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(54) Title: METHOD OF IMPROVED DIRECTIONAL INTRA PREDICTION FOR VIDEO CODING

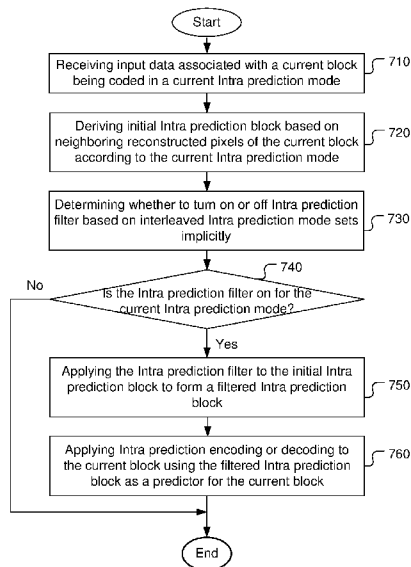


Fig. 7

(57) Abstract: A method of Intra prediction filtering to determine whether to turn on or off the Intra prediction filter based on interleaved Intra prediction mode sets implicitly is disclosed. In one embodiment, initial Intra prediction block is derived based on neighboring reconstructed pixels of the current block. If the Intra prediction filter is on for the current Intra prediction mode, the Intra prediction filter is applied to the initial Intra prediction block to form a filtered Intra prediction block and Intra prediction encoding or decoding is applied to the current block using the filtered Intra prediction block as a predictor for the current block. For example, Intra gradient filter can be applied for even modes of Intra prediction modes from v to (v+8) and/or from h and (h+8). Bi-directional Intra prediction filter can be applied to some or all other modes.



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# **METHOD OF IMPROVED DIRECTIONAL INTRA PREDICTION FOR VIDEO CODING**

## **CROSS REFERENCE TO RELATED APPLICATIONS**

[0001] The present invention claims priority to U.S. Provisional Patent Application,  
5 Serial No. 62/073,209, filed on October 31, 2014. The U.S. Provisional Patent  
Application is hereby incorporated by reference in its entirety.

## **TECHNICAL FIELD**

[0002] The present invention relates video coding. In particular, the present  
10 invention relates to advanced Intra prediction to improve coding efficiency of Intra  
prediction.

## **BACKGROUND**

[0003] High-Efficiency Video Coding (HEVC) is a new international video coding  
15 standard developed by the Joint Collaborative Team on Video Coding (JCT-VC).  
HEVC is based on the hybrid block-based motion-compensated DCT-like transform  
coding architecture. The basic unit for compression, termed coding unit (CU), is a  
2N×2N square block. A CU may begin with a largest CU (LCU), which is also  
referred as coded tree unit (CTU) in HEVC and each CU can be recursively split into  
20 four smaller CUs until the predefined minimum size is reached. Once the splitting of  
CU hierarchical tree is done, each CU is further split into one or more prediction units  
(PUs) according to prediction type and PU partition. Each CU or the residual of each  
CU is divided into a tree of transform units (TUs) to apply 2D transforms such as  
DCT (discrete cosine transform) or DST (discrete sine transform).

25 [0004] In High Efficiency Video Coding (HEVC), the generation of Intra prediction  
samples includes three parts: Intra smoothing filter, Intra prediction, and Intra gradient  
filter. A smoothing operation is first applied to the reference samples as a pre-

processing step before calculating the prediction. This smoothing operation corresponds to applying an FIR-filter corresponding to  $[121] \gg 2$ . The smoothing operation corresponds to applying low-pass filter to the samples in the left column and the above row of the current TU (transform unit). The Intra prediction of each TU is produced with the reconstructed samples of neighboring TUs. The samples involved in Intra smoothing are highlighted with line-filled blocks in Fig. 1. Whether this smoothing operation is used depends on the TU size and the Intra prediction mode. The Intra prediction of current block is then derived from neighboring reference samples adjacent to boundaries of the current block as shown by line-filled blocks in Fig. 1 for certain Intra prediction modes. The Intra prediction modes according to HEVC include DC mode, planar mode, and 33 directional modes. An Intra prediction mode is selected for a current block by the encoder and is signaled in the bitstream. After the initial Intra prediction samples are generated, Intra gradient filter is further applied to the initial Intra prediction samples at the left column and top row within the current TU when the Intra prediction mode is DC, horizontal, or vertical mode.

[0005] The concept of Intra gradient filter is to utilize the gradient information along the Intra prediction direction to improve the quality of Intra prediction. The Intra gradient filter is further extended to other Intra prediction modes as described in JCTVC-G279 (Guo, et al., *CE6 Subset d: Direction based Angular Intra Prediction*, Joint Collaborative Team on Video Coding (JCT-VC) of ITU-T SG16 WP3 and ISO/IEC JTC1/SC29/WG11, 7th Meeting: Geneva, CH, 21-30 Nov., 2011, Document: JCTVC-G279). For the 33 directional Intra prediction modes, the mode designation for various directions is shown in Fig. 2, where the mode designation is from h-7 through h+8 and from v-8 through v+8. For the Intra prediction modes from v to (v+8), Intra gradient filter is applied to selected Intra prediction samples. In the example of vertical Intra prediction mode (i.e., v), the Intra gradient filter is applied to the Intra prediction samples in the left column of the current block. Two boundary samples representing two reconstructed samples adjacent to the left column of the current block are located first for a current Intra prediction sample to be filtered. The gradient information is calculated based on the difference of the two boundary samples to improve the Intra prediction. Fig.3 illustrates the example of Intra gradient filter for the vertical mode.  $P_{ij}$  denotes the predictor at row  $i$  and column  $j$ .  $AL$  represents the reconstructed sample at the upper-left corner of the current block.  $L_i$  represents the reconstructed sample adjacent to the left column of the current block. A

new predictor is calculated according to:

$$P'_{ij} = P_{ij} + \alpha \cdot (L_i - AL), \quad (1)$$

where  $\alpha$  corresponds to the weighting factor and is a fractional number from 0 to 1 as determined according to  $j$ . For example,  $\alpha=1/2$  when  $j=0$ , and  $\alpha=1/4$  when  $j=1$ .  $P'_{ij}$  is used as the final predictor. Similarly, the Intra gradient filter is also applied to the horizontal Intra prediction mode. As for the Intra gradient filter of the horizontal directional mode, the final predictor  $P'_{ij}$  is calculated according to:

$$P'_{ij} = P_{ij} + \alpha \cdot (A_j - AL), \quad (2)$$

where  $A_j$  is the reconstructed sample in the above row as shown in Fig. 3.

[0006] As for the directional modes from  $(v+1)$  to  $(v+8)$ , the Intra gradient filter process will first identify a reference sample  $RL_i$  along the direction of Intra prediction for a corresponding boundary sample  $L_i$ . If  $RL_i$  is not located at an integer pixel position,  $RL_i$  can be generated by interpolation of integer pixels in the above boundary row. The Intra gradient filter is applied to Intra prediction samples in selected columns of the current Intra prediction mode. An example of gradient based prediction for directional mode from  $(v+1)$  to  $(v+8)$  is shown in Fig. 4. The final predictor  $P'_{ij}$  is calculated according to:

$$P'_{ij} = P_{ij} + \alpha \cdot (L_i - RL_i). \quad (3)$$

[0007] Similar to the vertical directional mode,  $\alpha$  is a fractional number from 0 to 1 and is selected according to  $j$ .

[0008] Similar gradient based prediction is applied to directional modes from  $(h+1)$  to  $(h+8)$ . A reference sample  $RA_j$  in the boundary column adjacent to the left column of the current block along the direction of Intra prediction is determined for a corresponding boundary sample  $A_j$  first. If  $RA_j$  is not located at an integer pixel position,  $RA_j$  can be generated by interpolation of integer pixels in the left column. The final predictor  $P'_{ij}$  is calculated according to:

$$P'_{ij} = P_{ij} + \alpha \cdot (A_j - RA_j), \quad (4)$$

where  $\alpha$  is a fractional number from 0 to 1 and is selected according to  $i$ .

[0009] For directional modes from  $v$  to  $(v+8)$  and from  $h$  to  $(h+8)$ , the Intra gradient filter is applied to multiple Intra prediction columns or rows in the Intra prediction block. However, in HEVC, the Intra gradient filter is only applied to selected samples in the first row, first column or both the first row and first column of the Intra prediction block when the Intra prediction mode is DC, horizontal, or vertical mode.

For example, if the Intra prediction is DC mode, the samples at the first row and first column are filtered by Intra gradient filter. If the Intra prediction is horizontal mode, then the samples at the first row are filtered by Intra gradient filter. If the Intra prediction is vertical mode, then the samples at the first column are further filtered by Intra gradient filter.

[0010] Besides Intra gradient filtering, another smoothing filter called bi-directional Intra prediction is also disclosed to improve the quality of Intra prediction in JCT-VC meetings, where bi-directional Intra prediction is also referred to as bi-boundary intra prediction. For directional Intra prediction modes (v+1) to (v+8) and (h+1) to (h+8), a weighted sum of a reconstructed sample in the above boundary row and a reconstructed samples in the left boundary column along the Intra prediction mode direction is used as the Intra predictor. An example of bi-directional Intra prediction for directional modes from (v+1) to (v+8) is shown in Fig. 5. For each Intra prediction sample  $P_{ij}$ , a corresponding reference sample  $F_{ij}$  in the left column along the prediction direction is identified. If  $F_{ij}$  is not located at an integer pixel position,  $F_{ij}$  is generated by interpolation of integer pixels in the left column. Then the final predictor  $P'_{ij}$  is calculated as the weighted sum of  $P_{ij}$  and  $F_{ij}$  according to:

$$P'_{ij} = \alpha \cdot P_{ij} + (1 - \alpha) \cdot F_{ij}, \quad (5)$$

$\alpha$  is a fractional number from 0 to 1 and is selected according to the direction of Intra prediction and  $j$  for (v+1) to (v+8) directional modes.

[0011] For the directional modes (h+1) to (h+8), the bi-directional Intra prediction can be derived similarly. In this case,  $F_{ij}$  corresponds to a reference sample in the above row. If  $F_{ij}$  is not located at an integer pixel position,  $F_{ij}$  is generated by interpolation of integer pixels in the above row. The final predictor  $P'_{ij}$  is calculated as the weighted sum of  $P_{ij}$  and  $F_{ij}$  according to equation (5), where  $\alpha$  is a fractional number from 0 to 1 and is selected according to the direction of Intra prediction and  $i$  for (h+1) to (h+8) directional modes.

[0012] After generating Intra predictors, the prediction error is formed between a current block and its corresponding predictor. The prediction error is further processed by transform, quantization and entropy coding. For entropy coding, the quantized coefficients are divided into multiple 4x4 coefficient groups, first. The coding order of different coefficient groups and scan order of coefficients in one coefficient group is selected according to Intra prediction mode and transform size. If

the transform size is smaller than or equal to  $8 \times 8$ , then intra-mode-dependent scan will be used for the coding order of different coefficient groups and scan order of coefficients in one coefficient group. Otherwise, diagonal scan is used for the coding order of different coefficient groups and scan order of coefficients in one coefficient group.

[0013] It is desirable to develop Intra prediction filter to further improve coding efficiency.

## SUMMARY

[0014] A method of Intra prediction filtering to determine whether to turn on or off the Intra prediction filter based on interleaved Intra prediction mode sets implicitly is disclosed. In one embodiment, initial Intra prediction block is derived based on neighboring reconstructed pixels of the current block according to a current Intra prediction mode. If the Intra prediction filter is on for the current Intra prediction mode, the Intra prediction filter is applied to the initial Intra prediction block to form a filtered Intra prediction block and Intra prediction encoding or decoding is applied to the current block using the filtered Intra prediction block as a predictor for the current block.

[0015] In one embodiment, the Intra prediction filter corresponds to Intra gradient filter, and wherein the Intra prediction filter is on if the current Intra prediction mode belongs to a first interleaved Intra prediction mode set. The first interleaved Intra prediction mode set corresponds to a plurality of directional Intra prediction modes selecting from  $(v+0)$  through  $(v+Nv)$ , from  $(h+0)$  through  $(h+Mh)$ , or both, where  $Nv$  and  $Mh$  are positive integer numbers. For example, the first interleaved Intra prediction mode set corresponds to  $\{(v+0), (v+2), (v+4), (v+6), (v+8)\}$ ,  $\{(h+0), (h+2), (h+4), (h+6), (h+8)\}$ , or both. In another example, the first interleaved Intra prediction mode set corresponds to  $\{(v+0), (v+1), (v+3), (v+5), (v+7)\}$ ,  $\{(h+0), (h+1), (h+3), (h+5), (h+7)\}$ , or both. In yet another example, the first interleaved Intra prediction mode set corresponds to  $\{(v+1), (v+3), (v+5), (v+6)\}$ ,  $\{(h+1), (h+3), (h+5), (h+6)\}$ , or both.

[0016] When the Intra gradient filter is used, the Intra prediction filter process will identify two boundary neighboring reconstructed pixels located in a top boundary row

or a left boundary column adjacent to the current block according to the current Intra prediction mode. A weighted difference of the two boundary neighboring reconstructed pixels is added to each Intra prediction sample in one or more selected columns or rows of the initial Intra prediction block to form the filtered Intra prediction block. If any of the two boundary neighboring reconstructed pixels is not located at one integer position in the top boundary row or the left boundary column adjacent to the current block, interpolation is used to generate any of the two boundary neighboring reconstructed pixels not at one integer position.

[0017] In yet another embodiment, the Intra prediction filter corresponds to bi-directional Intra prediction filter, and where the Intra prediction filter is on when the current Intra prediction mode belongs to a second interleaved Intra prediction mode set. The Intra prediction filter process will identify two boundary neighboring reconstructed pixels located in a top boundary row and a left boundary column adjacent to the current block according to the current Intra prediction mode. If one or both boundary neighboring reconstructed pixels are unavailable for the current block, one or more unavailable boundary neighboring reconstructed pixels are padded with padded data to form padded reference samples. The bi-directional Intra prediction is applied based on the padded reference samples to selected initial Intra prediction sample in selected rows or columns of the initial Intra prediction block to form the filtered Intra prediction block. If any of the two boundary neighboring reconstructed pixels is not located at one integer position in the top boundary row or the left boundary column adjacent to the current block, interpolation is used to generate any of the two boundary neighboring reconstructed pixels not at one integer position.

[0018] The padded data can be generated by repeating from one or more available neighboring reconstructed pixels, extending from one or more available neighboring reconstructed pixels with even/odd symmetry, or setting the padded data to pre-defined pixel value.

[0019] The bi-directional Intra prediction filtering can be enabled or disabled according to indication in a sequence level, picture level, or slice level. The second interleaved Intra prediction mode set can be determined depending on block size of current block, wherein the current block corresponds to a coding unit (CU) or a transform unit (TU).

[0020] In yet another embodiment, Intra gradient filter is applied to the initial Intra prediction block to form a filtered Intra prediction block if the current Intra prediction

mode belongs to an interleaved subset of selected directional Intra prediction modes.

[0021] In yet another embodiment, bi-directional Intra prediction is applied to selected initial Intra prediction sample in selected rows or columns of the initial Intra prediction if the current Intra prediction mode belongs to a set of selected directional  
5 Intra prediction modes. If one or both boundary neighboring reconstructed pixels are unavailable for the current block, one or more unavailable boundary neighboring reconstructed pixels are padded with padded data to form padded reference samples. The padded reference samples are then used for the directional Intra prediction. Again, the padded data can be generated by repeating from one or more available  
10 neighboring reconstructed pixels, extending from one or more available neighboring reconstructed pixels with even/odd symmetry, or setting the padded data to pre-defined pixel value.

## BRIEF DESCRIPTION OF DRAWINGS

15 [0022] Fig. 1 illustrates an example of boundary neighboring reconstructed pixels used for generating Intra prediction sample according to the current HEVC (high efficiency video coding) standard.

[0023] Fig. 2 illustrates the 33 Intra prediction directions and their corresponding designations according to the current HEVC (high efficiency video coding) standard.

20 [0024] Fig. 3 illustrates an example Intra gradient filter for the vertical Intra prediction mode according to the current HEVC (high efficiency video coding) standard.

[0025] Fig. 4 illustrates an example Intra gradient filter for the Intra prediction modes from  $(v+1)$  to  $(v+8)$  according to the current HEVC (high efficiency video coding) standard.  
25

[0026] Fig. 5 illustrates an example bi-directional prediction filter for the Intra prediction modes from  $(v+1)$  to  $(v+8)$  according to the current HEVC (high efficiency video coding) standard.

[0027] Fig. 6 illustrates an example of an unavailable boundary neighboring  
30 reconstructed pixel for bi-directional Intra prediction filter.

[0028] Fig. 7 illustrates an exemplary flowchart of a coding system incorporating Intra prediction filtering according to an embodiment of the present invention.

## DETAILED DESCRIPTION

[0029] As mentioned before, the Intra gradient filter and bi-directional Intra prediction according to the HEVC (high efficiency video coding) standard and JCTVC-G279 is applied to Intra prediction modes from  $(v+1)$  to  $(v+8)$  and from  $(h+1)$  to  $(h+8)$ . However, such application may not achieve the best coding performance. In order to improve the coding efficiency of Intra prediction, new methods to derive or refine the Intra predictor for video coding are disclosed as follow.

### [0030] First Embodiment

[0031] In HEVC, the Intra gradient filter is used only for the Intra prediction mode equal to DC, horizontal, or vertical mode. According to JCTVC-G279, the Intra gradient filter can be applied on all directional modes from  $v$  to  $(v+8)$  and from  $h$  to  $(h+8)$ . Applying the Intra gradient filter to all directional modes from  $v$  to  $(v+8)$  and from  $h$  to  $(h+8)$  will increase the complexity substantially due to the increased number of filtered rows/columns. However, the coding efficiency may not be increased for all modes in the group of selected Intra prediction modes. In order to solve this problem, an Intra gradient filter for a group of interleaved Intra prediction modes is disclosed, the proposed scheme is also referred to as "Interleaved Intra gradient filter". In other words, Intra gradient filter is applied in an interleaved fashion to the directional modes from  $v$  to  $(v+Nv)$  and/or from  $h$  to  $(h+Mh)$ , where  $Nv$  and  $Mh$  are positive integers. For example,  $Nv$  and  $Mh$  can be equal to 8 or 6, and Intra gradient filter will only be applied to the even Intra prediction modes, i.e.,  $v$ ,  $(v+2)$ ,  $(v+4)$ ,  $(v+6)$  and  $(v+8)$ , and/or  $h$ ,  $(h+2)$ ,  $(h+4)$ ,  $(h+6)$  and  $(h+8)$ . In another example, the interleaved Intra prediction mode set to apply the Intra gradient filter correspond to  $\{(v+0), (v+1), (v+3), (v+5), (v+7)\}$ ,  $\{(h+0), (h+1), (h+3), (h+5), (h+7)\}$ , or both. In yet another example, the interleaved Intra prediction mode set to apply the Intra gradient filter correspond to  $\{(v+1), (v+3), (v+5), (v+6)\}$ ,  $\{(h+1), (h+3), (h+5), (h+6)\}$ , or both. For other Intra prediction modes, Intra prediction samples will not be filtered by Intra gradient filter.

[0032] In the above example of interleaved Intra prediction modes, Intra gradient filter is on for every other directional Intra prediction mode (e.g., even or odd directional modes from  $v$  to  $(v+8)$  and/or from  $h$  to  $(h+8)$ ). However, other interleaving patterns may also be used. For example, the pattern can be every other

two directional Intra prediction modes. In other words, the on/off pattern for applying the Intra gradient filter to the directional Intra prediction modes from  $v$  to  $(v+8)$  and/or from  $h$  to  $(h+8)$  can be {on, on, off, off, on, on, off, off, on }. In another example, the pattern can be every other three directional Intra prediction modes. The on/off pattern for applying the Intra gradient filter to the directional Intra prediction modes from  $v$  to  $(v+8)$  and/or from  $h$  to  $(h+8)$  can be, for example, {on, on, on, off, off, off, on, on, on}. In yet another example, the interleaving pattern for applying the Intra gradient filter to the directional Intra prediction modes from  $v$  to  $(v+8)$  and/or from  $h$  to  $(h+8)$  is not uniform, and can be {on, off, off, on, off, off, on, on, off}, {on, on, off, on, off, on, off, on, off}, { off, on, on, off, off, on, on, off, off}, { on, off, off, on, on, off, on, off, on}, { off, on, off, on, off, on, on, off, off}, or { on, off, on, off, on, on, off, off, on}, the present application is not limited thereto.

[0033] In one example, whether the Interleaved Intra gradient filter is enabled or disabled can be indicated in a sequence level, picture level, or slice level. In another example, whether the Interleaved Intra gradient filter is enabled or disabled may be dependent on the block size of the current block, where the current block corresponds to a coding unit (CU) or a transform unit (TU). For instance, the Interleaved Intra gradient filter can only be applied to CU or TU with a size smaller than or equal to a threshold. However, the intra gradient filter is always enabled or disabled for CU or TU with a size larger than the threshold. The size constraint can be signaled at sequence level, picture level, or slice level.

[0034] The present application also discloses a mode coding scheme associated with the Interleaved Intra gradient filter. For example, assuming that the original most probable mode (MPM) is { Dir, Dir+1, Dir-1}, where Dir represents a directional Intra prediction mode. When the Interleaved Intra gradient filter is enabled, the MPM mode can be changed as { Dir, Dir+N, Dir-N}, where Dir+N and Dir-N are directional Intra prediction modes closest to Dir with the same intra gradient filter process (enabled or disabled).

[0035] The Intra prediction filter according to this embodiment may result in more distinct Intra predictors for two successive Intra prediction modes. This is especially true when the TU size is small. The interleaved Intra prediction filter also has the potential to improve the coding performance.

[0036] **Second Embodiment**

[0037] In bi-directional Intra prediction, the final Intra predictor is a weighted sum

of  $P_{ij}$  and  $F_{ij}$ . However, the  $F_{ij}$  may not be available for the current block. This occurs more likely especially when the number of rows/columns processed by bi-directional Intra prediction increases. Fig. 6 illustrates an example of an unavailable boundary neighboring reconstructed pixel. The boundary neighboring reconstructed pixels for the current block are shown as line-filled pixel areas, which are located in a top boundary row and a left boundary column adjacent to the current block. The top boundary row extends beyond the width of the current block as shown in Fig. 6. Similarly, the left boundary column also extends downward beyond the height of the current block. For the Intra prediction direction indicated by the arrows, sample  $F_{ij}$  for the Intra prediction sample indicated by a circle is not available (indicated by “?” in Fig. 6) since this sample  $F_{ij}$  is outside the left boundary column. This imposes a difficulty for applying bi-directional Intra prediction to more directional Intra modes or more to-be-processed rows/columns.

[0038] In order to solve this problem, a padding technique is disclosed according to an embodiment of the present invention. According to the padding process, when  $F_{ij}$  is not included in the reconstructed samples of neighboring TUs, padding techniques are used to generate  $F_{ij}$  for bi-directional Intra prediction for all selected directional Intra modes. The padding technique is also useful for the case with increased number of rows/columns processed by bi-directional Intra prediction. In this case, it becomes more likely that  $F_{ij}$  is not included in the reconstructed samples of neighboring TUs.

[0039] Various padding techniques are known in the field. For example, the padded data can be generated by repeating from one or more available neighboring reconstructed pixels, extending from one or more available neighboring reconstructed pixels with even/odd symmetry, or setting the padded data to pre-defined pixel value. Furthermore, if any of the two boundary neighboring reconstructed pixels is not located at one integer position in the top boundary row or the left boundary column adjacent to the current block, interpolation can be used to generate any of the two boundary neighboring reconstructed pixels not at one integer position.

[0040] The selected directional Intra prediction modes for applying the bi-directional Intra prediction filter may be dependent on the block size of current block, where the current block corresponds to a coding unit (CU) or a transform unit (TU). Furthermore, whether bi-directional Intra prediction filtering is enabled or disabled can be indicated in a sequence level, picture level, or slice level.

[0041] **Third Embodiment**

[0042] In this embodiment, whether to turn on or off Intra prediction filter can be determined based on interleaved Intra prediction mode sets implicitly. For example, the Intra gradient filter can be applied to a first interleaved directional Intra prediction mode set. For those directional Intra prediction modes not belonging to the first interleaved directional Intra prediction mode set, the bi-directional Intra prediction filter can be applied for some or all of those directional Intra prediction modes. Various techniques associated with individual Intra gradient filter or bi-directional Intra prediction filter mentioned above can also be applied to this embodiment. For example, the selection of the interleaved Intra prediction mode set for the Intra gradient filter mentioned above is also applicable to this embodiment. In one example, the Intra gradient filter will only be applied to the directional Intra prediction modes  $v$ ,  $(v+2)$ ,  $(v+4)$ , and  $(v+6)$ , and/or  $h$ ,  $(h+2)$ ,  $(h+4)$  and  $(h+6)$ . For bi-directional Intra prediction filter, it can be applied for directional Intra prediction modes equal to  $(v+8)$  and/or  $(h+8)$ . In another example, the bi-directional Intra prediction filter can be applied for directional Intra prediction modes equal to  $(v+7)$  and  $(v+8)$  and/or  $(h+7)$  and  $(h+8)$ .

[0043] In yet another example, the first interleaved directional Intra prediction mode set comprises the directional intra prediction modes from  $v$  to  $(v+Nv)$  and/or from  $h$  to  $(h+Mh)$ , where  $Nv$  and  $Mh$  are positive integers and can be identical or different. In one example,  $Nv$  and  $Mh$  are both equal to 8. In another example,  $Nv$  and  $Mh$  are both equal to 4. The Intra gradient filter can be applied to all directional intra prediction modes belonging to the first interleaved directional Intra prediction mode set, while the bi-directional Intra prediction filter can be applied to the rest of the directional intra prediction modes (i.e., those directional Intra prediction modes not belonging to the first interleaved directional Intra prediction mode set).

[0044] In the foregoing embodiments, the number of to-be-filtered pixels in the intra gradient filter or the bi-directional Intra prediction filter depends on the size of the current block, where the current block corresponds to a coding unit (CU) or a transform unit (TU). For example, the number of to-be-filtered pixels in intra gradient filter or bi-directional Intra prediction filter can be increased when the size of the current block is large. The number of to-be-filtered pixels in intra gradient filter or bi-directional Intra prediction filter can be small when the size of the current block is small.

[0045] **Fourth Embodiment**

[0046] In the current HEVC standard, the Intra residual is coded by CABAC (context adaptive binary arithmetic coding) with the scan order which depends on the Intra prediction mode and TU size. If the transform size is smaller than or equal to 8x8, then intra-mode-dependent scan will be used for the coding order of coefficient groups in one TU and scan order of coefficients in one coefficient group. Otherwise, diagonal scan is used for the coding order of coefficient groups in one TU and scan order of coefficients in one coefficient group. In order to further simplify the Intra residual coding, a diagonal scan for the coding order of coefficient groups in one Intra TU is disclosed. When different square or non-square transform sizes are used, intra-mode-dependent scans for the coding order of coefficient groups in one TU will require increased computation complexity. This may also introduce some redundancy between different scan orders. For example, if the transform type is non-square transform with size equal to 16x4, then the coding orders among diagonal scan, horizontal scan, and vertical scans of coefficient groups in one TU are exactly the same. As the supported transform size increases, more memories are needed to store the coding orders of coefficient groups in one TU for different scan patterns. Therefore, diagonal scan for the coding order of coefficient groups in one TU is used to simply the computation with little coding performance loss. In addition to the scan order of coefficient groups in one TU, intra-mode-dependent scan is also used as the scan order of coefficients in one coefficient group for all TUs. According to the current practice, one TU is divided into multiple 4x4 coefficient groups and only three scans for one 4x4 coefficient group need to be designed. Therefore, intra-mode-dependent scan can be used as the scan order of coefficients in one coefficient group for all TUs without extra cost.

25 [0047] **ALF Syntax**

[0048] Besides the improvement of Intra coding, another aspect of the present invention addresses the syntax design of adaptive loop filter (ALF). ALF has been disclosed in HEVC standard meeting. The ALF parameter set is signaled at picture level and ALF on/off flag associated with coding tree block data is signaled at coding-tree-unit level. For example, ALF parameter set can be signaled in adaptive parameter set. Adaptive parameter set (APS) is a type of independent picture parameter sets as described for HEVC. APS can be referenced by different pictures. In this case, the information in adaptive parameter set can be referenced by different pictures regardless of the dependency between different pictures. Therefore, the functionality

of random access will not be affected. In another implementation case, ALF parameter set can be coded in a picture-level header associated with one individual picture, instead of independent picture parameter set. In this case, the functionality of random access may not be provided if referencing ALF parameter set requires data across a random access point. For example, there are 60 frames in one bitstream, the first frame and 30-th frame are random access points, and one ALF parameter set is coded in the picture-level header of the 27-th frame. This ALF parameter set is used for the 27-th frame. If the ALF parameter set is referenced by the 32-nd frame, while the 30-th frame being a random access point, frames from the 32-th frame to the last frame cannot be directly decoded from the bitstream since the 32-nd frame refers to the ALF parameter set of the 27-th frame. The functionality of random access cannot be achieved in this case. Therefore, according to another embodiment of the present invention, referencing to the ALF parameter set is disallowed when referencing to ALF parameter set crosses any random access points to remove data dependency across a random access point. In the above example, if the rule is applied, referencing to the ALF parameter set in the 27-th frame for the 32-nd frame will be forbidden due to data dependency across the random access point associated with the 30-th frame. Hence, the functionality of random access can be guaranteed. In yet another embodiment, the buffer of ALF parameter sets for the reference is reset by other frames when decoding one random access picture.

[0049] Fig. 7 illustrates an exemplary flowchart of a coding system incorporating Intra prediction filtering according to an embodiment of the present invention. The system receives input data associated with a current block being coded in a current Intra prediction mode in step 710. The input data may correspond to pixel data of the current block to be coded at the encoder side or the coded data of the current block in the decoder side. The current block may be retrieved from storage such as a computer memory or buffer (RAM or DRAM). The video bitstream may also be received from a processor such as a processing unit or a digital signal. The initial Intra prediction block is derived based on neighboring reconstructed pixels of the current block according to the current Intra prediction mode in step 720. Whether to turn on or off Intra prediction filter is determined based on interleaved Intra prediction mode sets implicitly in step 730. Whether the Intra prediction filter is on for the current Intra prediction mode is checked in step 740. If the Intra prediction filter is on for the current Intra prediction mode (i.e., the “Yes” branch), steps 750 and 760 are

performed. Otherwise (i.e., the “No” path), steps 750 and 760 are skipped. In step 750, the Intra prediction filter to the initial Intra prediction block is applied to form a filtered Intra prediction block. In step 760, Intra prediction encoding or decoding is applied to the current block using the filtered Intra prediction block as a predictor for the current block.

[0050] The flowchart shown above is intended to illustrate examples of Intra prediction filtering according an embodiment of the present invention. A person skilled in the art may modify each step, re-arranges the steps, split a step, or combine steps to practice the present invention without departing from the spirit of the present invention.

[0051] The above description is presented to enable a person of ordinary skill in the art to practice the present invention as provided in the context of a particular application and its requirement. Various modifications to the described embodiments will be apparent to those with skill in the art, and the general principles defined herein may be applied to other embodiments. Therefore, the present invention is not intended to be limited to the particular embodiments shown and described, but is to be accorded the widest scope consistent with the principles and novel features herein disclosed. In the above detailed description, various specific details are illustrated in order to provide a thorough understanding of the present invention. Nevertheless, it will be understood by those skilled in the art that the present invention may be practiced.

[0052] Embodiment of the present invention as described above may be implemented in various hardware, software codes, or a combination of both. For example, an embodiment of the present invention can be one or more electronic circuits integrated into a video compression chip or program code integrated into video compression software to perform the processing described herein. An embodiment of the present invention may also be program code to be executed on a Digital Signal Processor (DSP) to perform the processing described herein. The invention may also involve a number of functions to be performed by a computer processor, a digital signal processor, a microprocessor, or field programmable gate array (FPGA). These processors can be configured to perform particular tasks according to the invention, by executing machine-readable software code or firmware code that defines the particular methods embodied by the invention. The software code or firmware code may be developed in different programming languages and

different formats or styles. The software code may also be compiled for different target platforms. However, different code formats, styles and languages of software codes and other means of configuring code to perform the tasks in accordance with the invention will not depart from the spirit and scope of the invention.

- 5 [0053] The invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described examples are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims
- 10 are to be embraced within their scope.

## CLAIMS

1. A method of Intra prediction filtering, the method comprising:  
receiving input data associated with a current block being coded in a current Intra  
5 prediction mode;  
deriving initial Intra prediction block based on neighboring reconstructed pixels  
of the current block according to the current Intra prediction mode;  
determining whether to turn on or off Intra prediction filter based on interleaved  
Intra prediction mode sets implicitly;  
10 if the Intra prediction filter is on for the current Intra prediction mode:  
applying the Intra prediction filter to the initial Intra prediction block to form a  
filtered Intra prediction block; and  
applying Intra prediction encoding or decoding to the current block using the  
filtered Intra prediction block as a predictor for the current block.
- 15 2. The method of Claim 1, wherein the Intra prediction filter corresponds to  
Intra gradient filter, and wherein the Intra prediction filter is on if the current Intra  
prediction mode belongs to a first interleaved Intra prediction mode set.
3. The method of Claim 2, wherein the first interleaved Intra prediction mode  
set corresponds to a plurality of directional Intra prediction modes selecting from (v+0)  
20 through (v+Nv), from (h+0) through (h+Mh), or both, wherein Nv and Mh are  
positive integer numbers.
4. The method of Claim 3, wherein Nv and Mh are equal to eight or six.
5. The method of Claim 4, wherein the first interleaved Intra prediction mode  
set corresponds to {(v+0), (v+2), (v+4), (v+6), (v+8)}, {(h+0), (h+2), (h+4), (h+6),  
25 (h+8)}, or both.
6. The method of Claim 4, wherein the first interleaved Intra prediction mode  
set corresponds to {(v+0), (v+1), (v+3), (v+5), (v+7)}, {(h+0), (h+1), (h+3), (h+5),  
(h+7)}, or both.
7. The method of Claim 4, wherein the first interleaved Intra prediction mode  
30 set corresponds to {(v+1), (v+3), (v+5), (v+6)}, {(h+1), (h+3), (h+5), (h+6)}, or both.
8. The method of Claim 2, said applying the Intra prediction filter to the initial  
Intra prediction block comprises:  
identifying two boundary neighboring reconstructed pixels located in a top

boundary row or a left boundary column adjacent to the current block; and

adding a weighted difference of the two boundary neighboring reconstructed pixels to each Intra prediction sample in one or more selected columns or rows of the initial Intra prediction block to form the filtered Intra prediction block.

5           9. The method of Claim 8, wherein if any of the two boundary neighboring reconstructed pixels is not located at one integer position in the top boundary row or the left boundary column adjacent to the current block, interpolation is used to generate any of the two boundary neighboring reconstructed pixels not at one integer position.

10          10. The method of Claim 1, wherein the Intra prediction filter corresponds to bi-directional Intra prediction filter, and wherein the Intra prediction filter is on when the current Intra prediction mode belongs to a second interleaved Intra prediction mode set.

15          11. The method of Claim 10, said applying the Intra prediction filter to the initial Intra prediction block comprises:

identifying two boundary neighboring reconstructed pixels located in a top boundary row and a left boundary column adjacent to the current block; and

if one or both boundary neighboring reconstructed pixels are unavailable for the current block:

20          padding one or more unavailable boundary neighboring reconstructed pixels with padded data to form padded reference samples; and

applying bi-directional Intra prediction based on the padded reference samples to selected initial Intra prediction sample in selected rows or columns of the initial Intra prediction block to form the filtered Intra prediction block.

25          12. The method of Claim 11, wherein if any of the two boundary neighboring reconstructed pixels is not located at one integer position in the top boundary row or the left boundary column adjacent to the current block, interpolation is used to generate any of the two boundary neighboring reconstructed pixels not at one integer position.

30          13. The method of Claim 11, wherein the padded data is generated by repeating from one or more available neighboring reconstructed pixels, extending from one or more available neighboring reconstructed pixels with even/odd symmetry, or setting the padded data to pre-defined pixel value.

14. The method of Claim 11, wherein the bi-directional Intra prediction filter is

enabled or disabled according to indication in a sequence level, picture level, or slice level.

15. The method of Claim 11, wherein the second interleaved Intra prediction mode set is determined depending on block size of current block, wherein the current  
5 block corresponds to a coding unit (CU) or a transform unit (TU).

16. A method of Intra prediction filtering, the method comprising:

receiving input data associated with a current block being coded in a current Intra prediction mode;

10 determining initial Intra prediction block based on neighboring reconstructed pixels of the current block according to the current Intra prediction mode;

applying Intra gradient filter to the initial Intra prediction block to form a filtered Intra prediction block if the current Intra prediction mode belongs to an interleaved subset of selected directional Intra prediction modes; and

15 applying Intra prediction encoding or decoding to the current block using the filtered Intra prediction block as a predictor for the current block.

17. The method of Claim 16, wherein the selected directional Intra prediction modes correspond to directional Intra prediction modes selecting from  $(v+0)$  through  $(v+Nv)$ , from  $(h+0)$  through  $(h+Mh)$ , or both, wherein  $Nv$  and  $Mh$  are positive integer numbers.

20 18. The method of Claim 17, wherein  $Nv$  and  $Mh$  are equal to eight or six.

19. The method of Claim 18, wherein the interleaved subset corresponds to  $\{(v+0), (v+2), (v+4), (v+6), (v+8)\}$ ,  $\{(h+0), (h+2), (h+4), (h+6), (h+8)\}$ , or both.

20. The method of Claim 18, wherein the interleaved subset corresponds to  $\{(v+0), (v+1), (v+3), (v+5), (v+7)\}$ ,  $\{(h+0), (h+1), (h+3), (h+5), (h+7)\}$ , or both.

25 21. A method of bi-directional Intra prediction filtering for Intra prediction, comprising:

receiving input data associated with a current block being coded in a current Intra prediction mode;

30 determining initial Intra prediction block based on neighboring reconstructed pixels of the current block according to the current Intra prediction mode;

identifying two boundary neighboring reconstructed pixels located in a top boundary row and a left boundary column adjacent to the current block; and

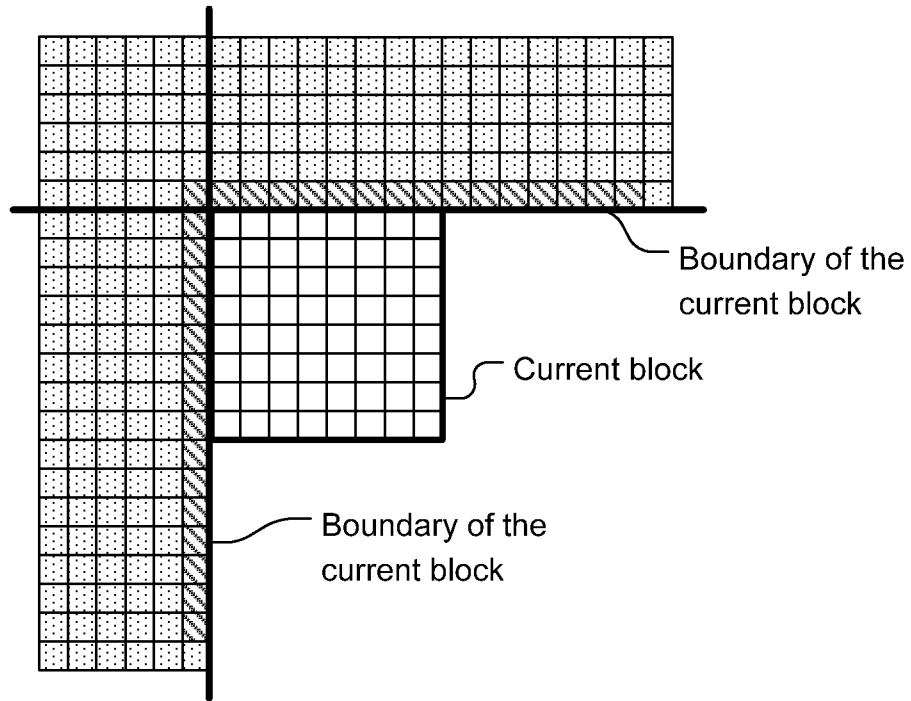
if one or both boundary neighboring reconstructed pixels are unavailable for the current block:

padding one or more unavailable boundary neighboring reconstructed pixels with padded data to form padded reference samples;

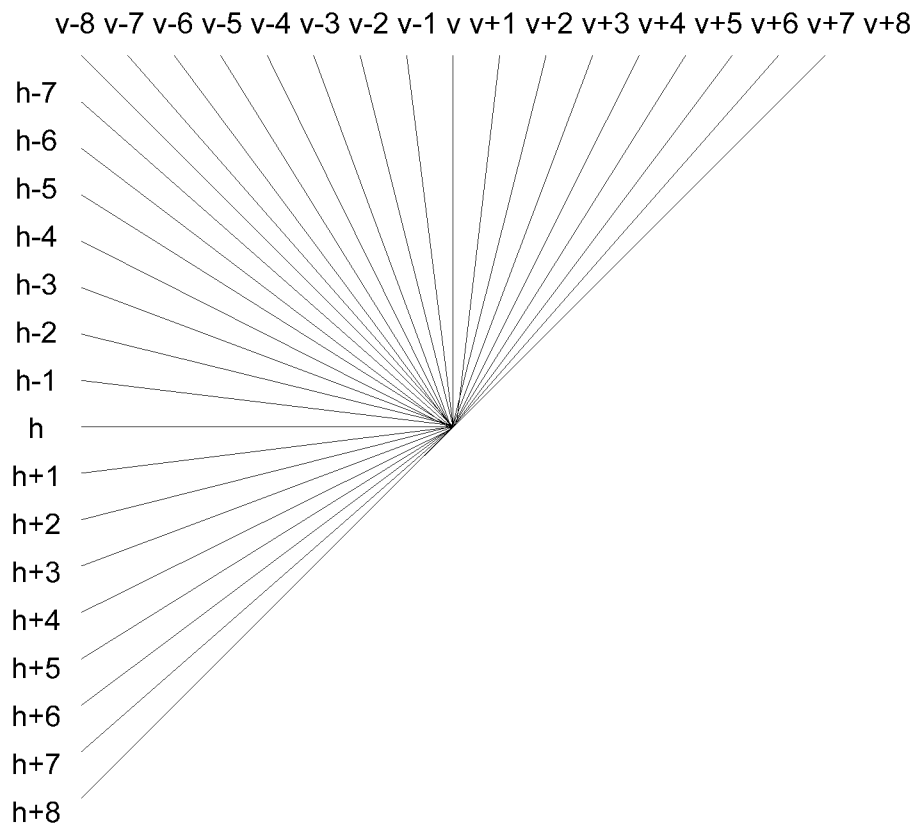
5 applying bi-directional Intra prediction based on the padded reference samples to selected initial Intra prediction sample in selected rows or columns of the initial Intra prediction block to form a filtered Intra prediction block if the current Intra prediction mode belongs to a set of selected directional Intra prediction modes; and

applying Intra prediction encoding or decoding to the current block using the filtered Intra prediction block as a predictor for the current block.

10 22. The method of Claim 21, wherein the padded data is generated by repeating from one or more available neighboring reconstructed pixels, extending from one or more available neighboring reconstructed pixels with even/odd symmetry, or setting the padded data to pre-defined pixel value.



**Fig. 1**



**Fig. 2**

A diagram showing a matrix with eight downward-pointing arrows above it. The matrix has a thick vertical line on the left and a thick horizontal line at the top. The cells contain the following text:

<b>AL</b>	<i>A0</i>		<i>Aj</i>			<i>Ak</i>
<i>L0</i>	<i>P00</i>	...	<i>P0j</i>	...		<i>P0k</i>
<i>L1</i>	<i>P10</i>		<i>P1j</i>			<i>P1k</i>
	.					
	.					
	.					
<i>Li</i>	<i>Pi0</i>		<i>Pij</i>			<i>Pik</i>
	.					
	.					
	.					
<i>Lk</i>	<i>Pk0</i>		<i>Pkj</i>			<i>Pkk</i>

**Fig. 3**

A diagram showing a matrix with eight downward-pointing arrows above it and two diagonal arrows on the left. The matrix has a thick vertical line on the left and a thick horizontal line at the top. The cells contain the following text:

<b>AL</b>	<i>A0</i>		<i>Aj</i>			<i>Ak</i>
<i>L0</i>	<i>P00</i>	...	<i>P0j</i>	...		<i>P0k</i>
<i>L1</i>	<i>P10</i>		<i>P1j</i>			<i>P1k</i>
	.					
	.					
	.					
<i>Li</i>	<i>Pi0</i>		<i>Pij</i>			<i>Pik</i>
	.					
	.					
	.					
<i>Lk</i>	<i>Pk0</i>		<i>Pkj</i>			<i>Pkk</i>

**Fig. 4**

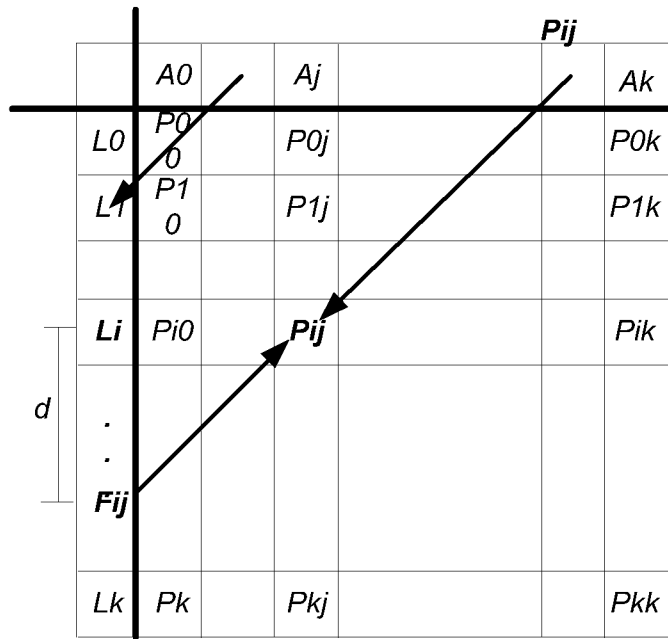


Fig. 5

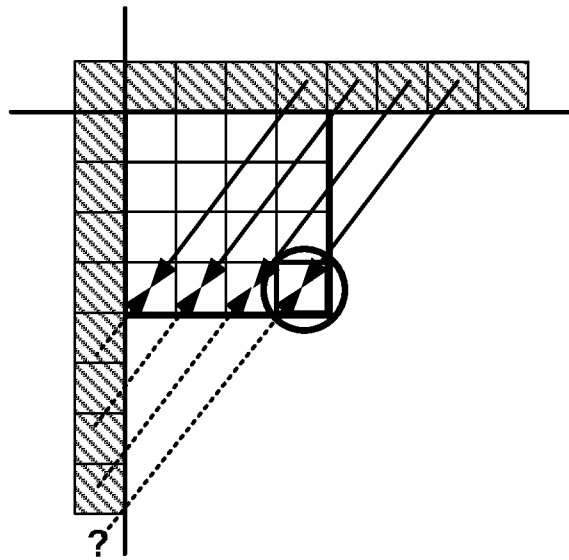
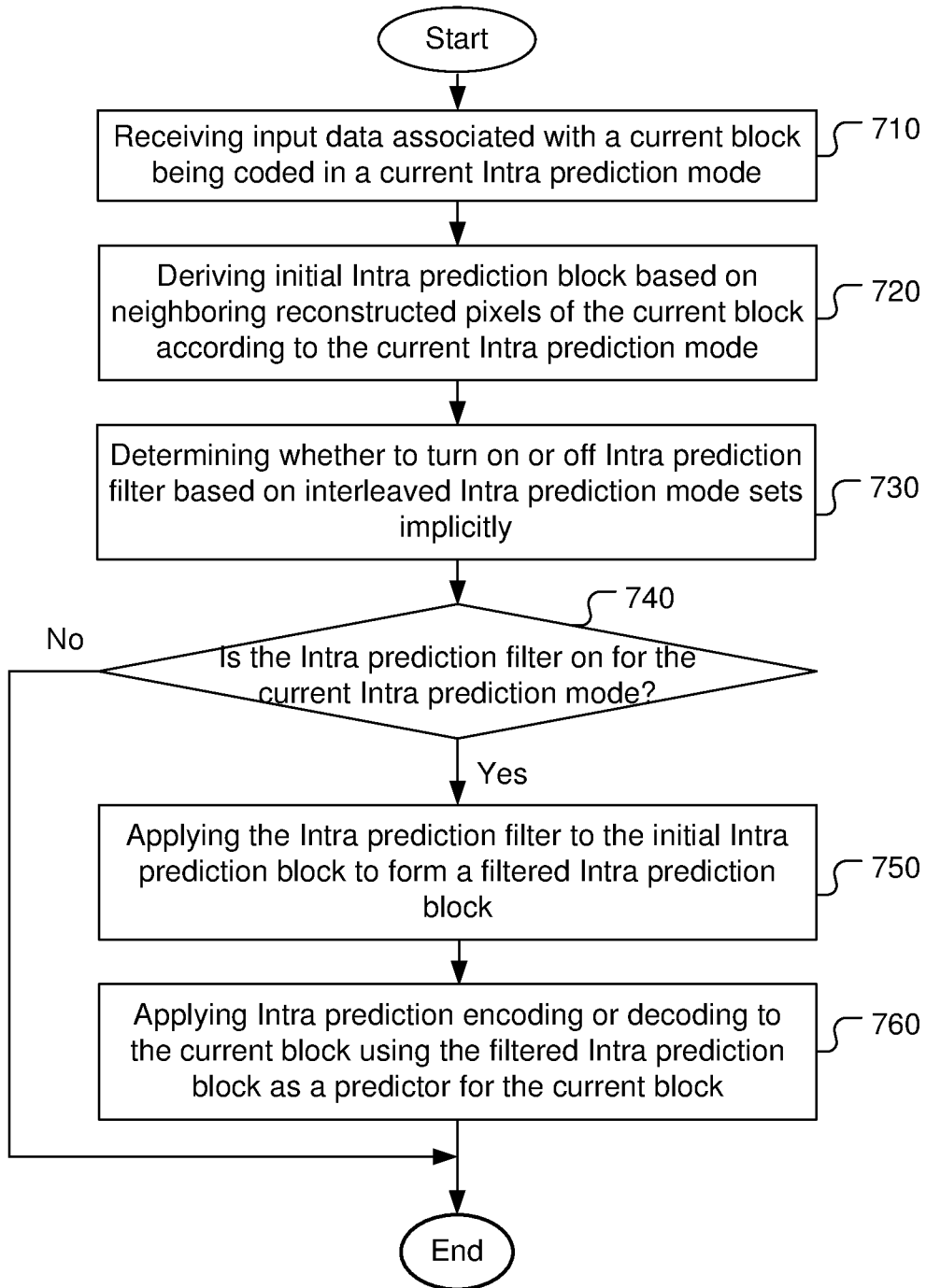


Fig. 6



**Fig. 7**

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2015/093048

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>		
H04N 19/117(2014.01)i; H04N 19/82(2014.01)i; H04N 19/105(2014.01)i; H04N 19/176(2014.01)i		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols)		
H04N		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
CNTXT;SIPOABS; Google; JCTVC; IEEE: mediatek, bi-directional, gradient, filter, hevc, intra prediction, disable, enable, turn on, turn off, padding, interpolation		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Jewon Kang et al. "Non-RCE3: Implicit derivation for adaptively turning filtering off in intra prediction" <i>Joint Collaborative Team on Video Coding (JCT-VC) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/Joint Collaborative Team on Video Coding (JCT-VC) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, 15th Meeting: Geneva, CH, 23Oct. – 1No, Document: JCTVC-00181, 24 October 2013 (2013-10-24),</i> abstract and section 1 to 2	1-20
Y	Mei Guo et al. "CE6 Subset d: Direction based Angular Intra Prediction" <i>Joint Collaborative Team on Video Coding (JCT-VC) of ITU-T SG16 WP3 and ISO/IEC JTC1/SC29/WG11, 7th Meeting: Geneva, CH, 21-30 Nov., 2011, Document: JCTVC-G279,</i> 28 November 2011 (2011-11-28), abstract and section 1 to 2	1-22
Y	Yao-Jen Chang et al. "Non-RCE3: Horizontal/vertical padding scheme for intra block copy" <i>Joint Collaborative Team on Video Coding (JCT-VC) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, 16th Meeting: San José, US, 9–17 Jan. 2014, Document: JCTVC-P0255, 10 January 2014 (2014-01-10),</i> abstract	11
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents:		
“A”	document defining the general state of the art which is not considered to be of particular relevance	“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
“E”	earlier application or patent but published on or after the international filing date	“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
“L”	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
“O”	document referring to an oral disclosure, use, exhibition or other means	“&” document member of the same patent family
“P”	document published prior to the international filing date but later than the priority date claimed	
Date of the actual completion of the international search		Date of mailing of the international search report
06 January 2016		18 January 2016
Name and mailing address of the ISA/CN		Authorized officer
STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA 6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China		GAO, Weiwei
Facsimile No. (86-10)62019451		Telephone No. (86-10)62089149

C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Xianguo Zhang et al. "CE9 Test A.1: Optionally disabling the usage of the intra boundary filters" <i>Joint Collaborative Team on Video Coding (JCT-VC) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, 19th Meeting: Strasbourg, FR, 17-24 Oct. 2014, Document: JCTVC-S0102, 16 October 2014 (2014-10-16),</i> abstract and section 4	14
A	CN 103329538 A (SK TELECOM CO. LTD.) 25 September 2013 (2013-09-25) the whole document	1-22
A	WO 2014045919 A1 (SONY CORP) 27 March 2014 (2014-03-27) the whole document	1-22

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

- [1] This Authority considers that there are 3 inventions covered by the claims indicated as follows: claims 1-15, 16-20 and 21-22. Claims 1-15 directed to an intra prediction filtering method with enabling or disabling the intra prediction filter under a criterion; claims 16-20 directed to an intra prediction filtering method with intra gradient filter under a criterion; and claims 21-22 directed to a bi-directional intra prediction filtering method with padding unavailable neighboring pixels. These claims are not linked by common or corresponding special technical features, thus not form a single general inventive concept. The application, hence does not meet the requirements of unity of invention as defined in Rules 13.1 and 13.2 PCT.

1.  As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2.  As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3.  As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4.  No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

- Remark on Protest**
- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
  - The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
  - No protest accompanied the payment of additional search fees.

**INTERNATIONAL SEARCH REPORT**  
**Information on patent family members**

International application No.

**PCT/CN2015/093048**

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	103329538	A	25 September 2013	KR	20120082960	A	25 July 2012
				WO	2012096550	A2	19 July 2012
				WO	2012096550	A3	22 November 2012
				US	2013301709	A1	14 November 2013
				KR	1444667	B1	30 September 2014
.....							
WO	2014045919	A1	27 March 2014	CN	104620586	A	13 May 2015
				WO	2014045920	A1	27 March 2014
.....							