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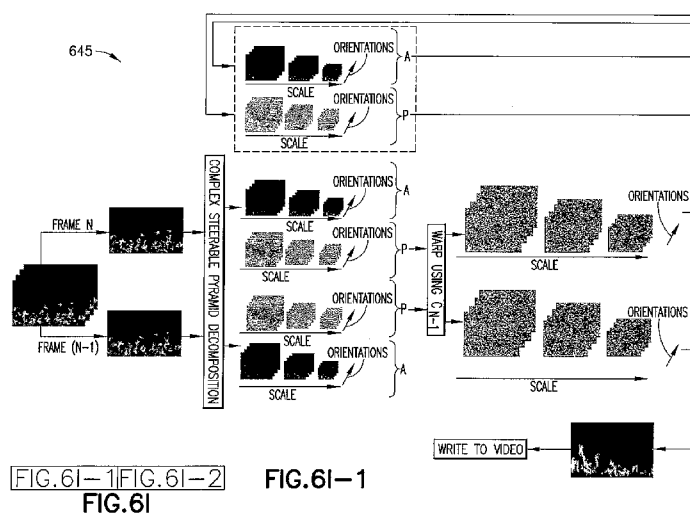
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(54) **Title:** METHODS AND APPARATUS FOR PROCESSING MOTION INFORMATION IMAGES



(57) **Abstract:** Systems and techniques for processing images to add motion of a video sequence to a still image. Successive frames of a video sequence are processed to extract phase difference information between pairs of successive frames. Processing may suitably comprise decomposition of each frame in a pair to a complex steerable pyramid. Phase information may suitably be warped to a still image frame to be updated with motion information, based on a correspondence map. Phase difference information is determined and added to phase information of a still image frame that is to be updated. This addition creates output frame phase information, and this information is combined with amplitude information to create an updated frame with variations from a previous frame. These variations represent the motion between the successive video sequence frames. Additional embodiments include determining similarity between video sequences, creation of motion layers, and creation of interpolated frames.

METHODS AND APPARATUS FOR PROCESSING MOTION INFORMATION IN IMAGES

FIELD OF THE INVENTION

One or more embodiments of the present invention relate generally to image creation and modification. More particularly, embodiments of the invention relate to systems and techniques for adding motion information from video sequences to still images so as to enhance the still images with motion.

BACKGROUND

Numerous electronic devices have the ability to display still and moving images. A user of an electronic device may wish to display still images using a device, and a still image may be more engaging, may attract more attention, or may meet other needs of a user, if motion can be added to areas of the image. For example, water may ripple, trees may sway, flames may flicker, or clouds may drift. Moving images, such as those taken with electronic video equipment, are a ubiquitous source of motion elements, but the images need to be analyzed both for resemblance to a still image to which motion is to be added and to recover motion elements to be added to the still image. Moving images are made up of numerous elements – a moving image comprises a number of frames, each of which includes numerous pixels. Analysis of a moving image with respect to another image, such as a still image, has generally been computationally complex. Similarly, analysis within a moving image, involving frame-to-frame computations and comparisons involving corresponding pixels and changes of pixels from frame to frame, has also been complex.

SUMMARY OF THE INVENTION

In one embodiment of the invention, an apparatus comprises at least one processor and memory storing a program of instructions. The memory storing the program of instructions is configured to, with the at least one processor, configure the apparatus to at least analyze successive frames of a video sequence to extract phase difference information indicating motion, successively construct frames based on a still image, wherein successively constructing the frames based on a still image comprises using the phase difference information to successively update phase information and adding the phase information to successively created still image frames so as to introduce variations representing motion, and assemble the successively constructed frames to create a reconstructed output video sequence based on the still image.

In another embodiment of the invention, an apparatus comprises at least one processor and memory storing a program of instructions. The memory storing the program of instructions

is configured to, with the at least one processor, configure the apparatus to at least identify two or more video sequences for similarity analysis, for each of the video sequences, analyze phase variations between frames of the video sequence to determine local motion in the video sequence, and determine similarity between two or more of the video sequences based on the analysis of the phase variations.

In another embodiment of the invention, an apparatus comprises at least one processor and memory storing a program of instructions. The memory storing the program of instructions is configured to, with the at least one processor, configure the apparatus to at least identify motion layers of a video sequence based on phase difference information representing variations between frames of the video sequence and identify and classify types of motion in one or more of the motion layers.

In another embodiment of the invention, an apparatus comprises at least one processor and memory storing a program of instructions. The memory storing the program of instructions is configured to, with the at least one processor, cause the apparatus to at least analyze successive frames of a video sequence to extract phase difference information indicating motion, and create an interpolated updated frame between a pair of successive frames using phase information representing intermediate values between information for members of the pair of successive video frames.

In another embodiment of the invention, a method comprises analyzing successive frames of a video sequence to extract phase difference information indicating motion, successively construct frames based on a still image, wherein successively constructing the frames based on a still image comprises using the phase difference information to successively update phase information, adding the phase information to successively created still image frames so as to introduce variations representing motion, and assembling the successively constructed frames to create a reconstructed output video sequence based on the still image.

In another embodiment of the invention, a method comprises identifying two or more video sequences for similarity analysis; for each of the video sequences, analyzing phase variations between frames of the video sequence to determine local motion in the video sequence, and determining similarity between two or more of the video sequences based on the analysis of the phase variations.

In another embodiment of the invention, a method comprises identifying motion layers of a video sequence based on phase difference information representing variations between frames

of the video sequence, and identifying and classifying types of motion in one or more of the motion layers.

In another embodiment of the invention, a method comprises analyzing successive frames of a video sequence to extract phase difference information indicating motion, and creating an interpolated updated frame between a pair of successive frames using phase information representing intermediate values between information for members of the pair of successive video frames.

In another embodiment of the invention, a computer readable medium stores a program of instructions. Execution of the program of instructions by at least one processor configures an apparatus to at least analyze successive frames of a video sequence to extract phase difference information indicating motion, successively construct frames based on a still image, wherein successively constructing the frames based on a still image comprises using the phase difference information to successively update phase information and adding the phase information to successively created still image frames so as to introduce variations representing motion, and assemble the successively constructed frames to create a reconstructed output video sequence based on the still image.

In another embodiment of the invention, a computer readable medium stores a program of instructions. Execution of the program of instructions by at least one processor configures an apparatus to at least identify two or more video sequences for similarity analysis, for each of the video sequences, analyze phase variations between frames of the video sequence to determine local motion in the video sequence, and determine similarity between two or more of the video sequences based on the analysis of the phase variations.

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BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates a system for constructing an image with motion elements according to an embodiment of the present invention;

Figs. 2-5 illustrate processes according to an embodiment of the present invention;

Figs. 6A-6I illustrate exemplary processing stages undertaken in processing frames according to an embodiment of the present invention; and

Fig. 7 illustrates elements that may suitably be used to carry out an embodiment of the present invention.

DETAILED DESCRIPTION

One or more embodiments of the present invention provide mechanisms for matching a video sequence to a still image, analyzing frames of the video sequence to isolate information representing motion, and using the information representing motion to iteratively construct successive frames of the still image, with variations representing motion.

In one or more embodiments of the invention, one or more video images in a set of video sequences is compared to a still image to which motion elements are to be added. The best matched video sequence is selected, and all of the frames of the video sequence are decomposed into complex steerable pyramids. A complex steerable pyramid can be represented as an amplitude pyramid and a phase pyramid. The decomposition provides a complex, multi-scale, multi-orientation decomposition of the image (still image or frame of a video sequence). Temporal phase variations between frames at each pixel may be seen as encoding the motion in the video sequence. Phase differences in the complex steerable pyramids representing consecutive frames of video can be used to represent motion elements, or changes caused by motion. The motion elements representing motion between a pair of video frames can be mapped to corresponding elements of the still image and, thus, used to reconstruct a new, changed frame of the still image to provide the appearance of motion. In one or more embodiments of the present invention, an output video is constructed, comprising a succession of such new, changed frames of the still image, with the new, changed frames being created in an iterative process.

For each frame of the selected video sequence, a correspondence map is created based on visual similarity with the still image. The phase pyramid of video frames is warped using the correspondence maps. After warping, phase differences between consecutive frames are determined, to generate a phase difference pyramid. The phase difference pyramid is added to the phase pyramid of the last created frame of the output video (depending on the stage of the

operation, either to the phase of the initial image frame or the phase of the preceding frame calculated in the previous iteration). The updated phase pyramid and the amplitude pyramid are then used to create a reconstructed image, which can be stored to a video file. In appropriate cases, complexity may be reduced by reconstructing only using a limited number of frames, particularly in cases in which the motion goes back and forth within a relatively tight bound. This may be the case with motions such as flames or swaying trees, for example.

Fig. 1 illustrates an exemplary processing and display device 100 according to an embodiment of the present invention. The device 100 comprises a processor 102, memory 104, and long term storage 106, as well as a display 108. The system 100 may store a collection of moving images, suitably stored in the form of video sequences (with each sequence suitably being stored as a video file in a desired format), with the collection taking the form of a video sequence database 110, residing in storage 106. The system 100 may also store a collection of still images stored as a still image database 112, also residing in storage 106. In addition, the system 100 may receive still images as inputs – for example through a user interface 114 or a remote interface 116.

The system 100 performs processing, suitably using an image processing application 118, residing in storage 106 and transferred to memory 104 as needed for execution by the processor 102. Processing is performed to select images, to perform matching between images and image frames, and to use a still image frame and video sequence frames to add motion elements to construct an animated image with motion elements. The still image frame may, for example, be elected from among images stored in the still image database 112, or received as an input through the user interface 114 or the remote interface 116. Processing to add motion elements to the image comprises selecting a video sequence similar to the image and with qualities conducive to extracting motion elements and adding the motion elements to the still image. A suitable video sequence is, as previously noted, generally similar to the still image. Desired characteristics of a video sequence are, for example, that it does not change drastically with time and that the amplitude of the motion displayed falls within a specified range.

Fig. 2 illustrates a process 200 according to an embodiment of the present invention. The process 200 is performed iteratively, with an initial still image being decomposed, and successive video frames being similarly decomposed. Phase information representing motion between the successive video frames is used to determine variations to be used to represent motion of the scene depicted in the still image frame, and used to reconstruct a still image frame exhibiting the variations. The process continues to successively add the warped phase variation from video

sequence to the previously calculated phase of the preceding frame and reconstructing a succeeding frame exhibiting variation representing motion between successive pairs of video frames.

At block 202, a selected still image frame, and successive frames of a video sequence identified as suitably similar to the still image are decomposed into complex steerable pyramids. The pyramids representing phase information for the video sequence frames are analyzed to identify phase variations between corresponding pixels in successive frames. Temporal phase variations at each pixel in this complex steerable pyramid encode the motion in the video sequence, and this phase information can be used to represent motion-caused changes between successive frames. Phase differences between successive frames of the video represent motion, and the motion represented by phase differences can animate the still image by introducing appropriate variations into successive duplicate frames of the still image.

At block 204, correspondence maps are calculated, with each map being calculated based on visual similarity between the still image and each frame of video. At block 206, the phases of the complex steerable pyramid of video frames are warped using the correspondence maps. At block 208, phase differences between successive frames are calculated and at block 210, the phase differences are added to phases of the preceding output frame calculated in the previous iteration. At block 212, the newly computed phase information, and amplitude information, is used to construct a new frame of the still image, varying from the previous frame by changes represented by the phase information. At block 214, postprocessing may be performed using the magnitude of the steerable pyramid decomposition of the original still image.

The analysis described above may, as noted, be accomplished by decomposition of each image into a complex steerable pyramid and comparison of elements of the still image to corresponding elements of the video sequence. Decomposition may be accomplished using a set of rotated bandpass filters, with the exception that the initial and final filters are highpass and lowpass, respectively. The decomposition thus achieved is a complex, multi-scale, multi-orientation decomposition of the image. Basis functions for the transform thus achieved may resemble Gabor wavelets, and may suitably be over-complete.

In one or more embodiments of the invention, video sequences are analyzed to determine motion similarity between pairs of sequences. Each video frame of each video is decomposed to a complex steerable pyramid. The phase differences between frames of the complex steerable pyramid correspond to motion. Phase differences between corresponding elements of frames are used as descriptors to calculate motion similarity between videos. Such analysis can also be used

for activity recognition: for example, phase differences between corresponding elements of frames can be used as motion descriptors and these motion descriptors can be compared to descriptors characteristic of motions associated with particular activities, with the activity most closely fitted to the example being identified as the activity taking place.

Figure 3, then, illustrates a process 300 according to an embodiment of the present invention. At block 302, each frame of a video is decomposed to a complex steerable pyramid. At block 304, pairs of successive frames are analyzed and phase differences between corresponding elements of each frame are calculated. Blocks 302 and 304 may be performed for a number of videos. At block 306, a pair of video sequences for which phase difference values have been computed are compared in terms of phase difference values. A similarity metric comparing the phase difference values is computed indicating the similarity between the two videos. This similarity metric may be used to compare different pairs of videos in terms of their motion similarity to choose for example the most similar pair, trio, or other grouping of videos. Similarity may suitably be in terms of frequency of motion and locality (area of the image in which the motion occurs) and amplitude of motion.

It will be noted, however, that different elements of an image, or frame of a video sequence, may be characterized by differing types of motion, or motion of different elements of a video may occur at different frequencies. For example, many videos have relatively static backgrounds with motion occurring in the foreground. For example, a traffic scene may include static buildings and streets with moving vehicles and pedestrians. Accuracy is increased and processing complexity is reduced by separating elements of the video.

In one or more embodiments of the present invention, therefore (as noted above), a complex steerable pyramid is used to decompose video frames into magnitude and phase pyramids. The phase differences between subsequent frames are then used as a feature to cluster pixels together into motion layers. A phase difference encodes motion, and using the phase difference as a motion feature provides for an efficient, lower complexity estimation procedure.

Therefore, figure 4 illustrates a process 400 according to an embodiment of the present invention. At block 402, a video sequence is selected which is presumed to be taken from a fixed viewpoint. If this is not the case, image alignment may be performed before processing in order to give the video presented for processing the appearance of a fixed viewpoint. At block 404, frames of the video are decomposed into complex steerable pyramids, which are represented by amplitude and phase pyramids. Subsequent blocks discussed below perform processing to estimate and segment motion layers. At block 406, phase differences are computed between the

pyramids of every pair of successive frames. At block 408, for each pixel in the video, a feature vector is created by concatenating the phase differences for that pixel between every pair of successive frames of the video. At block 410, clustering is performed to cluster the pixels in different layers based on the phase difference feature vectors. In one or more embodiments of the invention, one or more motion layers may be selected and successive frames of an output video may be constructed to reflect changes in one or more selected motion layers.

It will also be recognized that the proliferation of smaller, lower-cost video camera equipment has led to the capture of many videos with lower frame rates than can be achieved by larger, more expensive equipment. In addition, it will be recognized that the frame rate of every video device is finite. Therefore, mechanisms to increase the effective frame rate without degrading accuracy can create a smoother video appearance, as well as more data that can be applied to still images. It may be desirable, therefore, given two successive frames A and B of an input video, to generate additional frames intermediate between A and B as if they had been captured in time between frames A and B. If moving objects are present in the video, the generated frames represent intermediate states as the objects move from their locations in frame A to their locations in frame B, or undergo changes or movements from frame A to frame B.

Therefore, a complex steerable pyramid may be used to decompose frames into magnitude and phase pyramids and then interpolate motion by interpolating the phase difference between the pyramids representing frame A and frame B, with motion being encoded by the phase differences.

Figure 5, therefore, illustrates a process 500 according to an embodiment of the present invention. At block 502, successive frames A and B are selected representing initial and succeeding frames of video in which it is desired to interpolate an intermediate frame. At block 504, the frames A and B are decomposed into amplitude and phase pyramids. Motion is then interpolated between frames A and B. At block 506, the phase differences between the pyramids of frames A and B are computed. At block 508, the phase difference value of each pixel is multiplied by a number between zero and 1, with the multiplier being chosen by the stage between frames A and B that is being represented. For example, if the intermediate frame is midway between frames A and B, the multiplier will be 0.5. If the intermediate frame is one quarter of the way between frames A and B, the multiplier will be 0.25. At block 510, the multiplied phase difference will be added to the phase pyramid representing frame A, producing a new pyramid. At block 512, an image is reconstructed from the updated phase pyramid and the original amplitude pyramid of frame A.

Figs. 6A-6I illustrate a succession of processing stages on an exemplary input still image and video image according to one or more embodiments of the present invention. A still image (in the present example, consisting of a single frame) is chosen as one input and a video image (consisting of multiple successive frames) is chosen as another input. The video image is chosen based in part on its similarity to the still image. The video image is processed (for example, in a pixel-by-pixel analysis) to identify changes in successive frames that represent motion, and extract (in the form of phase changes) information identifying such changes. The phase change information is mapped to the still image in order to tie changes caused by motion to pixels of the still image, and variations are added to successive frames of the still image.

Fig. 6A, then, presents a diagram 600 illustrating a still image 602 and an exemplary video sequence 603, suitable for processing to extract motion elements. Successive frames 604A-604D of the video sequence 603 can be seen. Processing yields an animation 605 of the still image, of which frames 606A-606D can be seen. The animation 605 is an output video constructed by processing the still image 602 and the video sequence 603, which are provided as inputs. In the present example, a still image such as the still image 602 may often have a higher resolution than does the frame 604A of the video sequence (as is often the case with dual-function still and video cameras that have become ubiquitous with the rise of portable electronic devices), and embodiments of the present invention may provide an image with a higher resolution than a typical video sequence, but the image thus produced may be made more engaging by realistic animation taken from a video sequence of real motion.

Fig. 6B presents a diagram 609, illustrating decomposition of the still image 602 into a complex steerable pyramid 610, which can be represented by amplitude and phase pyramids 612A and 612B. The pyramids represent decomposition of the image along multiple scales and orientations. As previously noted, decomposition may be accomplished with initial high pass, final low pass, and intermediary rotated bandpass filters.

Fig. 6C presents a diagram 613, illustrating the complex steerable pyramid decomposition of successive video frames of the video sequence 603. Frames 614A and 614B of the sequence 603 are each decomposed into complex steerable pyramids representing amplitude and phase, and the phase portions of the pyramids 616A and 616B are processed to obtain phase difference information representing the motion between frames 614A and 14B.

Once phase difference information has been obtained for each pair of successive frames of a video sequence, the phase differences are used to create variations in the still image, and this process is conducted iteratively to generate a changing succession of copies of the still frame,

with variations mirroring the variations between frames of the video sequence. That is, second frame of the still image is created, varying from the original according to the variations between the first and second frames of the video sequence. A third frame is created, varying from the second frame according to the variations between the second and third frames of the video sequence, and so on.

Fig. 6D presents a diagram 617, illustrating an operation, performed at each iteration, of warping the phases of the pair of frames to the image to create a correspondence map between each output frame of the animated still image and the corresponding frame of the video sequence. Shown in Fig. 6D are the (N-1)th frame (618) of the reconstructed image and the (N-1)th frame (620A) of the video sequence. This operation maps the phases of the video sequence frame onto equivalent points of the reconstructed output video frame, creating (in the present example) a correspondence map C_{N-1} .

Fig. 6E presents a diagram 619, illustrating warping of successive frames (for example 620A and 620B) of the video sequence, using the correspondence map C_{N-1} . The frames are decomposed into complex steerable pyramids 622A and 622B, which are warped using the correspondence map C_{N-1} . The phase information is thus made suitable for further processing and application to the still image frame to which it is to be applied.

Fig. 6F presents a diagram 623, providing a more expanded view of the process of decomposition of a still image frame 618, warping of successive video sequence frames, determination of phase differences between the video sequence frames, and their use in processing the still image frame. The scenario presented in Fig. 6E is shown as the diagram 619 and in addition, phase information 628 is obtained from the complex steerable pyramid 626. The (N-1)th and Nth frames of the selected video sequence are (as discussed above) decomposed into a complex steerable pyramid, and the phase pyramids are warped using the correspondence map C_{N-1} to produce the warped pyramids 624A and 624B. The phase pyramids 624A and 624B are processed to determine a warped phase difference between the (N-1)th frame and the Nth frame, and the phase difference information is added to the phase information of the (N-1)th frame of the reconstructed output video at iteration (N-1) to calculate the phase information for the reconstructed output video frame N that is to be constructed.

Fig. 6G presents a diagram 631, illustrating reconstruction of the Nth output frame, using the previously calculated phase in the (N-1)th iteration and the computed phase difference between the (N-1)th and the Nth frames. The scenario 623 of Fig. 6F is illustrated here, and an

amplitude pyramid 632 of the output of the (N-1)th iteration is combined with the computed phase 630 for the Nth frame, to create the Nth reconstructed output frame 634.

Fig. 6H presents a diagram 635, illustrating post-processing that may be performed on the reconstructed output frame 634. The reconstructed frame is decomposed into its complex steerable pyramid 638 and the amplitude of the decomposition is set to match the amplitude pyramid 640 of the original image 602.

Fig. 6I presents a diagram 645, illustrating an overall process of generating an Nth frame from an (N-1)th frame. The phase and magnitude of (N-1)th frame of the reconstructed output video from previous iteration is used with the magnitude and phase of the complex steerable decomposition of the (N-1)th and Nth frame of the input video to construct frame N of the reconstructed output video. The phase pyramids for the (N-1)th and Nth video frames are warped using the C_{N-1} correspondence map. The warped phase difference is computed and added to the phase pyramid for the (N-1)th frame of the constructed output video to yield phase information for reconstruction of the Nth frame. The phase information is combined with the amplitude pyramid information for the (N-1)th frame and used to generate the Nth reconstructed frame. Further processing may be performed, and the Nth frame is added to a succession of previously created frames.

Figure 7 presents details of a data processing device 700, suitable for carrying out one or more embodiments of the present invention. The device 700 may suitably comprise a data processor (DP) 708 and memory (MEM) 710. The device 700 may employ data 712 and programs (PROGS) 714, residing in memory 710.

At least one of the PROGS 714 employed by the device 700 is assumed to include a set of program instructions that, when executed by the associated DP 708, enable the device to operate in accordance with embodiments of this invention. In these regards, embodiments of this invention may be implemented at least in part by computer software stored on the MEM 710, which is executable by the DP 708 of the device 700, or by hardware, or by a combination of tangibly stored software and hardware (and tangibly stored firmware). Electronic devices implementing these aspects of the invention need not be the entire devices as depicted at Figure 1 or Fig. 7 or may be one or more components of same such as the above described tangibly stored software, hardware, firmware and DP, or a system on a chip SOC or an application specific integrated circuit ASIC.

In general, the various embodiments of the device 700 can include, but are not limited to personal portable digital devices having wireless communication capabilities, including but not

limited to cellular telephones, navigation devices, laptop/palmtop/tablet computers, digital cameras and music devices, and Internet appliances, or may also include dedicated data processing systems (for example, remotely accessible systems performing processing tasks submitted by remote users).

Various embodiments of the computer readable MEM 710 include any data storage technology type which is suitable to the local technical environment, including but not limited to semiconductor based memory devices, magnetic memory devices and systems, optical memory devices and systems, fixed memory, removable memory, disc memory, flash memory, DRAM, SRAM, EEPROM and the like. Various embodiments of the DP 708 include but are not limited to general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and multi-core processors.

Various modifications and adaptations to the foregoing exemplary embodiments of this invention may become apparent to those skilled in the relevant arts in view of the foregoing description. While various exemplary embodiments have been described above it should be appreciated that the practice of the invention is not limited to the exemplary embodiments shown and discussed here.

Further, some of the various features of the above non-limiting embodiments may be used to advantage without the corresponding use of other described features. The foregoing description should therefore be considered as merely illustrative of the principles, teachings and exemplary embodiments of this invention, and not in limitation thereof.

We claim:

1. An apparatus comprising:
at least one processor;
memory storing a program of instructions;
wherein the memory storing the program of instructions is configured to, with the at least one processor, cause the apparatus to at least:
analyze successive frames of a video sequence to extract phase difference information indicating motion;
successively construct frames based on a still image, wherein successively constructing the frames based on a still image comprises using the phase difference information to successively update phase information and adding the phase information to successively created still image frames so as to introduce variations representing motion; and
assemble the successively constructed frames to create a reconstructed output video sequence based on the still image.
2. The apparatus of claim 1, wherein analyzing the successive frames of the video sequence comprises decomposing frames of the video sequence into complex steerable pyramids and processing complex steerable pyramids from successive frames to obtain phase difference information.
3. The apparatus of claim 2, wherein analyzing the successive frames of the video sequence comprises analyzing complex steerable pyramids taken from pairs of successive frames.
4. The apparatus of claim 3, wherein processing the complex steerable pyramids comprises warping phase information to a still image frame to be updated, using a correspondence map created based on similarity between the video sequence and the still image.
5. The apparatus of claim 4, wherein processing the complex steerable pyramids comprises determining phase difference information between the complex steerable pyramids.
6. The apparatus of claim 5, wherein the apparatus is further caused to add phase difference information to phase information of the still image frame or the previously calculated phase of a preceding output video frame being updated, to create an output frame phase pyramid.
7. The apparatus of claim 6, wherein the output frame phase pyramid is used to construct an updated frame of the reconstructed output video, which is an animation of the still image .

8. The apparatus of claim 1, wherein the apparatus is further caused to:
for each video sequence of one or more of video sequences, decompose each frame of the video sequence into a complex steerable pyramid;
compute phase variations between successive frames of each of the one or more video sequences; and
for each of the one or more video sequences, compute a similarity metric based on phase variations throughout the video sequence.

9. The apparatus of claim 8, wherein the one or more video sequences comprise two or more video sequences and the apparatus is further caused to use the similarity metric for each video sequence to compare the two or more video sequences.

10. The apparatus of claim 9, wherein the similarity metric is based at least in part on one or more of motion frequency, locality, and amplitude represented by the phase variations.

11. The apparatus of claim 1, wherein the apparatus is further caused to:
for each frame of a video sequence, decompose the frame into complex steerable pyramids;
compute the phase difference between the pyramids of each pair of successive frames of the video sequence;
for each pixel appearing in two or more frames of the video, create a feature vector by concatenating phase differences for the pixel between every pair of successive frames in which the pixel appears;
analyze each pixel throughout all frames in which the pixel appears to cluster pixels into pixel layers based on the phase difference feature vectors; and
analyze the pixel layers to estimate and segment motion layers.

12. The apparatus of claim 11, wherein the apparatus is further caused to analyze and classify motion in one or more motion layers of a video sequence.

13. The apparatus of claim 11, wherein the perspective of the video sequence is a fixed viewpoint.

14. The apparatus of claim 12, wherein the fixed viewpoint is achieved through image alignment.

15. The apparatus of claim 1, wherein the apparatus is further caused to create an interpolated updated frame between a pair of successive frames using phase information representing intermediate values between information for the members of the pair of successive video frames.

16. The apparatus of claim 14, wherein creation of the interpolated updated frame comprises:

- decomposing each of the first and second frames into complex steerable pyramids;
- computing the phase difference between phase pyramids for the first and second frames;
- adjusting the phase difference to reflect an intermediate difference between the first and second frames;

- updating the phase pyramid for the first frame using the intermediate difference; and
- reconstructing an interpolated image using the updated phase pyramid.

17. The apparatus of claim 16, wherein adjusting the phase difference comprises selecting a multiplier between 0 and 1 and multiplying the phase difference by the multiplier.

18. An apparatus comprising:

- at least one processor;
- memory storing a program of instructions;
- wherein the memory storing the program of instructions is configured to, with the at least one processor, cause the apparatus to at least:

- identify two or more video sequences for similarity analysis;
- for each of the video sequences, analyze phase variations between frames of the video sequence to determine local motion in the video sequence; and
- determine similarity between two or more of the video sequences based on the analysis of the phase variations.

19. The apparatus of claim 17, wherein analyzing the phase variations comprises decomposing the frames of each video sequence into complex steerable pyramids and analyzing the complex steerable pyramids for each frame to determine phase variations for each frame.

20. The apparatus of claim 17, wherein the apparatus is further caused to calculate a similarity metric indicating similarity between video sequences.

21. The apparatus of claim 19, wherein the similarity metric is based on one or more of frequency, locality, and amplitude of motion.

22. An apparatus comprising:

- at least one processor;
- memory storing a program of instructions;
- wherein the memory storing the program of instructions is configured to, with the at least one processor, cause the apparatus to at least:

identify motion layers of a video sequence based on phase difference information representing variations between frames of the video sequence; and

identify and classify types of motion in one or more of the motion layers.

23. The apparatus of claim 21, wherein identifying the motion layers comprises:
for each frame of a video sequence, decomposing the frame into complex steerable pyramids;

computing the phase difference between the pyramids of each pair of successive frames of the video sequence;

for each pixel appearing in two or more frames of the video, creating a feature vector by concatenating phase differences for the pixel between every pair of successive frames in which the pixel appears;

analyzing each pixel throughout all frames in which the pixel appears to cluster pixels into pixel layers based on the phase difference feature vectors; and

analyzing the pixel layers to estimate and segment motion layers.

24. An apparatus comprising:
at least one processor;
memory storing a program of instructions;
wherein the memory storing the program of instructions is configured to, with the at least one processor, cause the apparatus to at least:

analyze successive frames of a video sequence to extract phase difference information indicating motion; and

create an interpolated updated frame between a pair of successive frames using phase information representing intermediate values between information for members of the pair of successive video frames.

25. A method comprising:
analyzing successive frames of a video sequence to extract phase difference information indicating motion;

successively constructing frames based on a still image, wherein successively constructing the frames based on a still image comprises using the phase difference information to successively update phase information and adding the phase information to successively created still image frames so as to introduce variations representing motion; and

assembling the successively constructed frames to create a reconstructed output video sequence based on the still image.

26. The method of claim 25, wherein analyzing the successive frames of the video sequence comprises decomposing frames of the video sequence into complex steerable pyramids and processing complex steerable pyramids from successive frames to obtain phase difference information.

27. The method of claim 26, wherein analyzing the successive frames of the video sequence comprises analyzing complex steerable pyramids taken from pairs of successive frames.

28. The method of claim 27, wherein processing the complex steerable pyramids comprises warping phase information to a still image frame to be updated, using a correspondence map created based on similarity between the video sequence and the still image.

29. The method of claim 28, wherein processing the complex steerable pyramids comprises determining phase difference information between the complex steerable pyramids.

30. The method of claim 29, further comprising adding phase difference information to phase information of the still image frame or the previously calculated phase of a preceding output video frame being updated, to create an output frame phase pyramid.

31. The method of claim 30, wherein the output frame phase pyramid is used to construct an updated frame of the reconstructed output video, which is an animation of the still image.

32. The method of claim 25, further comprising:
for each video sequence of one or more of video sequences, decomposing each frame of the video sequence into a complex steerable pyramid;
computing phase variations between successive frames of each of the one or more video sequences; and
for each of the one or more video sequences, computing a similarity metric based on phase variations throughout the video sequence.

33. The method of claim 32, wherein the one or more video sequences comprise two or more video sequences and the apparatus is further caused to use the similarity metric for each video sequence to compare the two or more video sequences.

34. The method of claim 33, wherein the similarity metric is based at least in part on one or more of motion frequency, locality, and amplitude represented by the phase variations.

35. The method of claim 25, further comprising:
for each frame of a video sequence, decomposing the frame into complex steerable pyramids

computing the phase difference between the pyramids of each pair of successive frames of the video sequence;

for each pixel appearing in two or more frames of the video, creating a feature vector by concatenating phase differences for the pixel between every pair of successive frames in which the pixel appears;

analyzing each pixel throughout all frames in which the pixel appears to cluster pixels into pixel layers based on the phase difference feature vectors; and

analyzing the pixel layers to estimate and segment motion layers.

36. The method of claim 35, further comprising analyzing and classifying motion in one or more motion layers of a video sequence.

37. The method of claim 35, wherein the perspective of the video sequence is a fixed viewpoint.

38. The method of claim 36, wherein the fixed viewpoint is achieved through image alignment.

39. The method of claim 35, further comprising creating an interpolated updated frame between a pair of successive frames using phase information representing intermediate values between information for the members of the pair of successive video frames.

40. The method of claim 37, wherein creation of the interpolated updated frame comprises:

decomposing each of the first and second frames into complex steerable pyramids;
computing the phase difference between phase pyramids for the first and second frames;
adjusting the phase difference to reflect an intermediate difference between the first and second frames;

updating the phase pyramid for the first frame using the intermediate difference; and
reconstructing an interpolated image using the updated phase pyramid.

41. The method of claim 40, wherein adjusting the phase difference comprises selecting a multiplier between 0 and 1 and multiplying the phase difference by the multiplier.

42. A method comprising:

identifying two or more video sequences for similarity analysis;
for each of the video sequences, analyzing phase variations between frames of the video sequence to determine local motion in the video sequence; and
determining similarity between two or more of the video sequences based on the analysis of the phase variations.

43. The method of claim 42, wherein analyzing the phase variations comprises decomposing the frames of each video sequence into complex steerable pyramids and analyzing the complex steerable pyramids for each frame to determine phase variations for each frame.

44. The method of claim 42, further comprising calculating a similarity metric indicating similarity between video sequences.

45. The method of claim 43, wherein the similarity metric is based on one or more of frequency, locality, and amplitude of motion.

46. A method comprising:
identifying motion layers of a video sequence based on phase difference information representing variations between frames of the video sequence; and
identifying and classifying types of motion in one or more of the motion layers.

47. The method of claim 46, wherein identifying the motion layers comprises:
for each frame of a video sequence, decomposing the frame into complex steerable pyramids;

computing the phase difference between the pyramids of each pair of successive frames of the video sequence;

for each pixel appearing in two or more frames of the video, creating a feature vector by concatenating phase differences for the pixel between every pair of successive frames in which the pixel appears;

analyzing each pixel throughout all frames in which the pixel appears to cluster pixels into pixel layers based on the phase difference feature vectors; and

analyzing the pixel layers to estimate and segment motion layers.

48. A method comprising:
analyzing successive frames of a video sequence to extract phase difference information indicating motion; and

creating an interpolated updated frame between a pair of successive frames using phase information representing intermediate values between information for members of the pair of successive video frames.

49. A computer readable medium storing a program of instructions, execution of which by at least one processor configures a computer readable medium to at least:

analyze successive frames of a video sequence to extract phase difference information indicating motion;

successively construct frames based on a still image, wherein successively constructing the frames based on a still image comprises using the phase difference information to successively update phase information and adding the phase information to successively created still image frames so as to introduce variations representing motion; and

assemble the successively constructed frames to create a reconstructed output video sequence based on the still image.

50. The computer readable medium of claim 49, wherein analyzing the successive frames of the video sequence comprises decomposing frames of the video sequence into complex steerable pyramids and processing complex steerable pyramids from successive frames to obtain phase difference information.

51. The computer readable medium of claim 50, wherein analyzing the successive frames of the video sequence comprises analyzing complex steerable pyramids taken from pairs of successive frames.

52. The computer readable medium of claim 51, wherein processing the complex steerable pyramids comprises warping phase information to a still image frame to be updated, using a correspondence map created based on similarity between the video sequence and the still image.

53. The computer readable medium of claim 52, wherein processing the complex steerable pyramids comprises determining phase difference information between the complex steerable pyramids.

54. The computer readable medium of claim 53, wherein the apparatus is further configured to add phase difference information to phase information of the still image frame or the previously calculated phase of a preceding output video frame being updated, to create an output frame phase pyramid.

55. The computer readable medium of claim 54, wherein the output frame phase pyramid is used to construct an updated frame of the reconstructed output video, which is an animation of the still image .

56. The computer readable medium of claim 49, wherein the apparatus is further configured to:

for each video sequence of one or more of video sequences, decompose each frame of the video sequence into a complex steerable pyramid;

compute phase variations between successive frames of each of the one or more video sequences; and

for each of the one or more video sequences, compute a similarity metric based on phase variations throughout the video sequence.

57. The computer readable medium of claim 56, wherein the one or more video sequences comprise two or more video sequences and the apparatus is further configured to use the similarity metric for each video sequence to compare the two or more video sequences.

58. The computer readable medium of claim 57, wherein the similarity metric is based at least in part on one or more of motion frequency, locality, and amplitude represented by the phase variations.

59. The computer readable medium of claim 49, wherein the apparatus is further configured to:

for each frame of a video sequence, decompose the frame into complex steerable pyramids

compute the phase difference between the pyramids of each pair of successive frames of the video sequence;

for each pixel appearing in two or more frames of the video, create a feature vector by concatenating phase differences for the pixel between every pair of successive frames in which the pixel appears;

analyze each pixel throughout all frames in which the pixel appears to cluster pixels into pixel layers based on the phase difference feature vectors; and

analyze the pixel layers to estimate and segment motion layers.

60. The computer readable medium of claim 59, wherein the apparatus is further configured to analyze and classify motion in one or more motion layers of a video sequence.

61. The computer readable medium of claim 59, wherein the perspective of the video sequence is a fixed viewpoint.

62. The computer readable medium of claim 60, wherein the fixed viewpoint is achieved through image alignment.

63. The computer readable medium of claim 49, wherein the apparatus is further configured to create an interpolated updated frame between a pair of successive frames using phase information representing intermediate values between information for the members of the pair of successive video frames.

64. The computer readable medium of claim 63, wherein creation of the interpolated updated frame comprises:

decomposing each of the first and second frames into complex steerable pyramids;

computing the phase difference between phase pyramids for the first and second frames;
adjusting the phase difference to reflect an intermediate difference between the first and second frames;

updating the phase pyramid for the first frame using the intermediate difference; and
reconstructing an interpolated image using the updated phase pyramid.

65. The computer readable medium of claim 64, wherein adjusting the phase difference comprises selecting a multiplier between 0 and 1 and multiplying the phase difference by the multiplier.

66. A computer readable medium storing a program of instructions, execution of which by at least one processor configures an apparatus to at least:

identify two or more video sequences for similarity analysis;

for each of the video sequences, analyze phase variations between frames of the video sequence to determine local motion in the video sequence; and

determine similarity between two or more of the video sequences based on the analysis of the phase variations.

67. The computer readable medium of claim 66, wherein analyzing the phase variations comprises decomposing the frames of each video sequence into complex steerable pyramids and analyzing the complex steerable pyramids for each frame to determine phase variations for each frame.

68. The computer readable medium of claim 66, wherein the apparatus is further configured to calculate a similarity metric indicating similarity between video sequences.

69. The computer readable medium of claim 68, wherein the similarity metric is based on one or more of frequency, locality, and amplitude of motion.

70. A computer readable medium storing a program of instructions, execution of which by a processor configures an apparatus to at least:

identify motion layers of a video sequence based on phase difference information representing variations between frames of the video sequence; and

identify and classify types of motion in one or more of the motion layers.

71. The computer readable medium of claim 70, wherein identifying the motion layers comprises:

for each frame of a video sequence, decomposing the frame into complex steerable pyramids;

computing the phase difference between the pyramids of each pair of successive frames of the video sequence;

for each pixel appearing in two or more frames of the video, creating a feature vector by concatenating phase differences for the pixel between every pair of successive frames in which the pixel appears;

analyzing each pixel throughout all frames in which the pixel appears to cluster pixels into pixel layers based on the phase difference feature vectors; and

analyzing the pixel layers to estimate and segment motion layers.

72. A computer readable medium storing a program of instructions, execution of which by at least one processor configures an apparatus to at least:

analyze successive frames of a video sequence to extract phase difference information indicating motion;

and create an interpolated updated frame between a pair of successive frames using phase information representing intermediate values between information for members of the pair of successive video frames.

1/18

100 →

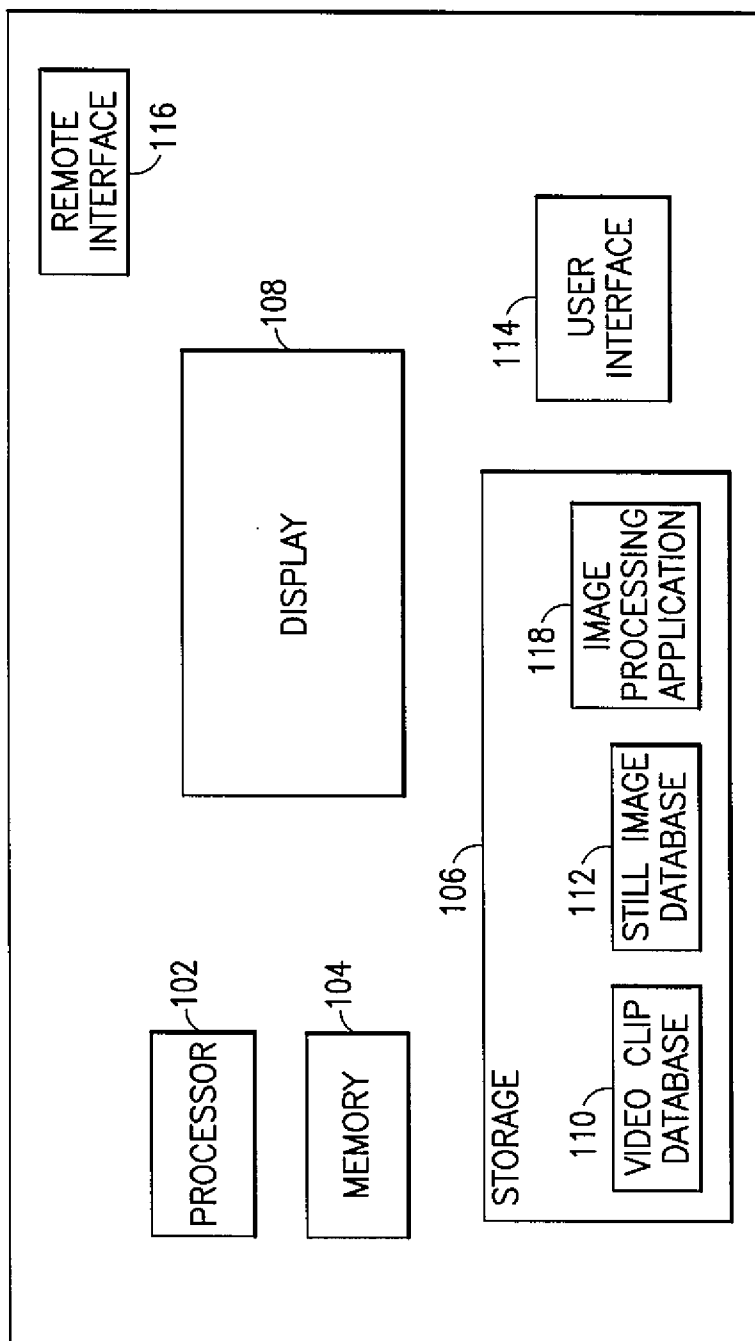
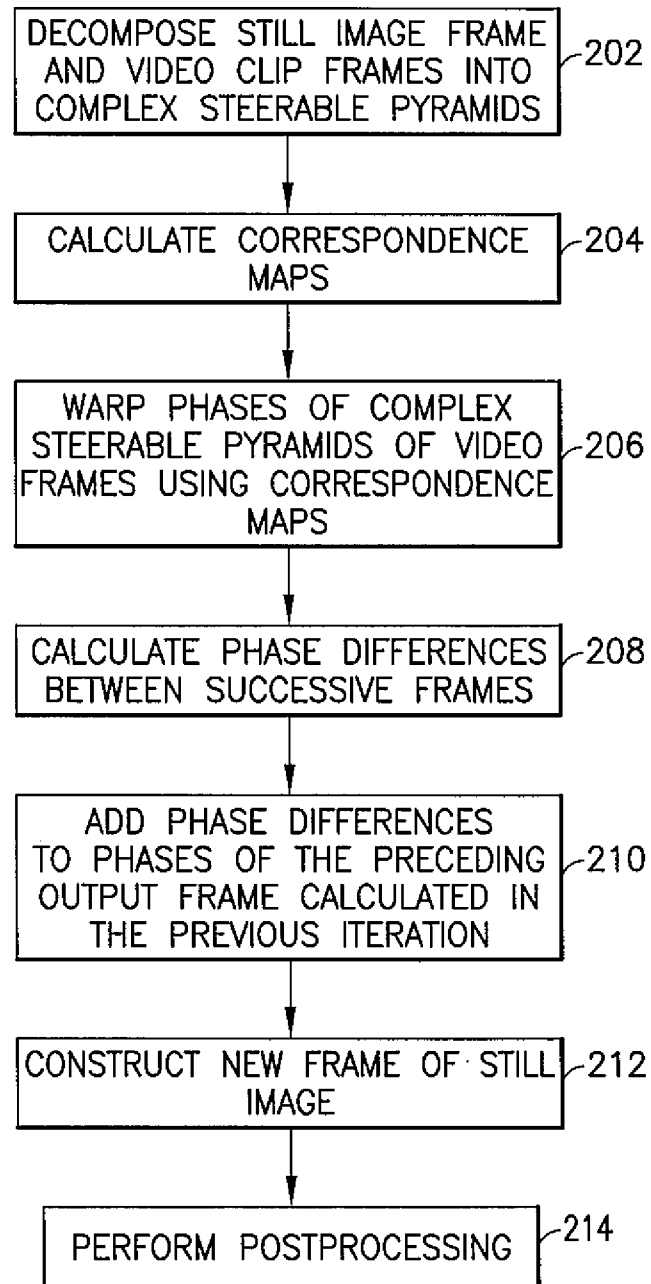


FIG.1

2/18

200

**FIG.2**

3/18

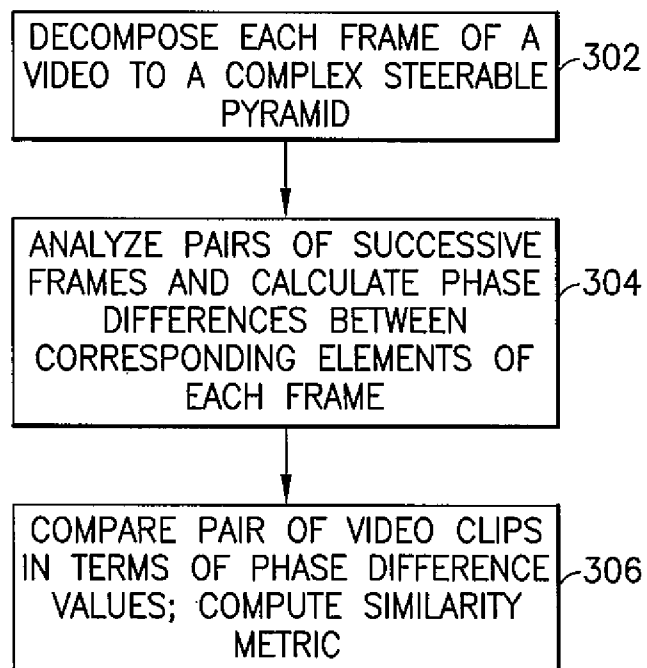
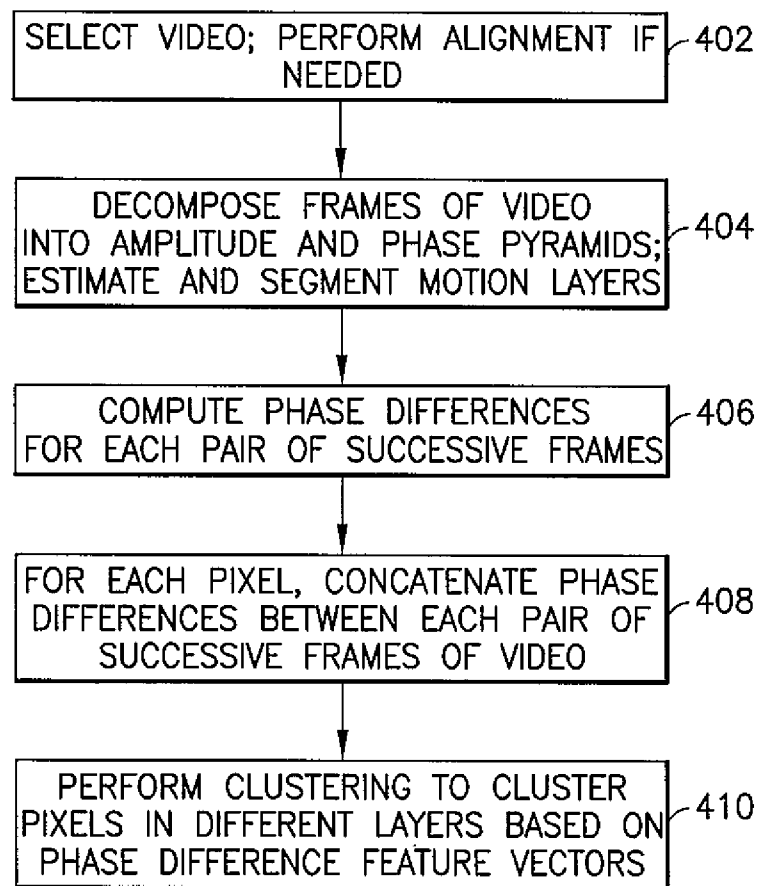
300 

FIG.3

4/18

400

**FIG.4**

5/18

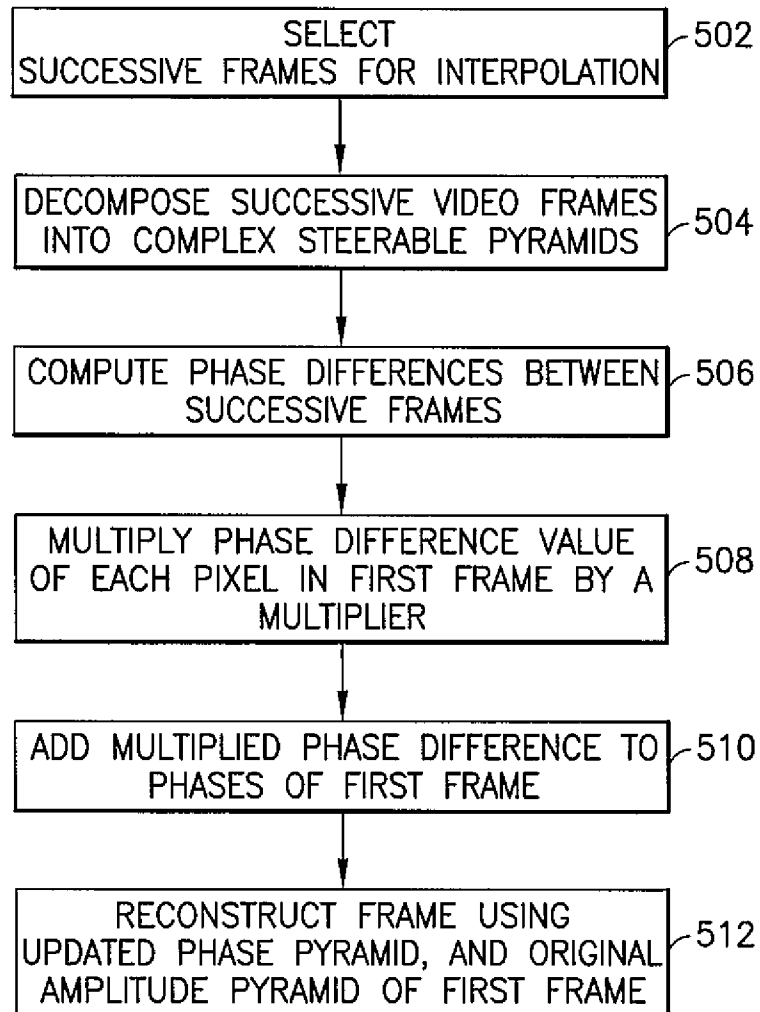
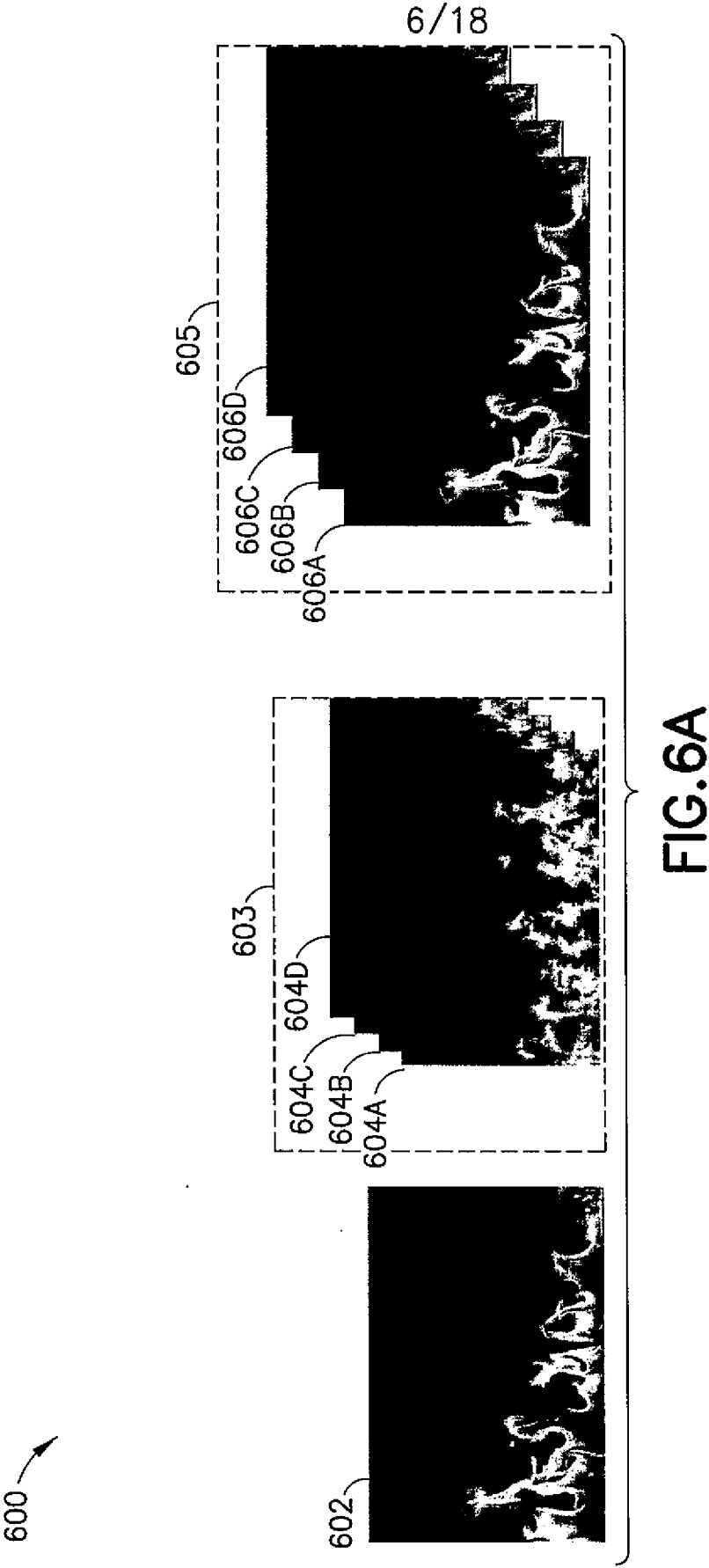
500 

FIG.5



7/18

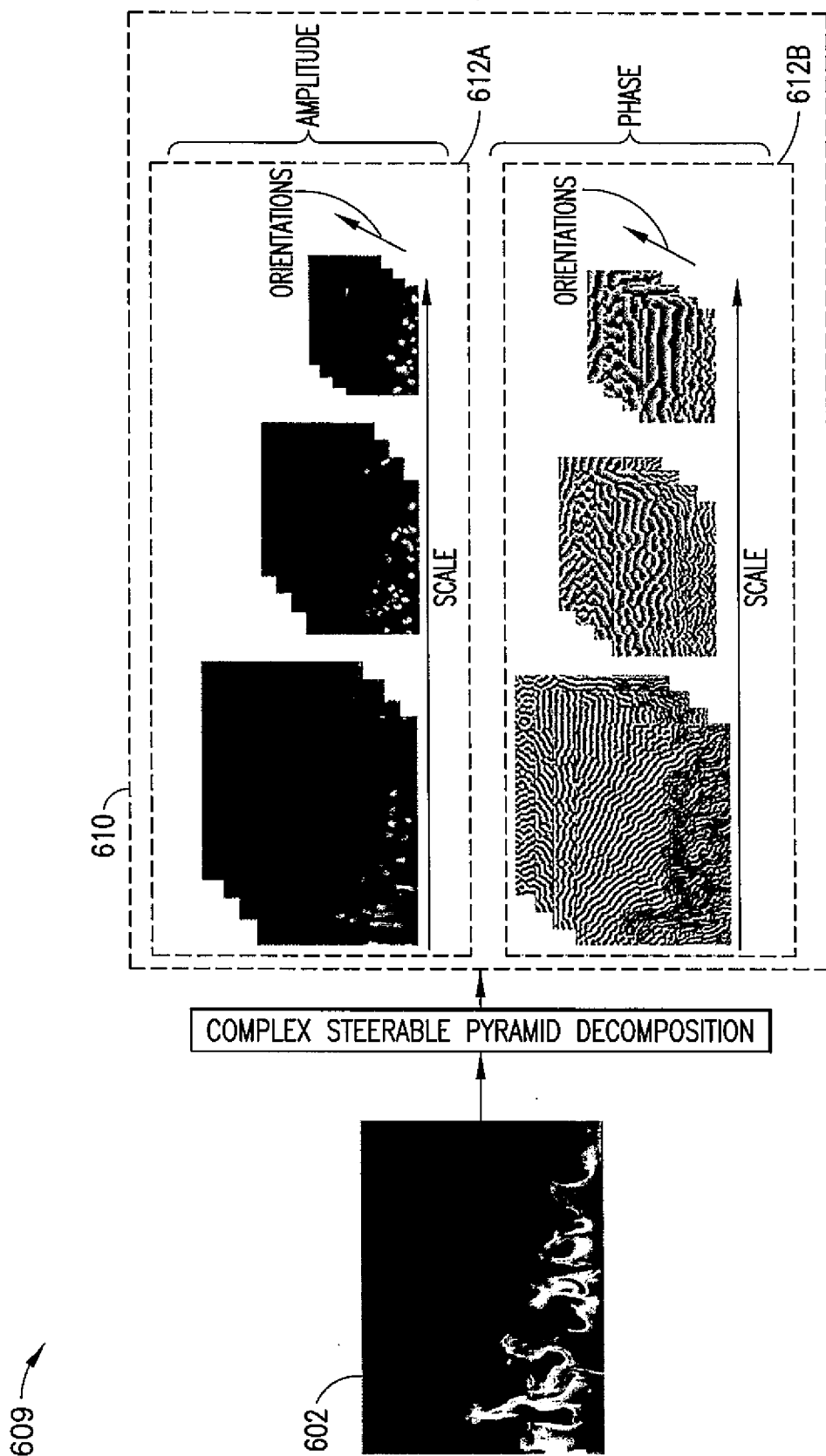
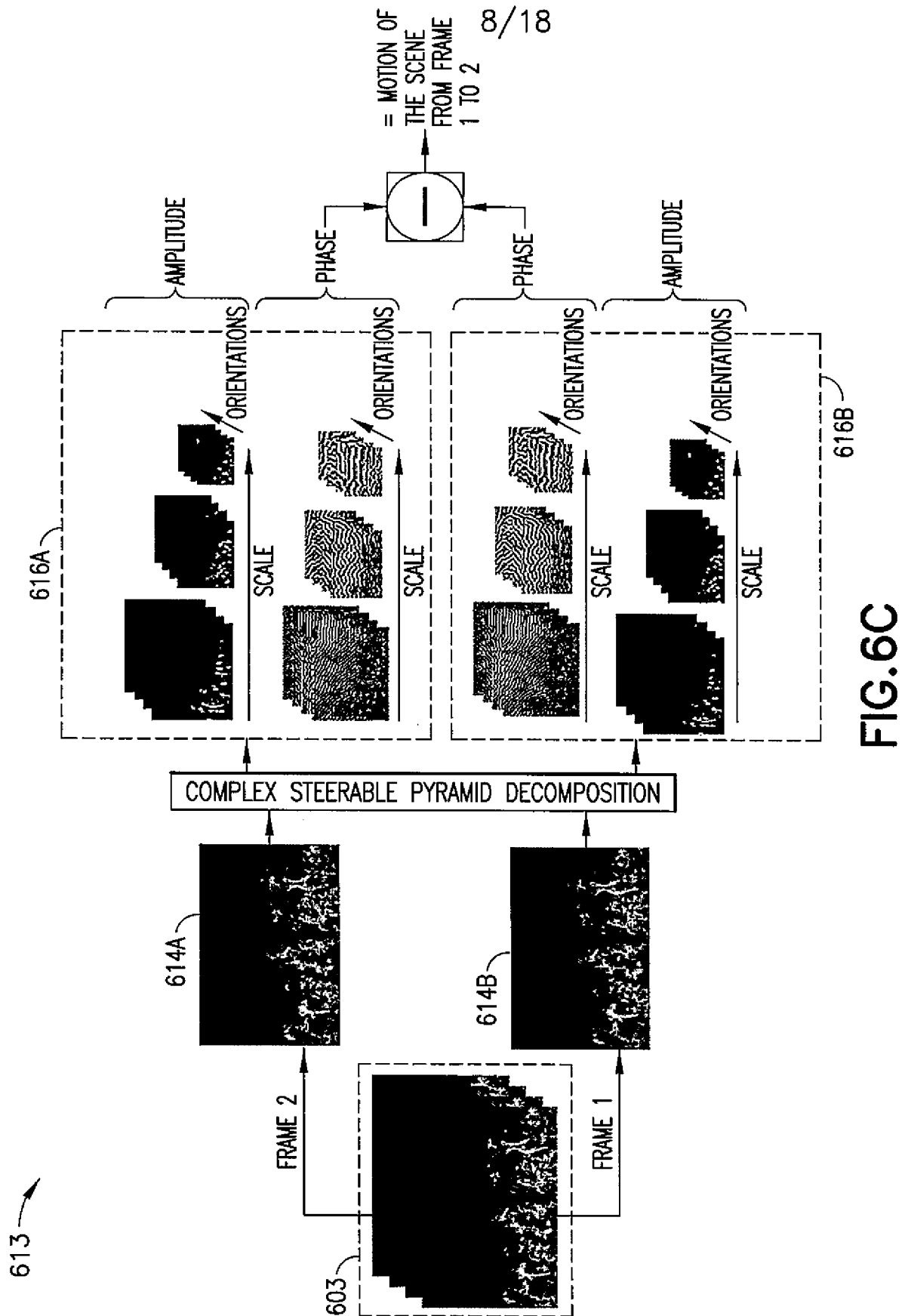


FIG.6B

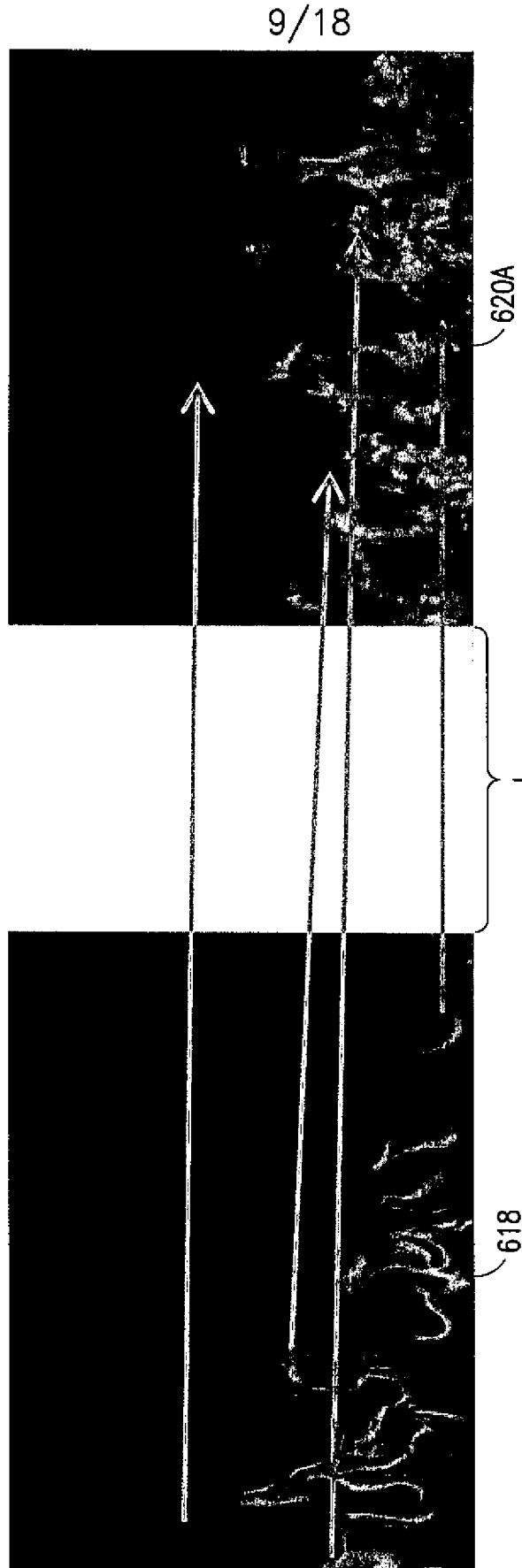


617 →

AT N^{th} ITERATION IN THE ALGORITHM:

RECONSTRUCTED FRAME
AT ITERATION No. (N-1)

FRAME No. (N-1) OF
EXAMPLE VIDEO



DENSE CORRESPONDENCE MAP C_{N-1}
(SUBSCRIPT $N-1$ SIGNIFIES A MAP BETWEEN $(N-1)^{\text{th}}$
OUTPUT FRAME AND $(N-1)^{\text{th}}$ INPUT VIDEO FRAME)

FIG.6D

619

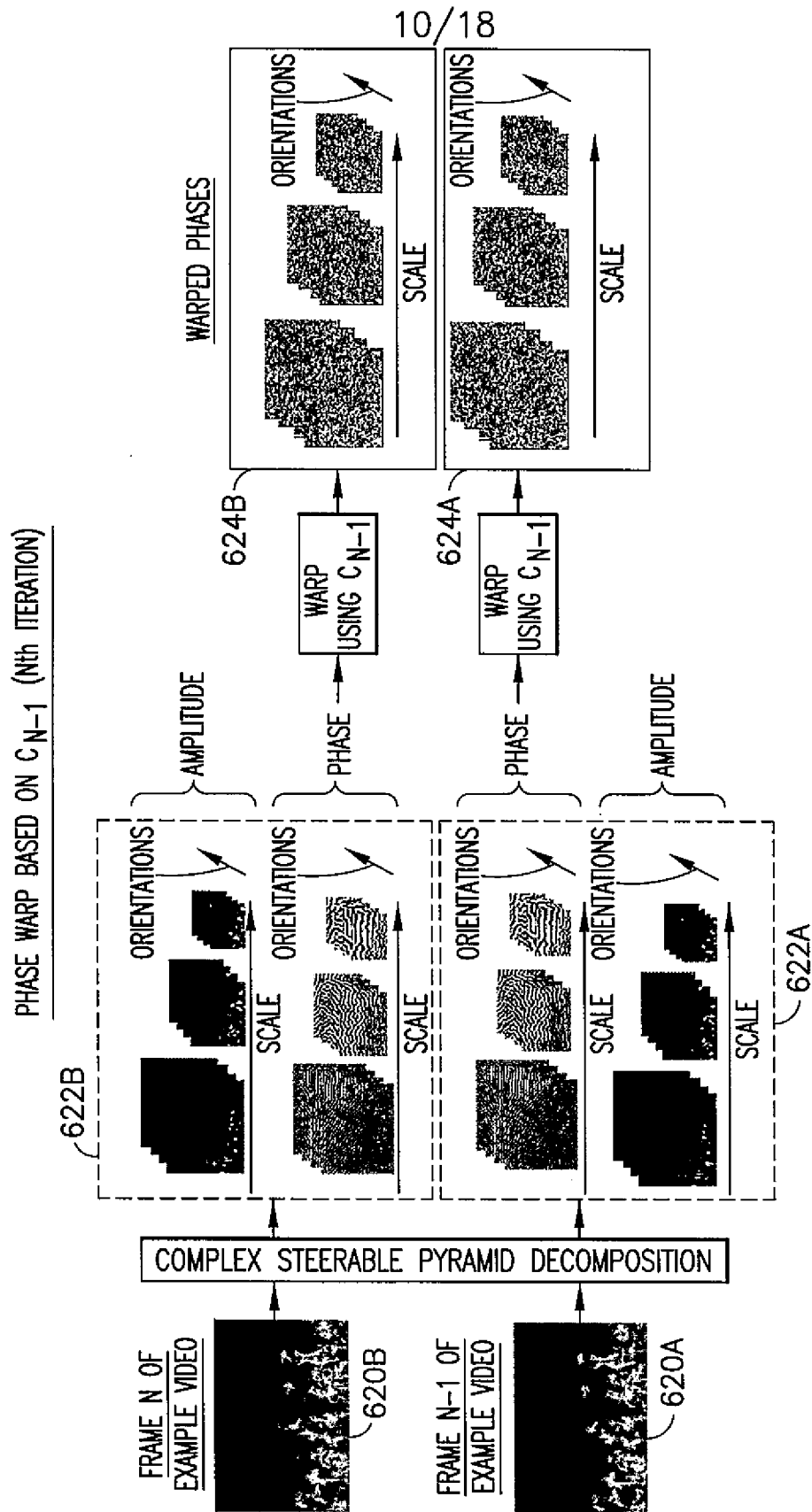
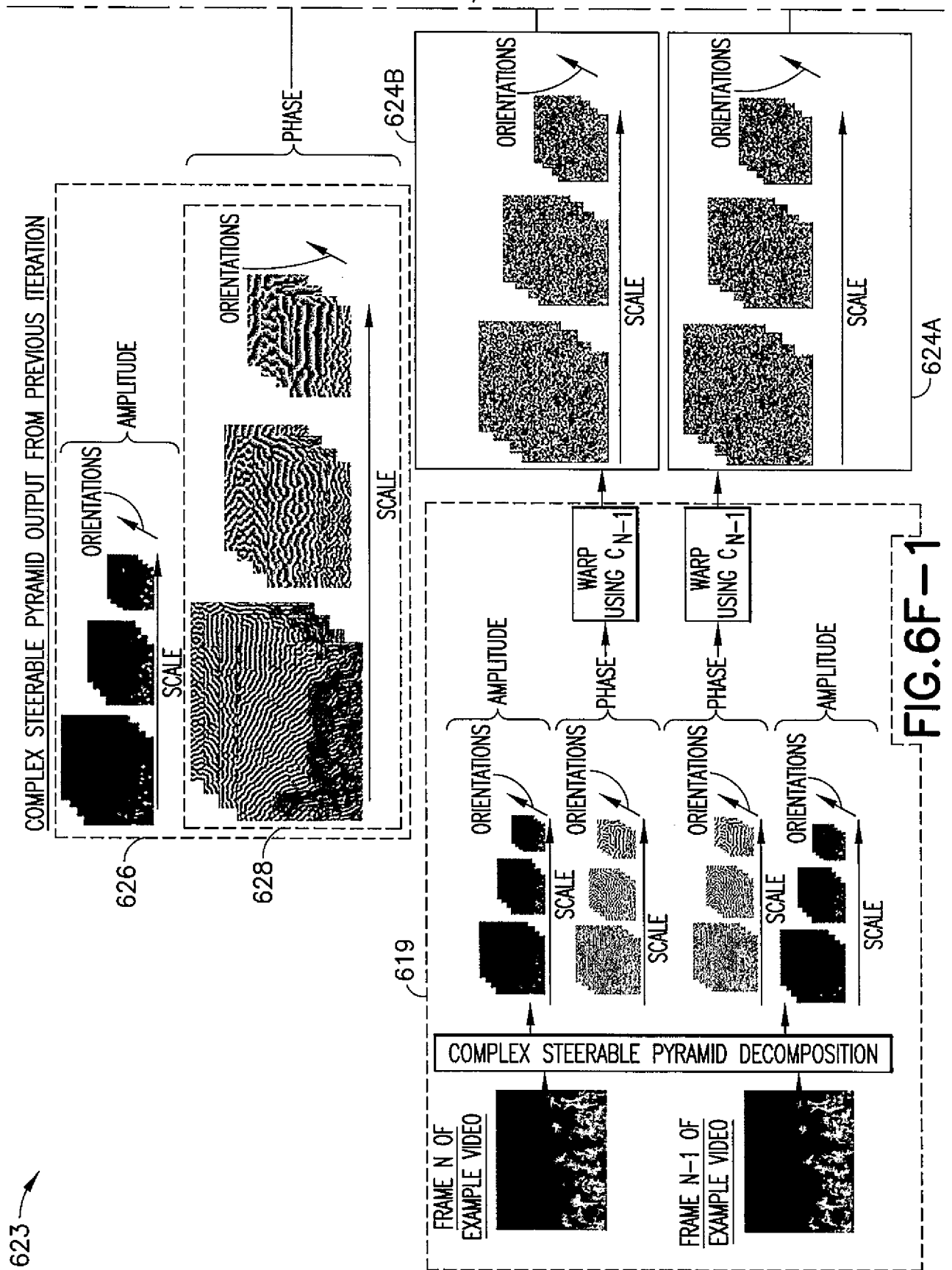


FIG.6E



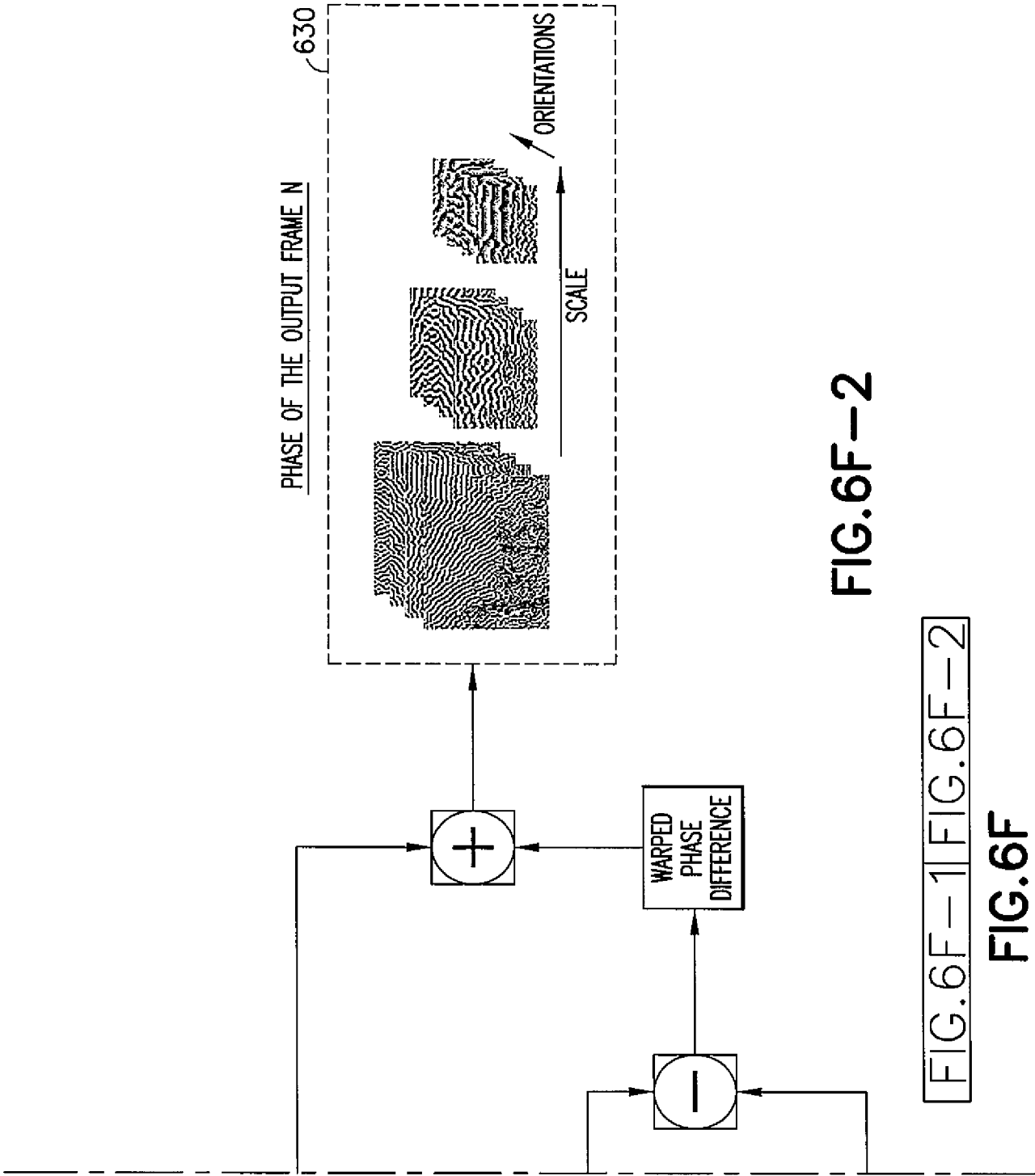
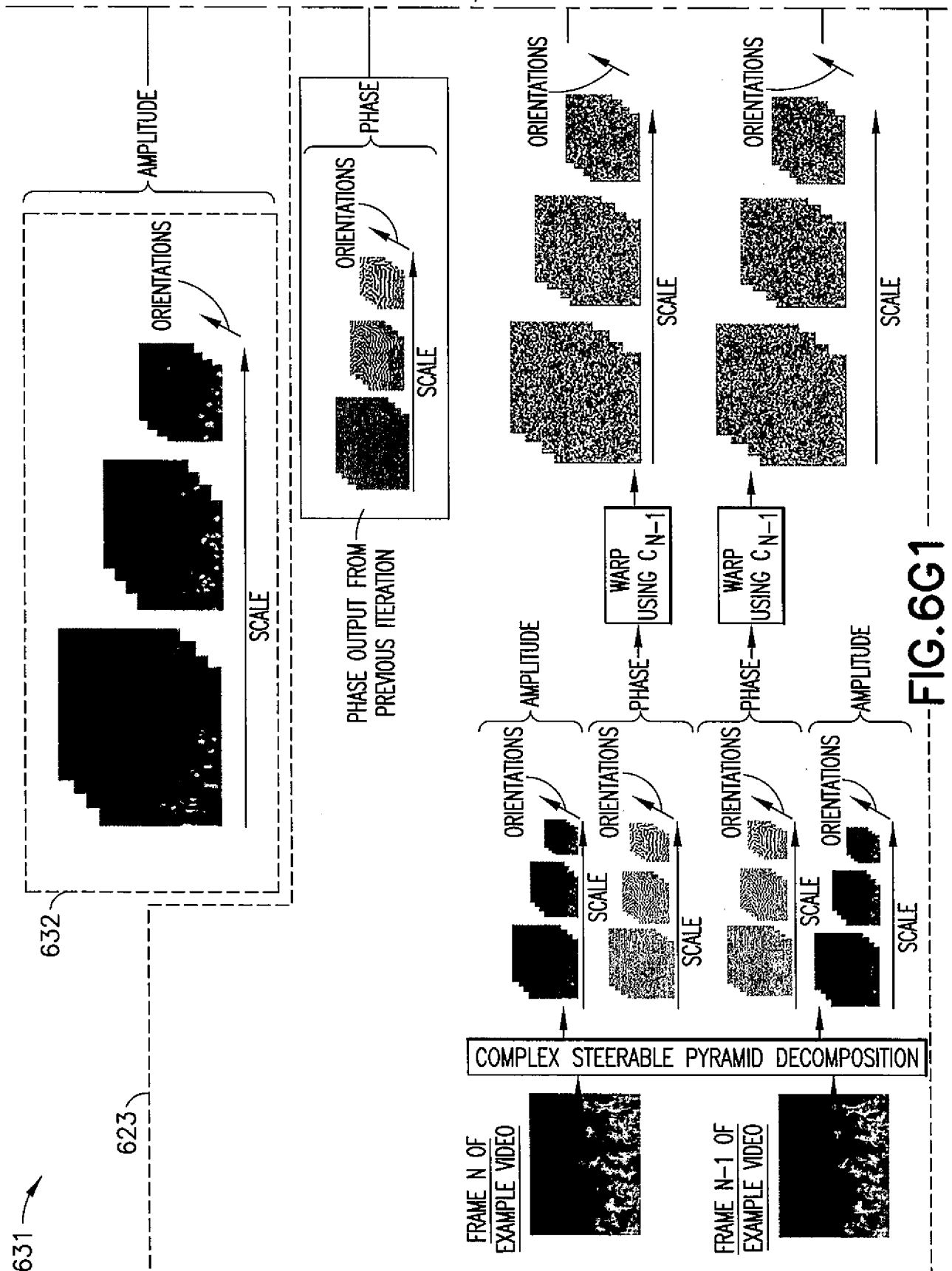


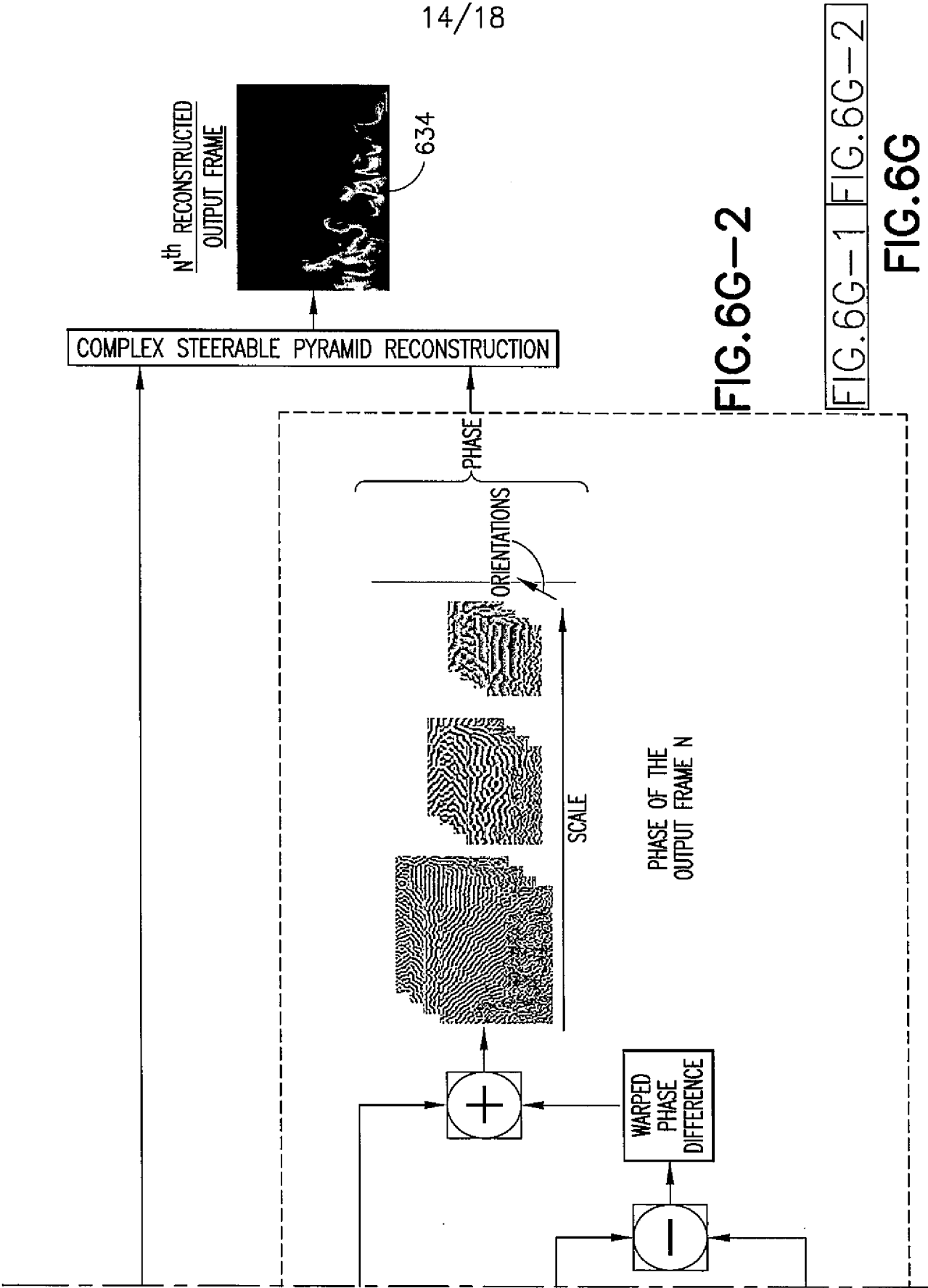
FIG.6F-2

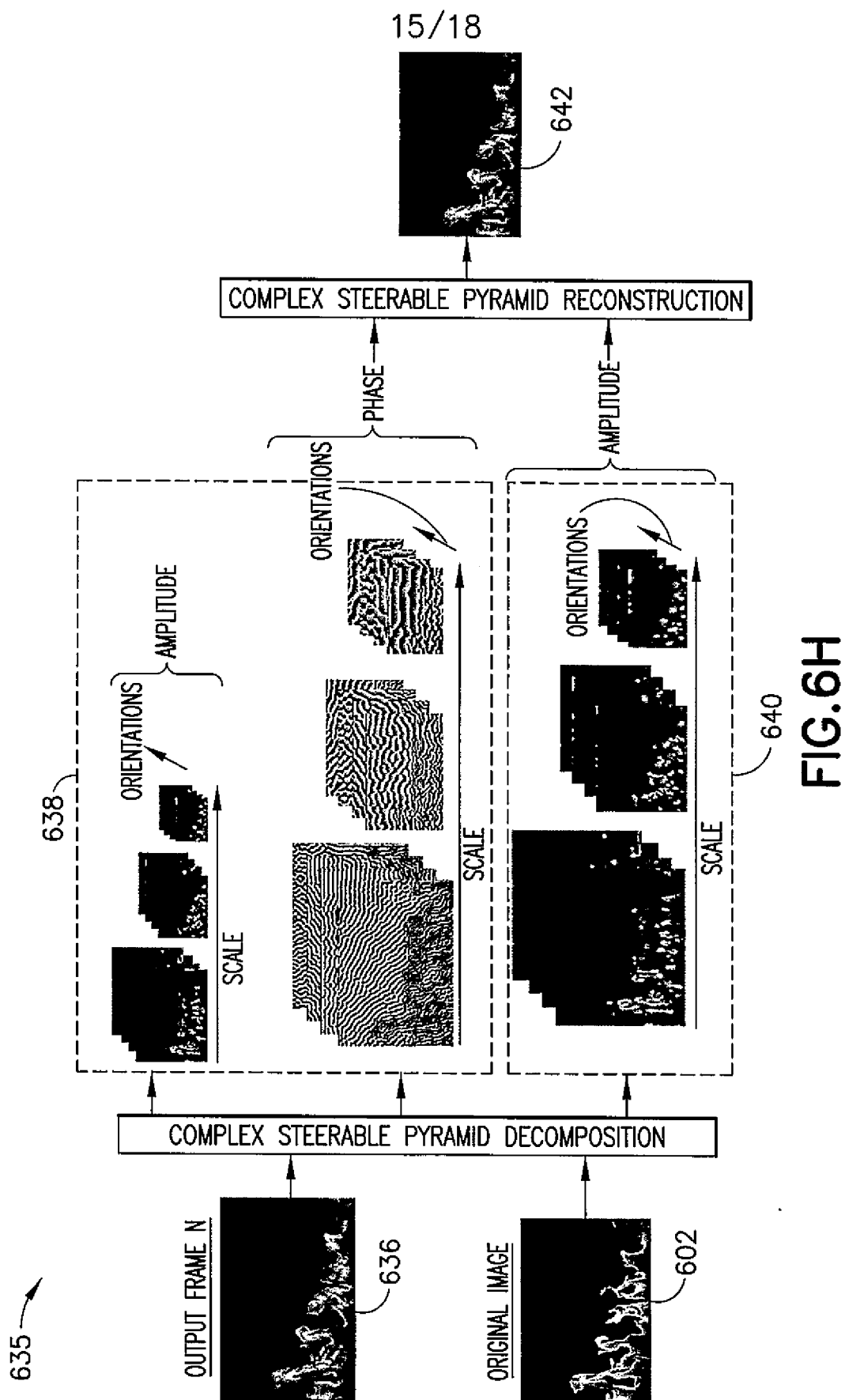
FIG.6F-1|FIG.6F-2

FIG.6F

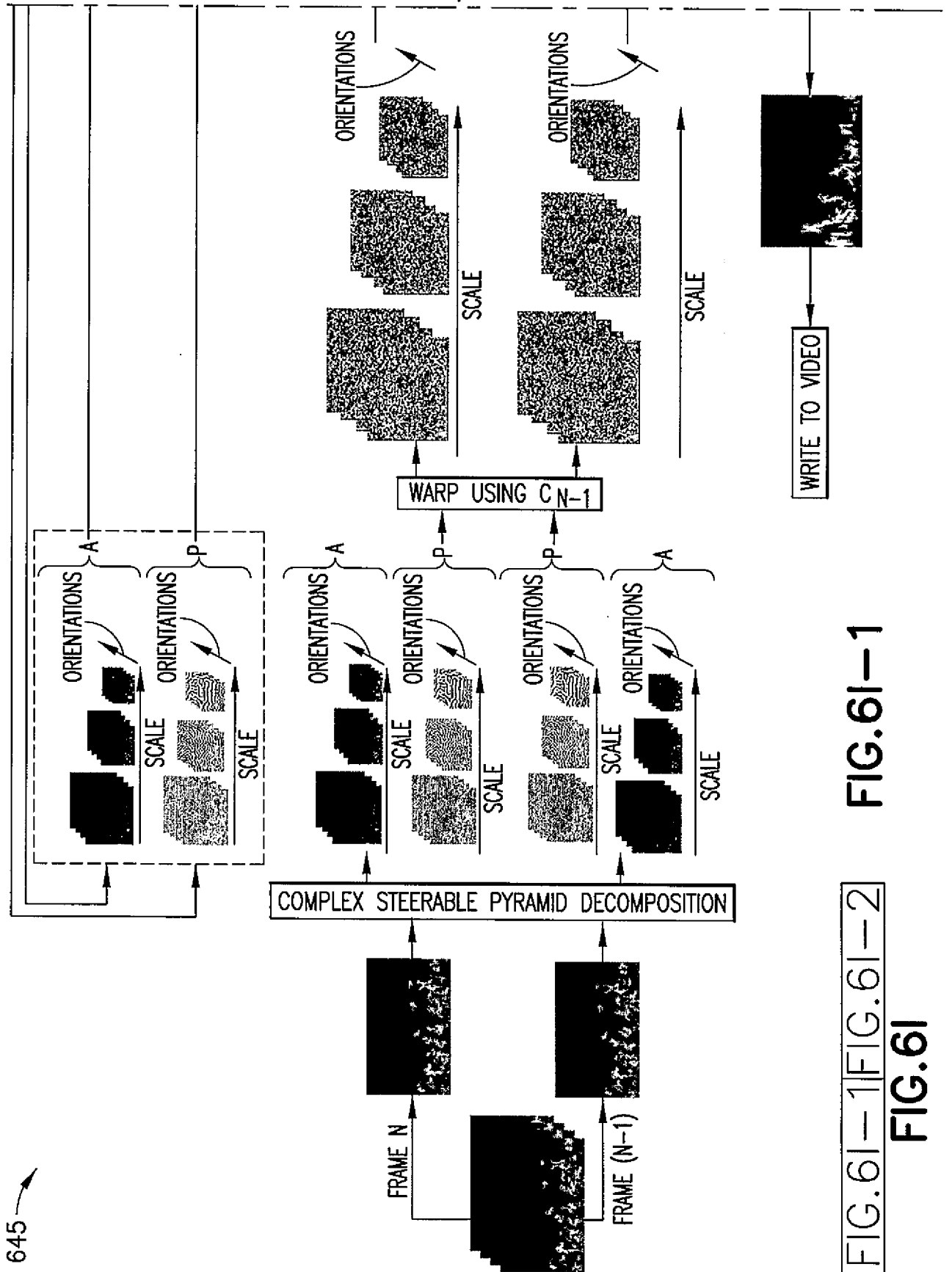
13/18







16/18



17/18

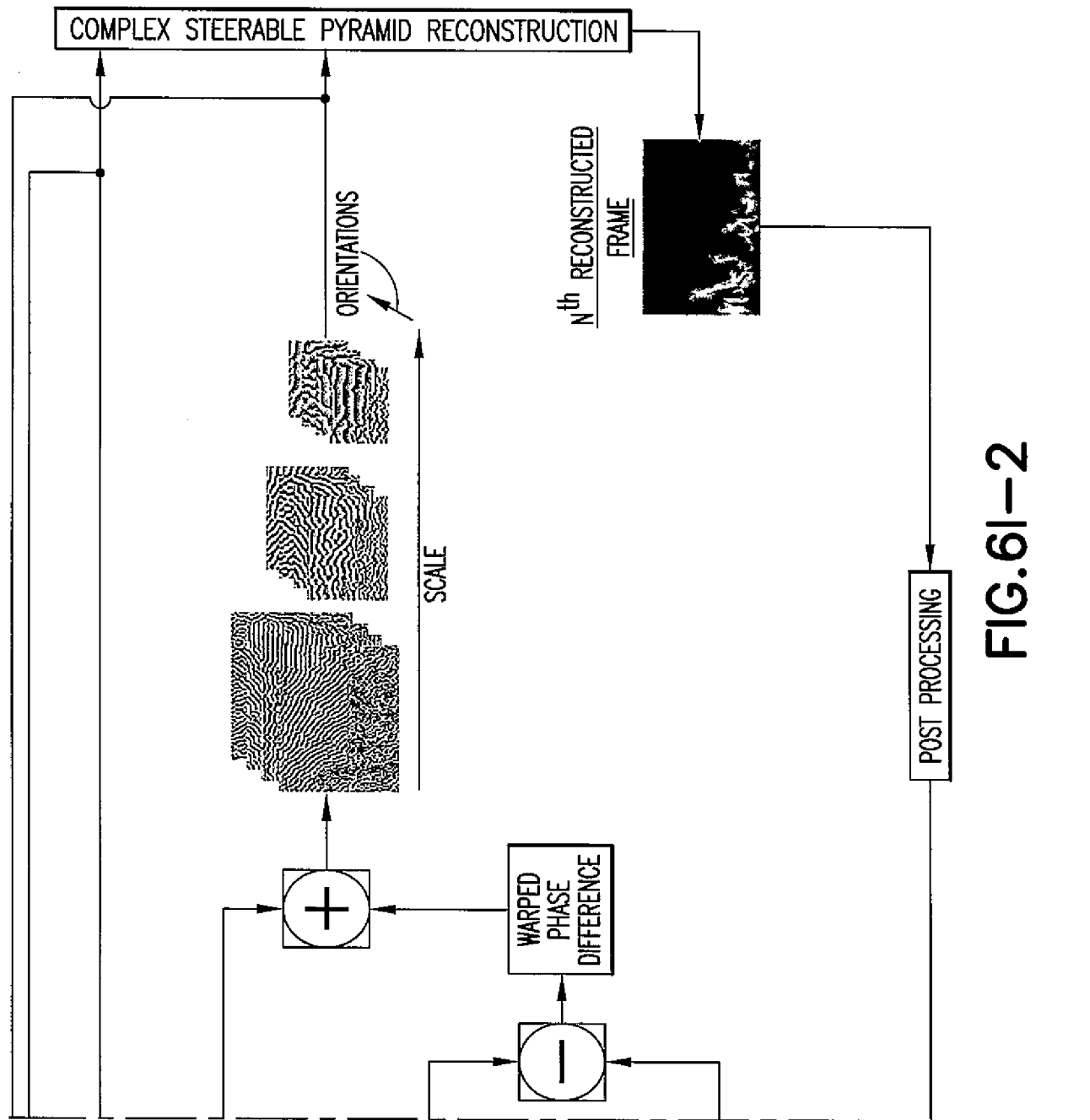
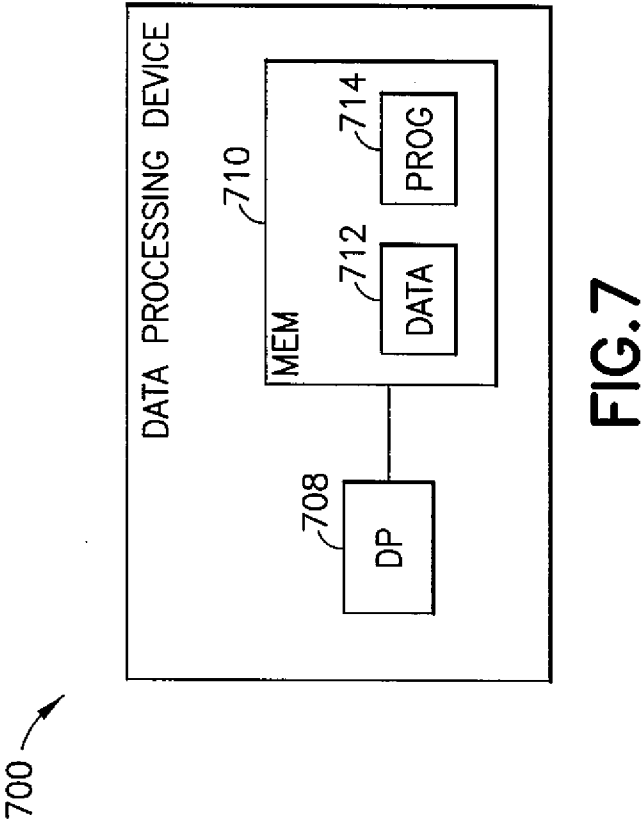


FIG. 6I-2



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/072764A. CLASSIFICATION OF SUBJECT MATTER
INV. G06T13/80 G06T7/20
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06T

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PIOTR DIDYK ET AL: "Joint view expansion and filtering for automultiscopic 3D displays", ACM TRANSACTIONS ON GRAPHICS (TOG), ACM, US, vol. 32, no. 6, 1 November 2013 (2013-11-01), pages 221:1-221:8, XP058033872, ISSN: 0730-0301, DOI: 10.1145/2508363.2508376 abstract section 3.2; page 221:3; figure 3 ----- -/--	1-7, 15-17, 24-31, 39-41, 48-55, 63-65,72



Further documents are listed in the continuation of Box C.



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

"E" earlier application or patent but published on or after the international filing date

"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)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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

"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

"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

"&" document member of the same patent family

Date of the actual completion of the international search

21 September 2015

Date of mailing of the international search report

07/12/2015

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
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Fax: (+31-70) 340-3016

Authorized officer

Krawczyk, Grzegorz

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/072764

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	YUNG-YU CHUANG ET AL: "Animating pictures with stochastic motion textures", ACM TRANSACTIONS ON GRAPHICS, vol. 24, no. 3, 1 July 2005 (2005-07-01), page 853, XP055213866, ISSN: 0730-0301, DOI: 10.1145/1073204.1073273 abstract section 3; page 856 - page 858	1-7, 15-17, 24-31, 39-41, 48-55, 63-65,72
A	NEAL WADHWA ET AL: "Phase-based video motion processing", ACM TRANSACTIONS ON GRAPHICS, vol. 32, no. 4, 1 July 2013 (2013-07-01), page 1, XP055154489, ISSN: 0730-0301, DOI: 10.1145/2461912.2461966 abstract; figure 2	1-7, 15-17, 24-31, 39-41, 48-55, 63-65,72
A	US 2014/072228 A1 (RUBINSTEIN MICHAEL [US] ET AL) 13 March 2014 (2014-03-13) paragraphs [0049], [0054] - [0060]; figure 9	1-7, 15-17, 24-31, 39-41, 48-55, 63-65,72

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/072764

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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:

see additional sheet

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 an 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.:

1-7, 15-17, 24-31, 39-41, 48-55, 63-65, 72

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/US2014/072764

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014072228	A1	13-03-2014	NONE

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-7, 15-17, 24-31, 39-41, 48-55, 63-65, 72

Construction of frames based on a still image. The images are constructed by updating the phase information of the still image based on the phase difference information extracted from a video sequence.

2. claims: 8-10, 18-21, 32-34, 42-45, 56-58, 66-69

Similarity analysis between two video sequences. The similarity is analysed based on phase variations between frames which determine local motion.

3. claims: 11-14, 22, 23, 35-38, 46, 47, 59-62, 70, 71

Identification and classification of motion layers in a video sequence. Motion layers are identified based on feature vectors containing per pixel phase difference information between video frames.
