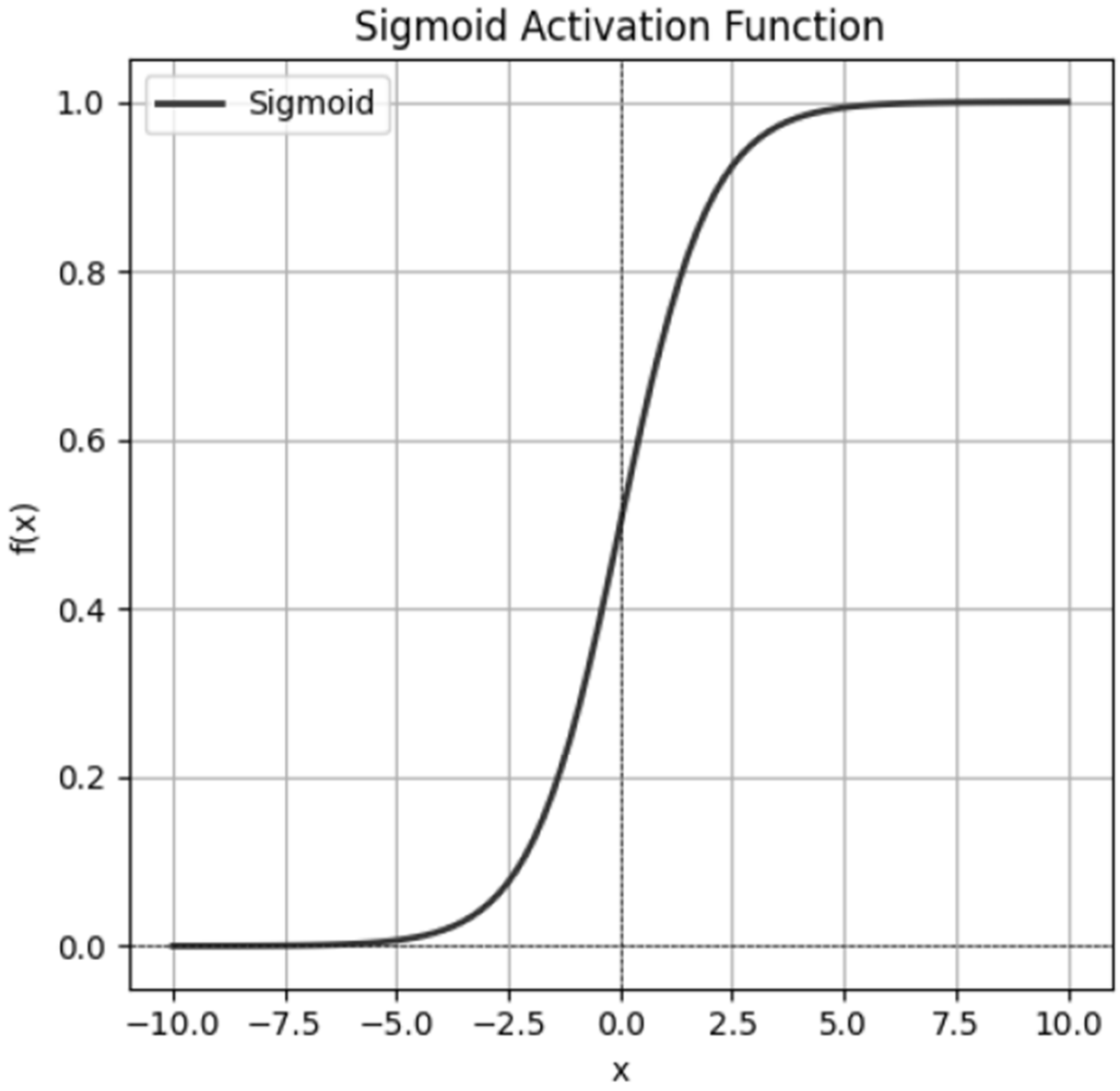


Figure 17

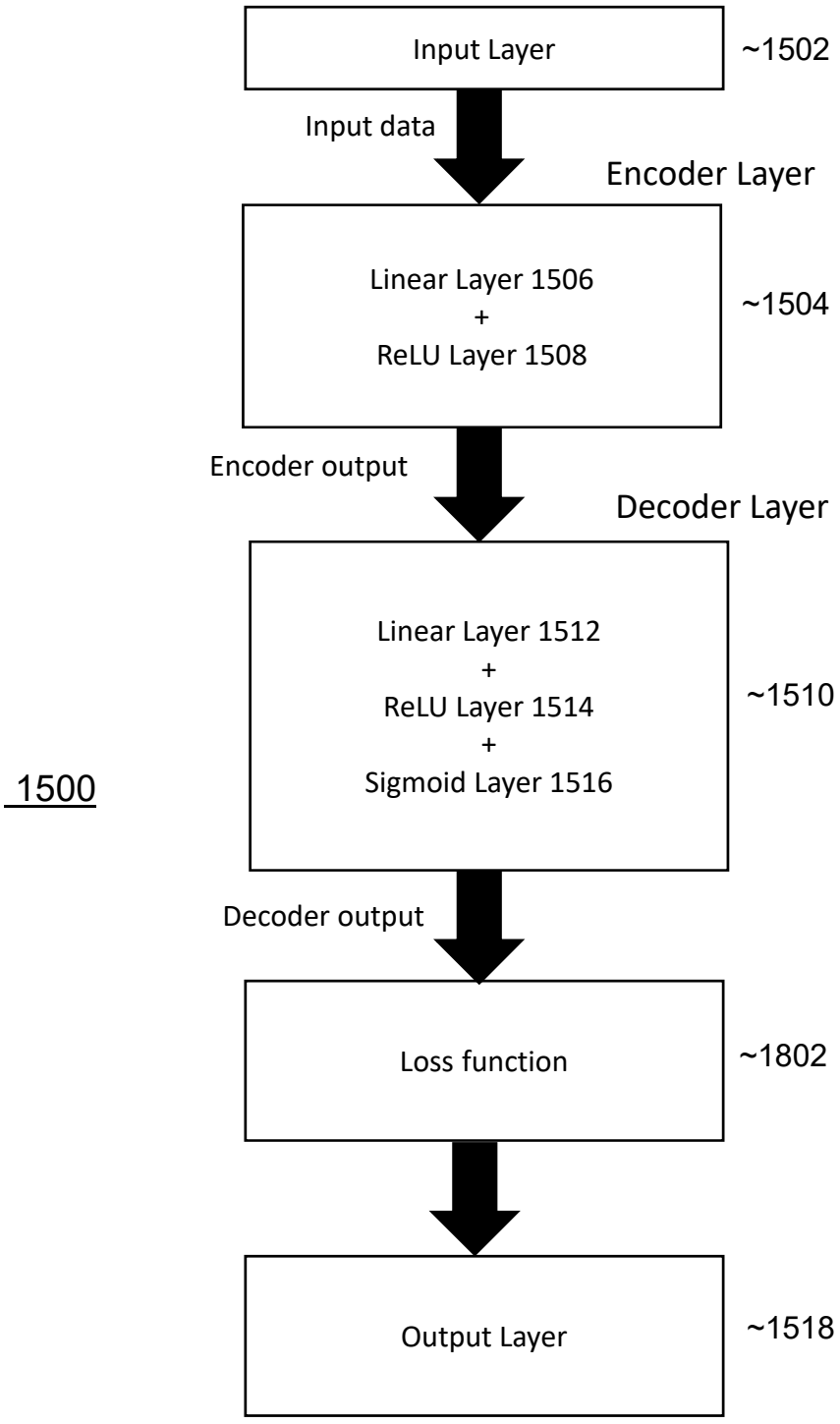

Input Layer
~1502
Input data
Encoder Layer
Linear Layer 1506
+
ReLU Layer 1508
~1504
Encoder output
Decoder Layer
Linear Layer 1512
+
ReLU Layer 1514
+
Sigmoid Layer 1516
~1510
1500
Decoder output
Loss function
~1802
Output Layer
~1518

Figure 18