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(54) **METHOD AND APPARATUS FOR REAL-TIME SAO PARAMETER ESTIMATION**

(71) Applicant: **TEXAS INSTRUMENTS INCORPORATED**, Dallas, TX (US)

(72) Inventors: **Hrushikesh Tukaram Garud**, Maharashtra (IN); **Mihir Narendra Mody**, Bangalore (IN); **Soyeb Nagori**, Bangalore (IN)

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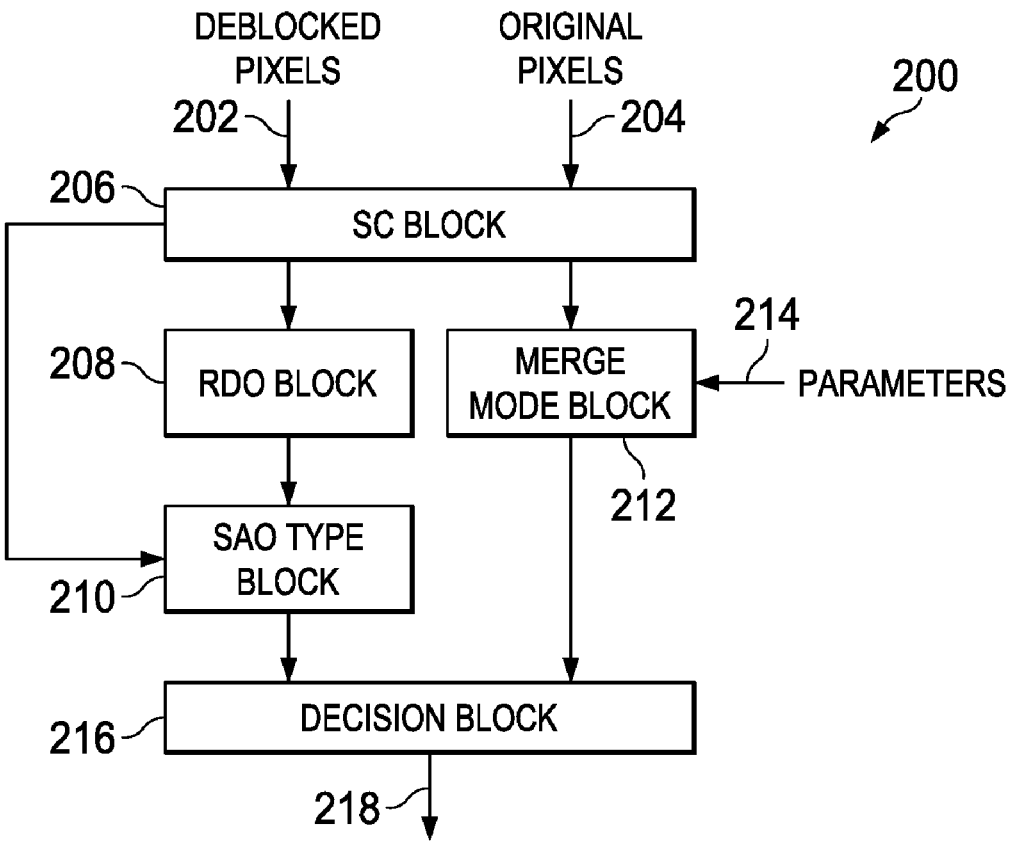
(57) **ABSTRACT**

The disclosure provides a sample adaptive offset (SAO) encoder. The SAO encoder includes a statistics collection (SC) block and a rate distortion optimization (RDO) block coupled to the SC block. The SC block receives a set of deblocked pixels and a set of original pixels. The SC block categorizes each deblocked pixel of the set of deblocked pixels in at least one of a plurality of band and edge categories. The SC block estimates an error in each category as difference between a deblocked pixel of the set of deblocked pixels and corresponding original pixel of the set of original pixels. The RDO block determines a set of candidate offsets associated with each category and selects a candidate offset with a minimum RD cost. The minimum RD cost is used by a SAO type block and a decision block to generate final offsets for the SAO encoder.



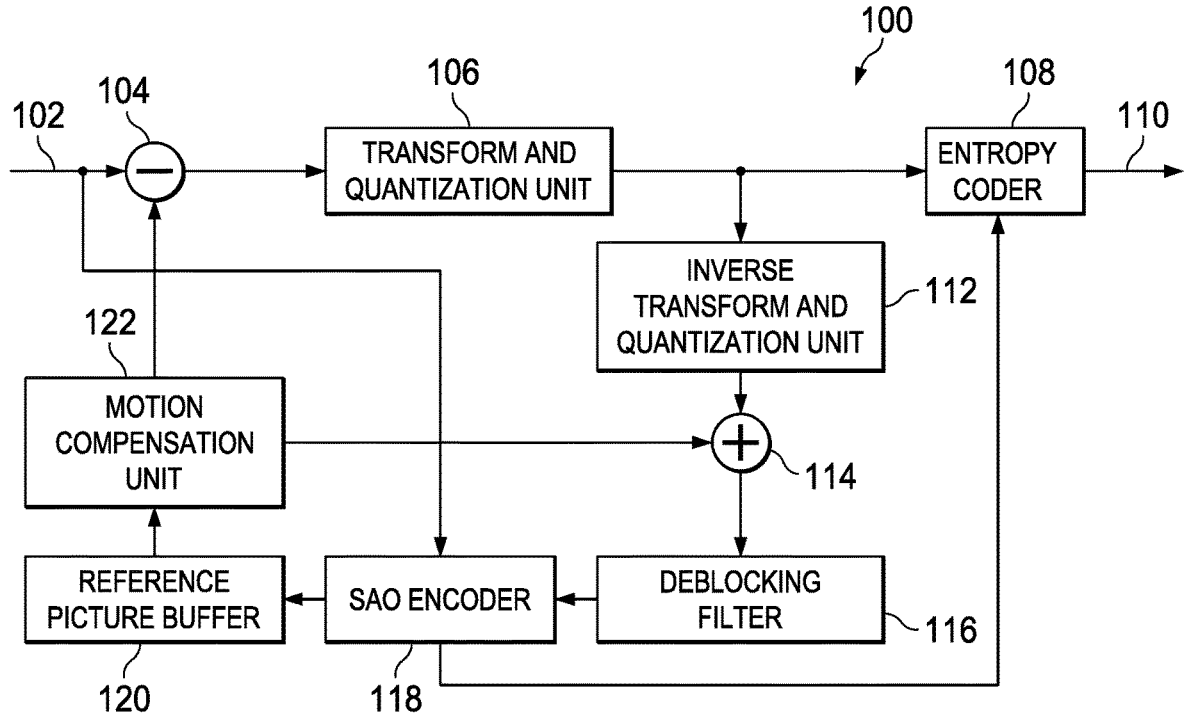

100
102
104
106
108
110
TRANSFORM AND QUANTIZATION UNIT
ENTROPY CODER
INVERSE TRANSFORM AND QUANTIZATION UNIT
112
122
MOTION COMPENSATION UNIT
114
REFERENCE PICTURE BUFFER
SAO ENCODER
DEBLOCKING FILTER
116
120
118

FIG. 1

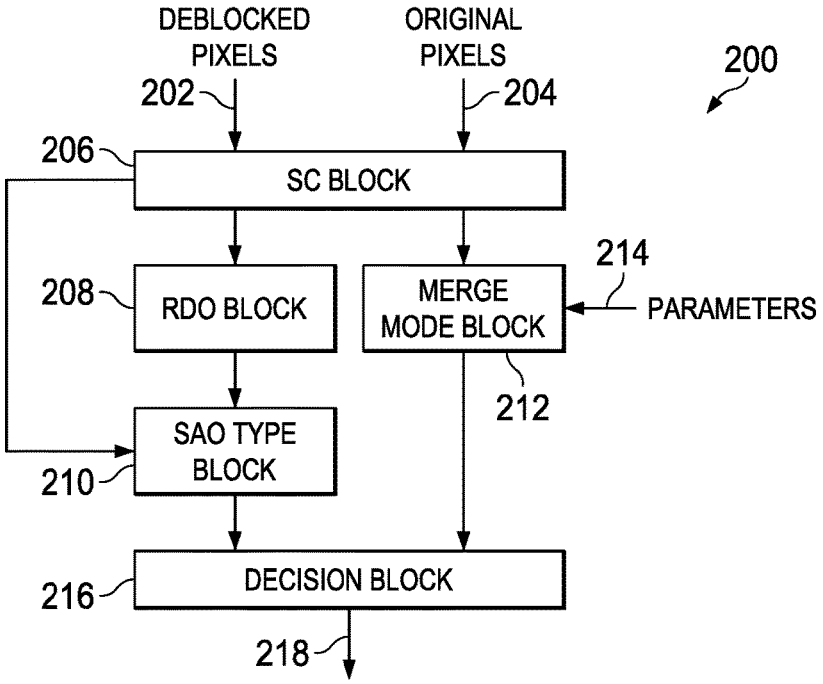

DEBLOCKED PIXELS
ORIGINAL PIXELS
200
202
204
206
SC BLOCK
214
208
RDO BLOCK
MERGE MODE BLOCK
PARAMETERS
212
SAO TYPE BLOCK
210
216
DECISION BLOCK
218

FIG. 2

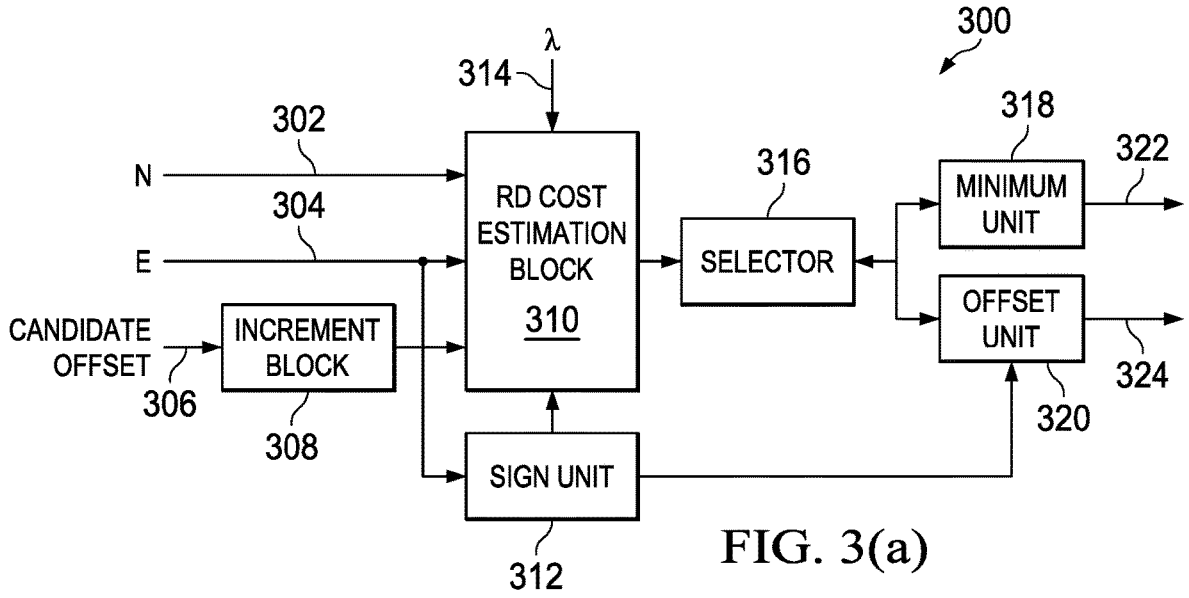

300
λ
314
302
N
304
E
CANDIDATE OFFSET
306
INCREMENT BLOCK
308
RD COST ESTIMATION BLOCK
310
SIGN UNIT
312
316
SELECTOR
318
MINIMUM UNIT
322
OFFSET UNIT
320
324

FIG. 3(a)

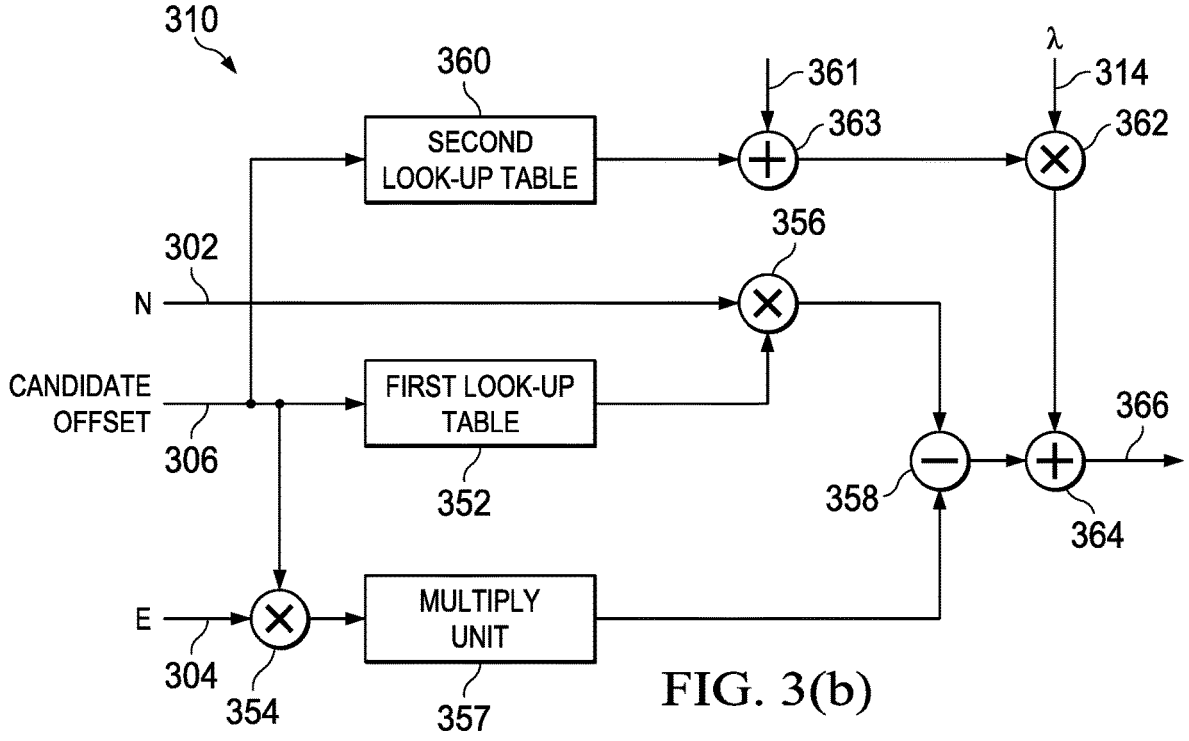

310
360
SECOND LOOK-UP TABLE
361
363
λ
314
362
356
302
N
CANDIDATE OFFSET
306
FIRST LOOK-UP TABLE
352
366
358
364
E
304
354
MULTIPLY UNIT
357

FIG. 3(b)

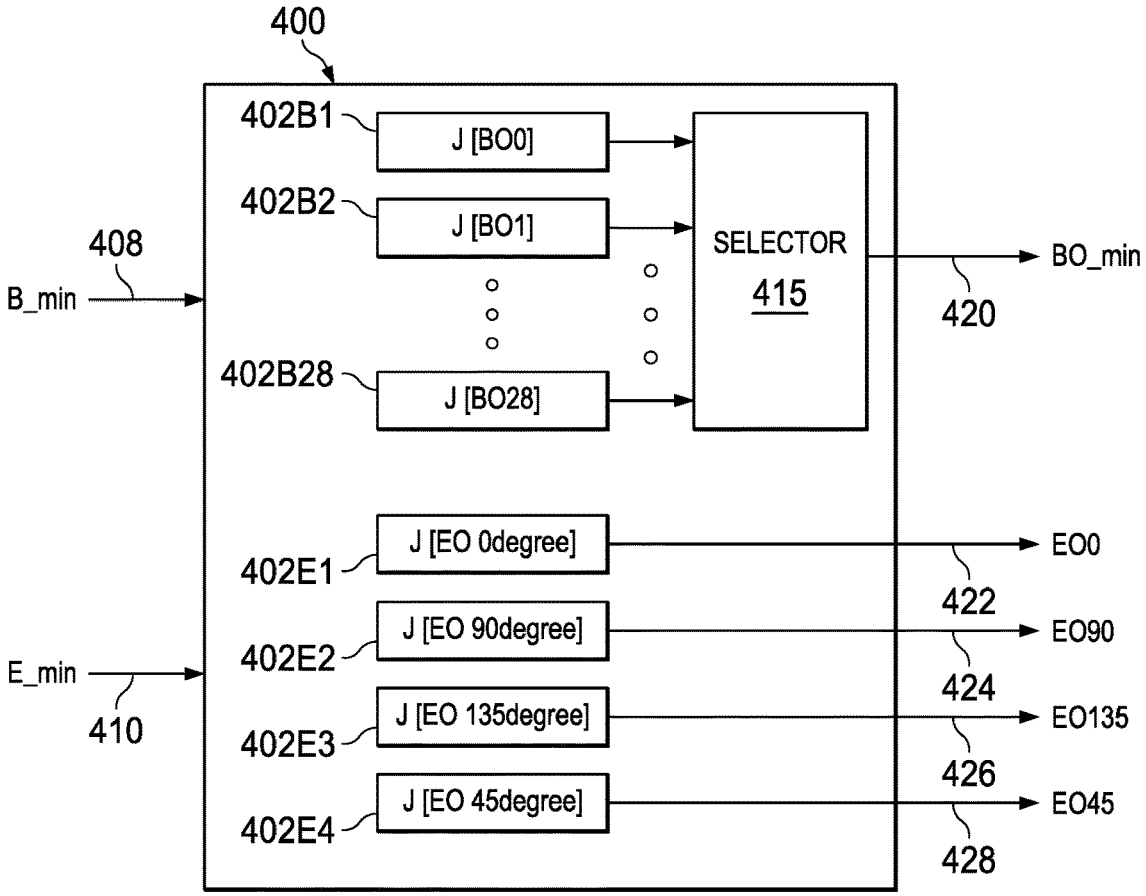

400
402B1
J [BO0]
402B2
J [BO1]
408
B_min
SELECTOR
415
BO_min
420
402B28
J [BO28]
J [EO 0degree]
402E1
EO0
422
J [EO 90degree]
402E2
EO90
E_min
424
410
J [EO 135degree]
402E3
EO135
426
J [EO 45degree]
402E4
EO45
428

FIG. 4(a)

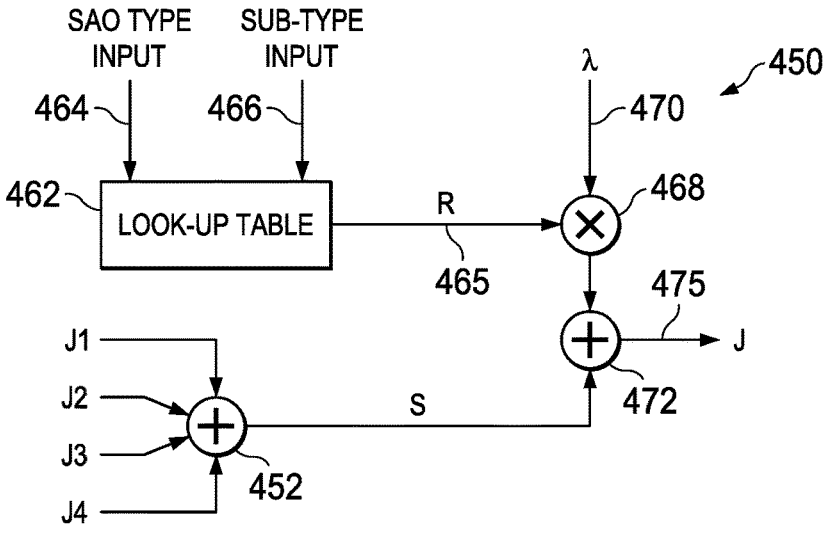

SAO TYPE INPUT
SUB-TYPE INPUT
λ
450
464
466
470
462
LOOK-UP TABLE
R
468
465
475
J1
J
J2
S
472
J3
452
J4

FIG. 4(b)

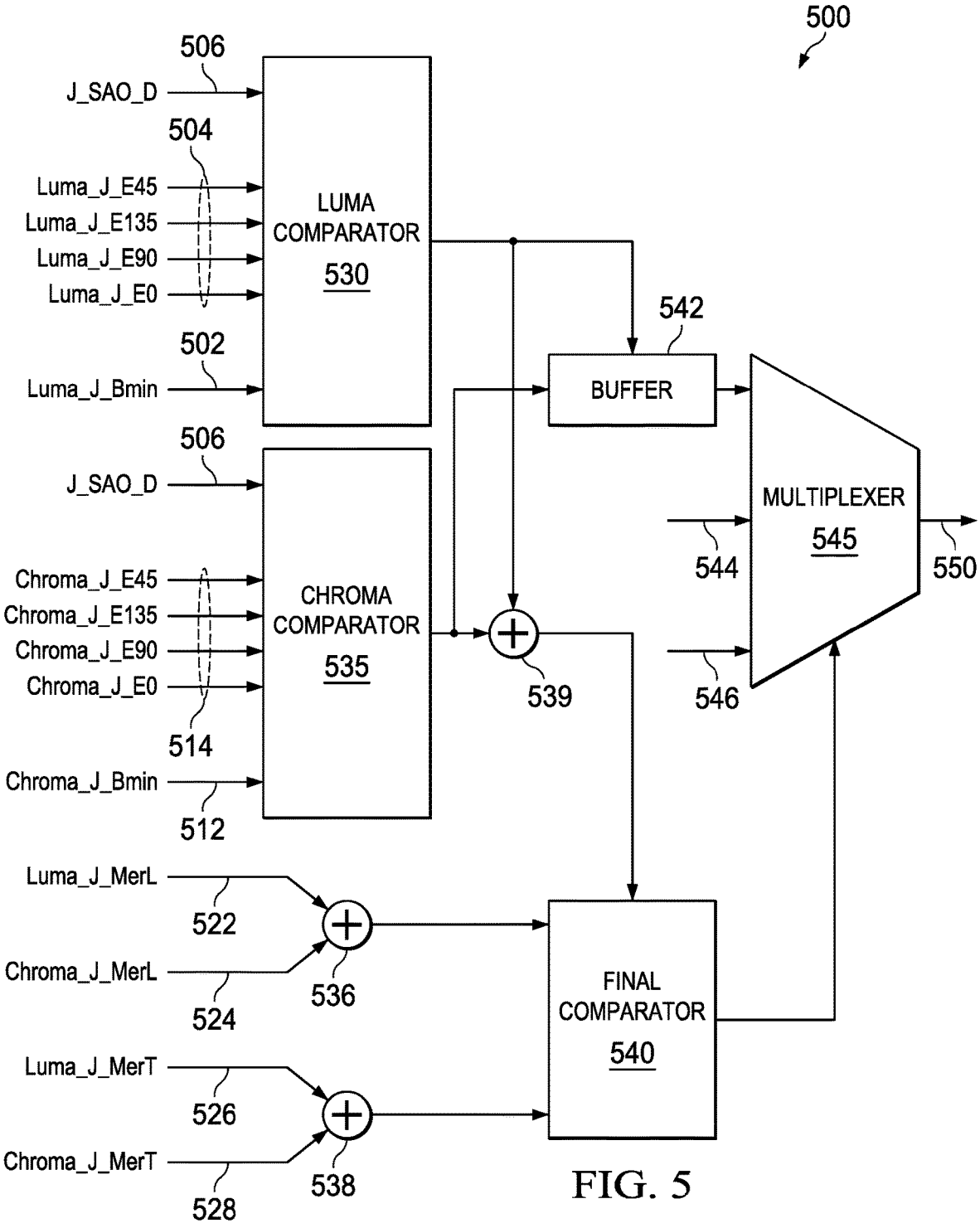

500
506
J_SAO_D
504
Luma_J_E45
Luma_J_E135
Luma_J_E90
Luma_J_E0
LUMA COMPARATOR 530
502
Luma_J_Bmin
542
BUFFER
506
J_SAO_D
Chroma_J_E45
Chroma_J_E135
Chroma_J_E90
Chroma_J_E0
514
CHROMA COMPARATOR 535
Chroma_J_Bmin
512
539
MULTIPLEXER 545
544
546
550
Luma_J_MerL
522
Chroma_J_MerL
524
536
Luma_J_MerT
526
Chroma_J_MerT
528
538
FINAL COMPARATOR 540

FIG. 5

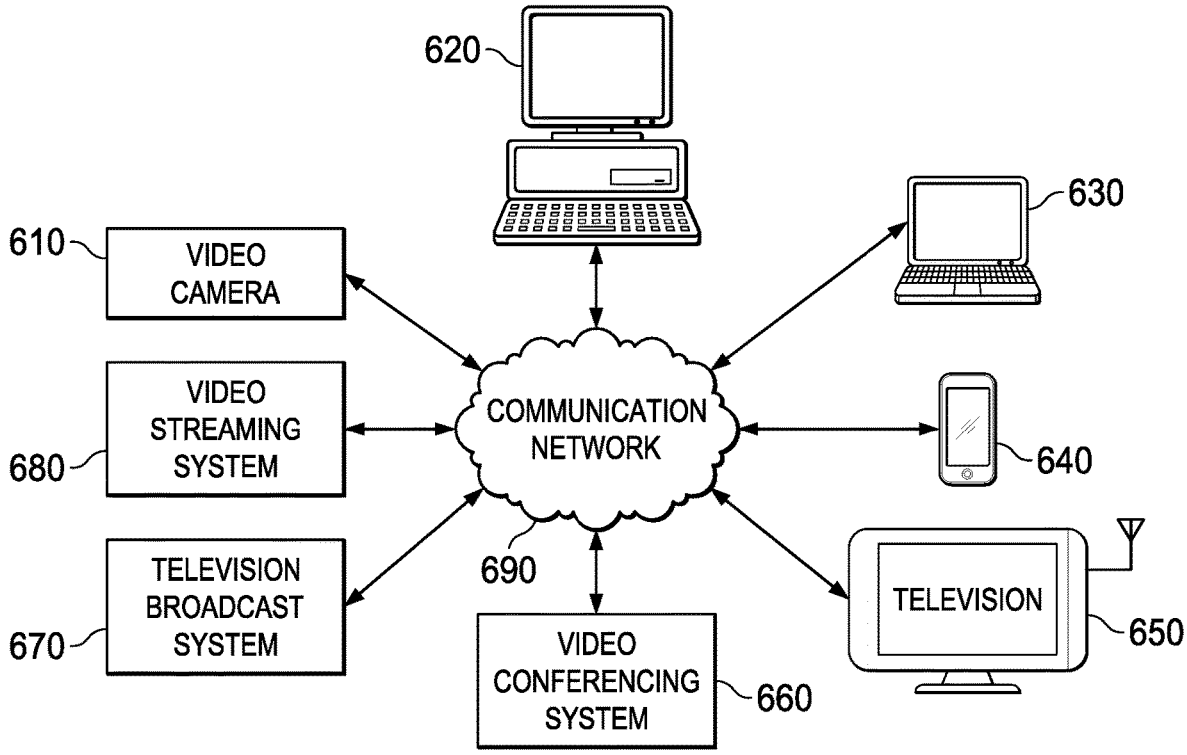

620
630
610
VIDEO CAMERA
VIDEO STREAMING SYSTEM
680
COMMUNICATION NETWORK
640
TELEVISION BROADCAST SYSTEM
670
690
TELEVISION
650
VIDEO CONFERENCING SYSTEM
660

FIG. 6

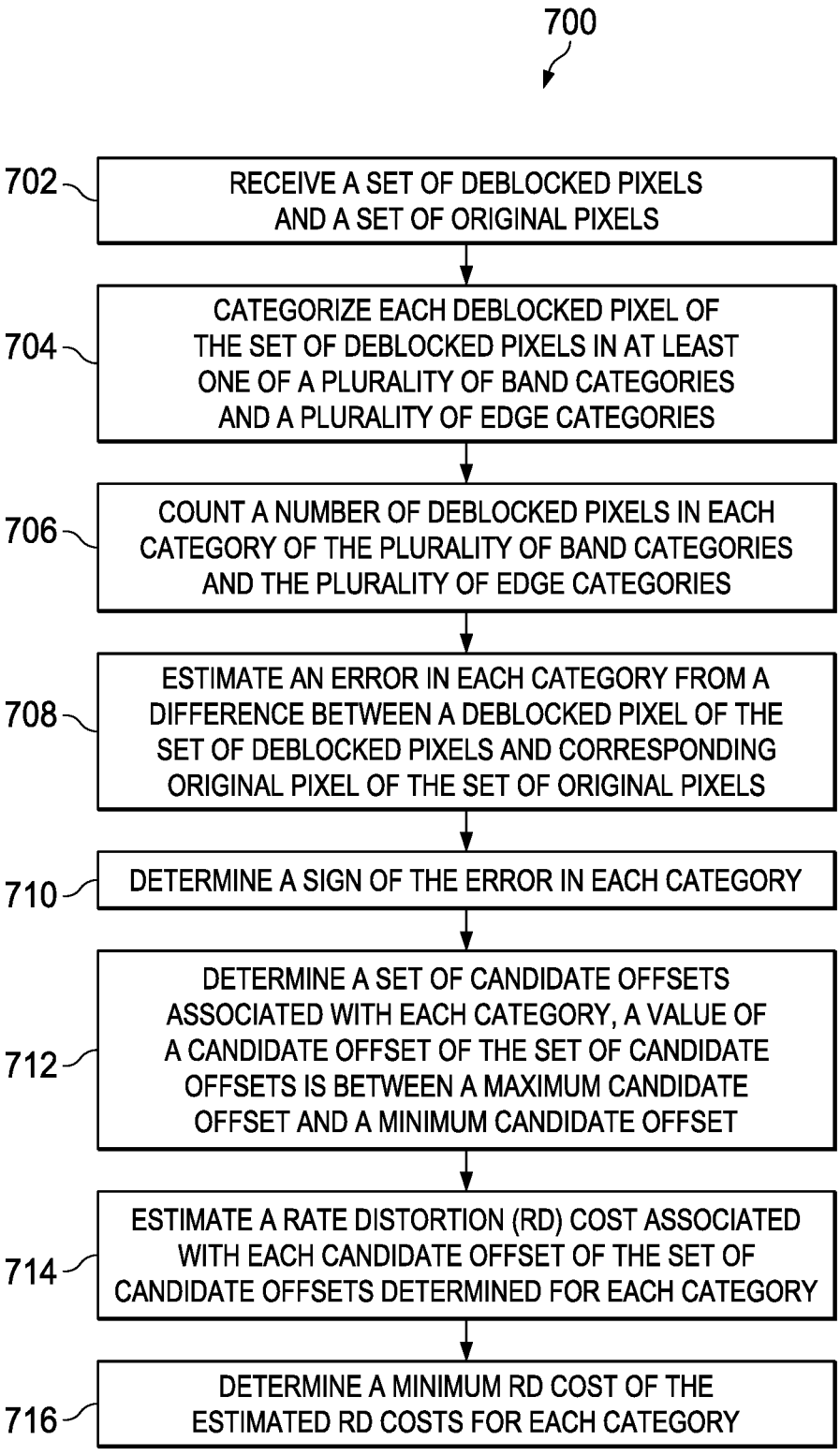

700
702
RECEIVE A SET OF DEBLOCKED PIXELS AND A SET OF ORIGINAL PIXELS
704
CATEGORIZE EACH DEBLOCKED PIXEL OF THE SET OF DEBLOCKED PIXELS IN AT LEAST ONE OF A PLURALITY OF BAND CATEGORIES AND A PLURALITY OF EDGE CATEGORIES
706
COUNT A NUMBER OF DEBLOCKED PIXELS IN EACH CATEGORY OF THE PLURALITY OF BAND CATEGORIES AND THE PLURALITY OF EDGE CATEGORIES
708
ESTIMATE AN ERROR IN EACH CATEGORY FROM A DIFFERENCE BETWEEN A DEBLOCKED PIXEL OF THE SET OF DEBLOCKED PIXELS AND CORRESPONDING ORIGINAL PIXEL OF THE SET OF ORIGINAL PIXELS
710
DETERMINE A SIGN OF THE ERROR IN EACH CATEGORY
712
DETERMINE A SET OF CANDIDATE OFFSETS ASSOCIATED WITH EACH CATEGORY, A VALUE OF A CANDIDATE OFFSET OF THE SET OF CANDIDATE OFFSETS IS BETWEEN A MAXIMUM CANDIDATE OFFSET AND A MINIMUM CANDIDATE OFFSET
714
ESTIMATE A RATE DISTORTION (RD) COST ASSOCIATED WITH EACH CANDIDATE OFFSET OF THE SET OF CANDIDATE OFFSETS DETERMINED FOR EACH CATEGORY
716
DETERMINE A MINIMUM RD COST OF THE ESTIMATED RD COSTS FOR EACH CATEGORY

FIG. 7

METHOD AND APPARATUS FOR REAL-TIME SAO PARAMETER ESTIMATION

CROSS REFERENCES TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 16/432,453 filed on Jun. 5, 2019, which is a continuation of U.S. patent application Ser. No. 15/970,497 filed on May 3, 2018, (now U.S. Pat. No. 10,321,135) which is a continuation of U.S. patent application Ser. No. 15/367,378 filed on Dec. 2, 2016, (now U.S. Pat. No. 9,967,569) which is a continuation of U.S. patent application Ser. No. 14/447,062, filed on Jul. 30, 2014, which claims priority from India Provisional Patent Application No. 3400/CHE/2013 filed on Jul. 30, 2013, the entireties of which are all hereby incorporated by reference.

TECHNICAL FIELD

[0002] Embodiments of the disclosure relate generally to video coding and more particularly to a SAO filter used in video coding standards such as H.264 and H.265.

BACKGROUND

[0003] High Efficiency Video Coding (HEVC) is a video coding standard being developed jointly by ITU-T, also known as the Video Coding Experts Group (VCEG), and by ISO/IEC, also known as the Moving Picture Experts Group (MPEG) in the joint collaborative team on video coding (JCT-VC).

[0004] A video input signal has multiple frames. HEVC divides a frame into rectangular blocks or LCU (largest coding unit) or macro-blocks of 16×16, 32×32 or 64×64. An optimal size of the LCU is selected based on the video content. The rectangular blocks can be predicted from previously decoded data either by motion compensated prediction or intra prediction. The resulting prediction error is coded by applying block transforms based on an integer approximation of the discrete cosine transform which is followed by the quantization and coding of the transform coefficients.

[0005] Transform coding with quantization is a type of data compression which is commonly "lossy" as the quantization process discards a portion of data associated with the transform of the video input, thereby lowering its bandwidth requirement but often also results in quality loss in the reconstructed video.

[0006] SAO (Sample Adaptive Offset) encoder is placed in a reconstruction loop of a video encoder and it is placed in the video encoder after a de-blocking filter. SAO is a process of adding offset to de-blocked pixels received from the de-blocking filter. The offset reduces the distortion in the reconstructed image and thus provides a reconstructed video with high quality and PSNR (peak signal to noise ratio) and simultaneously achieving bitrate reduction. SAO encoder is a computation intensive block in HEVC and increases the video decoder/encoder complexity. Therefore, SAO encoder process needs to be optimized to minimize the computational complexity while maximizing bitrate saving, improving visual quality and maintaining compliance set by the HEVC standard.

SUMMARY

[0007] This Summary is provided to comply with 37 C.F.R. § 1.73, requiring a summary of the invention briefly indicating the nature and substance of the invention. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

[0008] An embodiment provides a sample adaptive offset (SAO) encoder. The SAO encoder includes a statistics collection (SC) block that receives a set of deblocked pixels and a set of original pixels. The SC block categorizes each deblocked pixel of the set of deblocked pixels in at least one of a plurality of band categories and a plurality of edge categories. The SC block counts a number of deblocked pixels in each category of the plurality of band categories and the plurality of edge categories and also estimates an error in each category from a difference between a deblocked pixel of the set of deblocked pixels and corresponding original pixel of the set of original pixels.

[0009] The SAO encoder also includes a rate distortion optimization (RDO) block that is coupled to the SC block. The RDO block determines a sign of the error in each category, and also determines a set of candidate offsets associated with each category. A value of a candidate offset of the set of candidate offsets is between a maximum candidate offset and a minimum candidate offset. The RDO block estimates a rate distortion (RD) cost associated with each candidate offset of the set of candidate offsets determined for each category. The RDO block also determines a minimum RD cost of the estimated RD costs for each category.

[0010] Other aspects and example embodiments are provided in the Drawings and the Detailed Description that follows.

BRIEF DESCRIPTION OF THE VIEWS OF DRAWINGS

[0011] FIG. **1** illustrates a block diagram of a video encoder;

[0012] FIG. **2** illustrates a block diagram of a SAO (sample adaptive offset) encoder, according to an embodiment;

[0013] FIG. **3**(*a*) illustrates a block diagram of a RDO (rate distortion optimization) block, according to an embodiment;

[0014] FIG. **3**(*b*) illustrates a block diagram of an RD (rate distortion) cost estimation block, according to an embodiment;

[0015] FIG. **4**(*a*) illustrates a block diagram of a SAO (sample adaptive offset) type block, according to an embodiment;

[0016] FIG. **4**(*b*) illustrates a block diagram of a cost estimation module, according to an embodiment;

[0017] FIG. **5** illustrates a block diagram of a decision block, according to an embodiment;

[0018] FIG. **6** is an example environment in which various aspect of the present disclosure may be implemented; and

[0019] FIG. **7** illustrates a method of generating final offsets in a SAO encoder, according to an embodiment.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0020] FIG. **1** illustrates a block diagram of a video encoder **100**. The video encoder **100** receives a video input

102. A subtractor **104** in the video encoder **100** receives the video input **102**. A transform and quantization unit **106** is coupled to the subtractor **104**. An entropy coder **108** and an inverse transform and quantization unit **112** are coupled to the transform and quantization unit **106**. The entropy coder **108** generates a coded video output **110**. The inverse transform and quantization unit **112** is coupled to a summer **114**.

[0021] A deblocking filter **116** is coupled to the summer **114**. A SAO encoder **118**, coupled to the deblocking filter **116**, receives the video input **102**. The entropy coder **108** is coupled to the SAO encoder **118**. A reference picture buffer **120** is coupled to the SAO encoder **118**. A motion compensation unit **122** is coupled to the reference picture buffer **120** and provides an output to the summer **114** and the subtractor **104**. The inverse transform and quantization unit **112**, the summer **114**, the deblocking filter **116**, the SAO encoder **118**, the reference picture buffer **120** and the motion compensation unit **122** together form a reconstruction loop of the video encoder **100**.

[0022] The operation of the video encoder **100** illustrated in FIG. **1** is explained now. The video input **102** has multiple frames. A frame is divided into rectangular blocks or LCU (largest coding units) or macro-blocks and each LCU includes a plurality of pixels. The transform and quantization unit **106** performs transform and quantization on an original LCU received from the subtractor **104**. The transform and quantization unit **106** performs a discrete cosine transform (DCT). The transform and quantization unit **106** transforms the pixel data into a spatial frequency domain. This frequency domain data is quantized to form a quantization block.

[0023] The inverse transform and quantization unit **112** inversely quantizes the quantization block and performs inverse transform on the result of inverse quantization. As an example, if DCT is performed in the transform and quantization unit **106**, inverse DCT is performed in the inverse transform and quantization unit **112**.

[0024] The deblocking filter **116** smoothens artifacts created by the macroblock nature of the encoding process. The SAO encoder **118** adds an offset to deblocked pixels received from the deblocking filter **116**. The offset reduces the distortion in the reconstructed LCU. The reference picture buffer **120** stores the reconstructed LCU. The motion compensation unit **122** performs motion compensation on the motion information received in the reconstructed LCU received from the reference picture buffer **120** to generate a motion compensated LCU. The subtractor **104** subtracts the motion compensated LCU from the original LCU to generate a differential data. Thus, the transform and quantization unit **106** and the entropy coder **108** encodes the differential data rather than the original LCU.

[0025] The entropy coder **108** encodes the quantized data received from the transform and quantization unit **106** to generate the coded video output **110**. Entropy coder **108** employs a fewer bits to encode more frequently used symbols and more bits to encode less frequently used symbols. This process reduces the amount of encoded data that is to be transmitted and/or stored by the entropy coder **108**.

[0026] FIG. **2** illustrates a block diagram of a SAO (sample adaptive offset) encoder **200**, according to an embodiment. The SAO encoder **200** includes a statistics collection (SC) block **206**. The SC block **206** receives a set of deblocked pixels **202** and a set of original pixels **204**. A rate distortion optimization (RDO) block **208** and a merge mode block **212** are coupled to the SC block **206**. A SAO type block **210** is coupled to the RDO block **208** and the SC block **206**. A decision block **216** is coupled to the SAO type block **210** and the merge mode block **212**. The SAO encoder **200** may include one or more additional components known to those skilled in the relevant art and are not discussed here for simplicity of the description.

[0027] The operation of the SAO encoder **200** illustrated in FIG. **2** is explained now. The SC block **206** receives the set of deblocked pixels **202** and the set of original pixels **204**. The set of original pixels **204** corresponds to a current LCU. A deblocking filter (not illustrated in FIG. **2**) generates the set of deblocked pixels **202**. The current LCU includes a luma component and a chroma component. The chroma component further includes a Cb component and a Cr component. The SC block **206** categorizes each deblocked pixel of the set of deblocked pixels **202** in at least one of a plurality of band categories and a plurality of edge categories. In one example, the SAO encoder **200** includes 32 band categories and 4 edge types. Each of the four edge types are further sub-divided into four edge categories. Therefore, there are a total of 16 edge categories and a total of 48 categories (32 band categories and 16 edge categories).

[0028] In another example, the 32 band categories are B0, B1 till B31. The four edge types are 0 degree, 90 degree, 135 degree and 45 degree. Each of these edge types is further sub divided into edge categories defined as category 1, category 2, category 3 and category 4. In yet another example, the band categories and the edge categories are compliant with the HEVC standard.

[0029] Each deblocked pixel is categorized into one of these categories. In one example, a deblocked pixel is categorized in multiple edge categories. In another example, a deblocked pixel is categorized in multiple edge types. For example, a deblocked pixel categorized in edge type 0 degree—category 1, is also categorized in edge type 135 degree—category 2. In yet another example, the SC block **206** discards a deblocked pixel if the SC block **206** is not able to categorize a deblocked pixel in any of these categories. The SC block **206** counts a number of deblocked pixels in each category of the plurality of band categories and the plurality of edge categories. The SC block **206** estimates an error in each category from a difference between a deblocked pixel of the set of deblocked pixels **202** and corresponding original pixel of the set of original pixels **204**.

[0030] The RDO block **208** receives the estimated error in each category and the count of the number of deblocked pixels in each category from the SC block **206**. The RDO block **208** determines a sign of the estimated error in each category. The sign is a positive sign or a negative sign. The RDO block **208** determines a set of candidate offsets for each category. A value of a candidate offset of the set of candidate offsets is between a maximum candidate offset and a minimum candidate offset. In an example, when a video input processed by the SAO encoder **200** is an 8 bit input, the set of candidate offsets are integers from 0 to +7. In another example, when the video input processed by the SAO encoder **200** is a 10 bit input, the set of candidate offsets are integers from 0 to +31.

[0031] The RDO block **208** estimates a rate distortion (RD) cost for each candidate offset of the set of candidate offsets determined in each category. The RDO block **208** estimates the RD cost associated with each candidate offset using the count of the number of deblocked pixels in the

category and an absolute value of the estimated error in that category. The RDO block **208** also uses a bitrate data from a look-up table stored in the SAO encoder **200** for estimating the RD cost associated with each candidate offset.

[0032] In one example, when the sign of the estimated error in a category is a positive sign, the set of candidate offsets are 0, 1, 2 till 7. Thus, the RDO block **208** estimates an RD cost for each of these candidate offsets. The RDO block **208** determines a minimum RD cost of the estimated RD costs for each category. In the above example, when there are 48 categories, the RDO block **208** determines a minimum RD cost for each of these 48 categories. The RDO block **208** also maintains a record of the candidate offset for which the minimum RD cost is obtained for a category. For example, when the set of candidate offsets are 0, 1, 2 till 7 for a category, the RDO block **208** estimates an RD cost for each of these candidate offset. Now, if for a candidate offset 2, the RD cost obtained is minimum, the RDO block **208** provides this minimum RD cost and the corresponding candidate offset (i.e. candidate offset 2) to the SAO type block **210**.

[0033] In addition, the RDO block **208** modifies a sign of the corresponding candidate offset, for which the minimum RD cost is obtained, based on the sign of the estimated error in each category. For example, when a sign of the estimated error in a category is negative, the RDO block **208** changes a sign of the corresponding candidate offset to negative for which the minimum RD cost is obtained for that category.

[0034] The SAO type block **210** receives the minimum RD cost and the corresponding candidate offset for each category from the RDO block **208**. The SAO type block **210** generates a set of band SAO types such that each band SAO type of the set of band SAO types includes a set of band categories. Thus, the SAO type block **210** combines a set of band categories to generate a band SAO type. For example, the SAO type block **210** combines a first four categories of the plurality of band categories to generate a first SAO type and the SAO type block **210** combines a next four categories of the plurality of band categories to generate a second SAO type.

[0035] Similarly, the SAO type block **210** generates a set of edge SAO types such that each edge SAO type of the set of edge SAO types comprises a set of edge categories. For example, the SAO type block **210** combines a set of edge categories of the plurality of edge categories to generate an edge SAO type. The SAO type block **210** estimates a band cost associated with each band SAO type. The band cost associated with a band SAO type is estimated by summing the minimum RD cost associated with each category that is combined to form the band SAO type. In one example, a set of band categories (B0, B 1, B2 and B3) are combined to form a first band SAO type and a minimum RD cost for the respective band categories is 2, 5, 7 and 4. The band cost associated with the first band SAO type is 18 (2+5+7+4=18).

[0036] The SAO type block **210** determines a minimum band cost of the estimated band costs. The SAO type block **210** maintains a record of a set of band categories combined to form the band SAO type for which the minimum band cost is obtained and the corresponding candidate offsets associated with each band category of the set of band categories. The SAO type block **210** provides the minimum band cost, the corresponding SAO type along with the corresponding candidate offsets associated with each band category of the set of band categories to the decision block **216**.

[0037] Similarly, the SAO type block **210** estimates an edge cost associated with each edge SAO type. The edge cost associated with an edge SAO type is estimated by summing the minimum RD cost associated with each edge category combined to form the edge SAO type. The SAO type block **210** provides the edge cost associated with each edge SAO type and corresponding candidate offsets associated with each edge category combined to form the edge SAO type, to the decision block **216**.

[0038] Table 1 illustrates the operation of the SC block **206** and the RDO block **208**.

TABLE 1

SC block			RDO block			
Category	Deblocked Pixel Count	Error	Candidate Offsets	RD cost	Minimum RD cost	Corresponding candidate offset
B0	23	178	0 to +7	16, −317, −588, −829, −1024, −1157, −1260, −1317	−1317	7
B1	64	151	0 to +7	16, −222, −316, −298, −152, 138, 540, 1070	−316	2
B2	4	33	0 to +7	16, −46, −84, −130, −168, −182, −204, −218	−218	7
B3	27	187	0 to +7	16, −331, −608, −847, −1032, −1147, −1224, −1247	−1247	7
B4	7	−21	0 to +7	16, −19, −24, −31, −24, 13, 48, 97	−31	−3
E0	64	558	0 to +7	16, −1036, −1944, −2740, −3408, −3932, −4344, −46	−4628	7
E1	43	124	0 to +7	16, −189, −292, −325, −272, −117, 108, 419	−325	3
E2	56	−208	0 to +7	16, −344, −576, −712, −736, −632, −432, −120	−736	−4
E3	4	−23	0 to +7	16, −26, −44, −70, −88, −82, −84, −78	−88	−4

[0039] In Table 1, B0-B4 are band categories of the plurality of band categories and E0-E3 are edge categories of the plurality of edge categories. The SC block **206** counts the number of deblocked pixels in each category and estimates an error in each category as represented in column 'Deblocked pixel count' and 'Error' respectively.

[0040] The RDO block **208** determines the set of candidate offsets. The RDO block **208** estimates a RD cost associated with each candidate offset as illustrated in column 'RD cost'. The RDO block **208** determines the minimum RD cost of the estimated RD costs for each category. For example, as illustrated in Table 1, the minimum RD cost for band category B0 is −1317 and for edge category E2 is −736. The RDO block **208** modifies a sign of the corresponding candidate offset for which the minimum RD cost is obtained for a given category. For example, for band category B4, a minimum RD cost is obtained for offset 3, the RDO block **208** modifies the sign of the offset and the corresponding candidate offset for band category B4 is −3.

[0041] Table 2 illustrates the operation of the SAO type block **210**.

TABLE 2

SAO Type Block					
Band SAO Type	Band Categories	Band Cost	Minimum Band cost	Corresponding categories	Corresponding candidate offsets
BO0	B0, B1, B2 and B3	1317 − 316 − 218 − 1247 = −3098	−3098	B0, B1, B2 and B3	7, 2, 7, 7
BO1	B1, B2, B3 and B4	−316 − 218 − 1247 − 31 = −1812			
	Edge SAO Type	Edge Cost			
EO	E0, E1, E2 and E3	−4628 − 325 − 736 − 88 = −5777			

[0042] Table 2 illustrates Band SAO type BO0 and BO1. The SAO type block **210** generates Edge SAO type EO. The SAO type block **210** estimates the band cost associated with each band SAO types by summing the minimum RD cost associated with each band category combined to form the band SAO type. For example, the band cost for band SAO type BO0 is estimated by summing the minimum RD cost associated with B0, B1, B2 and B3. Similarly, the SAO type block **210** estimates the edge cost associated with each edge SAO type.

[0043] The SAO type block **210** determines a minimum band cost of the estimated band costs. As illustrated in column 'Minimum Band Cost' the SAO type block **210** determines that the minimum band cost is −3098 of all the estimated band costs. The SAO type block **210** maintains a record of the corresponding categories (B0, B1, B2 and B3) for which the minimum band cost is obtained and also the corresponding candidate offsets (7, 2, 7, 7) for these categories (B0, B1, B2 and B3) respectively.

[0044] The SAO type block **210** provides the edge cost associated with each edge SAO type and corresponding candidate offsets associated with each edge category combined to form the edge SAO type, to the decision block **216**. Thus, the SAO type block **210** provides edge SAO type EO to the decision block **216** along with the estimated edge costs. The SAO type block **210** also maintains a record of the corresponding candidate offsets for each of the edge categories combined to form the edge SAO type.

[0045] The merge mode block **212** receives the count of the number of deblocked pixels in each category and the estimated error in each category. The merge mode block **212** also receives a set of parameters **214**. The set of parameters **214** includes a final left SAO type associated with a left LCU. The left LCU is adjacent to the current LCU and spatially positioned on left side of the current LCU. The merge mode block **212** also receives final offsets corresponding to the final left SAO type associated with the left LCU. The merge mode block **212** estimates a left merge cost associated with the current LCU from the final offsets associated with the left LCU.

[0046] The set of parameters **214** also includes a final top SAO type associated with a top LCU. The top LCU is adjacent to the current LCU and spatially positioned on top of the current LCU. The merge mode block **212** also receives final offsets corresponding to the final top SAO type associated with the top LCU. The merge mode block **212** estimates a top merge cost associated with the current LCU from the final offsets associated with the top LCU.

[0047] The current LCU includes the luma component and the chroma component. The chroma component further includes the Cb component and the Cr component.

[0048] When the deblocked pixels **202** corresponds to the luma component of the current LCU, the minimum band cost is a luma minimum band cost and the edge cost associated with each edge SAO type is a luma edge cost. The candidate offsets corresponding to the minimum band cost are candidate offsets corresponding to the luma minimum band cost. The candidate offsets associated with each edge category combined to form the edge SAO type are candidate offsets corresponding to each luma edge cost.

[0049] Also, when the deblocked pixels **202** corresponds to the luma component of the current LCU, the left merge cost is a luma left merge cost and the top merge cost is a luma top merge cost.

[0050] When the deblocked pixels **202** corresponds to the chroma component of the current LCU, the minimum band cost is a chroma minimum band cost and the edge cost associated with each edge SAO type is a chroma edge cost. The candidate offsets corresponding to the minimum band cost are candidate offsets corresponding to the chroma minimum band cost. The candidate offsets associated with each edge category combined to form the edge SAO type are candidate offsets corresponding to each chroma edge cost.

[0051] Also, when the deblocked pixels **202** corresponds to the chroma component of the current LCU, the left merge cost is a chroma left merge cost and the top merge cost is a chroma top merge cost. In addition, each of the final left SAO type and the final top type includes a final luma SAO type and a final chroma SAO type.

[0052] In one embodiment, the SAO encoder **200** is first provided with deblocked pixels **202** corresponding to the luma component of the current LCU followed by deblocked pixels **202** corresponding to the Cb component and in the end the SAO encoder **200** is provided the deblocked pixels **202** corresponding to the Cr component. The SC block **206**, the RDO block **208**, the SAO type block **210** and the merge mode block **212** processes these deblocked pixels **202** in a serial fashion. Thus, all these blocks process the deblocked pixels corresponding to the luma component followed by the deblocked pixels corresponding to the chroma component. This is also enabled by the functionality of the decision block **216** as described later in the description.

[0053] In an embodiment, a data generated by the SAO type block **210** and the merge mode block **212** are stored in a buffer in the SAO encoder **200**. In another embodiment,

data generated by the SAO type block **210** and the merge mode block **212** are stored in a buffer in the decision block **216**.

[0054] The decision block **216** receives the following (but not limited to) from the merge mode block **212**; the luma left merge cost, the chroma left merge cost, the luma top merge cost, the chroma top merge cost, final offsets corresponding to the final left SAO type and the final offsets corresponding to the final top SAO type.

[0055] The decision block **216** receives the following (but not limited to) from the SAO type block **210**; the luma minimum band cost, the luma edge cost associated with each edge SAO type, the chroma minimum band cost, the chroma edge cost associated with each edge SAO type and the candidate offsets corresponding to each of the luma minimum band cost, the luma edge cost, the chroma minimum band cost and the chroma edge cost.

[0056] The decision block **216** generates an output **218** based on inputs received from the SAO type block **210** and the merge mode block **212**. . The output **218** is a set of final offsets corresponding to the current LCU. The operation of the decision block **216** is explained later in the description in connection with FIG. **5**.

[0057] FIG. **3**(*a*) illustrates a block diagram of a RDO (rate distortion optimization) block **300**, according to an embodiment. The RDO block **300** is similar in connection and operation to the RDO block **208** illustrated in FIG. **2**. The RDO block **300** includes an RD (rate distortion) cost estimation block **310**. The RD cost estimation block **310** receives a count of a number of deblocked pixels (N) **302** in each category and an estimated error (E) **304** in each category. An increment block **308** receives a candidate offset **306** and the increment block **308** is coupled to the RD cost estimation block **310**. The RD cost estimation block **310** also receives a constant (λ) **314**. In one version, the constant (λ) **314** is predefined by a user. In another version, the constant (λ) **314** is selected based on parameters of a video encoder. The RD cost estimation block **310** is also coupled to the sign unit **312**.

[0058] A selector **316** is coupled to the RD cost estimation block **310**. A minimum unit **318** and an offset unit **320** are coupled to the selector **316**. The minimum unit **318** generates a minimum RD cost **322** and the offset unit **320** generates a corresponding offset **324**. A sign unit **312** receives the estimated error (E) **304** and is coupled to the offset unit **320**. The RDO block **300** may include one or more additional components known to those skilled in the relevant art and are not discussed here for simplicity of the description.

[0059] The operation of the RDO block **300** illustrated in FIG. **3**(*a*) is explained now. For a category, the RD cost estimation block **310** receives the count of the number of deblocked pixels (N) **302** in the category and the estimated error (E) **304** in that category. A value of the candidate offset **306** is between a maximum candidate offset and a minimum candidate offset. The RDO block **300** determines a set of candidate offsets for the category. In an example, the set of candidate offsets are integers from 0 to +7.

[0060] The RD cost estimation block **310** estimates a rate distortion (RD) cost for each candidate offset of the set of candidate offsets determined for each category. In one example, the candidate offset **306** has an initial value of 0. The increment block **308** increments the value of the candidate offset **306** by a defined integer. In an example, the increment block **308** increments the value of the candidate offset **306** by one. Thus, when the candidate offset **306** has an initial value of 0, an output of the increment block **308** is an integer value from 0 to +7.

[0061] The RD cost estimation block **310** is explained later in the description in connection with FIG. **3**(*b*). For a first candidate offset **306**, the RD cost estimation block **310** estimates a first RD cost using the count of the number of deblocked pixels (N) **302** in a category, the estimated error (E) **304** in that category and the constant (λ) **314**. The first RD cost is received by the selector **316**. The minimum unit **318** stores a value of the first RD cost and the offset unit **320** stores corresponding candidate offset for which the first RD cost is obtained. A second candidate offset **306** generated by the increment block **308**, in one example, is +1. The RD cost estimation block **310** estimates a second RD cost corresponding to the second candidate offset **306** using the count of the number of deblocked pixels (N) **302** in the category, the estimated error (E) **304** in that category and the constant (λ) **314**. The second RD cost is received by the selector **316**. The selector **316** compares the first RD cost and the second RD cost and stores a minimum of the first RD cost and the second RD cost in the minimum unit **318** and a corresponding candidate offset is stored in the offset unit **320**.

[0062] In one example, when the first RD cost is less than the second RD cost, the selector **316** stores the first RD cost in the minimum unit **318** and the corresponding candidate offset is stored in the offset unit **320**. The process is repeated for all candidate offsets of the set of candidate offsets determined for the category. It is to be noted that a candidate offset of the set of candidate offsets is between a maximum candidate offset and a minimum candidate offset. In an embodiment, a value of the maximum candidate offset and the minimum candidate offset are predefined for the RDO block **300**.

[0063] When a minimum RD cost of the estimated RD costs is determined for a category, a candidate offset corresponding to the minimum RD cost is stored in the offset unit **320**. The sign unit **312** receives a sign of the error in each category. The sign unit **312** modifies a sign of the candidate offset stored in the offset unit **320**. For example, when a sign of the estimated error (E) **304** in a category is negative, the sign unit **312** changes a sign of the corresponding candidate offset (stored in the offset unit **320**) to negative for which the minimum RD cost is obtained. The minimum unit **318** generates the minimum RD cost **322** and the offset unit **320** generates the corresponding offset **324** for a given category.

[0064] In one version, the RDO block **300** checks a sign of the candidate offset **324** generated for the given category. If the sign of the candidate offset **324** is non-compliant with the HEVC standard, the RDO block **300** generates a predefined candidate offset and the corresponding minimum RD cost is estimated for the predefined candidate offset. For example, when the sign of the candidate offset **324** is non-compliant with the HEVC standard, the RDO block **300** generates 0 as candidate offset and a corresponding minimum RD cost.

[0065] In one example, the RDO block **300** is used to estimate a minimum RD cost **322** for each category of the plurality of categories. In another example, a plurality of RDO blocks are used in the SAO encoder (for example SAO encoder **200**) and an RDO block of the plurality of RDO blocks is used to estimate a minimum RD cost **322** for a category. In yet another example, a number of RDO block

300 in the SAO encoder is equal to a total number of band categories and edge categories and each RDO block **300** estimates a minimum RD cost **322** for a category.

[0066] FIG. **3**(*b*) illustrates a block diagram of an RD (rate distortion) cost estimation block **310**, according to an embodiment. The RD cost estimation block **310** receives the count of a number of deblocked pixels (N) **302** in each category, the estimated error (E) **304** in each category, the candidate offset **306** and the constant (λ) **314**. A first look-up table **352** and a second look-up table **360** receive the candidate offset **306**. A first multiplier **354** receives the candidate offset **306** and the estimated error (E) **304**. A second multiplier **356** is coupled to the first look-up table **352** and receives the count of the number of deblocked pixels (N) **302**.

[0067] A multiply unit **357** is coupled to the first multiplier **354**. A subtractor **358** is coupled to the second multiplier **356** and the multiply unit **357**. A first adder **363** is coupled to the second look-up table **360** and receives a sign input **361**. A third multiplier **362** is coupled to the first adder **363** and receives the constant (λ) **314**. In one version, the constant (λ) **314** is predefined by a user. In another version, the constant (λ) **314** is selected based on parameters of a video encoder. A second adder **364** is coupled to the third multiplier **362** and the subtractor **358**. The second adder **364** generates the RD cost **366**. The RD cost estimation block **310** may include one or more additional components known to those skilled in the relevant art and are not discussed here for simplicity of the description.

[0068] The operation of the RD cost estimation block **310** illustrated in FIG. **3**(*b*) is explained now. The RD cost estimation block **310** estimates an RD cost for a category using the count of number of deblocked pixels (N) **302** in the category, the estimated error (E) **304** in that category and the constant (λ) **314**. According to an embodiment, the RD cost (J) is defined as:

$$J=((N\times O^2-2\times|E|\times O)+\lambda R) \quad (1)$$

where, O is the candidate offset **306** and R is a bitrate data.

[0069] The first look-up table **352** stores a value of O^2 corresponding to the candidate offset **306**. The second look-up table **360** stores a value of the bitrate data (R) corresponding to the candidate offset **306**. The bitrate data (R) represents a number of bits required by an entropy coder (for example, entropy coder **108** illustrated in FIG. **1**) to transmit a symbol generated by a video encoder (for example, video encoder **100** illustrated in FIG. **1**).

[0070] The first multiplier **354** multiplies an absolute value of the estimated error (E) **304** and the candidate offset **306**. The second multiplier **356** multiplies the count of the number of deblocked pixels (N) **302** and O^2 received from the first look-up table **352**. The multiply unit **357** multiply a set of bits received from the first multiplier **354**. The subtractor **358** subtracts an output of the multiply unit **357** from an output of the second multiplier **356**.

[0071] The first adder **363** receives the sign input **361**. The sign input **361** indicates the sign of the estimated error (E) **304** for a category. The first adder **363**, in one example, increments the bitrate data (R) when a sign of the estimated error (E) **304** for a category is negative and does not alter the bitrate data (R) when a sign of the estimated error (E) **304** for a category is positive. The third multiplier **362** multiplies the bitrate data (R) received from the first adder **363** and the constant (λ) **314**. An output of the third multiplier **362** is added to an output of the subtractor **358** by the second adder **364** to generate the RD cost (J) which is defined by equation 1. In an example embodiment, the RD cost (J) is estimated using equation 1 (irrespective of the components illustrated in FIG. **3**(*b*)), and wherein the bitrate data (R) is received from the second look-up table **360**.

[0072] In an embodiment, for a given category, multiple RD cost estimation blocks are utilized and each RD cost estimation block is used to estimate RD cost associated with an offset of the set of offsets determined for the given category. In another embodiment, the RD cost estimation block **310** is used to estimate RD cost associated with each candidate offset of the set of candidate offsets for the given category.

[0073] FIG. **4**(*a*) illustrates a block diagram of a SAO (sample adaptive offset) type block **400**, according to an embodiment. The SAO type block **400** is similar in connection and operation to the SAO type block **210** illustrated in FIG. **2**. The SAO type block **400** receives a minimum RD cost and the corresponding offset for each category. The SAO type block **400** is explained using 32 band categories and 16 edge categories. The specifically disclosed number of band categories and edge categories is provided to explain the logical flow and are understood not to limit the scope of the present disclosure.

[0074] The SAO type block **400** generates a set of band SAO types such the each band SAO type of the set of band SAO types includes a set of band categories. In one example, when the 32 band categories are B0, B1, B2 till B31, the set of band SAO types generated by the SAO type block **400** are BO0, BO1, BO2 till BO28, where BO is a start band of band SAO type. For example, the band categories B0, B1, B2 and B3 are combined to form band SAO type BO0 and B0 is a start band of band SAO type BO0. Similarly, the band categories B1, B2, B3 and B4 are combined to form band SAO type BO1 and B1 is the start band of SAO type BO1. The set of categories combined to form a SAO type is exemplary and it is understood that different combinations of categories are apparent and well within the spirit and scope of the disclosure

[0075] The SAO type block **400** generates a set of edge SAO types such that each edge SAO type of the set of edge SAO type includes a set of edge categories. The four edge types are 0 degree, 90 degree, 135 degree and 45 degree. Each of the four edge type is further sub-divided into four edge categories. In another example, the set of edge SAO types generated by the SAO type block **400** are EO 0 degrees, EO 90 degrees, EO 135 degrees and EO 45 degrees. The four edge categories corresponding to the edge type 0 degrees are combined to form edge SAO type EO 0 degrees. Similarly, the four edge categories corresponding to the edge type 90 degrees are combined to form edge SAO type EO 90 degrees.

[0076] The SAO type block **400** receives the minimum RD cost corresponding to each band category (B_Min) **408** and the minimum RD cost corresponding to each edge category (E_min) **410**. The SAO type block **400** includes multiple cost estimation modules such as **402**B**1**, **402**B**2** till **402**B**28**, **402**E**1**, **402**E**2**, **402**E**3** and **402**E**4**. A cost estimation module estimates a band cost associated with a band SAO type when a minimum RD cost associated with each band forming the band SAO type is provided to the cost estimation module. The cost estimation module also estimates an edge cost associated with an edge SAO type when

a minimum RD cost associated with each edge forming the edge SAO type is provided to the cost estimation module.

[0077] The cost estimation module is explained later in the description in connection with FIG. **4**(*b*). The cost estimation modules **402**B**1**, **402**B**2** till **402**B**28** estimates a band cost associated with band SAO types BO0, BO1 till BO28 respectively. Similarly, the cost estimation modules **402**E**1**, **402**E**2**, **402**E**3** and **402**E**4** estimates an edge cost associated with edge SAO types EO 0 degrees, EO 90 degrees, EO 135 degrees and EO 45 degrees respectively.

[0078] The SAO type block **400** includes a selector **415**. The selector **415** is coupled to the cost estimation modules **402**B**1**, **402**B**2** till **402**B**28**. The selector **415** receives the band cost associated with band SAO types BO0, BO1 till BO28. The selector **415** determines a minimum band cost of the estimated band costs associated with band SAO types BO0, BO1 till BO28. The SAO type block **400** generates a B0 min output **420**. The BO_min output **420** includes the minimum band cost, a set of band categories combined to form the band SAO type for which the minimum band cost is obtained and corresponding candidate offsets associated with each band category of the set of band categories.

[0079] For example, when a band cost estimated for band SAO type BO0 is minimum of all the estimated band costs for band SAO types BO0, BO1 till BO28, the minimum band cost is equal to the band cost associated with the band SAO type BO0. The SAO type block **400** generates the BO_min output **420** which includes the minimum band cost i.e. band cost associated with the band SAO type BO0, a set of band categories combined to form the band SAO type BO0 i.e. B0, B1, B2 and B3, and the candidate offsets corresponding to B0, B1, B2 and B3.

[0080] The SAO type block **400** also generates EO0 output **422** that includes the edge cost associated with edge SAO types EO 0 degrees and the corresponding candidate offsets associated with each edge category combined to form the edge SAO type EO 0 degrees. The SAO type block **400** generates EO90 output **424** that includes the edge cost associated with edge SAO types EO 90 degrees and the corresponding candidate offsets associated with each edge category combined to form the edge SAO type EO 90 degrees.

[0081] The SAO type block **400** also generates EO135 output **426** that includes the edge cost associated with edge SAO types EO 135 degrees and the corresponding candidate offsets associated with each edge category combined to form the edge SAO type EO 135 degrees. The SAO type block **400** generates EO45 output **428** that includes the edge cost associated with edge SAO types EO 45 degrees and the corresponding candidate offsets associated with each edge category combined to form the edge SAO type EO 45 degrees.

[0082] FIG. **4**(*b*) illustrates a block diagram of a cost estimation module **450**, according to an embodiment. The cost estimation module **450** is similar to at least one of the cost estimation modules **402**B**1**, **402**B**2** till **402**B**28**, **402**E**1**, **402**E**2**, **402**E**3** and **402**E**4** in connections and operation. The cost estimation module **450** receives four inputs J**1**, J**2**, J**3** and J**4**. A first summer **452** receives the four inputs J**1**, J**2**, J**3** and J**4**. A look-up table **462** receives a SAO type input **464** and a sub-type input **466** and generates a bitrate data (R) **465**. A multiplier **468** receives the bitrate date (R) **465** and a constant (λ) **470**. In one version, the constant (λ) **470** is predefined by a user. In another version, the constant (λ) **470** is selected based on parameters of a video encoder. A second summer **472** is coupled to the first summer **452** and the multiplier **468**. The second summer **472** generates an output (J) **475**. The cost estimation module **450** may include one or more additional components known to those skilled in the relevant art and are not discussed here for simplicity of the description.

[0083] The operation of the cost estimation module **450** illustrated in FIG. **4**(*b*) is explained now. In one example, the four inputs J**1**, J**2**, J**3** and J**4** are a minimum RD cost associated with each band forming the band SAO type. In another example, the four inputs J**1**, J**2**, J**3** and J**4** are a minimum RD cost associated with each edge forming the edge SAO type.

[0084] For example, the cost estimation module **450** receives a minimum cost RD cost associated with B0, B1, B2 and B3 that form the band SAO type BO0. In a further example, the cost estimation module **450** receives a minimum RD cost associated with the four edge categories corresponding to the edge type 0 degrees that form the edge SAO type EO 0 degrees. The first summer **452** sums the four inputs J**1**, J**2**, J**3** and J**4** to generate an output (S).

[0085] The SAO type input **464** indicates if the four inputs J**1**, J**2**, J**3** and J**4** belong to band categories or edge categories. The sub-type input **466** indicates a set of band categories that form a band SAO type or a set of edge categories that form an edge SAO type. The look-up table **462** generates the bitrate data (R) **465** based on the SAO type input **464** and the sub-type input **466**. The multiplier **468** multiplies the bitrate data (R) **465** and the constant (λ) **470**.

[0086] The second summer **472** sums an output of the multiplier **468** and the output (S) of the first summer **452**. The output (J) **475** generated by the second summer **472** is defined as:

$$J=S+\lambda R \tag{2}$$

where, S represents a sum of the minimum RD cost corresponding to a SAO type.

[0087] In one example, the output (J) **475** is the band cost associated with a band SAO type when the four inputs J**1**, J**2**, J**3** and J**4** are a minimum RD cost associated with each band forming the band SAO type. In another example, the output (J) **475** is the edge cost associated with an edge SAO type when the four inputs J**1**, J**2**, J**3** and J**4** are a minimum RD cost associated with each edge forming the edge SAO type.

[0088] FIG. **5** illustrates a block diagram of a decision block **500**, according to an embodiment. The decision block **500** is similar in connection and operation to the decision block **216** (illustrated in FIG. **2**) in connections and operation. The decision block **500** is explained using 32 band categories and 16 edge categories. The specifically disclosed number of band categories and edge categories is provided to explain the logical flow and are understood not to limit the scope of the present disclosure.

[0089] A luma comparator **530** in the decision block **500** receives a luma minimum band cost (Luma_J_Bmin) **502**, a luma edge cost associated with each edge SAO type **504** and a SAO disable cost (J_SAO_D) **506**. A luma edge cost associated with edge SAO type 0 degree is Luma_J_E0 and a luma edge cost associated with edge SAO type 90 degrees is Luma_J_E90. A luma edge cost associated with SAO type 135 degree is Luma_J_E135 and a luma edge cost associated with edge SAO type 45 degree is Luma_J_E45.

[0090] A chroma comparator **535** in the decision block **500** receives a chroma minimum band cost (Chroma_J_Bmin) **512**, a chroma edge cost associated with each edge SAO type **514** and the SAO disable cost (J_SAO_D) **506**. A chroma edge cost associated with edge SAO type 0 degree is Chroma_J_E0 and a chroma edge cost associated with edge SAO type 90 degrees is Chroma_J_E90. A chroma edge cost associated with edge SAO type 135 degree is Chroma_J_E135 and a chroma edge cost associated with edge SAO type 45 degree is Chroma_J_E45. Each of the chroma minimum band cost (Chroma_J_Bmin) **512** and the chroma edge cost associated with each edge SAO type **514** includes at least one of a Cb component and a Cr component.

[0091] The decision block **500** also receives candidate offsets corresponding to each of the luma minimum band cost (Luma_J_Bmin) **502**, the luma edge cost associated with each edge SAO type **504**, the chroma minimum band cost (Chroma_J_Bmin) **512** and the chroma edge cost associated with each edge SAO type **514**.

[0092] A first summer **536** in the decision block **500** receives a luma left merge cost (Luma_J_MerL) **522** and a chroma left merge cost (Chroma_J_MerL) **524**. A second summer **538** in the decision block **500** receives a luma top merge cost (Luma_J_MerT) **526** and a chroma top merge cost (Chroma_J_MerT) **528**. Each of the chroma left merge cost (Chroma_J_MerL) **524** and the chroma top merge cost (Chroma_J_MerT) **528** includes at least one of a Cb component and a Cr component.

[0093] A third summer **539** is coupled to the luma comparator **530** and the chroma comparator **535**. A final comparator **540** is coupled to the first summer **536**, the second summer **538** and the third summer **539**. The final comparator **540** is coupled to a multiplexer **545**. The multiplexer **545** receives final offsets corresponding to the final left SAO type **544** and final offsets corresponding to the final top SAO type **546**. A buffer **542** is coupled to the luma comparator **530** and the chroma comparator **535**. The buffer **542** is also coupled to the multiplexer **545**. The multiplexer **545** generates an output **550**.

[0094] The operation of the decision block **500** illustrated in FIG. **5** is explained now. The luma comparator **530** selects a minimum of the luma minimum band cost (Luma_J_Bmin) **502**, the luma edge cost associated with each edge SAO type **504** and the SAO disable cost (J_SAO_D) **506**. The luma comparator **530** generates a best luma cost. The chroma comparator **535** selects a minimum of the chroma minimum band cost (Chroma_J_Bmin) **512**, the chroma edge cost associated with each edge SAO type **514** and the SAO disable cost (J_SAO_D) **506**. The chroma comparator **535** generates a best chroma cost. The third summer **539** adds the best luma cost and the best chroma cost to generate a joint cost.

[0095] The buffer **542** receives offsets corresponding to the best luma cost and offsets corresponding to the best chroma cost. The offsets corresponding to the best luma cost are best luma offsets and the offsets corresponding to the best chroma cost are best chroma offsets. The best luma offsets includes at least one of offsets corresponding to the SAO disable cost (J_SAO_D) **506**, candidate offsets corresponding to the luma minimum band cost (Luma_J_Bmin) **502** and candidate offsets corresponding to luma edge cost associated with each edge SAO type **504**.

[0096] The best chroma offsets includes at least one of the offsets corresponding to the SAO disable cost (J_SAO_D) **506**, candidate offsets corresponding to the chroma minimum band cost (Chroma_J_Bmin) **512** and candidate offsets corresponding to chroma edge cost associated with each edge SAO type **514**.

[0097] In one example, the offsets corresponding to the SAO disable cost (J_SAO_D) **506** have zero value. In another example, when the best luma cost is equal to the SAO disable cost (J_SAO_D) **506**, no luma offsets corresponding to the current LCU are generated. Similarly, when the best chroma cost is equal to the SAO disable cost (J_SAO_D) **506**, no chroma offsets corresponding to the current LCU are generated. In an additional example, when at least one of the best luma cost and the best chroma cost is equal to the SAO disable cost (J_SAO_D) **506**, the SAO encoder **200** is deactivated.

[0098] The first summer **536** adds the luma left merge cost (Luma_J_MerL) **522** and the chroma left merge cost (Chroma_J_MerL) **524** to generate a joint left merge cost. The second summer **538** adds the luma top merge cost (Luma_J_MerT) **526** and the chroma top merge cost (Chroma_J_MerT) **528** to generate a joint top merge cost.

[0099] The final comparator **540** receives the joint cost, the joint left merge cost and the joint top merge cost. The final comparator **540** selects a minimum of the joint cost, the joint left merge cost and the joint top merge cost to generate a final cost.

[0100] The multiplexer **545** is controlled by the final comparator **540**. When the final cost is equal to the joint left merge cost, the output **550** of the multiplexer **545** are the final offsets corresponding to the final left SAO type **544**. When the final cost is equal to the joint top merge cost, the output **550** of the multiplexer **545** are the final offsets corresponding to the final top SAO type **546**. When the final cost is equal to the joint cost, the output **550** of the multiplexer **545** are the best luma offsets and the best chroma offsets. The output **550** represents a final offsets corresponding to the current LCU in a SAO encoder.

[0101] The SAO encoder **200** is able to provide a best offset for each SAO type in real time. The SAO encoder **200** selects a SAO type which results in minimal distortion between the deblocked pixels **202** and the current pixels **204**. The SAO encoder **200** has low complexity as all the processes such as statistics collection, parameter estimation, cost estimations are optimized and simple. Thus, the SAO encoder **200** reduces the distortion in image transmitted of the video encoder (such as video encoder **100**) and thus provides a video with high quality and PSNR. In one embodiment, 0.15 mm^2 of silicon area is utilized to perform 4K video encoding at 60FPS (frames per second) using the 28 nm LP process node. In another embodiment, the processes of the SAO encoder **200** are implemented on a fixed point programmable device such as DSP (digital signal processor). The SAO encoder **200** achieves bit rate reduction in HEVC. The SAO encoder **200** improves visual quality and maintains compliance with the constraints set by the HEVC standard.

[0102] FIG. **6** is an example environment in which various aspect of the present disclosure may be implemented. As shown, the environment may comprise, for example, one or more video cameras **610**, computers **620**, personal digital assistants (PDA) **630**, mobile devices **640**, televisions **650**, video conference systems **660**, video streaming systems **680**, TV broadcasting systems **670** and communication networks/channels **690**.

[0103] The video cameras **610** are configured to take continuous pictures and generate digital video, a signal comprising sequence of image frames. The video cameras **610** are configured to process the image frames for efficient storage and/or for transmission over the communication networks/channels **690**. The computers **620**, PDAs **630** and the mobile devices **640** are configured to encode the video signals for transmission and to decode encoded video signals received from the communication networks/channels **690**. The video streaming systems **680** is configured to encode video signal and to transmit the encoded video signals over the communication networks/channels **690** responsive to a received request and/or asynchronously. The television broadcasting systems **670** are configured to process video signals in accordance with one or more broadcast technologies and to broadcast the processed video signals over the communication networks/channels **690**. The video conference systems **660** are configured to receive a video signal from one or more participating/conferencing end-terminals (not shown) and to convert or compress the video signal for broadcasting or for transmitting to other participating user terminals. The television broadcasting systems **670** are configured to receive encoded video signals from one or more different broadcasting centers (or channels), to decode each video signal and to display the decoded video signals on a display device (not shown).

[0104] As shown in FIG. **6**, the devices and systems **610-680** are coupled to communication networks/channels **690**. Communication networks/channels **690** supports an exchange of video signal encoded in accordance with one or more video encoding standards such as, but not limited to, H. 263, H. 264/AEC, and HEVC (H. 266), for example. Accordingly, the devices and systems **610-680** are required to process (encode and/or decode) video signals complying with such standards. The systems and devices **610-680** are implemented with one or more functional units that are configured to perform signal processing, transmitting and/or receiving of video signals from communication networks/channels **690**. When each device in the described environment performs video coding or decoding, one or more embodiments described in this disclosure are used.

[0105] FIG. **7** illustrates a method **700** of generating final offsets in a SAO encoder, according to an embodiment. The method **700** depicted in the flow diagram may be executed by, for example, SAO encoder **200** explained with reference to FIG. **2**. Operations of the flowchart, and combinations of operation in the flowchart, may be implemented by, for example, hardware, firmware, a processor, circuitry and/or a different device associated with the execution of software that includes one or more computer program instructions. The operations of the method **700** are described herein with help of the SAO encoder **200**. However, the operations of the method **700** can be described and/or practiced by using a system other than the SAO encoder **200**. The method **700** starts at step **702**.

[0106] At step **702**, a set of deblocked pixels and a set of original pixels are received. For example, the SC block **206** receives the set of deblocked pixels and the set of original pixels. The set of original pixels corresponds to a current LCU. The current LCU includes a luma component and a chroma component. The chroma component further includes a Cb component and a Cr component. At step **704**, each deblocked pixel of the set of deblocked pixels is categorized in at least one of a plurality of band categories and a plurality of edge categories. In one example, the SAO encoder **200** includes 32 band categories and 16 edge categories.

[0107] At step **706**, a number of deblocked pixels in each category of the plurality of band categories and the plurality of edge categories are counted. An error in each category is estimated from a difference between a deblocked pixel of the set of deblocked pixels and corresponding original pixel of the set of original pixels, at step **708**.

[0108] At step **710**, a sign of the error in each category is determined. In an example, the RDO block **208** determines a sign of the error in each category. The sign is a positive sign or a negative sign. At step **712**, a set of candidate offsets associated with each category is determined. A value of a candidate offset of the set of candidate offsets is between a maximum candidate offset and a minimum candidate offset. In an example, when a video input processed by the SAO encoder **200** is an 8 bit input, the set of candidate offsets are integers from 0 to +7.

[0109] A rate distortion (RD) cost associated with each candidate offset of the set of candidate offsets determined for each category is estimated at step **714**. In one version, the RD cost associated with each candidate offset is estimated using the count of the number of deblocked pixels in the category and an absolute value of the estimated error in that category. A bitrate data from a look-up table stored in the SAO encoder **200** is also used for estimating the RD cost associated with each candidate offset. At step **716**, a minimum RD cost is determined of the estimated RD costs for each category. A record of the candidate offset for which the minimum RD cost is obtained for a category is also maintained. In a further example, a sign of the corresponding candidate offset, for which the minimum RD cost is obtained, is modified based on the sign of the estimated error in each category. The minimum RD cost is used to generate the final offsets for a SAO encoder (for example SAO encoder **200**).

[0110] The SAO encoder **200**, the RDO block **208**, the SAO type block **210**, the merge mode block **212** and the decision block **216** may be enabled using software and/or using transistors, logic gates, and electrical circuits (for example, integrated circuit circuitry such as ASIC circuitry). Various embodiments of the present disclosure may include one or more computer programs stored or otherwise embodied on a computer-readable medium, wherein the computer programs are configured to cause a processor or computer to perform one or more operations. A computer-readable medium storing, embodying, or encoded with a computer program, or similar language, may be embodied as a tangible data storage device storing one or more software programs that are configured to cause a processor or computer to perform one or more operations. Such operations may be, for example, any of the steps or operations described herein.

[0111] In some embodiments, the computer programs may be stored and provided to a computer using any type of non-transitory computer readable media. Non-transitory computer readable media include any type of tangible storage media. Examples of non-transitory computer readable media include magnetic storage media (such as floppy disks, magnetic tapes, hard disk drives, etc.), optical magnetic storage media (e.g. magneto-optical disks), CD-ROM (compact disc read only memory), CD-R (compact disc recordable), CD-R/W (compact disc rewritable), DVD (Digital Versatile Disc), BD (Blu-ray (registered trademark) Disc),

and semiconductor memories (such as mask ROM, PROM (programmable ROM), EPROM (erasable PROM), flash ROM, RAM (random access memory), etc.).

[0112] Additionally, a tangible data storage device may be embodied as one or more volatile memory devices, one or more non-volatile memory devices, and/or a combination of one or more volatile memory devices and non-volatile memory devices. In some embodiments, the computer programs may be provided to a computer using any type of transitory computer readable media. Examples of transitory computer readable media include electric signals, optical signals, and electromagnetic waves. Transitory computer readable media can provide the program to a computer via a wired communication line (e.g. electric wires, and optical fibers) or a wireless communication line.

[0113] In the foregoing discussion , the terms "connected" means at least either a direct electrical connection between the devices connected or an indirect connection through one or more passive intermediary devices. The term "circuit" means at least either a single component or a multiplicity of passive or active components, that are connected together to provide a desired function. The term "signal" means at least one current, voltage, charge, data, or other signal. Also, the terms "connected to" or "connected with" (and the like) are intended to describe either an indirect or direct electrical connection. Thus, if a first device is coupled to a second device, that connection can be through a direct electrical connection, or through an indirect electrical connection via other devices and connections.

[0114] One having ordinary skill in the art will understand that the present disclosure, as discussed above, may be practiced with steps and/or operations in a different order, and/or with hardware elements in configurations which are different than those which are disclosed. Therefore, although the disclosure has been described based upon these preferred embodiments, it should be appreciated that certain modifications, variations, and alternative constructions are apparent and well within the spirit and scope of the disclosure. In order to determine the metes and bounds of the disclosure, therefore, reference should be made to the appended claims.

What is claimed is:

1. A method comprising:

receiving a first pixel and a second pixel;

receiving a first deblocked pixel of the first pixel and a second deblocked pixel of the second pixel;

categorizing the first deblocked pixel in a band category;

categorizing the second deblocked pixel in an edge category;

estimating a first error based on a difference between the first deblocked pixel and the first pixel;

estimating a second error based on a difference between the second deblocked pixel and the second pixel;

determining a first candidate offset with the band category;

determining a second candidate offset with the edge category;

estimating a first rate distortion (RD) cost associated with the first candidate offset; and estimating a second RD cost associated with the second candidate offset .

2. The method of claim **1**, wherein estimating the first RD cost is based on bitrate data.

3. The method of claim **1**, further comprising:

determining a sign of the first error; and

modifying a sign of the first candidate offset based on the sign of the first error.

4. A video encoding system comprising:

an input to receive a first pixel, a second pixel, a first deblocked pixel of the first pixel, and a second deblocked pixel of the second pixel;

; and

a microprocessor coupled to the input and configured to:

categorize the first deblocked pixel in a band category;

categorize the second deblocked pixel in an edge category;

estimate a first error based on a difference between the first deblocked pixel and the first pixel;

estimate a second error based on a difference between the second deblocked pixel and the second pixel;

determine a first candidate offset with the band category;

determine a second candidate offset with the edge category;

estimate a first rate distortion (RD) cost associated with the first candidate offset; and

estimate a second RD cost associated with the second candidate offset

5. The video encoding system of claim **4**, wherein estimating the first RD cost is based on bitrate data.

6. The video encoding system of claim **4**, wherein the processor is configured to execute the instructions to encode the video input data by:

determine a sign of the estimated first error for each category; and modify a sign of a the first candidate offset corresponding to the estimated RD cost that is determined to be the minimum RD cost based on the sign of the estimated first error.

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