

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

ARASHI VISION (U.S.) LLC (D/B/A INSTA360)
Petitioner,

v.

GOPRO, INC.
Patent Owner.

Patent No. 11,336,832

Inter Partes Review No. IPR2024-01052

DECLARATION OF DR. AGGELOS KATSAGGELOS

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I, Aggelos Katsaggelos, make this declaration in connection with the proceeding identified above.

I. INTRODUCTION

1. I have been retained as an expert witness on behalf of Arashi Vision (U.S.) LLC (d/b/a Insta360) (“Petitioner” or “Insta360”) to provide expert opinions on the patentability of United States Patent No. 11,336,832 (“the ’832 patent”).

2. I am being compensated at my normal rate for my analysis, plus reimbursement for expenses. My compensation does not depend on the content of my opinions or the outcome of this proceeding.

II. EXPERIENCE AND QUALIFICATIONS

3. In formulating my opinions, I have relied upon my knowledge, training, and experience in the relevant art. My qualifications are stated more fully in my curriculum vitae, which has been provided as Appendix A. Here, I provide a brief summary of my qualifications.

4. As set forth in my resume, I have over 44 years of experience working on image/video processing and digital cameras, starting with my position as a Research Assistant at Georgia Institute of Technology in 1980. As shown in my curriculum vitae, I have worked on many projects relevant to the subject matter of the ’832 patent.

5. I earned a Bachelor of Science Degree in Electrical and Mechanical Engineering from Aristotelian University of Thessaloniki in 1979. I earned a Master of Science Degree in Electrical Engineering from Georgia Institute of Technology in 1981. I earned a Ph.D. in Electrical Engineering from Georgia Institute of Technology in 1985.

6. I am currently a professor at Northwestern University, holder of the Joseph Cummings chair, in the Department of Electrical and Computer Engineering and by courtesy Computer Science and Radiology. I am also the Director of the AI in Multimedia Image and Video Processing Lab (AIM-IVPL) and the Deputy Director of the Computation Center for Computational Imaging and Signal Analytics in Medicine. Over the past 44 years, I have developed and taught courses related to digital image and video processing, including image and video compression, algorithms, analysis, and enhancement techniques.

7. Over the course of my academic and professor career, I have authored numerous papers, actively participated in several organizations, received several awards, and presented at several conferences related to my work in image and video processing, which are detailed in my attached curriculum vitae (Appendix A).

III. MATERIALS CONSIDERED

8. In preparing this declaration, I have reviewed, among other things, the '832 patent and file history. I have also considered each of the documents cited in this Declaration and the documents specifically identified below and in the Exhibit List. In formulating my opinions, I have further relied upon my extensive experience in the relevant fields.

IV. OVERVIEW OF THE TECHNOLOGY

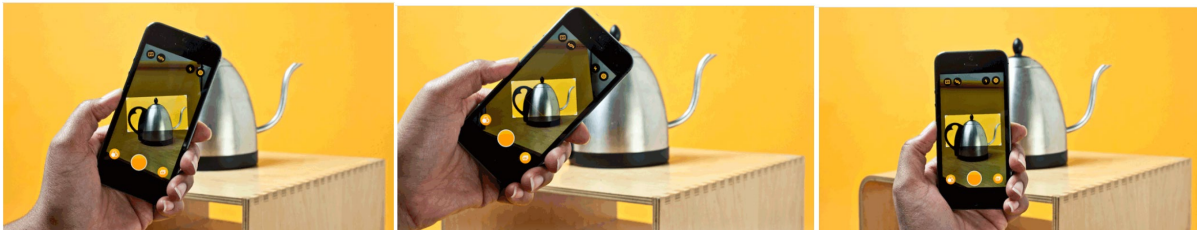
9. When an image capture device (e.g., a camera) is not level, the resulting captured image data would depict a tilted scene. In a tilted scene, the horizon line would appear off the horizontal axis. Image data depicting a titled scene is undesirable because it can disrupt the natural sense of balance and stability in the image, distract viewers from the main subject or focal point of the image, and cause viewer discomfort. Video data that is captured as the camera is moving can be particularly disorienting.

10. "Horizon-leveling" an image refers to techniques to correct the orientation of the image so that the horizon line (or any other reference line that should be horizontal) is leveled. To horizon-level a video, multiple image frames in the video may need to be corrected.

11. A variety of hardware sensors can be used to determine when an image capture device is not level, such as accelerometers, gyroscopes, and inertial

measurement units (IMUs). These hardware sensors can be coupled or mounted to the image capture device and make continuous measurements of the orientation of the image capture device.

12. The idea of using measurements from hardware sensors (e.g., accelerometers, gyroscopes, IMUs) to horizon-level image data and the associated benefits were known by at least August 30, 2019 (earliest priority date for the '832 patent). In fact, in as early as 2014, an app called “Horizon” was available for purchase to horizon-level videos on iPhone. (EX1009; EX1010.) The Horizon app can automatically horizon-level image data regardless the rotation of the camera, as shown below. (EX1010.)



(EX1009.)

13. To achieve horizon-leveling, the Horizon app uses rotational measurements from the iPhone’s sensors. Specifically:

Horizon is a new app for the iPhone (currently on sale for just \$1) making the rounds today that attempts to eliminate a major annoyance of modern society — portrait videos.

Horizon uses the iPhone’s motion sensors (the accelerometer and

gyroscope) to automatically scale and rotate input from the camera to generate videos that are always in landscape, no matter how the phone is actually being held.

It works by measuring the tilt of the phone and then *offsetting the effect digitally by rotating the video by the same amount in the other direction*. This results in a final image that is always orientated correctly. The app does this for every frame of the video. Thanks to the power of the processors inside iOS devices these days, this processing happens seamlessly. In my testing, [o]n an iPhone 5s, a one-minute clip was corrected and saved by the app in less than a second.

(EX1010 (emphases added).)

14. Numerous patent and patent publications, including those discussed herein, disclose this idea before the earliest priority date of the '832 patent.

V. OVERVIEW OF THE '832 PATENT

A. Filing Date and Priority Dates

15. The '832 patent was filed on August 28, 2020, and issued on May 17, 2022. The '832 patent claims priority to Provisional Application No. 62/894,649, which was filed on August 30, 2019.

B. Specification

16. The '832 patent is titled "Systems and Methods for Horizon Leveling Videos." (EX1001, Title.) "A video may have been captured by an image capture device in motion. The motion of the image capture device during the capture of the video may cause the video to depict a tilted view of a scene." (EX1001, 1:11-14.)

17. The '832 patent discloses techniques to generate a horizon-leveled view of the video by providing a "viewing window" of the video. (EX1001, Claim 1.) The viewing window "defin[es] extents of the visual content to be included within horizon-leveled visual content." (EX1001, claim 1.) "Horizon-leveled visual content may refer to visual content including depiction of a scene that is leveled with respect to ground, sea, earth, and/or the horizon." (EX1001, 6:30-33.)

18. For example, with respect to FIG. 5B, the '832 patent states: FIG. 5B illustrates example viewing windows 506, 508 to provide horizon-leveled views of images 522, 524. The image 522 may be captured by an image capture device that is leveled with respect to ground. The visual content of the image 522 may include a leveled depiction of a scene. A *viewing window 506* may be placed within the field of view of the visual content of the *image 522* to provide a leveled view of the scene. The image 524 may be captured by the image capture device that is rotated with respect to ground. The

visual content of the image 524 may include a tilted depiction of a scene. A *viewing window 508* may be placed within the field of view of the visual content of the *image 524* to provide a leveled view of the scene.

(EX1001, 11:19-31 (emphases added).)

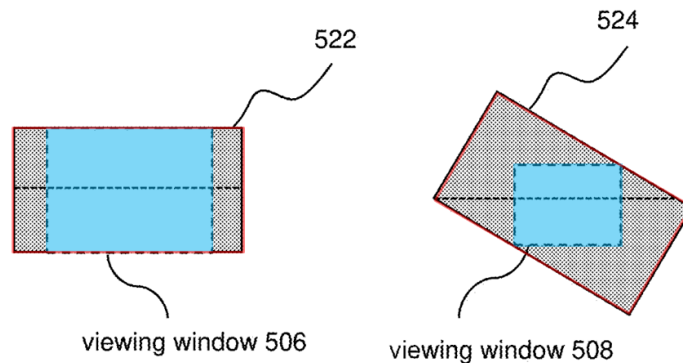


FIG. 5B

19. As shown in FIG. 5B of the '832 patent, “[d]ifferent amounts of rotation of the image capture device during capture of the images 522, 524 may result in different sizes of the viewing windows 506, 508.” (EX1001, 11:32-34.)

C. Claims

20. I was asked to evaluate whether claims 1-20 of the '832 patent are patentable.

21. There are two independent claims. Claim 1 is directed to a system for horizon leveling videos. The system comprises one or more physical processors configured by machine-readable instructions. The physical processors perform at

least four steps: (1) obtain video information defining a video, the video including video content captured by an image capture device during a capture duration, the video content having a progress length, the video content including visual content captured at different moments within the capture duration, the visual content viewable as a function of progress through the progress length, the visual content having a field of view; (2) obtain rotational position information for the video, the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration; (3) determine a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration, the viewing window defining extents of the visual content to be included within horizon-leveled visual content as the function of progress through the progress length, wherein determination of the viewing window includes determination of a placement of the viewing window within the field of view of the visual content as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration; and (4) generate the horizon-leveled visual content based on the viewing window, the horizon-leveled visual content including a punchout of the extents of the visual content defined by the viewing window, wherein inclusion of

the extents of the visual content defined by the viewing window within the horizon-leveled visual content effectuates horizon leveling of the visual content. Independent claim 10 recites similar limitations but is directed to a method.

22. There are 18 dependent claims. Claims 2 and 12 require the viewing window to have a one-by-one aspect ratio.

23. Claims 3 and 13 require the visual content to include a distortion such that a straight line within a scene depicted within the visual content appears as a curved line. Claims 4 and 14 require the distortion to include a barrel distortion or a pincushion distortion. Claims 5 and 15 require the visual content to include the distortion based on capture of the visual content through a wide field of view optical element. Claims 6 and 16 require the visual content to include the distortion based on application of the distortion to non-distorted visual content, the distortion applied to the non-distorted visual content based on the visual content including the non-distorted visual content.

24. Claims 7 and 17 require that the determination of the viewing window to include determination of a size of the viewing window. Claims 8 and 18 require that the size of the viewing window to change as the function of progress through the progress length to simulate changes in zoom for the visual content.

25. Claims 9 and 19 require that the determination of the placement of the viewing window within the field of view of the visual content to include determination of a rotation of the viewing window.

26. Claims 10 and 20 require that the determination of the placement of the viewing window within the field of view of the visual content to include determination of a location of the viewing window.

D. Prosecution History

27. I understand that during prosecution of the '832 patent, the Examiner did not issue any prior art-based Office Action.

28. On February 9, 2022, the Examiner issued a Notice of Allowance. (EX1003, p. 28.) In the Notice of Allowance, the Examiner characterizes the invention as follows:

Applicant's invention is drawn to a video may be captured by an image capture device in motion. A horizon- leveled view of the video may be generated by providing a punch out of the video. The punch out of the video may compensate for rotation of the image capture device during capture of the video. The placement of the punch out of the video may be changed based on different rotational positions [of] to provide a view in which a horizon depicted within the video is leveled.

(EX1003, p. 33.)

29. In the Notice of Allowance, the Examiner alleged that the closest prior art of record failed to teach the limitations of “determine a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration, the viewing window defining extents of the visual content to be included within horizon-leveled visual content as the function of progress through the progress length, wherein determination of the viewing window includes determination of a placement of the viewing window within the field of view of the visual content as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration” and “generate the horizon-leveled visual content based on the viewing window, the horizon-leveled visual content including a punch out of the extents of the visual content defined by the viewing window, wherein inclusion of the extents of the visual content defined by the viewing window within the horizon-leveled visual content effectuates horizon leveling of the visual content.” (EX1003, pp. 33-34.)

30. On February 23, 2022, Applicant submitted an Amendment after Notice of Allowance, requesting amendment of only the preamble of claim 1 from

a “system that horizon levels videos” to a “system for horizon leveling videos.”

(EX1003, p. 20.) The Examiner entered the claim amendment on March 4, 2022.

VI. RELEVANT LEGAL STANDARDS AND DEFINITIONS

A. Obviousness

31. I have been informed that a claim is unpatentable if the differences between the claimed subject matter and the prior art are such that the subject matter as a whole would have been obvious at the time the claimed subject matter was made to POSITA to which the subject matter pertains. I have also been informed that a patent claim may be obvious to a POSITA in view of the prior art teachings of a single reference or a combination of references.

32. To assess obviousness, I have been informed that I am to consider the scope and content of the prior art, the differences between the prior art and the claim, the level of ordinary skill in the art, and any secondary considerations to the extent that they exist.

33. I have also been informed that there are principles that may be used as further guidance in obviousness analysis (especially when considering combinations of references), which include considering whether:

- the claimed subject matter is simply a combination of prior art elements according to known methods to yield predictable results;
- the claimed subject matter is a simple substitution of one known element

for another to obtain predictable results;

- the claimed subject matter uses known techniques to improve similar devices or methods in the same way;
- the claimed subject matter applies a known technique to a known device or method that is ready for improvement to yield predictable results;
- the claimed subject matter would have been “obvious to try” choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success;
- there is known work in one field of endeavor that may prompt variations of it for use in either the same field or a different one based on design incentives or other market forces if the variations would have been predictable to a POSITA;
- there existed at the time of conception and reduction to practice a known problem for which there was an obvious solution encompassed by the patent’s claims; and
- there is some teaching, suggestion, or motivation in the prior art that would have led a POSITA to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed subject matter.

34. I have been informed that there are secondary considerations that may tend to show that a claimed invention would not have been obvious to a POSITA.

These include, for example, commercial success, long-felt but unsolved needs, failure of others, and unexpected results. I have been further informed that there must be a relationship, or nexus, between any secondary considerations and the novelty of the claimed invention.

B. Prior Art

35. I am informed and understand that prior art includes patents and printed publications that existed before the effective filing date of the claimed invention. The effective filing date is the earliest claimed priority date or the earliest filing date of the application that describes the subject matter. A patent or published patent application is prior art if it was filed before the earliest filing date of the claimed invention, absent a few exceptions. I am informed that a patent or published patent application is entitled to have its effective filing date as the filing date of its provisional application if the disclosure of the provisional application provides support for the claim(s) of the patent or published patent application.

VII. LEVEL OF ORDINARY SKILL IN THE ART FOR THE '832 PATENT

36. I am informed and understand that various factors can be considered in determining a person of ordinary skill in the art (POSITA). I am informed and understand that those factors include: (1) the education level of the inventors; (2) the type of problems encountered in the art; (3) prior art solutions to those

problems; (4) the rapidity with which innovations are made; (5) sophistication of the technology; and (6) education level of active workers in the field.

37. A POSITA in the field of the '832 patent would have a bachelor's degree in engineering or computer science, or equivalent field, and two years of experience working on image or video processing or digital cameras.

Alternatively, a POSITA would have four years of experience working on image or video processing or digital cameras. An advanced graduate degree in the disciplines cited above may make up for the work experience indicated above.

38. I agree with this level of ordinary skill for the '832 patent. Based on my experience, I understand and know of the capabilities of a person of this skill level as of the time the '832 patent priority application was filed in 2019. I am familiar with how a POSITA would have understood and used the terminology found in the '832 patent at the time of its filing, and with the state of the art at that time.

VIII. CLAIM CONSTRUCTION

39. I have been informed that claim construction requires consideration of the words of the claims themselves, the specification, the prosecution history, and extrinsic evidence concerning relevant scientific principles, the meaning of technical terms, and the state of the art. I have also been informed that the

specification is usually definitive, as it was the single best guide to the meaning of a disputed term.

40. I have been informed that, in the context of this proceeding, Petitioner did not propose any terms for construction. Instead, Petitioner believes each of the terms of the '832 patent carries its ordinary and customary meaning, which is the meaning that the term would have to a POSITA. I agree with Petitioner and apply the ordinary and customary meaning of the terms in my analysis below. For purposes of this declaration, I have also interpreted the challenged claims based on the breadth of GoPro infringement allegations in the related International Trade Commission (ITC) proceeding. (EX1011; EX1012.)

IX. PRIOR ART

41. I understand that each of the references discussed herein qualifies as prior art against the '832 patent:

42. U.S. Publication No. 2005/0168583 ("Thomason," EX1004) was filed on April 3, 2003, and published on August 4, 2005.

43. U.S. Publication No. 2015/0181123 ("Pacurariu," EX1005) was filed on December 19, 2013, and published on June 25, 2015.

44. U.S. Patent No. 10,778,896 ("Watanabe," EX1006) was filed on April 16, 2018, published on October 18, 2018, and issued on September 15, 2020.

45. International Publication No. WO 2015/183636 (“Voss,” EX1007) was filed on May 19, 2015, and published on December 3, 2015.

46. U.S. Patent No. 10,341,564 (“Derbanne,” EX1008) was filed on October 2, 2018, published on July 2, 2019, and issued on July 2, 2019.

X. ANALYSIS AND OPINIONS

A. Ground 1: Thomason Renders Obvious Claims 1, 2, 7-12, 17-20

1. Summary of Thomason

47. Thomason relates to “image rotation correction for video or photographic equipment.” (EX1004, Title.) Thomason states that “[c]ameras, such as video or still digital cameras, are frequently used by amateurs who may have difficulties in correctly orienting the camera. There is thus a need for a camera capable of reducing the effect of poor orientation.” (EX1004, [0002].)

48. Thomason discloses:

“According to the invention, there is provided an image recording apparatus comprising: a lens; a means for capturing an image projected by the lens; a rotation sensor for providing an output representing the angle of the captured image to the horizontal to an accuracy of 5° or better; and a data carrier for recording data based on both image data representing the captured image and angle data representing the angle measured by the rotation sensor *so that a*

rotated image corrected to have the true horizontal in the captured image displayed as horizontal can be displayed from the data recorded on the data carrier.

In this way, the image data can be used to output a corrected image with the horizontal of the scene captured by the camera displayed horizontally even if the camera is not exactly aligned.”

(EX1004, [0004]-[0005] (emphasis added).)

49. With reference to FIG. 3, Thomason discloses that “FIG. 3a shows the image that the user should have taken i.e., [] with the camera horizontally aligned. **FIG. 3b** shows the image taken with a camera angle at an angle of about 10° to the vertical. The true horizontal in the image is thus also at an angle of 10° to the horizontal in the recorded image.” (EX1004, [0034] (emphasis added).)

Thomason states that “[t]he image as shown in FIG. 3b is recorded in the memory together with the data item that records the camera angle.” (EX1004, [0035].)

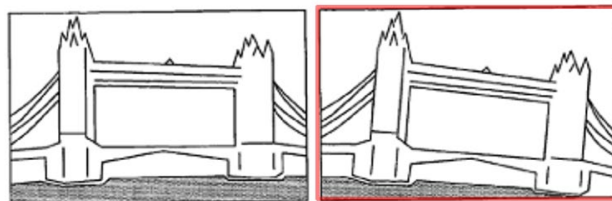


Fig.3a

Fig.3b

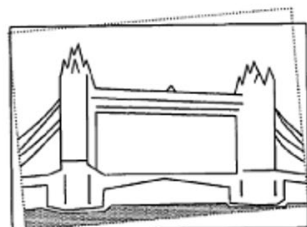


Fig.3c



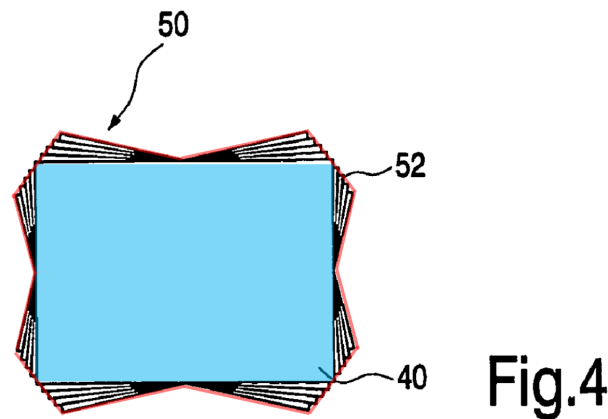
Fig.3d



Fig.3e

50. With reference to FIG. 3, Thomason further states that “[o]n replay, the processor 22 calculates the image on display 24 as shown in FIG. 3c, with a rotation correction applied using the camera item data angle by replay processor 22 so that true horizontals appear as horizontal. Some of the image frame of the rotation corrected image is blank, as may be seen. Accordingly, the image is cropped to eliminate blank space as illustrated in *FIG. 3d*. Frame 40 represents the recorded image and frame 42 represents the image frame of the displayed image.” (EX1004, [0036] (emphasis added).)

51. With reference to FIG. 4, Thomason discloses that “[i]n a modification of the invention, illustrated in FIG. 4, the *recorded image area 50* is greater than that of the *nominal image frame 40* in order that the image may be rotated without resizing. Marginal pixels 52 outside the nominal frame 40 may be switched on only when required to avoid excessive power drain when the automatic alignment feature is not in use.” (EX1004, [0038] (emphases added).)



52. With reference to FIG. 5, Thomason discloses “[i]n a further modification, the sensor array may be circular to enable arbitrary rotation to take place without any loss at the edges. FIG. 5 illustrates such a *circular sensor 60* with *nominal image frame 40*. Rotation to any angle is possible without size reduction. The individual pixels of circular sensor 60 may be arranged on a hexagonal grid.” (EX1004, [0039] (emphases added).)

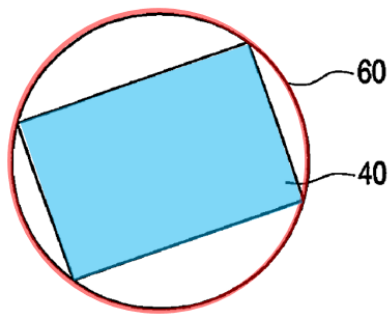


Fig.5

2. Summary of Pacurariu

53. Pacurariu discloses “[s]ystems and methods . . . to rotate an image recorded by an image sensor to compensate for angular rotation or tilt of the image sensor.” (EX1005, Abstract.) FIG. 1B below illustrates an example of a camera 100. With reference to FIG. 1B, Pacurariu states that “the camera 100 is rotated such that *images recorded by the camera 100 may not be aligned with the horizon and/or gravity.*” (EX1005, [0029] (emphasis added).)

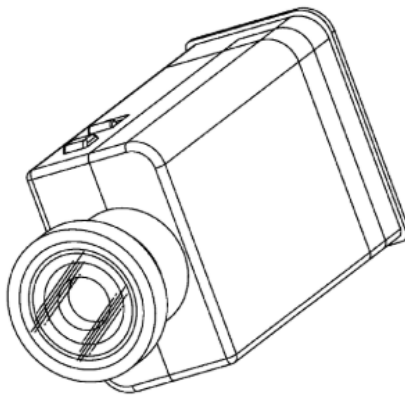


Figure 1B

54. Pacurariu discloses various techniques for “compensat[ing] for angular rotation or tilt of the image sensor.” (EX1005, Abstract.) “According to some embodiments described herein, the rotation, or tilt of images or video frames

collected by the camera 100 may be *corrected mathematically to provide images or video frames that are not tilted or rotated*. Such images, for example, may be more pleasing for viewing. Moreover, as another example, such corrections may allow for the camera 100 to be tilted or rotated when mounted, and yet *produce images or video frames that are not tilted or rotated*.” (EX1005, [0029] (emphases added).)

55. Pacurariu’s system can obtain tilt angle data for each video frame, as shown in FIG. 6 below. “At block 615 the tilt angle data may be saved with each video frame. The tilt angle data may be saved as metadata within a separate file or as part of each video frame.” (EX1005, [0052].)

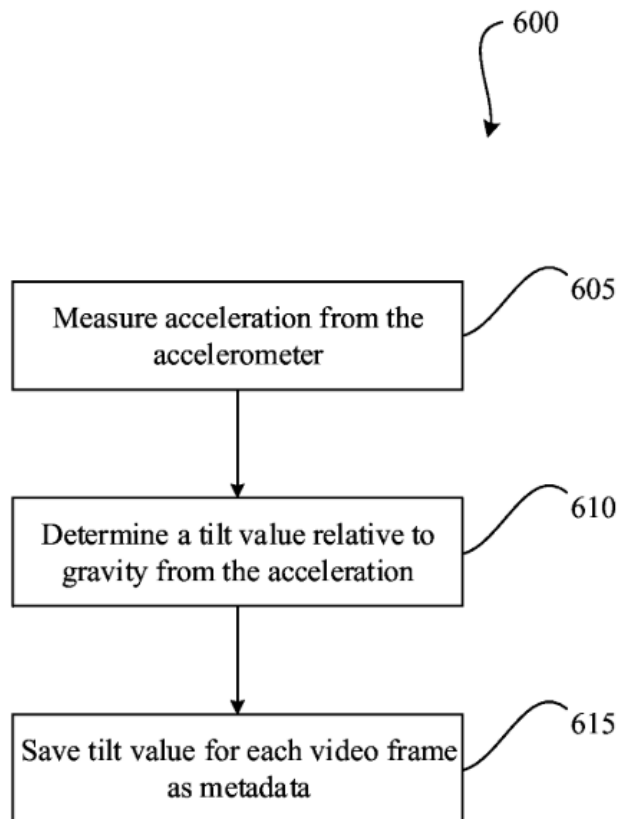


FIG. 6

56. FIG. 5A is an example of image rotation to compensate for angular rotation or tilt of the image sensor. “FIG. 5A illustrates a *graphical representation of the image sensor array 300* that is tilted relative to the gravitational vector 410 and relative to the horizon 415. *A reduced area of the image area 305* may be used to compensate for any rotation.” (EX1005, [0044] (emphases added).)

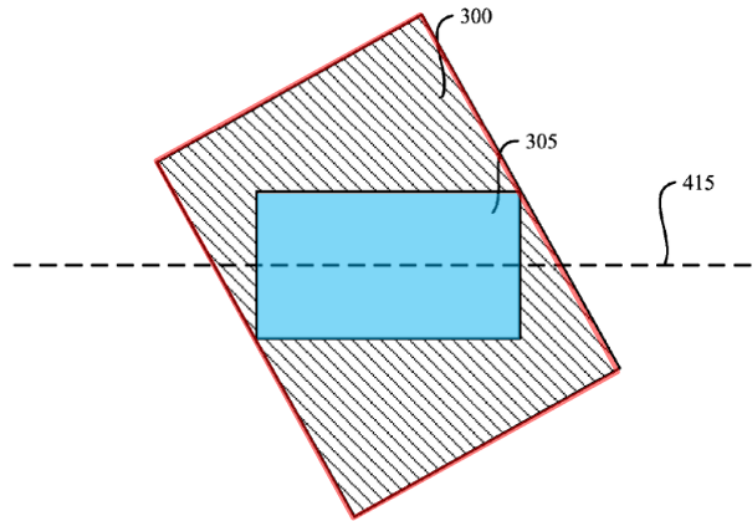


Figure 5A

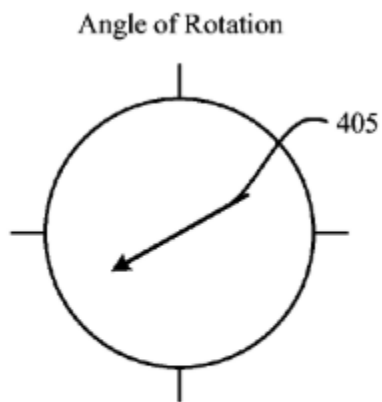


Figure 5B

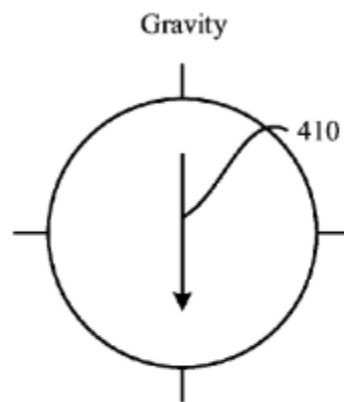


Figure 5C

3. Claim 1

a. Preamble: “A system for horizon leveling videos, the system comprising:”

57. Thomason discloses a system for horizon leveling videos. For example, Thomason discloses systems that “allow the captured image to be rotated

for display to have the true horizontal displayed as horizontal.” (EX1004, Abstract.)

b. 1[a]: “one or more physical processors configured by machine-readable instructions to:”

58. Thomason discloses the recited “one or more physical processors.” For example, Thomason’s system comprises a *processor 22*, which “uses the recorded rotation angle information to cause an image to be displayed on display 24 that has the horizontal [displayed as] horizontal, even if the camera was slightly misaligned when the image was recorded.” (EX1004, [0033].)

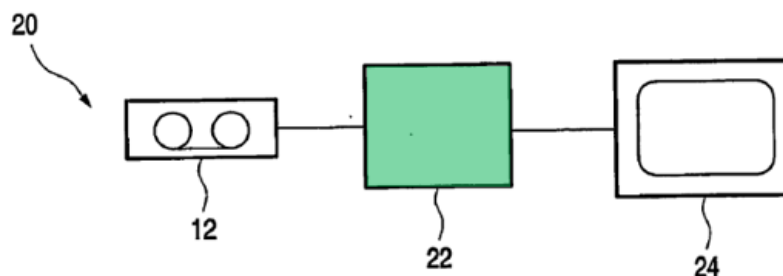


Fig.2

59. As another example, Thomason discloses a *processor 16*, which “may function as a correction module by taking the image captured by the sensor 6 and the angle of orientation of the camera 2 as output by rotation sensor 14, correcting the image data so that the image is accurately horizontal and storing the corrected image in memory 12.” (EX1004, [0042].)

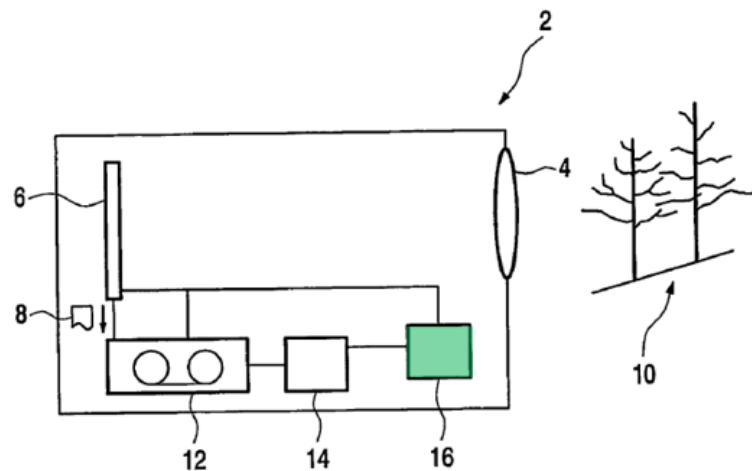


Fig.1

60. A POSITA would have understood that these are physical processors that are physically included in systems and are configured by machine-readable instructions to perform the steps described in Thomason.

c. **1[b][i]: “obtain video information defining a video,”**

61. Thomason discloses obtaining video information. For example, Thomason states that “the invention is applicable to any form of camera, whether a stills camera, a video camera, or a camera capable of both stills and video operation.” (EX1004, [0044].) In FIG. 1 below, “[a] camera 2 includes a lens 4 and a charge-coupled device (CCD) 6[,] which acts as a sensor to capture image data 8 representing a scene 10 in front of the camera. The camera may record either still images or *moving images, in the latter case by capturing a sequence of*

items of image data 8 representing sequential frames of the moving image.”

(EX1004, [0027] (emphasis added).)

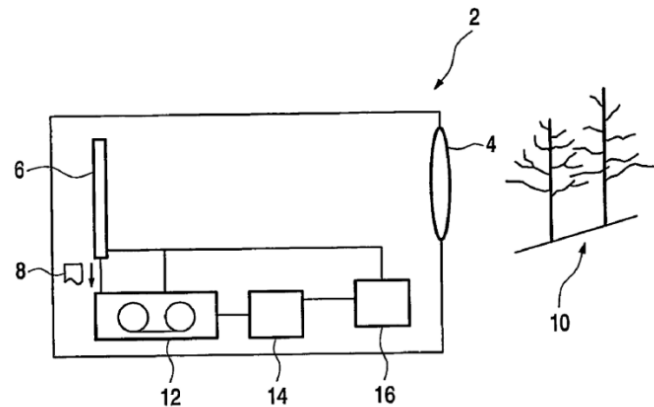


Fig.1

62. Thomason’s video information defines a video. As discussed above, Thomason’s video information includes “a sequence of items of image data 8 representing sequential frames of the moving image.” (EX1004, [0027].)

d. 1[b][ii]: “the video including video content captured by an image capture device during a capture duration,”

63. As shown for element 1[b][i], Thomason discloses that video content is captured by camera 2, which is an image capture device. (*Supra* § X.A.3.c.)

64. A POSITA would have understood that Thomason’s system would capture video content over a period of time, which corresponds to the recited “capture duration.”

e. 1[b][iii]: “the video content having a progress length, the video content including visual

content captured at different moments within the capture duration,”

65. Thomason discloses “the video content having a progress length” and “the video content including visual content captured at different moments within the capture duration.”

66. First, Thomason discloses “the video content having a progress length.” According to the ’832 patent, “[t]he progress length of the video content may correspond to the capture duration. The progress length of the video content may be determined based on the capture duration. The progress length of the video content may be same as the capture duration, shorter than the capture duration (e.g., playback rate of the video content is faster than the capture rate of the video content), and/or longer than the capture duration (e.g., playback rate of the video content is slower than the capture rate of the video content).” (EX1001, 14:14-23.)

67. Similarly, Thomason’s video content can be played back and the period of time during which the video content is played back can be “the progress length.” In Thomason, “[a] playback device 20 is provided that can accept memory 12 and process the recorded image data 8 and rotation angle in replay processor 22. The processed image data is *played back* on display device 24, for example a television set.” (EX1004, [0032] (emphasis added).) Similarly to the ’832 patent, a POSITA would have understood that, depending on the playback speed, the period of time during which Thomason’s video content can be played

back can be the same as the capture duration, shorter than the capture duration (e.g., if the playback is sped up), and/or longer than the capture duration (e.g., if the playback is slowed down). A display device such as Thomason's display device 24 should be able to provide playback of recorded image data as well as processed image data.

68. Thomason also discloses "the video content including visual content captured at different moments within the capture duration." Thomason's video content includes "a sequence of items of image data 8 representing sequential frames of the moving image." (EX1004, [0027].) A POSITA would have understood that, because the items of image data are captured in a sequence, each item of image data in the sequence can be captured at different moments within the capture duration.

f. **1[b][iv]: "the visual content viewable as a function of progress through the progress length, the visual content having a field of view;"**

69. Thomason discloses "the visual content viewable as a function of progress through the progress length."

70. Thomason's visual content is "viewable." For example, Thomason discloses that "[t]he processed image data is *played back* on display device 24, for example a television set." (EX1004, [0032] (emphasis added).) A display device

such as Thomason's display device 24 should be able to provide playback of recorded image data as well as processed image data.

71. Thomason's video content (i.e., the sequence of items of image data) is viewable "as a function of progress through the progress length." As shown for elements 1[b][i]-[iii], Thomason's video content includes "a sequence of items of image data 8 representing sequential frames of the moving image" and this sequence of items of image data can be played back by a "playback device 20" during a period of time (i.e., the progress length). (*Supra* §§ X.A.3.c - X.A.3.e.) This means that Thomason's sequential frames are viewable by the playback device 20 as a function of progress through the progress length.

72. Thomason also discloses "the visual content having a field of view." Thomason discloses multiple examples of visual content having a field of view. As a first example, FIG. 3b of Thomason is a "recorded image" and "shows the image taken with a camera angle at an angle of about 10° to the vertical." (EX1004, [0034].) This is an example of visual content having a rectangular *field of view*.



Fig.3b

73. As another example, FIG. 5 “illustrates a circular image frame.” (EX1004, [0024].) FIG. 5 is an image taken with a “circular sensor,” resulting in a circular *field of view*. (EX1004, [0039].)

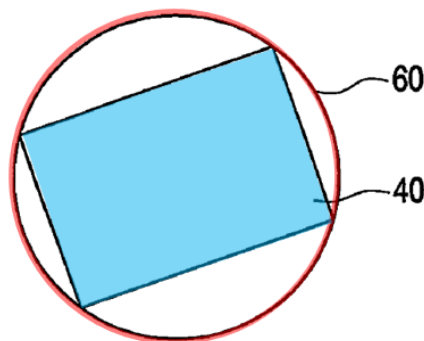
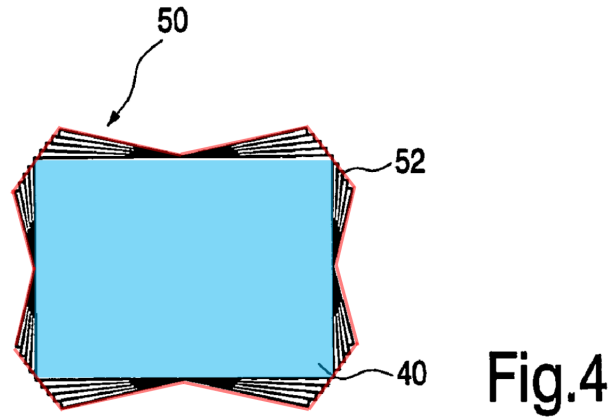


Fig.5

74. As another example, FIG. 4 is “an illustration of the frame area[.]” (EX1004, [0023].) In FIG. 4, “the recorded image area 50 is greater than that of the nominal image frame 40 in order that the image may be rotated without resizing.” (EX1004, [0038].) The “recorded image area 50” has a *field of view* as shown below.



- g. **1[c]: “obtain rotational position information for the video, the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration;”**

75. Thomason’s system includes “[a] *rotation sensor 14* [] that measures the angle of the camera to the vertical and outputs a corresponding measurement signal.” (EX1004, [0029] (emphasis added).) The rotation sensor 14 can be used to “obtain rotational position information for the video.”

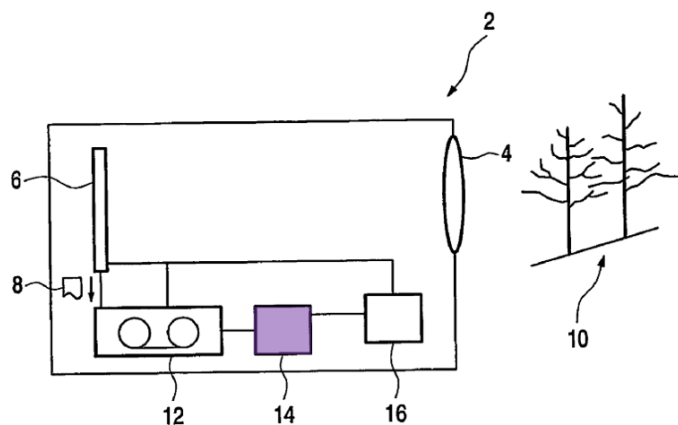


Fig.1

76. Thomason discloses “the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration.” Thomason discloses video data comprising “*a sequence of items of image data 8* representing sequential frames of the moving image.” (EX1004, [0027] (emphasis added).) Further, Thomason discloses “a rotation sensor for providing an output representing *the angle of the captured image* to the horizontal to an accuracy of 5° or better; and a data carrier for recording data based on *both image data representing the captured image and angle data representing the angle measured by the rotation sensor* so that a rotated image corrected to have the true horizontal in the captured image displayed as horizontal can be displayed from the data recorded on the data carrier.” (EX1004, [0004] (emphases added).) As a specific example, Thomason discloses that “[t]he image as shown in FIG. 3b is recorded in the memory *together with the data item that records the camera angle.*” (EX1004, [0035] (emphasis added).) Thomason further states, “[t]he step of recording image data may include recording the image information and the measured orientation of the camera as separate pieces of data. The method may further include correcting the recorded image data based on the measured orientation of the camera; and replaying the corrected image information.” (EX1004, [0018].)

77. Thus, Thomason can obtain a corresponding angle data for each captured image. In other words, each angle data is associated with a corresponding captured image in a sequence of images captured in a capture duration and thus is correlated with a time point over the capture duration. Thus, the angle data is characterized as a function of progress through the capture duration.

78. Further, Pacurariu discloses “obtain rotational position information for the video.” “FIG. 6 illustrates an example flowchart of a process 600 for saving a video frame with inclination data according to some embodiments described herein. The process 600 starts at block 605. At block 605 acceleration data may be measured and/or recorded from the accelerometer 215. In some embodiments, the acceleration data may be filtered, amplified, digitized, or modified, for example, based on calibration data, etc.” (EX1005, [0050].) “At block 610 the *tilt angle data of the image sensor array 300 within the camera* may be determined based on the acceleration data. Moreover, the tilt angle data may specify the tilt of the sensor array relative to the gravitational field or to the horizon.” (EX1005, [0051] (emphasis added).)

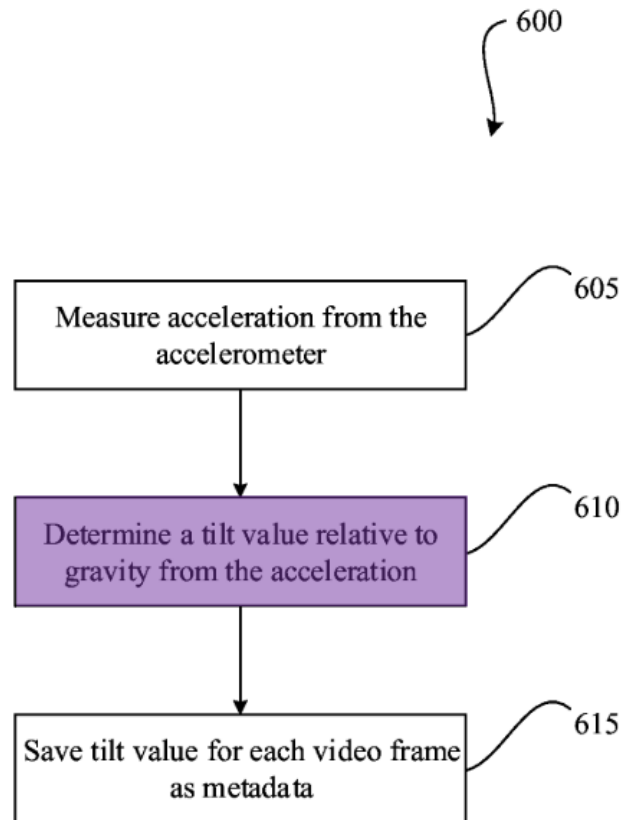


FIG. 6

79. Pacurariu further discloses “the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration.” “At block 615 the *tilt angle data may be saved with each video frame. The tilt angle data may be saved as metadata within a separate file or as part of each video frame.* For example, if images from the image sensor array 300 are being saved at a rate of 24 frames per second, then tilt angle of inclination data may also be saved at this rate.” (EX1005, [0052] (emphases added).) In other words, Pacurariu can obtain a tilt value for each video frame. Video frames in a video can be expressed as a function of progress through

the capture duration of the video because they are captured at different moments within the capture duration. (*Supra* § X.A.3.e.) Thus, it follows that the tilt values of the video frames can also be expressed as a function of progress through the capture duration.

80. It would have been obvious to a POSITA to combine the teachings in Thomason and Pacurariu. Both Thomason and Pacurariu relate to techniques for rotating visual content in video data to compensate for motion of the image capture device. (EX1004, Title; EX1005, Abstract.) Thomason relates to “image rotation correction for video or photographic equipment.” (EX1004, Title.) Similarly, Pacurariu discloses “[s]ystems and methods . . . to rotate an image recorded by an image sensor to compensate for angular rotation or tilt of the image sensor.” (EX1005, Abstract.) Thus, Thomason and Pacurariu are from the same field of endeavor and reasonably pertinent to the same technical problems of improving video content.

81. The Thomason-Pacurariu combination results in a system in which rotational position information, such as a tilt value as taught by Pacurariu, can be obtained for each video frame in Thomason’s video content, be saved as metadata or as part of each video frame as taught by Pacurariu, and be used to generate a rotated image for each video frame in Thomason’s video content. (EX1005, [0052], [0055]-[0057], FIGS. 6-7.) Further, the Thomason-Pacurariu system can

determine the placement of a viewing window, such as the reduced area 305 in FIG. 5A of Pacurariu, for a rectangular video frame such as FIG. 3b of Thomason to, allowing a horizon-leveled video frame to be obtained efficiently. Combining the technical features of Pacurariu with the teachings of Thomason would improve the horizon-leveling capabilities of Thomason in the same way. Combining the teachings of Thomason and Pacurariu as such would yield predictable results of effectively and efficiently horizon-leveling video data. Further, it would have been obvious to try combining the technical features of Pacurariu with the teachings of Thomason, as there is a finite number of identified, predictable solutions, with a reasonable expectation of success. Prior art such as Pacurariu has successfully demonstrated that per-frame determination of rotated image based on a viewing window (e.g., image area 305 in FIG. 5A) can be implemented to achieve better video quality and thus, there would have been a reasonable expectation of success for combining Thomason and Pacurariu. These technical features can be combined with the teachings in Thomason without requiring much effort and with a reasonable expectation of success. The known benefits of Pacurariu would prompt the application of Pacurariu in the same field based on design incentives and other market forces.

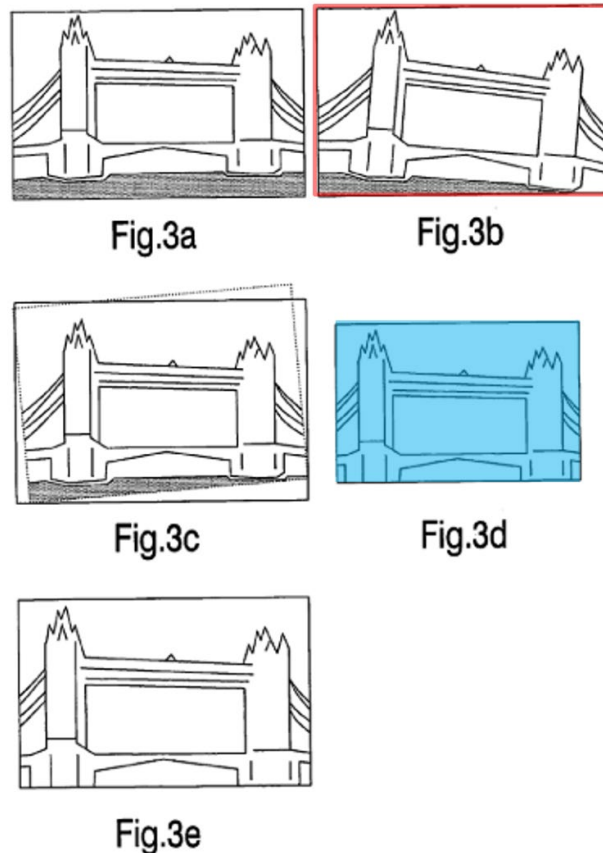
- h. 1[d][i]: “determine a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image capture device as the**

function of progress through the capture duration,”

82. Thomason discloses “determine a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration.” There are multiple examples of the recited “viewing window” as discussed below.

83. In a first example, FIG. 3b, which is a captured image, is the “visual content.” Further, FIG. 3d, which corresponds to a cropped portion of FIG. 3b, is the “viewing window” determined by Thomason based on rotational position of the camera. “**FIG. 3b shows the image taken** with a camera angle at an angle of about 10° to the vertical.” (EX1004, [0034] (emphasis added).) “The image as shown in FIG. 3b is recorded in the memory together with the data item that records the camera angle.” (EX1004, [0035].) “On replay, ***the processor 22 calculates the image on display 24 as shown in FIG. 3c, with a rotation correction applied using the camera item data angle by replay processor 22 so that true horizontals appear as horizontal.*** Some of the image frame of the rotation corrected image is blank, as may be seen. Accordingly, the image is cropped to eliminate blank space as illustrated in **FIG. 3d.**” (EX1004, [0036] (emphasis added).) This means that the visual content in FIG. 3b is rotated such that the visual content is horizon-leveled (resulting in FIG. 3c) and some outer pixels of FIG. 3b are cropped to

obtain FIG. 3d. Thus, FIG. 3d is a “viewing window” that defines the extents of visual content in FIG. 3b to be included as horizon-leveled content.



84. As a second example, in FIG. 5 of Thomason, the captured circular image is the “visual content” and the image frame 40 is the “viewing window” determined based on rotational position of the camera. FIG. 5 of Thomason illustrates “a circular sensor 60 with *nominal image frame 40*.” (EX1004, [0039] (emphasis added).) Thomason states that “[r]otation to any angle is possible without size reduction.” (EX1004, [0039].) Thus, even if the camera (i.e., the circular sensor) is rotated to an arbitrary degree (e.g., 10 degrees clockwise), the system can sample a nominal image frame 40 within captured circular image (e.g.,

10 degrees counter-clockwise to compensate for the rotation of the camera). The nominal image frame 40 is a “viewing window” that defines the extents of the captured circular image to be included as horizon-leveled content.

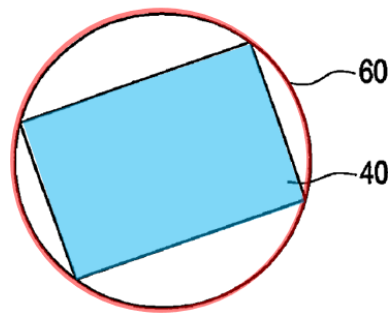


Fig.5

85. As yet another example, in FIG. 4 of Thomason, the recorded image area 50 is the “visual content” and the image frame 40 is the “viewing window” determined based on rotational position of the camera. In FIG. 4, “*the recorded image area 50*” is greater than that of the *nominal image frame 40* in order that the image may be rotated without resizing. Marginal pixels 52 outside the nominal frame 40 may be switched on only when required to avoid excessive power drain when the automatic alignment feature is not in use.” (EX1004, [0038] (emphases added).) Thus, Thomason’s system samples the nominal image 40 within the recorded image area 50. The nominal image 40 is a “viewing window” that defines the extents of the recorded image area 50 to be included as horizon-leveled content.

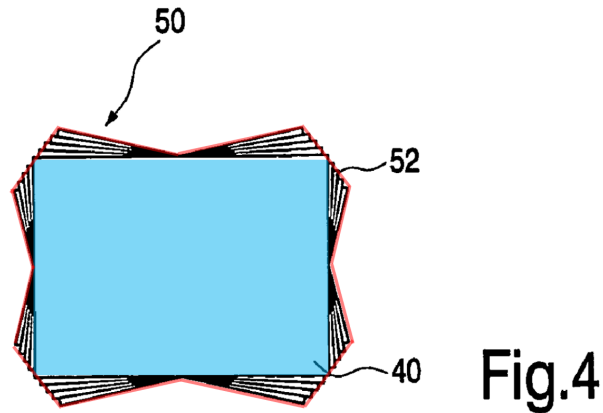


Fig.4

86. Thomason discloses that its viewing windows are determined “as a function of progress through the progress length.” Thomason discloses “[a] playback device 20 is provided that can accept memory 12 and process the recorded image data 8 and rotation angle in replay processor 22. The processed image data is played back on display device 24, for example a television set.” (EX1004, [0032].) In other words, Thomason discloses playing back the processed sequential frames of the video (with each processed frame defined by a viewing window). Thus, Thomason discloses “determine a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration.”

87. Further, Pacurariu discloses “determine a viewing window for the visual content . . . based on the rotational positions of the image capture device as the function of progress through the capture duration.” “FIG. 5A illustrates a

graphical representation of the image sensor array 300 that is tilted relative to the gravitational vector 410 and relative to the horizon 415. A *reduced area of the image area 305* may be used to *compensate for any rotation*. In this example, the image sensor array 300 is tilted 60.8° relative to the gravitational field and 29.2° relative to the horizon 415. The size of the image area may depend on the size of the image sensor and/or the desired aspect ratio of the image area.” (EX1005, [0044] (emphases added).) Thus, the reduced area 305 is the “viewing window for the visual content” determined based on the rotational information of the image capture device.

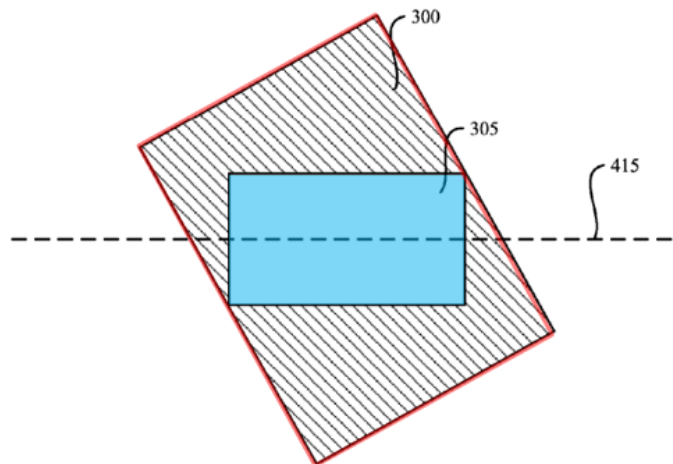


Figure 5A

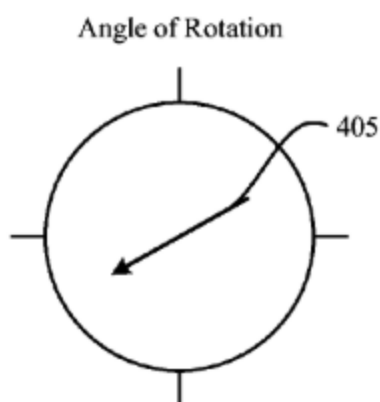


Figure 5B

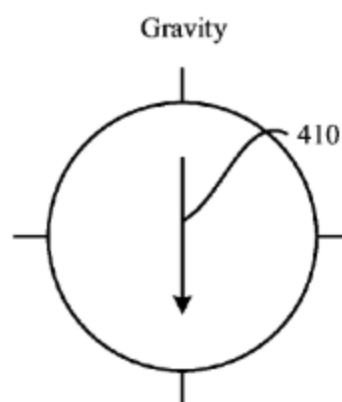


Figure 5C

88. Pacurariu further discloses that the viewing window is determined “as a function of progress through the progress length.” As shown in FIG. 7 below, “[a]t block 710, the *first frame* may be selected.” (EX1005, [0054] (emphasis added).) “At block 715 the tilt may be determined for the selected frame based on metadata. For example, if the metadata includes tilt angle data for each frame, then the tilt angle or rotation data may be retrieved.” (EX1005, [0055].) “At block 720 *the image area 305* defined by the tilt can be determined and then selected for the selected frame. For example, the pixels of the image corresponding to the image area 305 defined by the tilt may be cropped to exclude pixels outside of the image area 305 and/or the image area 305 may be rotated by the tilt.” (EX1005, [0056] (emphasis added).) “At block 730 it can be determined whether the last frame has been reached. If not, then the process 700 proceeds to block 725 where the next

frame in the video is selected.”¹ (EX1005, [0057].) Pacurariu further states, “After which, the process 700 proceeds to block 715 and *repeats until every frame has been operated on*. At block 730 the post processing may be complete.” (EX1005, [0057].) Thus, FIG. 7 shows that Pacurariu processes each video frame in a video based on a frame-specific tilt value.

¹ I believe this portion of Pacurariu contains a typo. The phrase “the process 700 proceeds to block **725** where the next frame in the video is selected” should read “the process 700 proceeds to block **735** where the next frame in the video is selected.” (EX1005, [0057] (emphases added).) This is evident from the label of block 735 (“Select the next frame in the video”) in FIG. 7. Further, in FIG. 7, the placements of “Yes” and “No” from block 730 should be swapped.

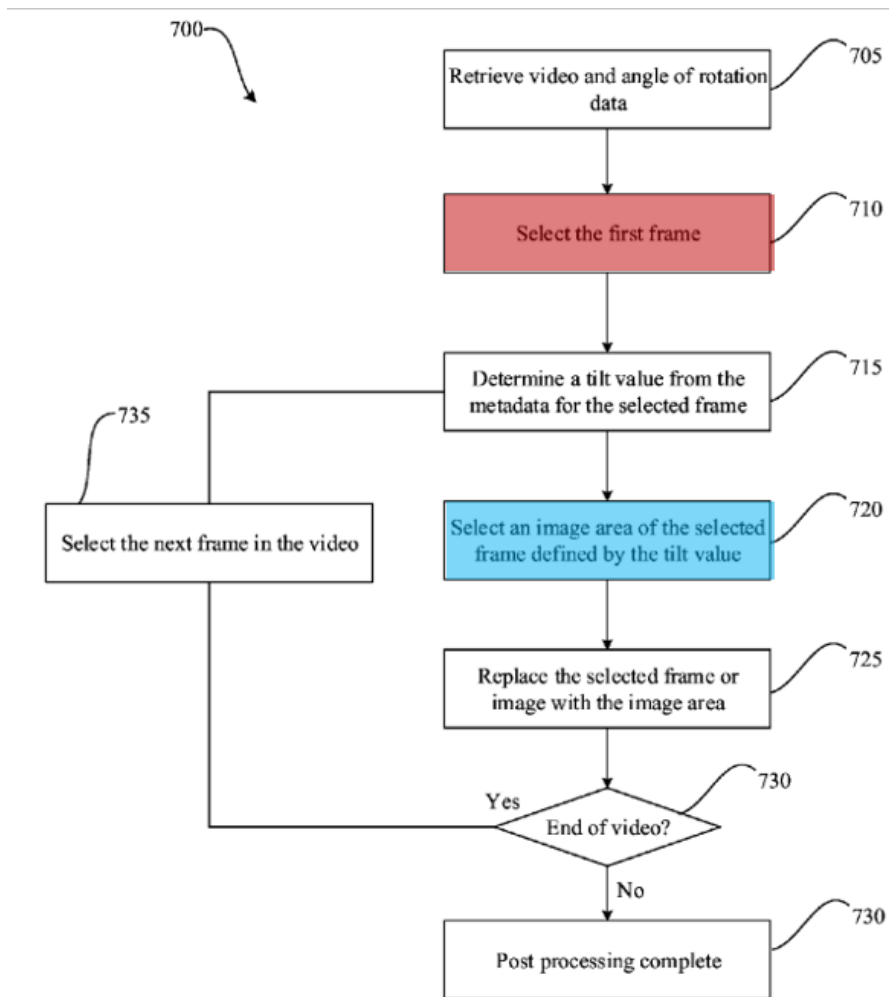


Figure 7

89. Pacurariu also discloses determining a viewing window for each video frame based on a frame-specific tilt value. (EX1005, [0057], FIG. 7.) In other words, Pacurariu can provide a playback of processed sequential frames of the video (with each processed frame defined by a viewing window). Thus, Thomason discloses “determine a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image

capture device as the function of progress through the capture duration.” It would have been obvious to a POSITA to combine the teachings of Thomason and Pacurariu. (*Supra* § X.A.3.g.)

90. Thomason discloses horizon-leveling either during post-processing or in real time. For example, Thomason states, “[c]onveniently, the stored image data can simply be the data output by the digital recording sensor and the angle measured by the rotation sensor, leaving correction to occur on playback.”

(EX1004, [0008].) Thomason also states that “[a] playback device 20 is provided that can accept memory 12 and process the recorded image data 8 and rotation angle in replay processor 22. The processed image data is played back on display device 24, for example a television set.” (EX1004, [0032].) This means that Thomason can store the original, uncorrected image data and then, during post-processing, generate the horizon-leveled visual content during post-processing.

91. Thomason also discloses horizon-leveling in real time. “Alternatively, the camera may include a correction module for correcting the image data captured by the camera based on the output of the digital recording sensor and storing the corrected image data in the memory.” (EX1004, [0009].) “In an alternative embodiment, the processor 16 may function as a correction module by taking the image captured by the sensor 6 and the angle of orientation of the camera 2 as output by rotation sensor 14, correcting the image data so that

the image is accurately horizontal and storing the corrected image in memory 12.” (EX1004, [0042].) This means that Thomason can directly generate and store the horizon-leveled visual content in real time.

92. Pacurariu also discloses horizon-leveling either during post-processing or in real time. “In some embodiments, the orientation data may be compared with the horizon and/or a gravity vector and used to mathematically rotate the recorded image area as the image is being sampled from the image sensor, as the image is being saved into memory, or during post processing.” (EX1005, [0026], [0041], [0046].)

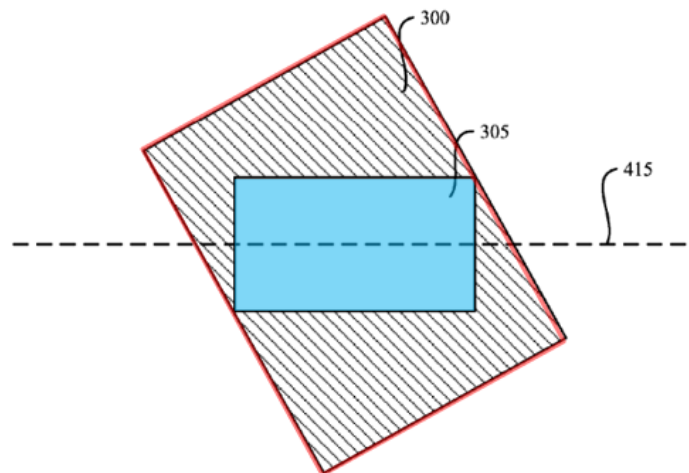


Figure 5A

- i. **1[d][ii]: “the viewing window defining extents of the visual content to be included within horizon-leveled visual content as the function of progress through the progress length,”**

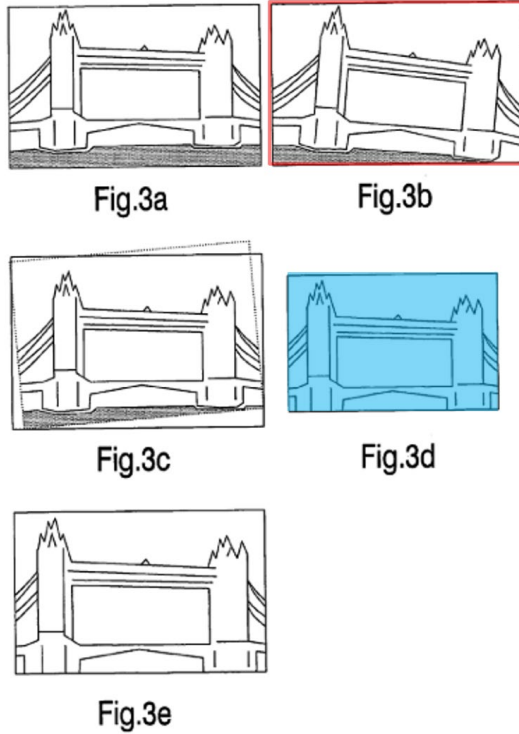
93. As shown for element 1[d][i], Thomason discloses multiple examples of viewing windows. (*Supra* § X.A.3.h.) “The stored data is based both on the image data and the output angle data to allow the captured image to be rotated for display to have the true horizontal displayed as horizontal.” (EX1004, Abstract.) FIG. 3d defines extents of the full captured raw image frame FIG. 3b to be included within horizon-leveled visual content. (*Supra* § X.A.3.h.) In FIG. 5, image frame 40 defines extents of captured circular image to be included within horizon-leveled visual content. (*Id.*) In FIG. 4, nominal image 40 defines extents of the recorded image area 50 to be included within horizon-leveled visual content. (*Id.*)

94. As shown for element 1[d][i], the viewing window is determined for the visual content as a function of progress through the progress length. (*Supra* § X.A.3.h.)

95. As shown for element 1[d][i], Pacurariu also discloses this limitation. (*Supra* § X.A.3.h.) It would have been obvious to a POSITA to combine the teachings of Thomason and Pacurariu. (*Supra* § X.A.3.g.)

- j. **1[d][iii]: “wherein determination of the viewing window includes determination of a placement of the viewing window within the field of view of the visual content as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration; and”**

96. Thomason discloses that “determination of the viewing window includes determination of a placement of the viewing window within the field of view of the visual content.” In FIG. 3, Thomason determines the placement of the viewing window FIG. 3d within the visual content of FIG. 3b. “**FIG. 3b** shows the image taken with a camera angle at an angle of about 10° to the vertical. The true horizontal in the image is thus also at an angle of 10 to the horizontal in the recorded image.” (EX1004, [0034] (emphasis added).) “On replay, *the processor 22 calculates the image on display 24 as shown in FIG. 3c, with a rotation correction applied using the camera item data angle by replay processor 22 so that true horizontals appear as horizontal. Some of the image frame of the rotation corrected image is blank, as may be seen.* Accordingly, the image is cropped to eliminate blank space as illustrated in **FIG. 3d**.” (EX1004, [0036] (emphases added).)



97. In FIG. 5, Thomason determines the placement of the viewing window 40 within the circular visual content. “In a further modification, the sensor array may be circular to enable arbitrary rotation to take place without any loss at the edges. FIG. 5 illustrates such a circular sensor 60 with nominal image frame 40. Rotation to any angle is possible without size reduction.” (EX1004, [0039].)

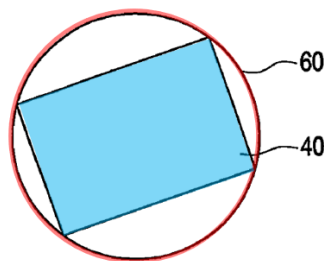
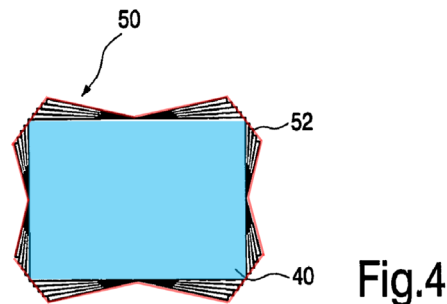


Fig.5

98. In FIG. 4, Thomason determines the placement of the viewing window 40 within the visual content 52. Specifically, “the recorded image area 50 is greater than that of the nominal image frame 40 in order that the image may be rotated without resizing.” (EX1004, [0038].)



99. The determination of placement of the viewing window is based on rotation data, specifically, “[t]he stored data is based both on the image data and the output angle data to allow the captured image to be rotated for display to have the true horizontal displayed as horizontal.” (EX1004, Abstract, FIG. 3.)

100. As shown for element 1[d][i], the viewing window is determined for the visual content as a function of progress through the progress length. (*Supra* § X.A.3.h.) Thus, the placement of the viewing window is also determined as the function of progress through the progress length.

101. As shown for element 1[d][i], Pacurariu also discloses this limitation. (*Supra* § X.A.3.h.) “FIG. 3 illustrates a **graphical representation of an image sensor array 300** and an **image area 305** of the image sensor array 300 that defines a number of image sensor elements within the image sensor array according to

some embodiments described herein. The *image area 305*, for example, may represent the portion of *the field of view* that the user would like recorded as an image or a video frame.” (EX1005, [0040] (emphases added).) The area 300 in FIG. 3 is “the field of view of the visual content.”

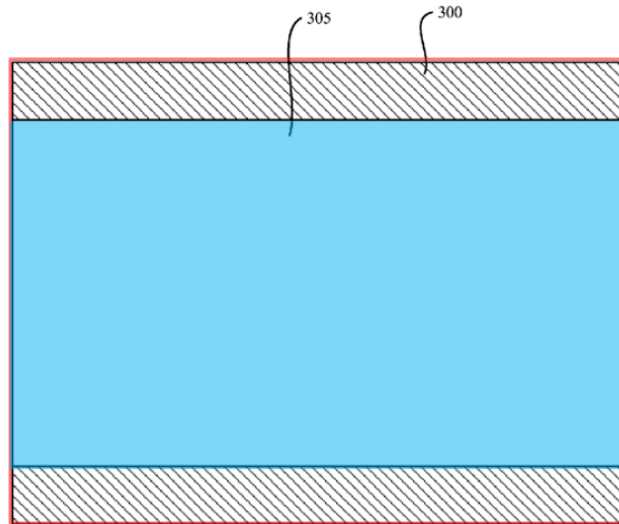


Figure 3

102. Pacurariu also discloses “determination of a placement of the viewing window within the field of view of the visual content.” “FIG. 5A illustrates a *graphical representation of the image sensor array 300* that is tilted relative to the gravitational vector 410 and relative to the horizon 415. A *reduced area of the image area 305* may be used to *compensate for any rotation*. In this example, the image sensor array 300 is tilted 60.8° relative to the gravitational field and 29.2° relative to the horizon 415. The size of the image area may depend on the size of

the image sensor and/or the desired aspect ratio of the image area.” (EX1005, [0044] (emphases added).) Thus, the image area 300 is the “field of view of the visual content” and the reduced area 305 is the “viewing window.”

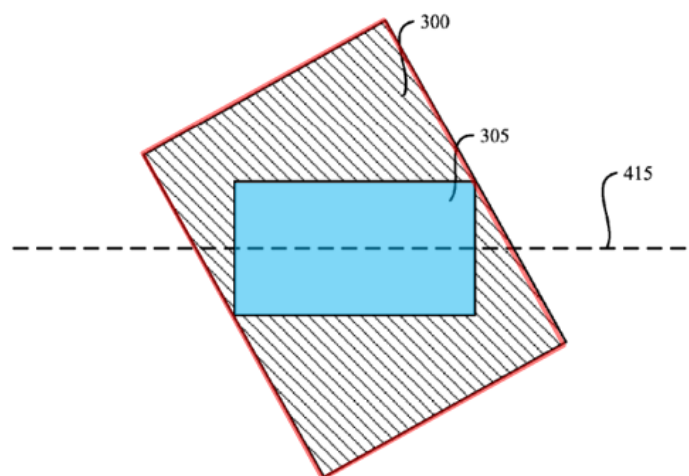


Figure 5A

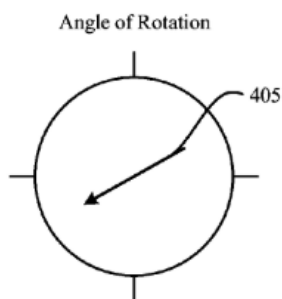


Figure 5B

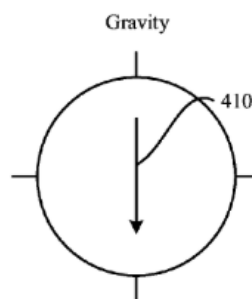


Figure 5C

103. As shown for element 1[d][i], the viewing window in Pacurariu is determined for the visual content as a function of progress through the progress length. (*Supra* § X.A.3.h.)

104. It would have been obvious to a POSITA to combine the teachings of Thomason and Pacurariu. (*Supra* § X.A.3.g.)

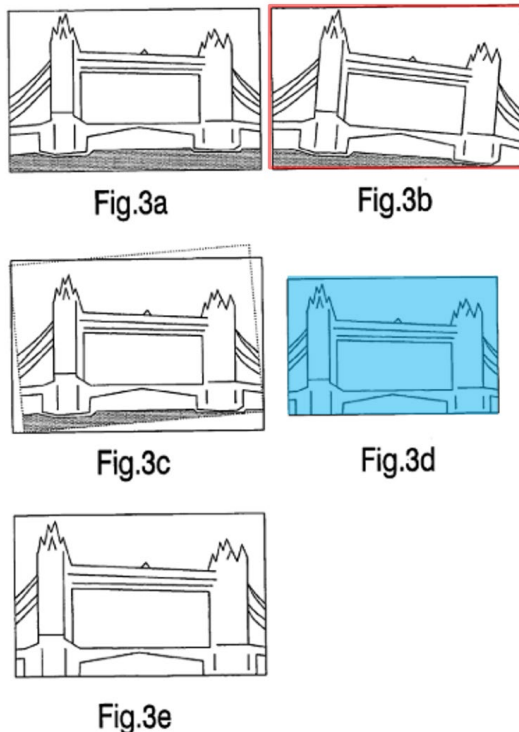
- k. **1[e][i]: “generate the horizon-leveled visual content based on the viewing window, the horizon-leveled visual content including a punchout of the extents of the visual content defined by the viewing window,”**

105. Thomason discloses “generate the horizon-leveled visual content.” In Thomason, “[a] playback device 20 is provided that can accept memory 12 and process the recorded image data 8 and rotation angle in replay processor 22.” (EX1004, [0032].) “[T]he processor 22 uses the recorded rotation angle information to cause an image to be displayed on display 24 that has the horizontal [displayed as] horizontal, even if the camera was slightly misaligned when the image was recorded.” (EX1004, [0033].)

106. As shown for elements 1[d][i]-1[d][iii], Thomason generates the horizon-leveled visual content based on the viewing window in multiple examples such as FIGS. 3-5. (*Supra* §§ X.A.3.h - X.A.3.j.)

107. According to the '832 patent, a “punchout of the visual content may refer to an output of one or more *portions* of the visual content for presentation (e.g., current presentation, future presentation based on video generated using the punchout).” (EX1001, 16:4-7 (emphasis added).)

108. In FIG. 3 of Thomason, the horizon-leveled visual content includes a punchout of the extents of the visual content defined by the viewing window as shown in FIG. 3d. “**FIG. 3b** shows the image taken with a camera angle at an angle of about 10° to the vertical. The true horizontal in the image is thus also at an angle of 10° to the horizontal in the recorded image.” (EX1004, [0034] (emphasis added).) “On replay, *the processor 22 calculates the image on display 24 as shown in FIG. 3c, with a rotation correction applied using the camera item data angle by replay processor 22 so that true horizontals appear as horizontal.* Some of the image frame of the rotation corrected image is blank, as may be seen. Accordingly, the image is cropped to eliminate blank space as illustrated in **FIG. 3d.**” (EX1004, [0036] (emphasis added).)



109. In FIG. 5, the horizon-leveled visual content includes a punchout of the extents of the visual content 60 defined by the viewing window 40. “In a further modification, the sensor array may be circular to enable arbitrary rotation to take place without any loss at the edges. FIG. 5 illustrates such a circular sensor 60 with nominal image frame 40. Rotation to any angle is possible without size reduction.” (EX1004, [0039].)

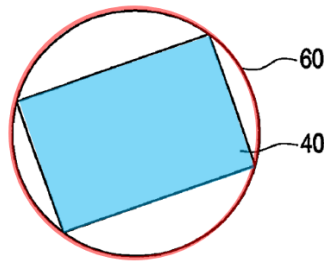


Fig.5

110. In FIG. 4, the horizon-leveled visual content includes a punchout of the extents of the visual content 52 defined by the viewing window 40. Specifically, “the recorded image area 50 is greater than that of the nominal image frame 40 in order that the image may be rotated without resizing.” (EX1004, [0038].)

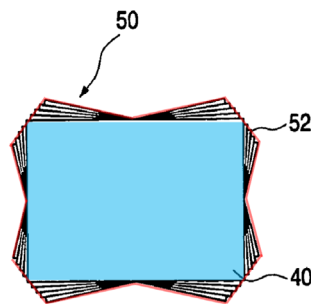


Fig.4

111. As shown for element 1[d][i], Pacurariu also discloses this limitation.

112. It would have been obvious to a POSITA to combine the teachings of Thomason and Pacurariu. (*Supra* § X.A.3.g.)

- I. **1[e][ii]: “wherein inclusion of the extents of the visual content defined by the viewing window within the horizon-leveled visual content effectuates horizon leveling of the visual content.”**

113. In FIGS. 3-5 of Thomason, the inclusion of the visual content as defined by the viewing window effectuates horizon leveling of the visual content. (*Supra* §§ X.A.3.h - X.A.3.j.) “In this way, the image data can be used to output a corrected image with the horizontal of the scene captured by the camera displayed horizontally even if the camera is not exactly aligned.” (EX1004, [0005].)

114. As shown for element 1[d][i], Pacurariu also discloses this limitation. (*Supra* § X.A.3.h.)

115. It would have been obvious to a POSITA to combine the teachings of Thomason and Pacurariu. (*Supra* § X.A.3.g.)

4. **Claim 2: “The system of claim 1, wherein the viewing window has a one-by-one aspect ratio, the one-by-one aspect ratio reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.”**

116. In Thomason, “FIG. 7 illustrates a frame aspect ratio of 1:1 in a circular image frame.” (EX1004, [0026].) A one-by-one aspect ratio, also known as square aspect ratio, indicates that the width equals to the height. The square viewing window in FIG. 7 below shows this.

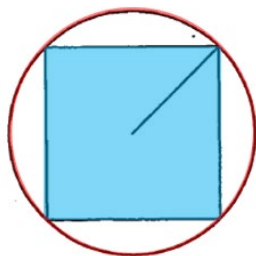


Fig.7

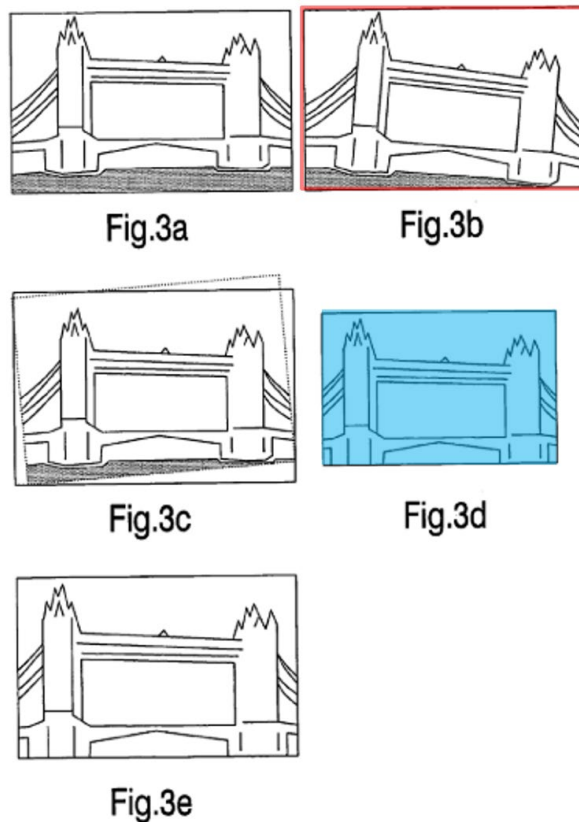
117. The one-by-one aspect ratio can reduce impact of an off-axis horizon depicted within the horizon-leveled visual content. A POSITA would have understood that, if the viewing window's width is longer than the height, a titled horizon can appear longer and more prominent. In contrast, if the viewing window's width equals the height, the tilted horizon can appear shorter and less noticeable.

5. **Claim 7: "The system of claim 1, wherein the determination of the viewing window further includes determination of a size of the viewing window as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration."**

118. Thomason determines that "the determination of the viewing window further includes determination of a size of the viewing window." As shown in FIG. 3b-d below, "[o]n replay, the processor 22 calculates the image on display 24 as shown in FIG. 3c, with a rotation correction applied using the camera item data angle by replay processor 22 so that true horizontals appear as horizontal. Some of the image frame of the rotation corrected image is blank, as may be seen.

Accordingly, *the image is cropped to eliminate blank space as illustrated in FIG.*

3d.” (EX1004, [0036] (emphasis added).) Thus, Thomason determines the size of the viewing window FIG. 3d to be smaller than the captured image FIG. 3b.



119. Thomason also discloses that determination of a size of the viewing window is “based on the rotational positions of the image capture device as the function of progress through the capture duration.” As shown in FIG. 3b-d above, “[o]n replay, the processor 22 calculates the image on display 24 as shown in FIG. 3c, with a *rotation correction applied using the camera item data angle by replay processor 22 so that true horizontals appear as horizontal*. Some of the image frame of the rotation corrected image is blank, as may be seen. Accordingly, *the image is cropped to eliminate blank space as illustrated in FIG. 3d.*” (EX1004,

[0036] (emphases added).) A POSITA would have understood that, based on the degree of rotation, more or less of the image would need to be cropped to obtain the viewing window showing horizon-leveled visual content. For example, FIG. 3b is taken with a camera angle at an angle of about 10° to the vertical, but if it is taken with a camera angle at an angle of about 20° to the vertical, more of the image may need to be cropped to obtain the viewing window showing horizon-leveled visual content, resulting in a viewing window having a smaller size.

120. In other words, in Thomason, the size of the viewing window is determined based on the rotational position of the camera – a more tilted camera angle may result in a smaller viewing window because there is less visual content in the image that can be horizon-leveled.

121. For each image in the video, the size of the viewing window is determined based on the corresponding rotational position of the camera. Thomason discloses “a rotation sensor for providing an output representing *the angle of the captured image* to the horizontal to an accuracy of 5° or better; and a data carrier for recording data based on *both image data representing the captured image and angle data representing the angle measured by the rotation sensor* so that a rotated image corrected to have the true horizontal in the captured image displayed as horizontal can be displayed from the data recorded on the data carrier.” (EX1004, [0004] (emphases added).) As a specific example, Thomason

discloses that “[t]he image as shown in FIG. 3b is recorded in the memory *together with the data item that records the camera angle.*” (EX1004, [0035] (emphasis added).)

122. Thomason discloses “determination of a size of the viewing window as the function of progress through the progress length.” The viewing window in Thomason is determined as a function of progress through the progress length as shown in element 1[d][i]. (*Supra* § X.A.3.h.) A POSITA would have understood that, because the determination of the viewing window includes determination of its size, so the size of the viewing window is also determined as the function of progress through the progress length.

6. Claim 8: “The system of claim 7, wherein the size of the viewing window changes as the function of progress through the progress length to simulate changes in zoom for the visual content.”

123. As shown in claim 7, the size of the viewing window changes as the rotational position of the camera changes and is determined as the function of progress through the progress length. (*Supra* § X.A.5.)

124. A POSITA would understand that a smaller viewing window can make the object in the viewing window appear more zoomed-in. With reference to FIG. 3 below, Thomason discloses that FIG. 3d is resized to FIG. 3e, specifically, “the corrected image 42 is resized so that the final image frame 44 is the same size as original image frame 40.” (EX1004, [0037].) Comparing to FIG. 3a (“the

image that the user should have taken i.e., [] with the camera horizontally aligned”), the scene in FIG. 3e appears more zoomed-in because the objects appear larger. (EX1004, [0034].) In other words, if the camera is tilted, the scene in the viewing window (e.g., FIGS. 3d and 3e) would appear to be more zoomed-in than if the camera is not titled (e.g., FIG. 3a). Thus, the changing size of the viewing window (i.e., FIG. 3d) can simulate changes in zoom for the visual content.

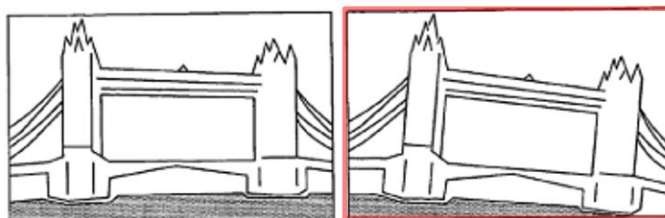


Fig.3a

Fig.3b

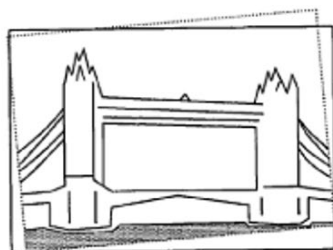


Fig.3c



Fig.3d



Fig.3e

7. **Claim 9: “The system of claim 1, wherein the determination of the placement of the viewing window within the field of view of the visual content includes**

**determination of a rotation of the viewing window
within the field of view of the visual content.”**

125. Thomason discloses that the determination of the placement of the viewing window “includes determination of a rotation of the viewing window within the field of view of the visual content.” In FIG. 4, “the recorded image area 50 is greater than that of the nominal image frame 40 in order that *the image may be rotated* without resizing.” (EX1004, [0038] (emphasis added).) Similarly, “FIG. 5 illustrates such a circular sensor 60 with nominal image frame 40.” *Rotation to any angle is possible* without size reduction.” (EX1004, [0039] (emphasis added).) Thus, depending on the rotation of the camera, the rotation of the viewing window 40 is determined to compensate for the rotation of the camera to obtain horizon-leveled visual content. Thus, Thomason’s determination of the placement of the viewing window (i.e., image frame 40) includes determination of a rotation of the viewing window (i.e., image frame 40) within the field of view of the visual content.

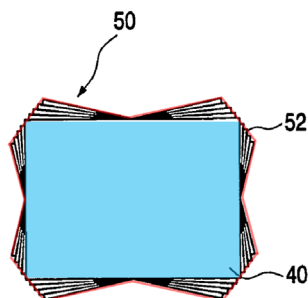


Fig.4

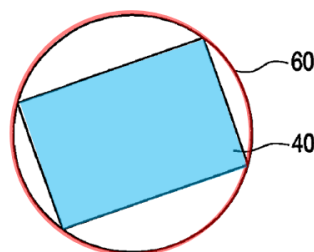


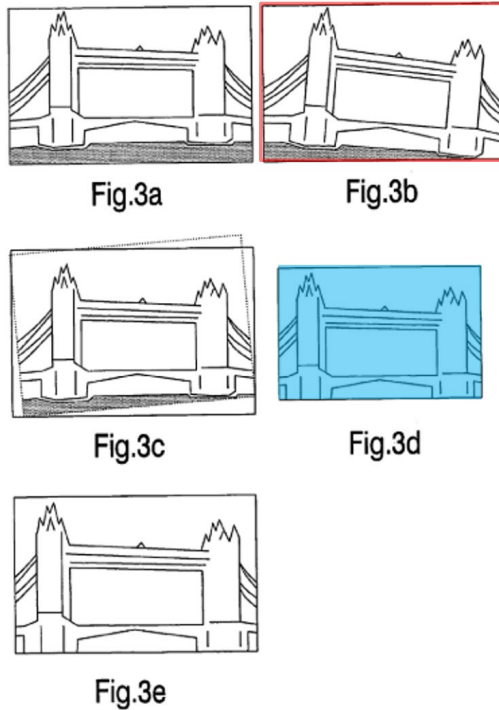
Fig.5

126. FIG. 3 provides yet another example. “On replay, the processor 22 calculates the image on display 24 as shown in FIG. 3c, *with a rotation correction*

applied using the camera item data angle by replay processor 22 so that true horizontals appear as horizontal.” (EX1004, [0036] (emphasis added).)

8. **Claim 10: “The system of claim 1, wherein the determination of the placement of the viewing window within the field of view of the visual content includes determination of a location of the viewing window within the field of view of the visual content, the location of the viewing window within the field of view of the visual content determining framing of the visual content.”**

127. Thomason discloses “determination of a location of the viewing window within the field of view of the visual content.” In Thomason, the location of the viewing window is determined within the recorded image data. With reference to FIG. 3, Thomason discloses “[t]he image as shown in **FIG. 3b** is recorded in the memory together with the data item that records the camera angle,” “the processor 22 calculates the image on display 24 as shown in FIG. 3c, with a rotation correction applied using the camera item data angle by replay processor 22 so that true horizontals appear as horizontal. Some of the image frame of the rotation corrected image is blank, as may be seen. Accordingly, the image is cropped to eliminate blank space as illustrated in **FIG. 3d**.” (EX1004, [0035] - [0036] (emphases added).) Thus, the location of FIG. 3d is determined within FIG. 3b. As shown in FIGS. 3b and 3d, the location of the viewing window (i.e., the portion of FIG. 3d that corresponds to FIG. 3b) determines the framing of the visual content.



128. Also, in FIGS. 4-5, the location of *image 40* is determined within the *recorded image area*. (EX1004, [0038]-[0039].)

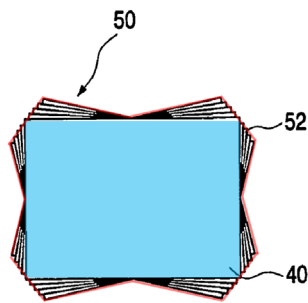


Fig.4

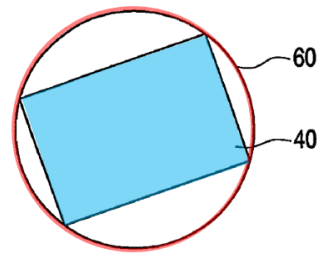


Fig.5

129. Thomason discloses “the location of the viewing window within the field of view of the visual content determining framing of the visual content.” The location of the viewing window in Thomason dictates the framing of the visual content to be displayed. As shown in the examples above, the location of the viewing window determines the framing of the visual content.

130. Pacurariu also discloses this limitation. “FIG. 5A illustrates a *graphical representation of the image sensor array 300* that is tilted relative to the gravitational vector 410 and relative to the horizon 415. A *reduced area of the image area 305* may be used to *compensate for any rotation.*” (EX1005, [0044] (emphases added).) Thus, the location of *image area 305* is determined within the *recorded image area 300* and the location of the viewing window determines the framing of the visual content.

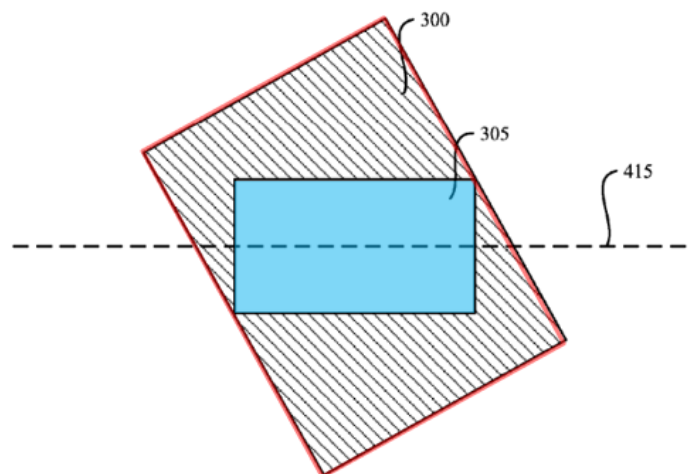


Figure 5A

131. It would have been obvious to a POSITA to combine the teachings of Thomason and Pacurariu. (*Supra* § X.A.3.g.)

9. Claim 11

- a. **Preamble: “A method for horizon leveling videos, the method performed by a computing system including one or more processors, the method comprising:”**

132. Thomason discloses “a *method* of processing image information[.]” (EX1004, [0017] (emphasis added), claim 10.) “A rotation sensor (14) measures the angle of orientation of the camera[.] The stored data is based both on the image data and the output angle data to allow the captured image to be rotated for display to have the true horizontal displayed as horizontal.” (EX1004, Abstract.)

133. Thomason further discloses “the method performed by a computing system including one or more processors.” (*Supra* § X.A.3.b.)

b. 11[a][i]: “obtaining, by the computing system, video information defining a video,”

134. Element 11[a][i] mirrors element 1[b][i], which Thomason-Pacurariu renders obvious. (*Supra* § X.A.3.c.) The table below shows the similarities.

Element 1[b][i]	Element 11[a][i]
obtain video information defining a video,	obtaining, by the computing system, video information defining a video,

c. 11[a][ii]: “the video including video content captured by an image capture device during a capture duration,”

135. Element 11[a][ii] mirrors element 1[b][ii], which Thomason-Pacurariu renders obvious. (*Supra* § X.A.3.d.) The table below shows the similarities.

Element 1[b][ii]	Element 11[a][ii]
the video including video content captured by an image capture device during a capture duration,	the video including video content captured by an image capture device during a capture duration,

d. 11[a][iii]: “the video content having a progress length, the video content including visual

content captured at different moments within the capture duration,”

136. Element 11[a][iii] mirrors element 1[b][iii], which Thomason-Pacurariu renders obvious. (*Supra* § X.A.3.e.) The table below shows the similarities.

Element 1[b][iii]	Element 11[a][iii]
the video content having a progress length, the video content including visual content captured at different moments within the capture duration,	the video content having a progress length, the video content including visual content captured at different moments within the capture duration,

- e. **11[a][iv]: “the visual content viewable as a function of progress through the progress length, the visual content having a field of view;”**

137. Element 11[a][iv] mirrors element 1[b][iv], which Thomason-Pacurariu renders obvious. (*Supra* § X.A.3.f.) The table below shows the similarities.

Element 1[b][iv]	Element 11[a][iv]
the visual content viewable as a function of progress through the progress length, the visual content having a field of view;	the visual content viewable as a function of progress through the progress length, the visual content having a field of view;

- f. **11[b]: “obtaining, by the computing system, rotational position information for the video, the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration;”**

138. Element 11[b] mirrors element 1[c], which Thomason-Pacurariu renders obvious. (*Supra* § X.A.3.g.) The table below shows the similarities.

Element 1[c]	Element 11[b]
obtain rotational position information for the video, the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration;	obtaining, by the computing system, rotational position information for the video, the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration;

- g. **11[c][i]: “determining, by the computing system, a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration,”**

139. Element 11[c][i] mirrors element 1[d][i], which Thomason-Pacurariu renders obvious. (*Supra* § X.A.3.h.) The table below shows the similarities.

Element 1[d][i]	Element 11[c][i]
determine a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration,	determining, by the computing system, a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration,

- h. **11[c][ii]: “the viewing window defining extents of the visual content to be included within horizon-leveled visual content as the function of progress through the progress length,”**

140. Element 11[c][ii] mirrors element 1[d][ii], which Thomason-Pacurariu renders obvious. (*Supra* § X.A.3.i.) The table below shows the similarities.

Element 1[d][ii]	Element 11[c][ii]
the viewing window defining extents of the visual content to be included within horizon-leveled visual content as the function of progress through the progress length,	the viewing window defining extents of the visual content to be included within horizon-leveled visual content as the function of progress through the progress length,

- i. **11[c][iii]: “wherein determining the viewing window includes determining a placement of the viewing window within the field of view of the visual content as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration; and”**

141. Element 11[c][iii] mirrors element 1[d][iii], which Thomason-Pacurariu renders obvious. (*Supra* § X.A.3.j.) The table below shows the similarities.

Element 1[d][iii]	Element 11[c][iii]
wherein determination of the viewing window includes determination of a placement of the viewing window within the field of view of the visual content as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration; and	wherein determining the viewing window includes determining a placement of the viewing window within the field of view of the visual content as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration; and

- j. **1[d][i]: “generating, by the computing system, the horizon-leveled visual content based on the viewing window, the horizon-leveled visual content including a punchout of the extents of the visual content defined by the viewing window,”**

142. Element 11[d][i] mirrors element 1[e][i], which Thomason-Pacurariu renders obvious. (*Supra* § X.A.3.k.) The table below shows the similarities.

Element 1[e][i]	Element 11[d][i]
generate the horizon-leveled visual content based on the viewing window, the horizon-leveled visual content including a punchout of the extents of the visual content defined by the viewing window,	generating, by the computing system, the horizon-leveled visual content based on the viewing window, the horizon-leveled visual content including a punchout of the extents of the visual content defined by the viewing window,

- k. **1[d][ii]: “wherein inclusion of the extents of the visual content defined by the viewing window within the horizon-leveled visual content effectuates horizon leveling of the visual content.”**

143. Element 11[d][ii] mirrors element 1[e][ii], which Thomason-Pacurariu renders obvious. (*Supra* § X.A.3.l.) The table below shows the similarities.

Element 1[e][ii]	Element 11[d][ii]
wherein inclusion of the extents of the visual content defined by the viewing window within the horizon-leveled visual content effectuates horizon leveling of the visual content.	wherein inclusion of the extents of the visual content defined by the viewing window within the horizon-leveled visual content effectuates horizon leveling of the visual content.

10. **Claim 12: “The method of claim 11, wherein the viewing window has a one-by-one aspect ratio, the one-by-one aspect ratio reducing impact of an off-axis**

horizon depicted within the horizon-leveled visual content.”

144. Claim 12 mirrors claim 2, which Thomason-Pacurariu renders obvious. (*Supra* § X.A.4.) The table below shows the similarities.

Claim 2	Claim 12
The system of claim 1, wherein the viewing window has a one-by-one aspect ratio, the one-by-one aspect ratio reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.	The method of claim 11, wherein the viewing window has a one-by-one aspect ratio, the one-by-one aspect ratio reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.

- 11. Claim 17: “The method of claim 11, wherein determining the viewing window further includes determining a size of the viewing window as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration.”**

145. Claim 17 mirrors claim 7, which Thomason-Pacurariu renders obvious. (*Supra* § X.A.5.) The table below shows the similarities.

Claim 7	Claim 17
The system of claim 1, wherein the determination of the viewing window further includes determination of a size of the viewing window as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration.	The method of claim 11, wherein determining the viewing window further includes determining a size of the viewing window as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration.

- 12. Claim 18: “The method of claim 17, wherein the size of the viewing window changes as the function of**

progress through the progress length to simulate changes in zoom for the visual content.”

146. Claim 18 mirrors claim 8, which Thomason-Pacurariu renders obvious. (*Supra* § X.A.6.) The table below shows the similarities.

Claim 8	Claim 18
The system of claim 7, wherein the size of the viewing window changes as the function of progress through the progress length to simulate changes in zoom for the visual content.	The method of claim 17, wherein the size of the viewing window changes as the function of progress through the progress length to simulate changes in zoom for the visual content.

13. Claim 19: “The method of claim 11, wherein determining the placement of the viewing window within the field of view of the visual content includes determining a rotation of the viewing window within the field of view of the visual content.”

147. Claim 19 mirrors claim 9, which Thomason-Pacurariu renders obvious. (*Supra* § X.A.7.) The table below shows the similarities.

Claim 9	Claim 19
The system of claim 1, wherein the determination of the placement of the viewing window within the field of view of the visual content includes determination of a rotation of the viewing window within the field of view of the visual content.	The method of claim 11, wherein determining the placement of the viewing window within the field of view of the visual content includes determining a rotation of the viewing window within the field of view of the visual content.

14. Claim 20: “The method of claim 11, wherein the determining the placement of the viewing window within the field of view of the visual content includes determining a location of the viewing window within the field of view of the visual content, the location of the viewing window within the field of view of the

visual content determining framing of the visual content.”

148. Claim 20 mirrors claim 10, which Thomason-Pacurariu renders obvious. (*Supra* § X.A.8.) The table below shows the similarities.

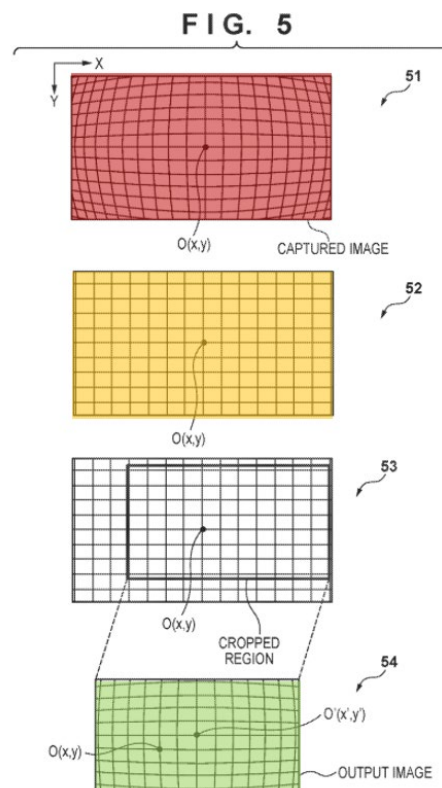
Claim 10	Claim 20
The system of claim 1, wherein the determination of the placement of the viewing window within the field of view of the visual content includes determination of a location of the viewing window within the field of view of the visual content, the location of the viewing window within the field of view of the visual content determining framing of the visual content.	The method of claim 11, wherein the determining the placement of the viewing window within the field of view of the visual content includes determining a location of the viewing window within the field of view of the visual content, the location of the viewing window within the field of view of the visual content determining framing of the visual content.

B. Ground 2: Thomason and Watanabe Render Obvious Claims 3-6 and 13-16

1. Summary of Watanabe

149. Watanabe provides “an image processing apparatus that generates a natural-looking image even from an image in which image shake has been corrected and distortion has been intentionally added.” (EX1006, Abstract.) Watanabe states that “[t]he present invention provides an image processing apparatus and an image processing method that make it possible to suppress the issue of such conventional technology, and generate a moving image that appears natural after image shake correction.” (EX1006, 1:44-48.)

150. With reference to FIG. 5, Watanabe states “**51** schematically shows distortion of an image captured by the image sensor 103 and stored in the image memory 105. Here, barrel distortion that is centered on image coordinates (x,y) corresponding to the intersection between an optical axis O and the image sensor (which is assumed here to match the center coordinates of the image) has occurred caused by aberration of the photographing lens 102.” (EX1006, 11:7-14 (emphasis added).) Watanabe further states “[d]ue to distortion correction performed by the distortion correction circuit 106, image distortion shown in 51 of FIG. 5 is corrected (removed) (**52**, FIG. 5).” (EX1006, 11:21-23 (emphasis added).)



151. With reference to FIG. 5, Watanabe further discloses:

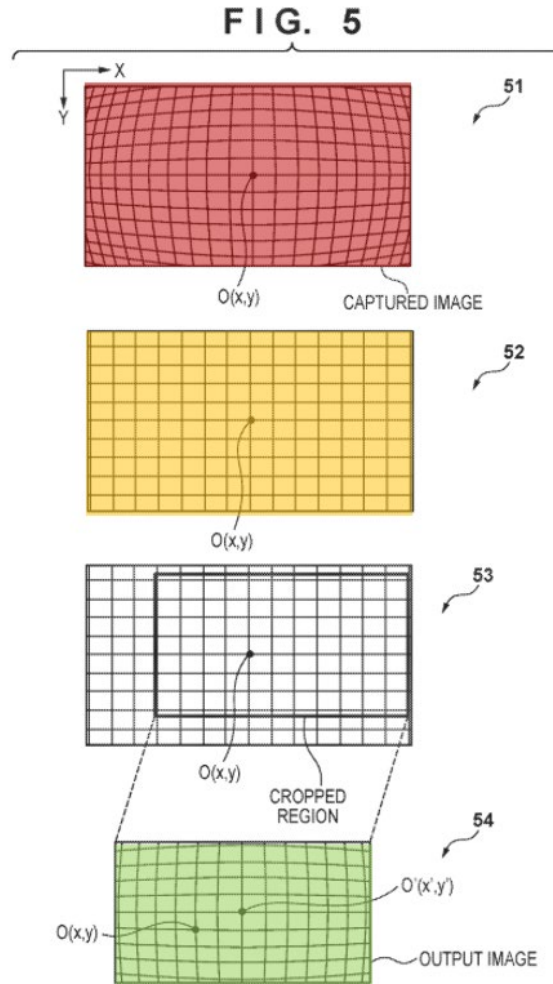
“The image shake correction circuit 107 performs image shake correction on the image in 52 of FIG. 5 in which distortion has been corrected. The image shake correction circuit 107 determines a cropping region so as to eliminate image shake resulting from shake of the video camera 100, based on an image shake correction amount calculated by the image shake correction amount calculation circuit 203. The image shake correction circuit 107 outputs the image of the determined cropping region as an image subjected to image shake correction. Unless the image shake correction amount is 0, the image coordinates (x,y) and the center coordinates of the image subjected to image shake correction (cropping region) do not match (53, FIG. 5).

The distortion addition circuit 108 adds a distortion effect to the image subjected to image shake correction (54, FIG. 5). . . . As a result, it is possible to add a point symmetric distortion effect in which the degree of distortion that is added to pixels equally distanced from the center of the image subjected to image shake correction is equal as shown in 54 of FIG. 5. Therefore, a distortion rate in a peripheral portion of a moving image ceases to change over time, and it is possible to generate a moving image that does not appear unnatural when observed.”

(EX1006, 11:24-54 (emphases added).)

2. **Claim 3: “The system of claim 1, wherein the visual content includes a distortion such that a straight line within a scene depicted within the visual content appears as a curved line, the distortion of the visual content reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.”**

152. Watanabe discloses “the visual content includes a distortion such that a straight line within a scene depicted within the visual content appears as a curved line.” As a first example, “**51 schematically shows distortion** of an image captured by the image sensor 103 and stored in the image memory 105.” (EX1006, 11:7-9 (emphasis added).) Further, FIG. 5 depicts a process in which “image **distortion shown in 51 of FIG. 5 is corrected** (removed) (52, FIG. 5),” “[t]he image shake correction circuit 107 performs image shake correction on the image in 52,” and “[t]he **distortion addition circuit 108 adds a distortion** effect to the image subjected to image shake correction (54, FIG. 5).” (EX1006, 11:22-25, 37-39 (emphases added).) Thus, both images 51 and 54 include distortions. As shown in distorted images 51 and 54, various straight lines within a scene appear as curved lines due to the distortions.



153. A POSITA would have understood that the distortion of the visual content can reduce impact of an off-axis horizon depicted within the horizon-leveled visual content. An off-axis horizon may be less noticeable in a distorted image than in a non-distorted image, for example, because the curvature can make the tilting of the horizon appear less noticeable.

154. It would have been obvious to a POSITA to combine the teachings of Thomason, Pacurariu, and Watanabe. Thomason, Pacurariu, and Watanabe all relate to correcting video data based on motion of the image capture device.

Thomason's systems "allow the captured image to be rotated for display to have the true horizontal displayed as horizontal." (EX1004, Abstract.) Pacurariu also discloses "[s]ystems and methods . . . to rotate an image recorded by an image sensor to compensate for angular rotation or tilt of the image sensor." (EX1005, Abstract.) Similarly, Watanabe's "image shake correction circuit 107 crops and reads out, from the image memory 105, an image . . . and changes the cropping position of the image so as to offset shake of the video camera 100." (EX1006, 5:22-26.) Thus, Thomason, Pacurariu, and Watanabe are from the same field of endeavor and reasonably pertinent to the same technical problems of improving video content.

155. Watanabe teaches additional image processing techniques, first correcting distortion before performing image shake correction, and then intentionally adding distortion after performing image shake correction to "generate a moving image that *appears natural after image shake correction*". (EX1006, 1:47-48 (emphasis added).) These technical features can be combined with the teachings of Thomason and Pacurariu to generate horizon-leveled video content that also appears more natural looking, with a reasonable expectation of success.

156. Specifically, the Thomason-Pacurariu-Watanabe combination results in a system that can achieve horizon-leveling of visual content while incorporating

the advantage of Watanabe to “generate a moving image that *appears natural after image shake correction*”. (EX1006, 1:47-48 (emphasis added).) For example, the Thomason-Pacurariu-Watanabe combination can remove image distortions from a captured image (e.g., caused by characteristics of the image sensor) as taught by Watanabe, obtain horizon-leveled visual content as taught by Thomason and Pacurariu, and intentionally add certain distortions such that the resulting image appear more natural looking as taught by Watanabe.

157. The technical features of removing undesirable distortions and adding desirable distortions improves the video quality produced by the Thomason-Pacurariu combination, yielding the predictable result of making the video content appear more natural looking. Because Thomason, Pacurariu, and Watanabe all relate to image correction, a POSITA would be motivated to use the known techniques of Watanabe to improve similar devices of Thomason and Pacurariu in the same way. Further, it would have been obvious to try combining the teachings of Thomason, Pacurariu, and Watanabe. Prior art such as Watanabe has successfully demonstrated that distortion removal and addition can be implemented to achieve better video quality and thus, there would have been a reasonable expectation of success for combining Thomason, Pacurariu, and Watanabe. Thus, it would have been obvious to a POSITA to combine the additional imaging processing techniques of Watanabe with the teachings of Thomason and Pacurariu

to obtain a more natural-looking video for display. The known benefits of Watanabe would prompt the application of Watanabe in the same field based on design incentives and other market forces.

3. Claim 4: “The system of claim 3, wherein the distortion includes a barrel distortion or a pincushion distortion.”

158. Watanabe discloses “the distortion includes a barrel distortion or a pincushion distortion.” Watanabe further discloses “it is known that image distortion caused by aberration can be classified into *barrel distortion* and *pincushion distortion*[.]” (EX1006, 1:16-18 (emphases added).) Watanabe discloses image 51 in FIG. 5 includes “barrel distortion.” “Here, *barrel distortion* that is centered on image coordinates (x,y) corresponding to the intersection between an optical axis O and the image sensor (which is assumed here to match the center coordinates of the image) has occurred caused by aberration of the photographing lens 102.” (EX1006, 11:9-14 (emphasis added).) Image 54 in FIG. 5 also includes barrel distortion “to generate a moving image that does not appear unnatural when observed”. (EX1006, 11:53-54.) Watanabe discloses that “barrel distortion appears more natural.” (EX1006, 1:18-19.)

159. It would have been obvious to a POSITA to combine the teachings of Thomason, Pacurariu, and Watanabe. (*Supra* § X.B.2.)

4. Claim 5: “The system of claim 3, wherein the visual content includes the distortion based on capture of the

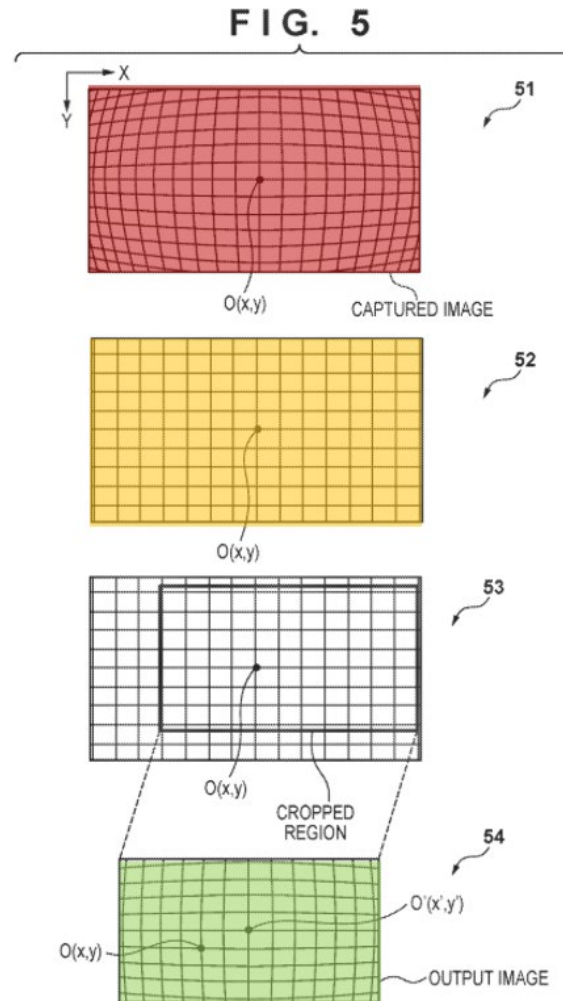
visual content through a wide field of view optical element.”

160. Watanabe discloses “the visual content includes the distortion based on capture of the visual content through a wide field of view optical element.” Watanabe discloses “an image shot using a (super) *wide-angle lens such as a fisheye lens* is recognized to have distortion caused by aberration as one feature.” (EX1006, 9:33-35 (emphasis added).) Further, “[a] *wide conversion lens* enables wider angle shooting than the photographing lens 102, but causes more intense barrel distortion.” (EX1006, 16:20-22 (emphasis added).) A POSITA would have understood that Watanabe’s “wide-angle lens” and “wide conversion lens” are examples of “wide field of view optical element.” It would have been obvious to a POSITA to combine the teachings of Thomason, Pacurariu, and Watanabe. (*Supra* § X.B.2.)

5. Claim 6: “The system of claim 3, wherein the visual content includes the distortion based on application of the distortion to non-distorted visual content, the distortion applied to the non-distorted visual content based on the visual content including the non-distorted visual content.”

161. Watanabe discloses “the visual content includes the distortion based on application of the distortion to non-distorted visual content.” FIG. 5 depicts a process in which “image *distortion shown in 51 of FIG. 5 is corrected* (removed) (52, FIG. 5),” “[t]he image shake correction circuit 107 performs image shake

correction on the image in 52,” and “[t]he distortion addition circuit 108 adds a *distortion* effect to the image subjected to image shake correction (54, FIG. 5).” (EX1006, 11:22-25 (emphasis added), 11:37-39 (emphasis added).) Thus, the *image 52* is the “non-distorted visual content” to which a distortion is applied.



162. It would have been obvious to a POSITA to combine the teachings of Thomason, Pacurariu, and Watanabe. (*Supra* § X.B.2.)

6. **Claim 13:** “The method of claim 11, wherein the visual content includes a distortion such that a straight line within a scene depicted within the visual

content appears as a curved line, the distortion of the visual content reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.”

163. Claim 13 mirrors claim 3, which Thomason-Pacurariu-Watanabe renders obvious. (*Supra* § X.B.2.) The table below shows the similarities.

Claim 3	Claim 13
The system of claim 1, wherein the visual content includes a distortion such that a straight line within a scene depicted within the visual content appears as a curved line, the distortion of the visual content reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.	The method of claim 11, wherein the visual content includes a distortion such that a straight line within a scene depicted within the visual content appears as a curved line, the distortion of the visual content reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.

7. Claim 14: “The method of claim 13, wherein the distortion includes a barrel distortion or a pincushion distortion.”

164. Claim 14 mirrors claim 4, which Thomason-Pacurariu-Watanabe renders obvious. (*Supra* § X.B.3.) The table below shows the similarities.

Claim 4	Claim 14
The system of claim 3, wherein the distortion includes a barrel distortion or a pincushion distortion.	The method of claim 13, wherein the distortion includes a barrel distortion or a pincushion distortion.

8. Claim 15: “The method of claim 13, wherein the visual content includes the distortion based on capture of the visual content through a wide field of view optical element.”

165. Claim 15 mirrors claim 5 which Thomason-Pacurariu-Watanabe renders obvious. (*Supra* § X.B.4.) The table below shows the similarities.

Claim 5	Claim 15
The system of claim 3, wherein the visual content includes the distortion based on capture of the visual content through a wide field of view optical element.	The method of claim 13, wherein the visual content includes the distortion based on capture of the visual content through a wide field of view optical element.

9. **Claim 16: “The method of claim 13, wherein the visual content includes the distortion based on application of the distortion to non-distorted visual content, the distortion applied to the non-distorted visual content based on the visual content including the non-distorted visual content.”**

166. Claim 16 mirrors claim 6, which Thomason-Pacurariu-Watanabe renders obvious. (*Supra* § X.B.5.) The table below shows the similarities.

Claim 6	Claim 16
The system of claim 3, wherein the visual content includes the distortion based on application of the distortion to non-distorted visual content, the distortion applied to the non-distorted visual content based on the visual content including the non-distorted visual content.	The method of claim 13, wherein the visual content includes the distortion based on application of the distortion to non-distorted visual content, the distortion applied to the non-distorted visual content based on the visual content including the non-distorted visual content.

C. Ground 3: Voss and Derbanne Render Obvious Claims 1, 2, 7-12, 17-20

1. Summary of Voss

167. Voss discloses a system that “dynamically maintain[s] a horizontal framing of a video.” (EX1007, Abstract). Voss states that “many videos on mobile devices are recorded in a manner where the user may inadvertently rotate the mobile device, thereby tilting the video horizon the vertical orientation of the

video for the viewer. In an extreme case, a user may start filming with the camera in a vertical orientation and change to a horizontal orientation. This would result in a video which starts out oriented properly, but ends up rotated 90 degrees when being displayed to a viewer.” (EX1007, 2:4-9.)

168. With reference to FIG. 2, Voss discloses “an exemplary mobile device display having an active display 200 according to the present invention is shown. The exemplary mobile device application is operative for allowing a user to record in any framing and *freely rotate their device while shooting*, visualizing the final output in an overlay on the device's viewfinder during shooting and ultimately *correcting for their orientation in the final output.*” (EX1007, 9:14-19 (emphases added).)

169. As shown in FIG. 2, Voss discloses that “[a]n *inset rectangle 225* is inscribed within the overall sensor that is best-fit to the maximum boundaries of the sensor given the desired optimal aspect ratio for the given (current) orientation. The boundaries of the sensor are slightly padded in order to provide 'breathing room' for correction. The *inset rectangle 225 is transformed to compensate for rotation 220, 230, 240 by essentially rotating in the inverse of the device's own rotation, which is sampled from the device's integrated gyroscope.* The transformed inner rectangle 225 is inscribed optimally inside the maximum available bounds of the overall sensor minus the padding. Depending on the

device's current most orientation, the dimensions of the transformed inner rectangle 225 are adjusted to interpolate between the two optimal aspect ratios, relative to the amount of rotation.” (EX1007, 10:2-11 (emphases added).)

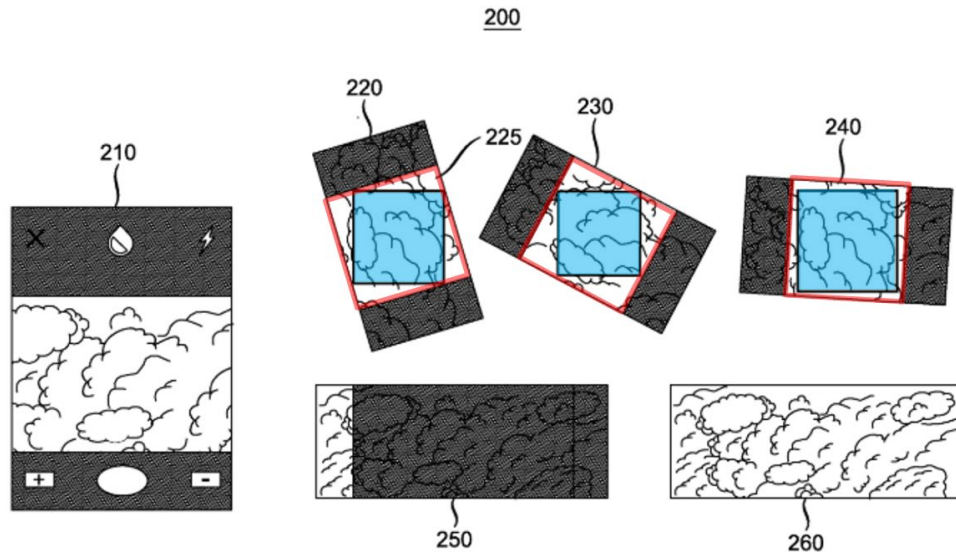


FIG. 2

170. Thus, as the user rotates an image capture device, Voss displays an *inset rectangle* 225, which defines extents of the visual content to be included within horizon-leveled visual content. (EX1007, FIG. 2, 10:2-11.) As shown in FIG. 2 of Voss, as the image capture device rotates over time, the inset rectangle updates to include different portions of the visual content, such that what is included in the inset rectangle is horizon-leveled visual content.

171. I note that a better rendering of Figure 2 appears to be provided in a related application of Voss. The related application International Publication No. WO 2015/038180 show the original photographic version of FIG. 2, reproduced

below, and also includes a substantially identical description of the inset rectangle 225.² (EX1013, FIG. 2.) As shown below, in what appears to be the original photographic version of FIG. 2, it is more apparent that the clouds in the inset rectangle 225 have substantially the same orientation despite rotation of the device. The slight variations in the orientation across three images can be due to movement of the clouds over time as the video is taken.

² International Publication No. WO 2015/038180 was filed on December 30, 2013, claims earliest priority to a provisional application filed on September 16, 2013, and published on March 19, 2015.

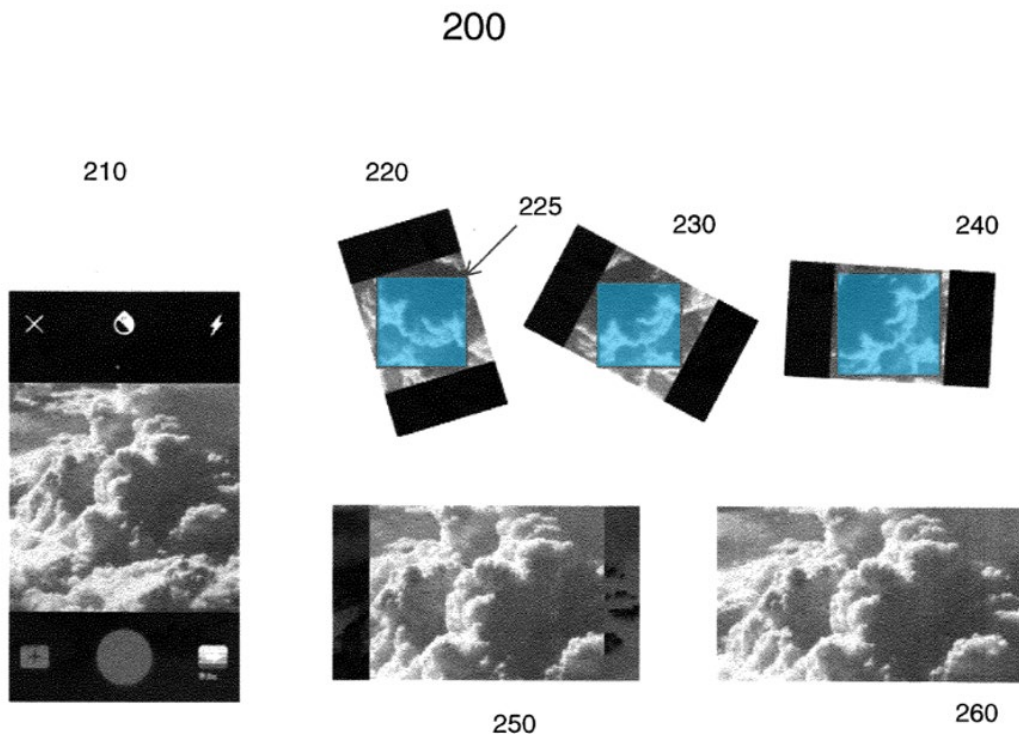


FIG. 2

2. Summary of Derbanne

172. Derbanne discloses systems and methods for “stabilizing videos using positions of an image capture device during a capture duration.” (EX1008, 1:6-7.) Derbanne discloses “[a]n optical element may be configured to guide light within an *optical field of view* to an image sensor. The optical field of view may be greater than a *capture field of view* for generating video content.” (EX1008, 1:63-66.) For example, Derbanne states, “FIG. 6A illustrates an example *optical field of view 602* and an example *capture field of view 604* for an image A 600. The image A 600 may include capture of a scene within an angle defined by the optical field of view 602. The *capture field of view 604 may provide a punch-out of the*

image A 600 to be used for video generation.” (EX1008, 12:3-8 (emphases added).)

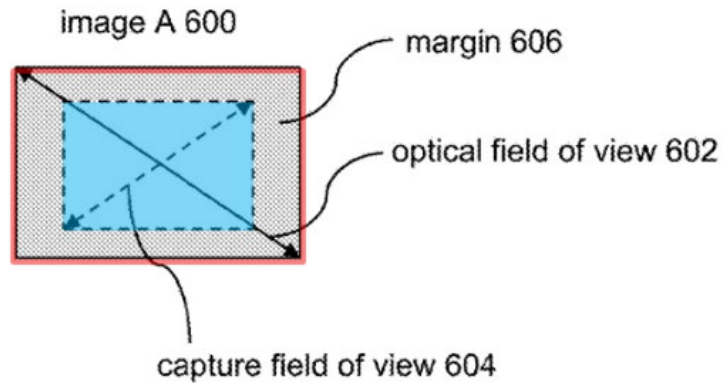


FIG. 6A

173. Derbanne further discloses that “[t]he orientations of the *capture field of view* for the images with respect to the *optical field of view* of the images may determine which portions of the visual content of the images (punch-outs) may be used to generate a video.” (EX1008, 12:66-13:2.) For example, in FIG. 6B, “a *capture field of view 614* may be rotated with respect to the *optical field of view 612* while not going beyond the pixels captured within an image B 610, and a *capture field of view 624* may be laterally moved with respect to a [sic] *optical field of view 622* while not going beyond the pixels captured within an image C 620.” (EX1008, 12:16-22 (emphases added).)

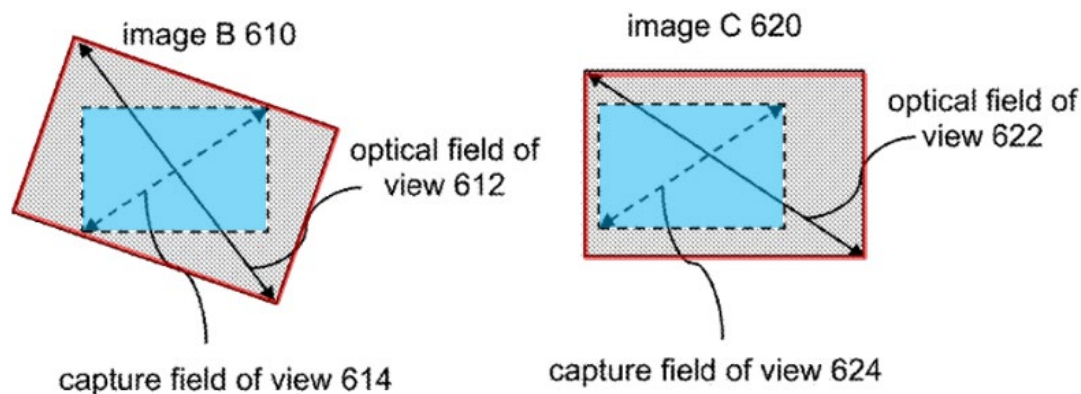


FIG. 6B

3. Claim 1

a. Preamble: “A system for horizon leveling videos, the system comprising:”

174. Voss discloses a system that “dynamically maintain[s] a horizontal framing of a video.” (EX1007, Abstract).

b. 1[a]: “one or more physical processors configured by machine-readable instructions to:”

175. Voss discloses “one or more physical processors.” Voss discloses that Voss’ system comprises one or more processors. (EX1007, 6:20-7:9.) FIG. 1 shows a **processor 150**, which “may be a single processor or more than one processor as known by one skilled in the art.” (EX1007, 6:21-22 (emphasis added).) “The main processor 150 also processes audio and video content for play back either directly on the device or on an external device through the audio/video interface. The main processor 150 is operative to control the various sub devices,

such as the camera 140, inertial sensor 170 touch screen 180, and the USB interface 130. The main processor 150 is further operative to execute subroutines in the mobile phone used to manipulate data similar to a computer. For example, the main processor may be used to manipulate image files after a photo has been taken by the camera function 140. These manipulations may include cropping, compression, color and brightness adjustment, and the like.” (EX1007, 7:1-9.) A POSITA would have understood that these are one or more physical processors that are physically included in systems and are configured by machine-readable instructions to perform the steps described in Voss.

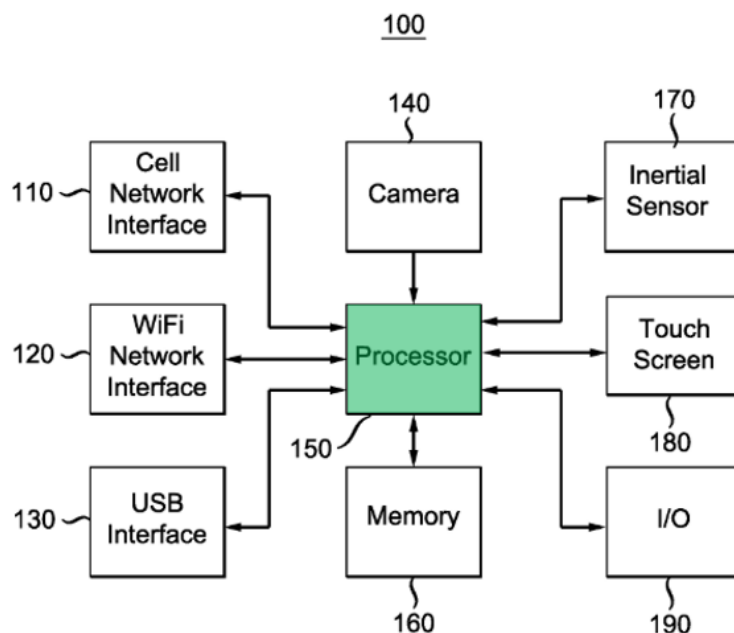


FIG. 1

- c. **1[b][i]: “obtain video information defining a video,”**

176. Voss discloses “obtaining video information defining a video.” Voss states that “holding a button for a predetermined time, such as 3 seconds, may indicate that a video has been selected and video recording on the mobile device will continue until the button is actuated a second time.” (EX1007, 11:21-12:2.) Voss’ system “saves [] the capture data as a video file in a video file format, such as mpeg or the like.” (EX1007, 15:2-3). The video file is the “video information defining a video.”

d. 1[b][ii]: “the video including video content captured by an image capture device during a capture duration,”

177. Voss discloses “the video including video content captured by an image capture device.” Voss states that “holding a button for a predetermined time, such as 3 seconds, may indicate that a video has been selected and video recording on the mobile device will continue until the button is actuated a second time.” (EX1007, 11:21-12:2.) Voss also states that “[o]nce the image capture indication has been received by the main processor 510, the device begins to save the data sent from the image sensor 520.” (EX1007, 14:10-11.) These devices are examples of an “image capture device.”

178. Voss also discloses “a capture duration.” “Once the image capture indication has been received by the main processor 510, the device begins to save the data sent from the image sensor 520. In addition, the system initiates a timer.

The system then continues to capture data from the image sensor as video data. In response to a second indication from the capture indication, indicating that capture has been ceased 530, the system stops saving data from the image sensor and stops the timer.” (EX1007, 14:10-15.) The period of time during which the video content is captured is “the capture duration.”

- e. **1[b][iii]: “the video content having a progress length, the video content including visual content captured at different moments within the capture duration,”**

179. Voss discloses “the video content having a progress length, the video content including visual content captured at different moments within the capture duration.” According to the ’832 patent, “[t]he progress length of the video content may be same as the capture duration, shorter than the capture duration (e.g., playback rate of the video content is faster than the capture rate of the video content), and/or longer than the capture duration (e.g., playback rate of the video content is slower than the capture rate of the video content).” (EX1001, 14:17-23.)

180. Similarly, Voss’ video content can be played back over a period of time and the period of time during which the video content is played back can be “the progress length.” Voss’ system “saves [] the capture data as a video file in a video file format, such as mpeg or the like.” (EX1007, 15:2-3.) Further, Voss’s “main processor 150 also processes audio and video content for *play back* either directly on the device or on an external device through the audio/video interface.”

(EX1007, 7:1-3 (emphasis added).) Similarly to the '832 patent, a POSITA would have understood that, depending on the playback speed, the period of time during which Voss' video content can be played back can be the same as the capture duration, shorter than the capture duration (e.g., if the playback is sped up), and/or longer than the capture duration (e.g., if the playback is slowed down).

181. Further, it would have been obvious to a POSITA that Voss' video file has a progress length and includes visual content captured at different moments within the capture duration. At the time of the invention in 2019, a video file format typically included a series of image frames captured at different moments within the time period during which the video is captured (i.e., the capture duration). Each image frame is time-stamped or associated with a specific point in time, indicating when it can be displayed during playback.

182. Further, Derbanne discloses "the video content having a progress length, the video content including visual content captured at different moments within the capture duration." Derbanne states, "[v]ideo content may define visual content viewable as a function of progress through a *progress length* of the video content. Video content may include video frames that define visual content. That is, visual content of the video content may be included within *video frames* of the video content." (EX1008, 13:49-53 (emphases added).) It would have been

obvious to a POSITA that Derbanne's "video frames" are captured at different moments within the capture duration.

183. It would have been obvious to a POSITA to combine the teachings of Voss and Derbanne. Both Voss and Derbanne relate to techniques for rotating visual content in video data to compensate for motion of the image capture device. (EX1007, Abstract, 10:5-7; EX1008, 13:2-8.) Derbanne states "[t]he orientations of the capture field of view for the images with respect to the optical field of view of the images may determine which portions of the visual content of the images (punch-outs) may be used to generate a video. That is, the orientation component 106 may determine how the punch-outs for the images may be oriented with respect to the capture field of view for the images." (EX1008, 12:66-13:5.) Thus, Voss and Derbanne are from the same field of endeavor and reasonably pertinent to the same technical problems of improving video content.

184. The Voss-Derbanne combination results in a system in which data (captured video data, rotational position information) is captured, stored, and maintained in accordance with the teaching of Derbanne and a punchout can be generated, yielding the predictable results of improving the video management and processing capabilities of Voss. Both Voss and Derbanne are related to image correction; thus, a POSITA would be motivated to use the known techniques of Derbanne to improve Voss in the same way. Further, it would have been obvious

to try combining the teachings of Voss and Derbanne. Prior art such as Derbanne has successfully demonstrated that its data processing techniques and its techniques for generating a punchout can be implemented to achieve better video quality and thus, there would have been a reasonable expectation of success for combining Voss and Derbanne. Thus, these technical features of Derbanne can be combined with the teachings of Voss without requiring much effort and with a reasonable expectation of success. Thus, it would have been obvious to a POSITA to combine the teachings of Derbanne with the teachings of Voss. The known benefits of Derbanne would prompt the application of Derbanne in the same field based on design incentives and other market forces.

f. 1[b][iv]: “the visual content viewable as a function of progress through the progress length, the visual content having a field of view;”

185. Voss discloses “the visual content viewable as a function of progress through the progress length.” Voss’s “main processor 150 also processes audio and video content for *play back* either directly on the device or on an external device through the audio/video interface.” (EX1007, 7:1-3 (emphasis added).) Thus, Voss’ video content can be viewed or is viewable. As shown in element 1[b][iii], Voss’ video content can be played back over a period of time and the period of time during which the video content is played back can be “the progress length.” (*Supra* § X.C.3.e.) A POSITA would understand providing a playback of

video content over a progress length, as taught by Voss, means that the video content is “viewable as a function of progress through the progress length.”

186. Voss discloses “the visual content having a field of view.” Voss states “[a]n inset rectangle 225 is inscribed within the overall sensor that is best-fit to the maximum boundaries of the sensor given the desired optimal aspect ratio for the given (current) orientation.” (EX1007, 10:2-4.) FIG. 2 depicts several example maximum boundaries of the sensor given the desired optimal aspect ratio, marked in red. Each of these constitutes *a field of view* of the visual content, or at least a portion of the field of view.

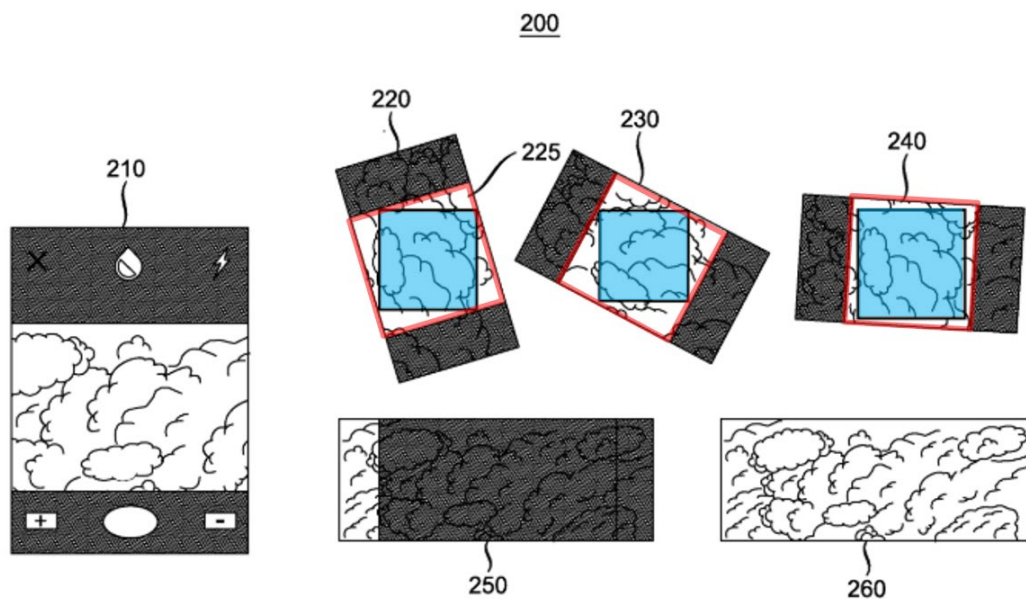


FIG. 2

187. Further, it would have been obvious to a POSITA that Voss’ video file includes visual content viewable as a function of progress through the progress length. As discussed above, at the time of the invention in 2019, a video file

format typically included a series of image frames and each image frame is time-stamped or associated with a specific point in time, indicating when each frame can be displayed during playback. (*Supra* § X.C.3.e.) During playback of the video data, the series of image frames can be displayed sequentially per the timestamps over time (i.e., through the progress length).

188. Further, Derbanne discloses “the visual content viewable as a function of progress through the progress length, the visual content having a field of view.” “Video content may define visual content *viewable as a function of progress through a progress length of the video content.*” (EX1008, 13:49-51 (emphasis added).) Derbanne further discloses a system in which “[i]mages with an *optical field of view* may be captured by an image capture device during a capture duration.” (EX1008, 1:18-20 (emphasis added).) FIG. 6B depicts example optical fields of view 612 and 622. It would have been obvious to a POSITA to combine the teachings of Voss and Derbanne. (*Supra* § X.C.3.e.)

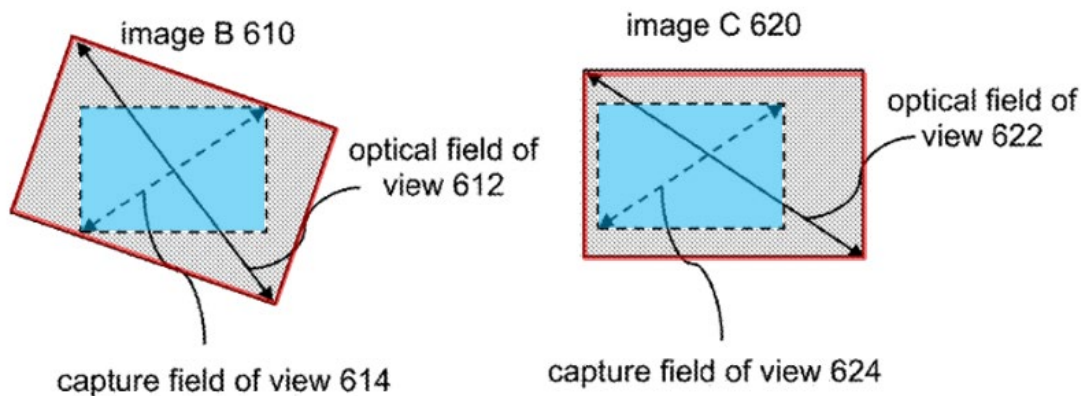


FIG. 6B

- g. **1[c]: “obtain rotational position information for the video, the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration;”**

189. Voss discloses “obtaining rotational position information for the video.” Voss’ system includes “*inertial sensor 170*.” (EX1007, 7:4 (emphasis added).) “The inertial sensor 170 may be a gyroscope, accelerometer, axis orientation sensor, light sensor or the like, which is used to determine a horizontal and/or vertical indication of the position of the mobile device.” (EX1007, 9:1-3.)

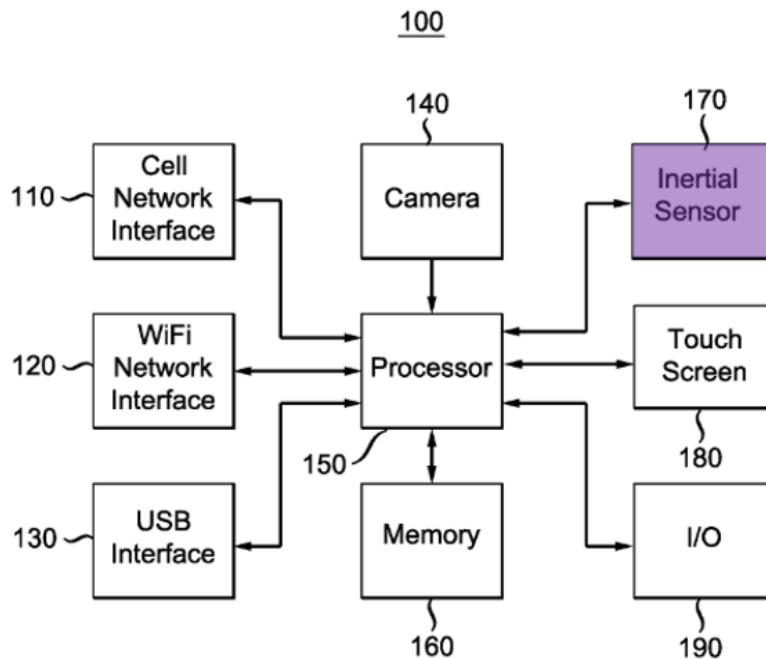


FIG. 1

190. In Voss, “[o]nce the appropriate capture sensor is selected, the system then requests a measurement from an inertial sensor 330. . . . The measurement sensor may send periodic measurements to the controlling processor thereby continuously indicating the vertical and/or horizontal orientation of the mobile device.” (EX1007, 12:4-10.) “[T]he frequency of rotational measurements may be increased during video capture to provide more accurate positional information *in time with the video*.” (EX1007, 16:23-17:2 (emphasis added), FIG. 7.) Voss also states that “[a]fter the inertial sensor has returned an indication of the vertical and/or horizontal orientation of the mobile device, the mobile device depicts an inset rectangle on the display indicating the captured orientation of the video or image 340. As the mobile device is rotated, the system processor *continuously*

synchronizes inset rectangle with the rotational measurement received from the inertial sensor 350.” (EX1007, 12:14-18 (emphasis added).)

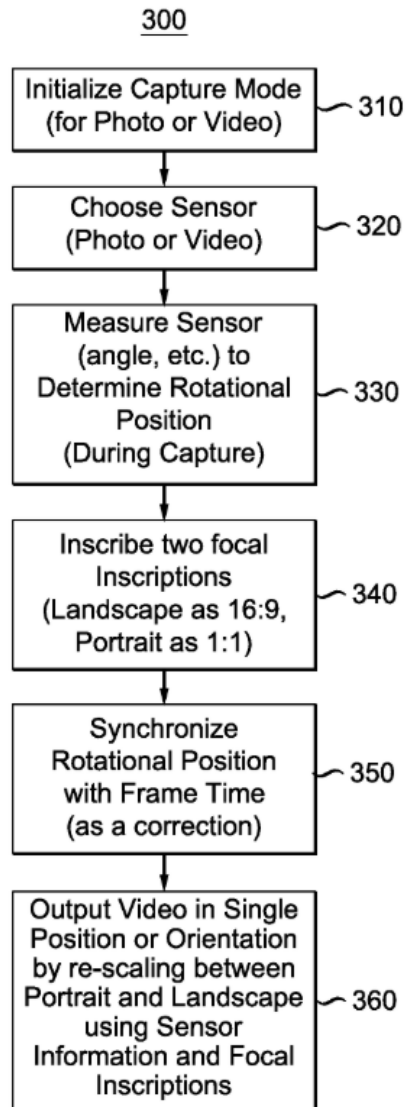


FIG. 3

191. Thus, Voss’ system establishes associations between rotational measurements and various time points through the capture duration of the video. The associations allow the video or image data captured at a particular time point to be processed based on a rotational measurement captured at the same or similar

time point. Accordingly, Voss discloses “the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration.”

192. Further, Derbanne discloses this limitation. For example, Derbanne discloses that “[t]he position information may characterize positions of the housing 312 based on specific translational and/or rotational positions of the housing 312 and/or based on changes in translational and/or rotational positions of the housing 312 *as a function of progress through the capture duration.*” (EX1008, 5:53-57 (emphasis added).) Further, “[t]he position output signal may convey position information that characterizes positions of the housing 312 at different moments (points in time, time durations) within the capture duration.” (EX1008, 5:49-52.) It would have been obvious to a POSITA to combine the teachings of Voss and Derbanne. (*Supra* § X.C.3.e.)

- h. 1[d][i]: “determine a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration,”**

193. Voss discloses “determine a viewing window for the visual content.”

Voss states:

According to the exemplary embodiment, when a user begins shooting the user’s current orientation is taken into account and the

vector of gravity based on the device's sensors is used to register a horizon. For each possible orientation, such as portrait 210, where the device's screen and related optical sensor is taller than wide, or landscape 250, where the device's screen and related optical sensor is wider than tall, an optimal target aspect ratio is chosen. An inset rectangle 225 is inscribed within the overall sensor that is best-fit to the maximum boundaries of the sensor given the desired optimal aspect ratio for the given (current) orientation. The boundaries of the sensor are slightly padded in order to provide 'breathing room' for correction.

The inset rectangle 225 is transformed to compensate for rotation 220, 230, 240 by essentially rotating in the inverse of the device's own rotation, which is sampled from the device's integrated gyroscope.

The transformed inner rectangle 225 is inscribed optimally inside the maximum available bounds of the overall sensor minus the padding. Depending on the device's current most orientation, the dimensions of the transformed inner rectangle 225 are adjusted to interpolate between the two optimal aspect ratios, relative to the amount of rotation.

(EX1007, 9:21-10:11 (emphases added).)

194. Voss' inset rectangle is a "viewing window" determined based on rotational information of the image capture device.

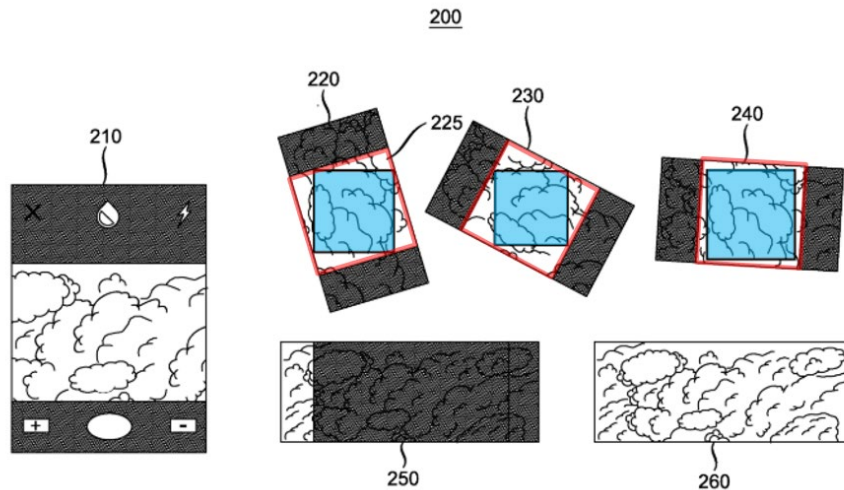


FIG. 2

195. Voss also discloses determining a viewing window “as a function of progress through the progress length.” Voss states, “[t]he system permits the user to freely rotate the device while filming, while visualizing the final output in an overly on the device viewfinder or screen during shooting. The resulting recording is subsequently corrected to maintain a single orientation with a stable horizon. The system and method is operative display an overly [sic] over a captured representation of the captured video wherein the overlay indicates a modified image with respect to said orientation.” (EX1007, Abstract.) Voss’s “main processor 150 also processes audio and video content for *play back* either directly on the device or on an external device through the audio/video interface.” (EX1007, 7:1-3 (emphasis added).) Thus, during playback (i.e., the progress length), Voss’ inset rectangle would change over time to compensate for the device’s rotation at different time points such that a single orientation is

maintained. This means that Voss' inset rectangle is determined as a function of progress through the progress length.

196. Voss further discloses that the processed image data can be played back, stating that “main processor 150 also processes audio and video content for *play back* either directly on the device or on an external device through the audio/video interface.” (EX1007, 7:1-3 (emphasis added).) In other words, Voss discloses playing back the processed video (with processed frames defined by a viewing window), thus disclosing that the viewing window is determined for the visual content as a function of progress through the progress length.

197. Further, Derbanne states “[v]ideo content may define visual content viewable *as a function of progress through a progress length of the video content.*” (EX1008, 13:49-51 (emphasis added).) The Voss-Derbanne combination would process the video content in Derbanne's format, which is “viewable as a function of progress through a progress length of the video content” as taught by Derbanne, to determine the viewing windows for different frames in the video content. This process means that the Voss-Derbanne combination would determine a viewing window for the visual content “as a function of progress through the progress length.”

198. Voss discloses horizon-leveling during post-processing or in real time. “The system permits the user to freely rotate the device while filming, while

visualizing the final output in an overlay on the device viewfinder or screen during shooting. The ***resulting recording is subsequently corrected*** to maintain a single orientation with a stable horizon.” (EX1007, 3:6-9 (emphasis added).) Voss also states, “[t]he exemplary mobile device application is operative for allowing a user to record in any framing and freely rotate their device while shooting, visualizing the final output in an overlay on the device's viewfinder during shooting and ***ultimately correcting for their orientation in the final output.***” (EX1007, 9:15-19 (emphasis added).) In one exemplary embodiment of Voss, the system “receiv[es] data representing a video stream (step 620). A representation of the video stream can then be displayed (step 630). . . . The fifth step is receiving data representing rotational position (step 650). The orientation can then be interpolated using the data representing rotational position (step 660)[.] The last step of the basic method is overlaying a graphic representative of said aspect ratio and said orientation over said representation of said video stream (step 670).” (EX1007, 15:23-16:6.) Thus, Voss discloses first capturing/generating a video stream that can be displayed and then, during post-processing, determining the overlay to generate horizon-leveled visual content.

199. Voss also discloses horizon-leveling in real time. “Thus, as the device is rotated, the controlling processor can continuously update the display and save the video or image in a way which has a continuous consistent horizon.” (EX1007,

12:10-12.) With reference to FIG. 4, Voss states “[t]he image 430 acts as a viewfinder indicating the current image being captured by the image sensor. An inscribed rectangle 440, as described previously, may also be overlaid on the image to indicate an aspect ratio of the image or video *to be captured.*” (EX1007, 14:2-5 (emphasis added).) Thus, Voss discloses directly generating and storing the horizon-leveled visual content in real time.

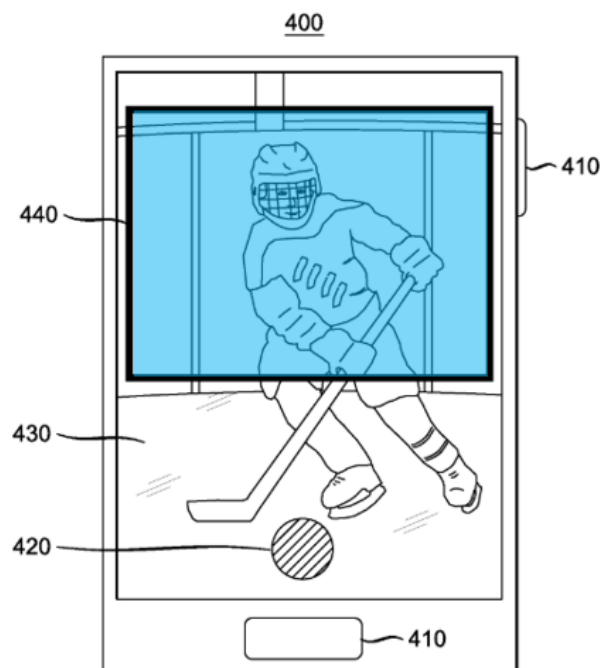


FIG. 4

- i. **1[d][ii]: “the viewing window defining extents of the visual content to be included within horizon-leveled visual content as the function of progress through the progress length,”**

200. Voss' inset rectangle defines "extents of the visual content to be included within horizon-leveled visual content." "The transformed inner rectangle 225 is inscribed optimally inside the maximum available bounds of the overall sensor minus the padding." (EX1007, 10:7-9.) As shown in FIG. 2 below, each of the inset rectangles (marked in blue) defines a boundary of the visual content, thus defining the extents of visual content.

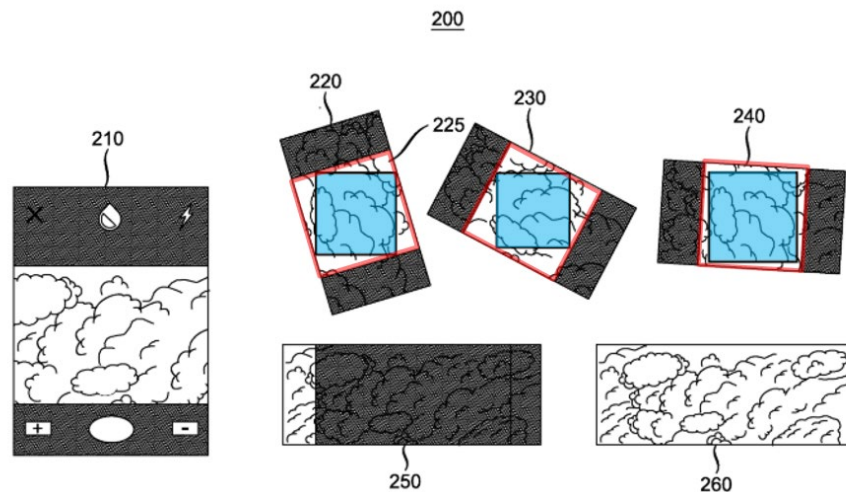


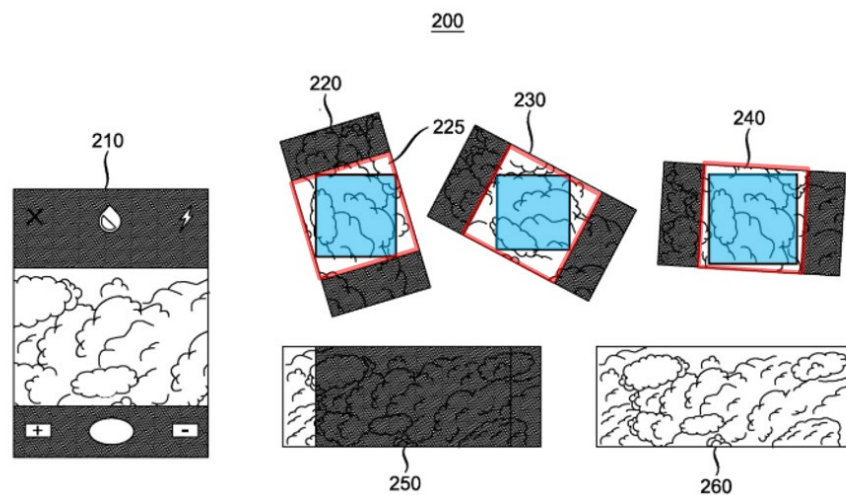
FIG. 2

201. The visual content in the inset rectangles is horizon-leveled. "The inset rectangle 225 is transformed to compensate for rotation 220, 230, 240 by essentially rotating in the inverse of the device's own rotation[.]" (EX1007, 10:5-7.) "The resulting recording is subsequently corrected to maintain a single orientation with a stable horizon." (EX1007, Abstract.)

202. As shown for element 1[d][i], the viewing window in the Voss-Derbanne combination is determined for the visual content as a function of progress through the progress length. (*Supra* § X.C.3.h.)

- j. **1[d][iii]: “wherein determination of the viewing window includes determination of a placement of the viewing window within the field of view of the visual content as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration; and”**

203. Voss discloses “determination of a placement of the viewing window within the field of view of the visual content.” “An *inset rectangle* 225 is inscribed within the overall sensor that is best-fit to the *maximum boundaries of the sensor* given the desired optimal aspect ratio for the given (current) orientation.” (EX1007, 10:2-4 (emphases added).)



204. FIG. 2 of Voss shows that, as the image capture device rotates over time, the inset rectangle is placed in different places within the boundaries to compensate for the device's own rotation at different time points. "The inset rectangle 225 is transformed to compensate for rotation 220, 230, 240 by essentially rotating in the inverse of the device's own rotation[.]" (EX1007, 10:5-7.) "The resulting recording is subsequently corrected to maintain a single orientation with a stable horizon." (EX1007, Abstract.)

205. As shown for element 1[d][i], the viewing window in the Voss-Derbanne combination is determined for the visual content as a function of progress through the progress length. (*Supra* § X.C.3.h.)

- k. **1[e][i]: "generate the horizon-leveled visual content based on the viewing window, the horizon-leveled visual content including a punchout of the extents of the visual content defined by the viewing window,"**

206. Voss discloses "generating horizon-leveled visual content." "The main processor 150 is further operative to execute subroutines in the mobile phone used to manipulate data similar to a computer. For example, the main processor may be used to manipulate image files after a photo has been taken by the camera function 140. These manipulations may include cropping, compression, color and brightness adjustment, and the like." (EX1007, 7:5-9.) "The resulting recording is subsequently corrected to maintain a single orientation with a *stable horizon*."

(EX1007, Abstract (emphasis added).) Voss further states that “as the device is rotated, the controlling processor can continuously update the display and save the video or image in a way which has a *continuous consistent horizon*.” (EX1007, 12:10-12 (emphasis added).)

207. In Voss, the horizon-leveled visual content is defined by the inset rectangle overlay discussed above. “The inset rectangle 225 is transformed to compensate for rotation 220, 230, 240 by essentially rotating in the inverse of the device's own rotation[.]” (EX1007, 10:5-7.) “The exemplary mobile device application is operative for allowing a user to record in any framing and freely rotate their device while shooting, visualizing the final output in an overlay on the device's viewfinder during shooting and ultimately correcting for their orientation in the final output.” (EX1007, 9:15-19.)

208. Voss discloses “the horizon-leveled visual content including a punchout of the extents of the visual content defined by the viewing window.” According to the ’832 patent, a “punchout of the visual content may refer to an output of one or more *portions* of the visual content for presentation (e.g., current presentation, future presentation based on video generated using the punchout).” (EX1001, 16:4-7 (emphasis added).) As shown in FIG. 2 of Voss, the inset rectangle defines a portion of the visual content for presentation. “The exemplary mobile device application is operative for allowing a user to record in any framing

and freely rotate their device while shooting, visualizing the final output in an overlay on the device's viewfinder during shooting and ultimately correcting for their orientation in the final output.” (EX1007, 9:15-19.) Voss further states that “as the device is rotated, the controlling processor can continuously update the display and save the video or image in a way which has a *continuous consistent horizon*.” (EX1007, 12:10-12 (emphasis added).)

209. Further, Derbanne discloses 1[e][i]. Derbanne states, “[v]ideo content is generated based on visual content of the images within the *punch-outs*.” (EX1008, Abstract (emphasis added).) Derbanne further explains that “[a] punch-out of an image may refer to one or more portions of the image that is used for presentation, such as a cut-out of the image or a cropped portion of the image. A punch-out of an image may include one or more visual portions of the image presented on a display and/or one or more visual portion portions [sic] of the image used to generate video frames of video content.” (EX1008, 8:10-16.) “[T]he orientation component 106 may determine how the punch-outs for the images may be oriented with respect to the capture field of view for the images.” (EX1008, 13:3-5.)

- I. **1[e][ii]: “wherein inclusion of the extents of the visual content defined by the viewing window within the horizon-leveled visual content effectuates horizon leveling of the visual content.”**

210. Voss discloses that its operations “effectuate[] horizon leveling of the visual content.” For example, “as the device is rotated, the controlling processor can continuously update the display and save the video or image in a way which has a *continuous consistent horizon*.” (EX1007, 12:10-12 (emphasis added).) “The resulting recording is subsequently corrected to maintain a single orientation with a *stable horizon*.” (EX1007, Abstract (emphasis added).)

4. Claim 2: “The system of claim 1, wherein the viewing window has a one-by-one aspect ratio, the one-by-one aspect ratio reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.”

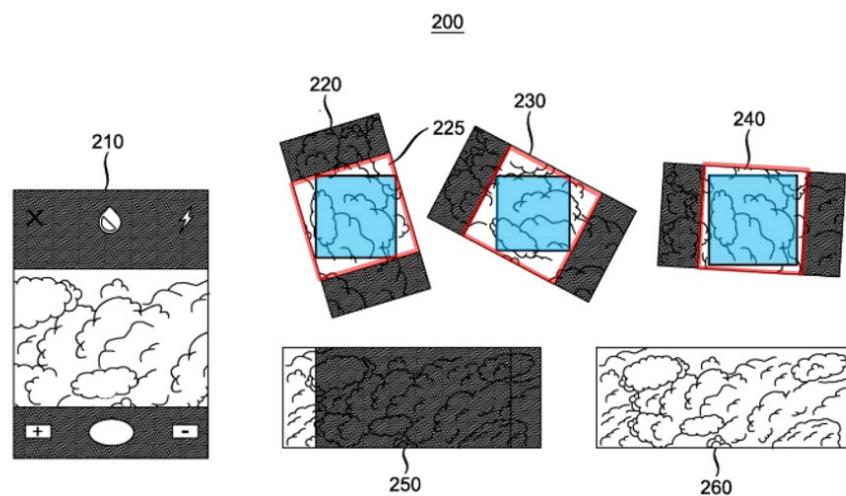
211. Voss discloses that “[t]he user may optionally indicate a preferred final video or image ration, such as *1:1*, 9:16, 16:9, or any other ratio selected by the user.” (EX1007, 12:22-23 (emphasis added).) Voss also discloses “the sampled rectangle is 1:1.” (EX1007, 10:18.)

212. The one-by-one aspect ratio can reduce impact of an off-axis horizon depicted within the horizon-leveled visual content. A POSITA would have understood that, if the viewing window’s width is longer than the height, a titled horizon can appear longer and more prominent. In contrast, if the viewing window’s width equals the height, the tilted horizon can appear shorter and less noticeable.

5. Claim 7: “The system of claim 1, wherein the determination of the viewing window further includes determination of a size of the viewing window as the

function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration.”

213. As shown in FIG. 2, the size of the inset rectangle changes over time based on different rotational positions of the image capture device. Thus, the size of the viewing window is determined based on the rotational information of the device.



214. As shown for element 1[d][i], the viewing window in the Voss-Derbanne combination is determined for the visual content as a function of progress through the progress length. (*Supra* § X.C.3.h.) Because the determination of the viewing window includes determination of its size, a POSITA would understand that the size of the viewing window is also determined as the function of progress through the progress length.

6. Claim 8: “The system of claim 7, wherein the size of the viewing window changes as the function of progress through the progress length to simulate changes in zoom for the visual content.”

215. As discussed for claim 7, Voss discloses “the size of the viewing window changes as the function of progress through the progress length.” (*Supra* § X.C.5.)

216. Voss further discloses the viewing window simulating “changes in zoom for the visual content.” For example, Voss states:

In certain other embodiments, the framing of the image inside the output box is maintained regardless of the aspect ratio. Thus, no matter how the device is oriented, scene is zoomed in or out to keep consistent framing. In some such cases, the object of interest in the video would stay the same size regardless of orientation and aspect ratio. In other cases, where maximum resolution is desired, the zooming in and out may change the size of the object of interest. Alternately, the image may be cropped to maintain the size regardless of orientation and aspect ratio.

(EX1007, 13:10-16; *see also* 17:4-23, FIG. 8.)

7. Claim 9: “The system of claim 1, wherein the determination of the placement of the viewing window within the field of view of the visual content includes determination of a rotation of the viewing window within the field of view of the visual content.”

217. In Voss, “[t]he inset rectangle 225 is transformed to compensate for rotation 220, 230, 240 by essentially rotating in the inverse of the device’s own rotation, which is sampled from the device’s integrated gyroscope.” (EX1007, 10:5-7.) Thus, Voss determines the rotation of the inset rectangle 225.

8. Claim 10: “The system of claim 1, wherein the determination of the placement of the viewing window within the field of view of the visual content includes determination of a location of the viewing window within the field of view of the visual content, the location of the viewing window within the field of view of the visual content determining framing of the visual content.”

218. Voss discloses “determination of a location of the viewing window.” As shown in FIG. 2, the location of the inset rectangle within the field of view changes over time based on different rotational positions of the image capture device. Further, different locations of the inset rectangle result in framing of different portions of visual content, as shown below.

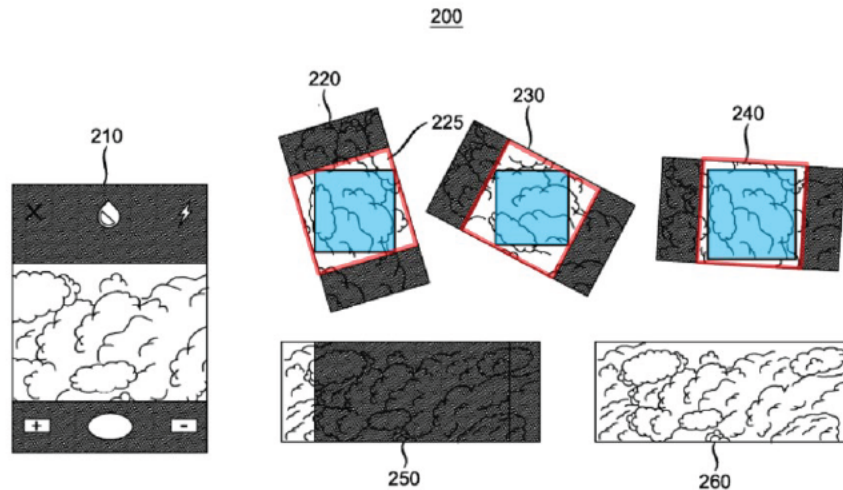


FIG. 2

9. Claim 11

- a. **Preamble: “A method for horizon leveling videos, the method performed by a computing system including one or more processors, the method comprising:”**

219. Voss discloses “[a] method and apparatus for dynamically maintaining a horizontal framing of a video.” (EX1007, Abstract.) Voss also discloses “a computing system including one or more processors.” (*Supra* § X.C.3.b.)

- b. **11[a][i]: “obtaining, by the computing system, video information defining a video,”**

220. Element 11[a][i] mirrors element 1[b][i], which Voss-Derbanne renders obvious. (*Supra* § X.C.3.c.) The table below shows the similarities.

Element 1[b][i]	Element 11[a][i]
obtain video information defining a video,	obtaining, by the computing system, video information defining a video,

- c. **11[a][ii]: “the video including video content captured by an image capture device during a capture duration,”**

221. Element 11[a][ii] mirrors element 1[b][ii], which Voss-Derbanne renders obvious. (*Supra* § X.C.3.d.) The table below shows the similarities.

Element 1[b][ii]	Element 11[a][ii]
the video including video content captured by an image capture device during a capture duration,	the video including video content captured by an image capture device during a capture duration,

- d. **11[a][iii]: “the video content having a progress length, the video content including visual content captured at different moments within the capture duration,”**

222. Element 11[a][iii] mirrors element 1[b][iii], which Voss-Derbanne renders obvious. (*Supra* § X.C.3.e.) The table below shows the similarities.

Element 1[b][iii]	Element 11[a][iii]
the video content having a progress length, the video content including visual content captured at different moments within the capture duration,	the video content having a progress length, the video content including visual content captured at different moments within the capture duration,

- e. **11[a][iv]: “the visual content viewable as a function of progress through the progress length, the visual content having a field of view;”**

223. Element 11[a][iv] mirrors element 1[b][iv], which Voss-Derbanne renders obvious. (*Supra* § X.C.3.f.) The table below shows the similarities.

Element 1[b][iv]	Element 11[a][iv]
the visual content viewable as a function of progress through the	the visual content viewable as a function of progress through the

progress length, the visual content having a field of view;	progress length, the visual content having a field of view;
---	---

- f. **11[b]: “obtaining, by the computing system, rotational position information for the video, the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration;”**

224. Element 11[b] mirrors element 1[c], which Voss-Derbanne renders obvious. (*Supra* § X.C.3.g.) The table below shows the similarities.

Element 1[c]	Element 11[b]
obtain rotational position information for the video, the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration;	obtaining, by the computing system, rotational position information for the video, the rotational position information characterizing rotational positions of the image capture device as a function of progress through the capture duration;

- g. **11[c][i]: “determining, by the computing system, a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration,”**

225. Element 11[c][i] mirrors element 1[d][i], which Voss-Derbanne renders obvious. (*Supra* § X.C.3.h.) The table below shows the similarities.

Element 1[d][i]	Element 11[c][i]
determine a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image	determining, by the computing system, a viewing window for the visual content as a function of progress through the progress length based on the rotational positions of the image

capture device as the function of progress through the capture duration,	capture device as the function of progress through the capture duration,
--	--

- h. 11[c][ii]: “the viewing window defining extents of the visual content to be included within horizon-leveled visual content as the function of progress through the progress length,”**

226. Element 11[c][ii] mirrors element 1[d][ii], which Voss-Derbanne renders obvious. (*Supra* § X.C.3.i.) The table below shows the similarities.

Element 1[d][ii]	Element 11[c][ii]
the viewing window defining extents of the visual content to be included within horizon-leveled visual content as the function of progress through the progress length,	the viewing window defining extents of the visual content to be included within horizon-leveled visual content as the function of progress through the progress length,

- i. 11[c][iii]: “wherein determining the viewing window includes determining a placement of the viewing window within the field of view of the visual content as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration; and”**

227. Element 11[c][iii] mirrors element 1[d][iii], which Voss-Derbanne renders obvious. (*Supra* § X.C.3.j.) The table below shows the similarities.

Element 1[d][iii]	Element 11[c][iii]
wherein determination of the viewing window includes determination of a placement of the viewing window within the field of view of the visual content as the function of progress through the progress length based on	wherein determining the viewing window includes determining a placement of the viewing window within the field of view of the visual content as the function of progress through the progress length based on

the rotational positions of the image capture device as the function of progress through the capture duration; and	the rotational positions of the image capture device as the function of progress through the capture duration; and
--	--

- j. **1[d][i]: “generating, by the computing system, the horizon-leveled visual content based on the viewing window, the horizon-leveled visual content including a punchout of the extents of the visual content defined by the viewing window,”**

228. Element 11[d][i] mirrors element 1[e][i], which Voss-Derbanne renders obvious. (*Supra* § X.C.3.k.) The table below shows the similarities.

Element 1[e][i]	Element 11[d][i]
generate the horizon-leveled visual content based on the viewing window, the horizon-leveled visual content including a punchout of the extents of the visual content defined by the viewing window,	generating, by the computing system, the horizon-leveled visual content based on the viewing window, the horizon-leveled visual content including a punchout of the extents of the visual content defined by the viewing window,

- k. **1[d][ii]: “wherein inclusion of the extents of the visual content defined by the viewing window within the horizon-leveled visual content effectuates horizon leveling of the visual content.”**

229. Element 11[d][ii] mirrors element 1[e][ii], which Voss-Derbanne renders obvious. (*Supra* § X.C.3.l.) The table below shows the similarities.

Element 1[e][ii]	Element 11[d][ii]
wherein inclusion of the extents of the visual content defined by the viewing window within the horizon-leveled	wherein inclusion of the extents of the visual content defined by the viewing window within the horizon-leveled

visual content effectuates horizon leveling of the visual content.	visual content effectuates horizon leveling of the visual content.
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10. **Claim 12: “The method of claim 11, wherein the viewing window has a one-by-one aspect ratio, the one-by-one aspect ratio reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.”**

230. Claim 12 mirrors claim 2, which Voss-Derbanne renders obvious.

(*Supra* § X.C.4.) The table below shows the similarities.

Claim 2	Claim 12
The system of claim 1, wherein the viewing window has a one-by-one aspect ratio, the one-by-one aspect ratio reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.	The method of claim 11, wherein the viewing window has a one-by-one aspect ratio, the one-by-one aspect ratio reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.

11. **Claim 17: “The method of claim 11, wherein determining the viewing window further includes determining a size of the viewing window as the function of progress through the progress length based on the rotational positions of the image capture device as the function of progress through the capture duration.”**

231. Claim 17 mirrors claim 7, which Voss-Derbanne renders obvious.

(*Supra* § X.C.5.) The table below shows the similarities.

Claim 7	Claim 17
The system of claim 1, wherein the determination of the viewing window further includes determination of a size of the viewing window as the function of progress through the progress length based on the rotational positions of the	The method of claim 11, wherein determining the viewing window further includes determining a size of the viewing window as the function of progress through the progress length based on the rotational positions of the

image capture device as the function of progress through the capture duration.	image capture device as the function of progress through the capture duration.
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12. Claim 18: “The method of claim 17, wherein the size of the viewing window changes as the function of progress through the progress length to simulate changes in zoom for the visual content.”

232. Claim 18 mirrors claim 8, which Voss-Derbanne renders obvious.

(*Supra* § X.C.6.) The table below shows the similarities.

Claim 8	Claim 18
The system of claim 7, wherein the size of the viewing window changes as the function of progress through the progress length to simulate changes in zoom for the visual content.	The method of claim 17, wherein the size of the viewing window changes as the function of progress through the progress length to simulate changes in zoom for the visual content.

13. Claim 19: “The method of claim 11, wherein determining the placement of the viewing window within the field of view of the visual content includes determining a rotation of the viewing window within the field of view of the visual content.”

233. Claim 19 mirrors claim 9, which Voss-Derbanne renders obvious.

(*Supra* § X.C.7.) The table below shows the similarities.

Claim 9	Claim 19
The system of claim 1, wherein the determination of the placement of the viewing window within the field of view of the visual content includes determination of a rotation of the viewing window within the field of view of the visual content.	The method of claim 11, wherein determining the placement of the viewing window within the field of view of the visual content includes determining a rotation of the viewing window within the field of view of the visual content.

14. Claim 20: “The method of claim 11, wherein the determining the placement of the viewing window

within the field of view of the visual content includes determining a location of the viewing window within the field of view of the visual content, the location of the viewing window within the field of view of the visual content determining framing of the visual content.”

234. Claim 20 mirrors claim 10, which Voss-Derbanne renders obvious.

(*Supra* § X.C.8.) The table below shows the similarities.

Claim 10	Claim 20
The system of claim 1, wherein the determination of the placement of the viewing window within the field of view of the visual content includes determination of a location of the viewing window within the field of view of the visual content, the location of the viewing window within the field of view of the visual content determining framing of the visual content.	The method of claim 11, wherein the determining the placement of the viewing window within the field of view of the visual content includes determining a location of the viewing window within the field of view of the visual content, the location of the viewing window within the field of view of the visual content determining framing of the visual content.

D. Ground 4: Voss, Derbanne, and Watanabe Render Obvious Claims 3-6 and 13-16

- 1. Claim 3: “The system of claim 1, wherein the visual content includes a distortion such that a straight line within a scene depicted within the visual content appears as a curved line, the distortion of the visual content reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.”**

235. Watanabe discloses claim 3. (*Supra* § X.B.2.)

236. It would have been obvious to a POSITA to combine the teachings of Voss, Derbanne, and Watanabe. Both Voss and Derbanne relate to techniques for

rotating visual content in video data to compensate for motion of the image capture device. (*Supra* § X.C.3.e.) Similarly, Watanabe’s “image shake correction circuit 107 crops and reads out, from the image memory 105, an image . . . and changes the cropping position of the image so as to offset shake of the video camera 100.” (EX1006, 5:22-26.) Thus, Voss, Derbanne, and Watanabe are from the same field of endeavor and reasonably pertinent to the same technical problems of improving video content.

237. Watanabe teaches additional image processing techniques, first correcting distortion before performing image shake correction, and then intentionally adding distortion after performing image shake correction to “generate a moving image that *appears natural after image shake correction*”. (EX1006, 1:47-48 (emphasis added).) These techniques can be combined with the teachings of Voss and Derbanne to generate horizon-leveled video content that also appears more natural looking, with a reasonable expectation of success.

238. Specifically, the combination of Voss, Derbanne, and Watanabe results in a system that can achieve horizon-leveling of visual content while incorporating the advantages of Watanabe to generate natural looking horizon-leveled video content. For example, the Voss-Derbanne-Watanabe combination can remove image distortions from a captured image (e.g., caused by characteristics of the image sensor) as taught by Watanabe, obtain horizon-leveled

visual content as taught by Voss and Derbanne, and intentionally add certain distortions to “generate a moving image that *appears natural after image shake correction*”. (EX1006, 1:47-48 (emphasis added).)

239. The technical features of removing undesirable distortions and adding desirable distortions improves the video quality produced by the Voss-Derbanne system, yielding the predictable result of making the video content appear more natural looking. Because Voss, Derbanne, and Watanabe all relate to image correction, a POSITA would be motivated to use the known techniques of Watanabe to improve similar devices of Voss and Derbanne in the same way. Further, it would have been obvious to try combining the teachings of Voss, Derbanne, and Watanabe. Prior art such as Watanabe has successfully demonstrated that distortion removal and addition can be implemented to achieve better video quality and thus, there would have been a reasonable expectation of success for combining Voss, Derbanne, and Watanabe. Thus, it would have been obvious to a POSITA to combine the additional imaging processing techniques with the teachings of Voss and Derbanne system to obtain a more natural-looking video for display. The known benefits of Watanabe would prompt the application of Watanabe in the same field based on design incentives and other market forces.

2. Claim 4: “The system of claim 3, wherein the distortion includes a barrel distortion or a pincushion distortion.”

240. Watanabe discloses claim 4. (*Supra* § X.B.3.)

241. It would have been obvious to a POSITA to combine the teachings of Voss, Derbanne, and Watanabe. (*Supra* § X.D.1.)

- 3. Claim 5: “The system of claim 3, wherein the visual content includes the distortion based on capture of the visual content through a wide field of view optical element.”**

242. Watanabe discloses claim 5. (*Supra* § X.B.4.) It would have been obvious to a POSITA to combine the teachings of Voss, Derbanne, and Watanabe. (*Supra* § X.D.1.)

- 4. Claim 6: “The system of claim 3, wherein the visual content includes the distortion based on application of the distortion to non-distorted visual content, the distortion applied to the non-distorted visual content based on the visual content including the non-distorted visual content.”**

243. Watanabe discloses claim 6. (*Supra* § X.B.5.) It would have been obvious to a POSITA to combine the teachings of Voss, Derbanne, and Watanabe. (*Supra* § X.D.1.)

- 5. Claim 13: “The method of claim 11, wherein the visual content includes a distortion such that a straight line within a scene depicted within the visual content appears as a curved line, the distortion of the visual content reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.”**

244. Claim 13 mirrors claim 3, which Voss-Derbanne-Watanabe renders obvious. (*Supra* § X.D.1.) The table below shows the similarities.

Claim 3	Claim 13
The system of claim 1, wherein the visual content includes a distortion such that a straight line within a scene depicted within the visual content appears as a curved line, the distortion of the visual content reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.	The method of claim 11, wherein the visual content includes a distortion such that a straight line within a scene depicted within the visual content appears as a curved line, the distortion of the visual content reducing impact of an off-axis horizon depicted within the horizon-leveled visual content.

6. Claim 14: “The method of claim 13, wherein the distortion includes a barrel distortion or a pincushion distortion.”

245. Claim 14 mirrors claim 4, which Voss-Derbanne-Watanabe renders obvious. (*Supra* § X.D.2.) The table below shows the similarities.

Claim 4	Claim 14
The system of claim 3, wherein the distortion includes a barrel distortion or a pincushion distortion.	The method of claim 13, wherein the distortion includes a barrel distortion or a pincushion distortion.

7. Claim 15: “The method of claim 13, wherein the visual content includes the distortion based on capture of the visual content through a wide field of view optical element.”

246. Claim 15 mirrors claim 5, which Voss-Derbanne-Watanabe renders obvious. (*Supra* § X.D.3.) The table below shows the similarities.

Claim 5	Claim 15
The system of claim 3, wherein the visual content includes the distortion based on capture of the visual content through a wide field of view optical element.	The method of claim 13, wherein the visual content includes the distortion based on capture of the visual content through a wide field of view optical element.

8. **Claim 16: “The method of claim 13, wherein the visual content includes the distortion based on application of the distortion to non-distorted visual content, the distortion applied to the non-distorted visual content based on the visual content including the non-distorted visual content.”**

247. Claim 16 mirrors claim 6, which Voss-Derbanne-Watanabe renders obvious. (*Supra* § X.D.4.) The table below shows the similarities.

Claim 6	Claim 16
The system of claim 3, wherein the visual content includes the distortion based on application of the distortion to non-distorted visual content, the distortion applied to the non-distorted visual content based on the visual content including the non-distorted visual content.	The method of claim 13, wherein the visual content includes the distortion based on application of the distortion to non-distorted visual content, the distortion applied to the non-distorted visual content based on the visual content including the non-distorted visual content.

* * *

I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and that these statements were made with knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code.

Dated:

6/20/24



Aggelos Katsaggelos

APPENDIX A

CURRICULUM VITAE

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May 24, 2024

EDUCATION

- 1985 Ph. D. Electrical Engineering
Georgia Institute of Technology, Atlanta, Georgia
Thesis advisor: R. W. Schafer
- 1981 M.S. Electrical Engineering
Georgia Institute of Technology, Atlanta, Georgia
- 1979 B.S. Electrical and Mechanical Engineering
Aristotelian University of Thessaloniki, Thessaloniki, Greece

EMPLOYMENT HISTORY

- | | |
|----------------|---|
| 2020-present | Deputy Director of Computation, Center for Computational Imaging & Signal Analytics in Medicine |
| 2021-present | Co-Director Center for Scientific Studies in the Arts |
| 1996 – present | Professor, Northwestern University, Department of EECS/ECE |
| 2015 - present | Joseph Cummings Chaired Professor, Department of ECE |
| 2011 - 2015 | AT&T Chaired Professor, Department of EECS |
| 2009 - present | STA Argonne National Laboratory |
| 2008 - present | Affiliated Faculty, Northwestern University, Department of Linguistics |
| 1998 - 2015 | Co-Founder and Director Motorola Center for Seamless Communications |
| 1998 - present | Academic Affiliate Staff, Department of Medicine, Division of Cardiology, NorthShore University HealthCare System, Evanston, IL |
| 1985 - present | Director, Image, and Video Processing Laboratory |
| 2003 - 2004 | Visiting Professor, University of Athens, Dept. of Physics, Athens, Greece |

1997 - 2003	Ameritech Chair of Information Technology, Northwestern University, Department of ECE
1992 - 1996	Associate Professor, Northwestern University, Department of EECS
1989 - 1998	Associate Staff, Department of Medicine, Division of Cardiology, Evanston Hospital, Evanston, IL
1987 (summer)	Visiting Professor, Delft University of Technology, Delft, The Netherlands
1986 - 1987	Assistant Professor, Polytechnic University, Department of EECS, Brooklyn, New York (on leave)
1985 - 1992	Assistant Professor, Northwestern University, Department of EECS
1980 - 1985	Research Assistant, School of Electrical Engineering, Georgia Institute of Technology, Atlanta, Georgia Teaching Assistant (Spring 1983, Spring 1984, Fall 1984)
1978 - 1979	Research Assistant, Aristotelian University of Thessaloniki, Greece

RESEARCH INTERESTS

Multidimensional Digital Signal Processing, Image Processing (Enhancement, Restoration, Coding, Analysis), Processing of Moving (Video) Images (Application of Rate-Distortion Theory to Motion Estimation, Very Low Bit Rate Coding, and Interpolation, Filtering, Recovery), Stereo and 3D Image Processing, Computational Vision, Implementations of Signal Processing Algorithms, Pattern Recognition, Computer Vision, Machine Learning, Multimodal Signal Processing (Speech-Assisted Video Analysis/Synthesis/Coding, bimodal speech recognition, biometrics), Multimedia Signal Processing, Multimedia Systems, (Wireless) Multimedia Communications, Multimedia over Networks, Multimedia and Knowledge, Multimedia and Internet Technologies, Medical and Biological Signal Processing, Scientific Studies in the Arts, Scientific Studies in Health, DNA-based Computing, Computational Imaging, AI, Machine and Deep Learning.

ACADEMIC ACTIVITIES

Courses and Laboratories Developed

“C59: Digital Signal Processing” (a lab was also developed) “D18: Advanced Digital Signal Processing” (with B.J. Sullivan)

“D19: Multidimensional Digital Signal Processing” (was later merged with D18) “D20: Digital Image Processing” (a lab was also later developed)

“EL913: Digital Image Processing and Pattern Recognition” (Polytechnic University)

A Digital Signal Processing TMS320C25-based lab was developed for “C98: Electrical Engineering Design.”

Instructional and Design Laboratory in Digital Signal Processing and Control (with J. C. Rutledge) Image and Video Processing Research Laboratory

“Multimedia Technologies”, a course for the Master’s in Information Technology Program (winter 1999)

“ECE 222: Fundamentals of Signals and Systems,” one of the five fundamental courses for the revised

ECE undergraduate curriculum (winter 2000)

“ECE 421: Multimedia Signal Processing,” Spring 2001.

“EECS 495: Sparse and low-rank recovery problems in signal processing and machine learning,” Winter 2014.

“Coursera: Fundamentals of Image and Video Processing,” 12-week course, Spring 2014. “EECS 375/475: Machine Learning: Foundations, Applications, and Algorithms,” Winter 2015

(this course was given the numbers EECS 375/475 and Data Science 423)

“EECS 395/495: Optimization Techniques for Machine Learning and Deep Learning,” Fall 2017.

“EECS 335/435: Deep Learning Foundations from Scratch,” Fall 2017 (this course was given the number EECS 435)

“EECS 373/473: Deep Reinforcement Learning from Scratch,” Spring 2018.

Courses Taught

“B42: Circuits II”

“C30: Linear Algebra and Eigenvalue Problems” “C51: Introduction to Computer Graphics”

“C07: Communications”

“D19: Multidimensional Digital Signal Processing” “D20: Digital Image Processing”

“C59: Digital Signal Processing”

“C02: Probabilistic Systems and Random Signals” “D23: Random Processes”

“C98: Electrical Engineering Design” “B43: Signals and Systems”

“C99: Electrical Engineering Design”

“222: Fundamentals of Signals and Systems” “420: Digital Image Processing”

“421: Multimedia Signal Processing”

“D25: Multimedia Technologies” (for the MITP program)

“495: Sparse and low-rank recovery problems in signal processing and machine learning”

“Coursera: Fundamentals of Image and Video Processing,” 12-week course

“375/475: Machine Learning: Foundations, Applications, and Algorithms” “435: Deep Learning Foundations from Scratch”

“395/495: Optimization Techniques for Machine Learning and Deep Learning”

Short Courses Taught

“Computer Graphics and Algorithms,” course offered to AT&T Teletype Corporation by the Continuing Education Studies, Northwestern University, Fall 1986.

“Image and Video Processing Techniques,” Bell and Howell, Fall 1993.

“Image and Video Compression: Theory, Standards, and Architectures,” Imperial College of Science Technology and Medicine, London, July 1-3, 1996.

“Fundamentals of Video Communications,” Master’s in Information Technology, Northwestern University, May 1998.

“Image and Video Recovery and Enhancement Techniques,” Signal and Image Processing Conference, Las Vegas, NV, Oct. 1998.

“Image and Video Compression and Transmission,” 2-day short course, University of Granada, Spain, July 1999.

“Image and Video Recovery,” 3-hour tutorial, International Conference on Image Processing (ICIP99), Kobe, Japan, Oct.24, 1999.

“Video Compression and Transmission,” 8-hour workshop, University of Genoa, Italy, Dec. 6-7, 1999.

“Multimedia Signal Processing,” 20-hour workshop, University of Trento, Trento, Italy, Sept. 11-16, 2002.

“Joint Audio-Visual Signal Processing,” 3 1/2-hour tutorial, with G. Potamianos, International Conference on Image Processing (ICIP03), Barcelona, Spain, Sept. 14, 2003.

“Multimedia Processing and Communications,” 15-hour short course, University of Granada, Granada, Spain, July 2004.

“Multimedia Processing and Communications,” 15-hour short course, University of Granada, Granada, Spain, Sept. 2005.

“Multimedia Signal Processing,” 3-hour tutorial, Summer School on Multimedia Semantics, Kallithea, Greece, Sept. 4-8, 2006.

“Multimedia Processing and Communications,” 15-hour short course, University of Granada, Granada, Spain, Sept. 2006.

“Multimedia Processing and Communications,” 15-hour short course, University of Granada, Granada, Spain, July 2007.

“Multimedia Processing and Communications,” 15-hour short course, University of Granada, Granada, Spain, June 2008.

“Multimedia Processing and Communications,” 15-hour short course, University of Granada, Granada, Spain, June 2009.

“Multimedia Processing and Communications,” 15-hour short course, University of Granada, Granada, Spain, June 2010.

“Multimedia Processing and Communications,” 15-hour short course, University of Granada, Granada, Spain, March 2011.

“Multimedia Processing and Communications,” 15-hour short course, University of Granada, Granada, Spain, March 2012.

“Multimedia Processing and Communications,” 15-hour short course, University of Granada, Granada, Spain, March 2013.

“Sparsity-Based Image Processing,” 3-hour short course, Latin American Conference on Networked and Electronic Media Conference, Manizales, Colombia, Sept. 3, 2013.

“Optimization Techniques for Sparse/Low-Rank Recovery Problems in Signal Processing and Machine Learning,” 3-hour short course, European Signal Processing Conference, Marrakesh, Morocco, Sept. 9, 2013.

“Optimization Techniques for Sparse/Low-rank Recovery Problems in Image Processing and Machine Learning,” 6-hour short course, Tarragona International Summer School on Trends in Computing (SSTiC), Tarragona, Spain, July 7-11, 2014.

“Optimization Techniques for Sparse/Low-Rank Recovery Problems in Signal Processing and Machine Learning,” 3-hour short course, IEEE International Conference on Image Processing, Paris, France, Oct. 27, 2014.

“Optimization Techniques for Sparse/Low-Rank Recovery Problems in Signal Processing and Machine Learning,” 4-hour short course, Hochschule fur Technik Rapperswil, Switzerland, Oct. 30, 2014.

“Deep Learning: from Foundations to Implementation,” 3-hour short course, The 30th AAAI conference on Artificial Intelligence, Phoenix, AZ, Feb. 12, 2016.

“Deep Learning for Computer Vision, 3-hour short course, IEEE Winter Conference on Applications of Computer Vision, Lake Placid, NY, March 7, 2016.

“Feature Learning for Image Data: from Dictionary Learning to Deep Learning,” 3-hour short course, IEEE Computer Vision and Pattern Recognition (CVPR) Conference, Las Vegas, Nevada, June 26, 2016.

“Machine Learning,” 10-hour short course, COFI Advanced Instrumentation and Analysis Techniques Summer School, San Juan, Puerto Rico, July 11-19, 2016.

“Better signal descriptions for better content understanding,” 3-hour short course, IEEE-EURASIP Summer School on Signal Processing (S3P-2016) Summer School on Semantics in Media, Cavalese, Italy, Sept. 4-10, 2016.

UNDERGRADUATE ADVISING

Kenneth L. Carr; Project title: *The Analysis of an Iterative Algorithm for Image Restoration*, Winter 1986.

Faisal Ishtiaq; Project title: *TMS320-based Implementation of Iterative Image Restoration Algorithms*, Winter-Spring 1993.

Elisabeth Cheng; Project title: *The Analysis of a Motion Estimation Algorithm Considering Illumination Changes*, Spring 1995.

Jacob J. Brick; Project title: *Real-Time Web-Based Tracking Control System*, Spring 2000 (Motorola funded project).

Jacob J. Brick; Project title: *Implementation of an Iterative Image Restoration Algorithm on a Parallel Processor*, Spring 2001 (Motorola funded project).

Jonathan Bender; Project title: *Video Deinterlacer for Audio-Visual Automatic Speech Recognition*, Spring 2006 (Motorola funded project).

Alice Zhao; Project title: *Audio-Visual Signal Processing*, Spring 2007. Max Chiswick; Project title: *Audio-Visual Signal Processing*, Spring 2007. Ron Chin; Project Title: *Object Tracking*,

Winter, Spring 2008.

Anna Tarnikowa; Project Title: *Colorization of Paintings*, Winter, Spring 2008.

Yang Yang Chen; Project Title: *Interface for Blind Image Deconvolution*, Fall 2009, Winter 2010.

Ece Tumer and Todd Poole; Project Title: *A Novel Image Retrieval Algorithm*, Fall 2010.

Ece Tumer; Project Title: *A Novel Image Retrieval Algorithm*, Winter and Spring 2011. Ahmad

Hazim Mobashar; Project Title: *Image Retrieval*, Winter 2012.

Churukanti Shashaank Reddy; Project Title: *Speech Processing*, Winter 2012, Spring 2012. Han

Hazel Hye Jung; Project Title: *Image Retrieval Systems*, Winter 2012, Spring 2012.

Shuang Zhang; Project Title: *Motion Extraction for Cardiopulmonary Resuscitation Video Sequence Using Microsoft's Kinect Depth Sensor*, Winter 2013, Spring 2013.

Tuofei Chen (Murphy Fellow); Project title: *RGB-D SLAM for MAV Autonomous Indoor Navigation*, Winter 2017, Spring 2017.

Eric Dexheimer (Murphy Fellow); Project title: *Computer Vision Approaches for MAV Autonomous Indoor Navigation*, Winter 2018, Spring 2018.

Amil Dravid; Project title: *Explainable AI*, 2019-present.

Juwon Park; Project title: CLIP processing, 2022-present.

Shreya Sridhar; Project title: Imputation Approaches, 2021-present.

Jennie Wang; Project title: Machine Learning for Cultural Heritage, 2022-present.

Dev Shah; Project title: Diffusion Models, 2023-present.

Derek Guo; Project title: Mathematical Aspects of Diffusion Models, 2023-present.

GRADUATE STUDENT SUPERVISION

M.S. Students

1. Patrick Brady, M.S. degree awarded June 1987; Thesis title: *Computer Simulation of Electric Discharge Using Fractal Noise Functions*.

2. Joon K. Paik, M.S. degree awarded June 1987; Project title: *Adaptive Iterative Color Image Restoration Algorithms*.

3. Stephanie Lam, M.S. degree awarded December 1987 (Polytechnic University); Thesis title: *Maximum Entropy Based Iterative Image Restoration Algorithms*.

4. Seraphim N. Efstratiadis, M.S. degree awarded June 1988; Thesis title: *Fast Iterative Signal Restoration Algorithms*.

5. Kuen Tsai Lay, M.S. awarded June 1988.

6. Leonid Tokman, M.S. degree awarded June 1989; Project title: *Nonlinear Iterative Signal Restoration*.

7. Chakravart R. Triplicane, M.S. degree awarded Dec. 1989 ; Thesis title: *Recursive Restoration of Noisy Image Sequences*.

8. Tomas De Roux, M.S. degree awarded Dec. 1989; Thesis title: *Optical Implementation of an Iterative Image Restoration Algorithm.*
9. Yu-Chun Kuo, M.S. degree awarded June 1990; Project title: *A Constrained Iterative Algorithm for Identification and Restoration of Images.*
10. Jaeyoung Kwak, M.S. degree awarded June 1990; Thesis title: *Motion Estimation Using Skeletons.*
11. Shu-Yuan Yang, M.S. degree awarded June 1990; Thesis title: *Image Restoration with Ringing Reduction.*
12. Cheuk L. Chan, M.S. awarded June 1990.
13. Brian Tom, M.S. degree awarded June 1991; Project title: *Elastic Registration of Skeletons.*
14. Moon Gi Kang, M.S. awarded June 1990.
15. Mark Banham, M.S. awarded June 1990.
16. Dong-Joon Shin, M.S. degree awarded Aug. 1991; Thesis title: *Adaptive Interpolation Schemes for Digital Angiographic Sequences.*
17. Gregory J. Alexopoulos, M.S. degree awarded Dec. 1991; Thesis title: *Inbetweening Techniques with Free-Form Deformations for Computer Animation.*
18. Taner Ozcelik, M.S. degree awarded June 1992; Thesis title: *Image Restoration Using Maximum Likelihood and Cross Validation.*
19. Ozan Erdogan, M.S. degree awarded June 1992; Project title: *Restoration of Image Sequences.*
20. Min-Cheol Hong, M.S. awarded June 1993.
21. Tom Kostas, M.S. degree awarded Dec. 1993; Project title: *Adaptation of JPEG-Based Compression of Radiographic Images.*
22. Damon Lee Tull, M.S. degree awarded June 1994; Project title: *Iterative Restoration of Space Variant Blurs Caused by Fast Moving Objects in Image Sequences.*
23. Chun-Jen Tsai, M.S. awarded June 1993.
24. Johannis Hashim, M.S. degree awarded Dec. 1995; Project title: *Removal of Fingerprints from Digital Images.*
25. Rachel Smith, M.S. degree awarded Dec. 1995; Thesis title: *An Approach to Region Based Motion Estimation.*
26. Vania Estrela, M.S. degree awarded Dec. 1995; Thesis title: *Motion Estimation Using the Total Least Squares Approach.*
27. Faisal Ishtiaq, M.S. degree awarded Dec. 1996; Thesis title: *On Vector Quantization and its Application to the Encoding of the Anchor Frame.*
28. Lysimachos Kondi, M.S. degree awarded Dec. 1996; Thesis title: *On the Encoding of the Anchor Frame in Video Coding.*
29. Fabian Meir, M.S. degree awarded June 1997; Thesis title: *Optimal Boundary Encoding in the Rate-Distortion Sense.*
30. Marshall Robers, M.S. degree awarded June 1997; Thesis title: *Scalable Video Compression.*

31. Jay Williams, M.S. awarded June 1998.
32. Carlos Luna, M.S. awarded June 1998.
33. Gerry Melnikov, M.S. degree awarded June 1998; Thesis title: *Hybrid Fractal/DCT Image Compression Algorithms Using an Orthogonal Basis and Non-Square Partitions.*
34. Passant Karunaratne, M.S. degree awarded Dec. 1999; Thesis title: *Compressed Video Enhancement.*
35. Stavros Tzavidas, M.S. degree awarded June 2001; Thesis title: *Stereo Panoramic Video Generation and Processing.*
36. Yiftach Eisenberg, M.S. degree awarded Dec. 2001; Thesis title: *Joint Source Coding and Transmission Power Management for Energy Efficient Wireless Video Communications.*
37. Fan Zhai, M.S. degree awarded Dec. 2001.
38. Petar S. Aleksic, M.S. degree awarded Dec. 2001; Thesis title: *Audio-Visual Continuous Speech Recognition Using MPEG-4 Compliant Visual Features.*
39. Xiaohuan Li, M.S. degree awarded June 2002; Thesis title: *MPEG-4 Shape Error Concealment Techniques.*
40. Elias Fradelos, M.S. degree awarded June 2002.
41. Tien F. Lee, M.S. degree awarded June 2002.
42. Fei Wang, M.S. degree awarded June 2002.
43. Peshala Pahalawatta, M.S. degree awarded, Dec. 2002; Thesis title: *Collaborative Video-Based Target Tracking in Wireless Sensor Networks.*
44. Sotirios Tsaftaris, M.S. degree awarded, June 2003; Thesis title: *DNA Computing.*
45. Kostantinos Zachariadis, M.S. degree awarded, June 2004; Thesis title: *Resource Allocation in Wireless Communications.*
46. Mark R. Trandel, M.S. degree awarded, June 2005; Thesis title: *Scalable Video Compression.*
47. Morris M. Kabuage, degree awarded, June 2005.
48. Roger Biffiger, degree awarded, Dec. 2005; Thesis title: *Audio-Visual Isolated Digit Recognition.*
49. Adrian Schuster, degree awarded June 2006.
50. Ramandeep Ahuja, degree awarded June 2006; Thesis title: *Microarray Image Processing.*
51. Derek Shiell, degree awarded June 2007; Thesis title: *Object Tracking for Audio-Visual Signal Processing.*
52. Louis Terry, degree awarded June 2007; Thesis title: *New HMM Design for Visual Speech.*
53. Ehsan Maani, degree awarded June 2007; Thesis title: *Scalable Video Transmission.*
54. Xiaoming Yin, degree awarded June 2007; Thesis title: *Super-Resolution of MRI Images.*
55. Serhan Uslubas, degree awarded Dec. 2008; Thesis title: *Macroblock Based Resolution Adaptive Video Encoding.*

- 56.Eren Soyak; M.S. degree awarded June 2008.
- 57.Martin Luessi; M.S. degree awarded June 2008.
- 58.Tuo Huang, degree awarded June 2010.
- 59.Bruno Amizic, degree awarded June 2011.
- 60.Zingnan Wang, degree awarded Dec. 2011.
- 61.George Tzu-Jui Liu, degree awarded June 2012.
- 62.Xin Xin, degree awarded June 2012.
- 63.Leonidas Spinoulas, degree awarded June 2012.
- 64.Bao Wang, degree awarded June 2012.
- 65.Armin Kappeler, degree awarded June 2012.
- 66.Jonathan Springer, degree awarded Dec. 2012; Thesis title: *Forest Hashing: Expediting Large Scale Image Retrieval*.
- 67.Reza Borhani, degree awarded June 2013.
- 68.Yushen Liu, degree awarded Dec. 2013.
- 69.Jian Zhang, degree awarded Dec. 2013.
- 70.Qiqin Dai, degree awarded Dec. 2013.
- 71.Thomas Niederberger, degree awarded Dec. 2013; Thesis title: *A High-Speed Video Camera using Compressive Sensing and a Coded Aperture*.
- 72.Mengdi Bian, degree awarded June 2014.
- 73.Mengwei Li, degree awarded June 2014.
- 74.Zhenyu Zhang, degree awarded June 2014.
- 75.Lukas Schmid, degree awarded August 2014; Thesis title: *Two Megapixel Compressive Sensing High-Speed Video Camera*.
- 76.Roman Koller, degree awarded August 2014; Thesis title: *Two Megapixel Compressive Sensing High-Speed Video Camera*.
- 77.Naif Almakhdhub, degree awarded Dec. 2014.
- 78.Feng Liu, degree awarded Dec. 2014.
- 79.Yanran Wang, degree awarded June 2015.
- 80.Emre Besler, degree awarded June 2015.
- 81.Baiyu Yang, degree awarded June 2015.
- 82.Yimin Chen, degree awarded June 2015.
- 83.Yifei Ge, degree awarded June 2015.
- 84.Jingming Guo, degree awarded June 2015.
- 85.Shitij Rastogi, degree awarded Dec. 2015; Thesis title: *Detection and Recognition of Human Bodies in a Scene from a Robot Mounted Kinect Camera*.

- 86.Chukwunyere Igbokwe, degree awarded Dec. 2015.
- 87.Prapul Nagaraja, degree awarded Dec. 2015.
- 88.Abdullah Thawad Althawad, degree awarded June 2016.
- 89.Da Li, degree awarded June 2016.
- 90.Ben Zhao, degree awarded June 2016.
- 91.Yaliang Wang, degree awarded June 2016.
- 92.Han Yu Tseng, degree awarded June 2016.
- 93.Huanyu Wang, degree awarded June 2016.
- 94.Omair Adnan Taibah, degree awarded June 2016.
- 95.Yunli Ma, degree awarded June 2016; Thesis title: *Image processing techniques for the accurate reading of low quality gray scale scans of lateral flow paper test strips from a low cost HIV diagnostic assay kit for point-of-care use.*
- 96.Hannes Badertscher, degree awarded February 2017; Thesis title: *Northwestern Visual Search.*
- 97.Tuofei Chen, degree awarded June 2017; Thesis title: *RGB-D SLAM for MAV Autonomous Indoor Navigation.*
- 98.Taorui Peng, degree awarded Dec. 2017.
- 99.Yuhang Peng, degree awarded Dec. 2017.
100. Eric Dexheimer, degree awarded June 2018; Thesis title: *Computer Vision Approaches for MAV Autonomous Indoor Navigation.*
101. Goutam Raju, degree awarded June 2018; Thesis title: *Visible-Light Transmission Approach to Watermark Imaging.*
102. Zhi-Xuan Chuo, degree awarded Dec. 2018.
103. Yikuan Li, degree awarded June 2019; Thesis title: *Land Usage Detection in Remote Sensing.*
104. Xining Yuan, degree awarded June 2024; Thesis title: *Multiple Instance Learning for 3D / 2D CT Scans of Brain.*

GRADUATE STUDENT SUPERVISION

Ph.D. Students

1. Joon K. Paik, Ph. D. degree awarded June 1990; Thesis title: *Image Restoration and Edge Detection Using Neural Networks*; current position: Associate Professor, Chung-Ang University, Seoul, Korea.
2. Kuen Tsair Lay, Ph. D. degree awarded Dec. 1991 (defense date Aug. 1991); Thesis title: *Blur Identification and Image Restoration Using the EM Algorithm*; current position: Associate Professor, National Taiwan Institute of Technology, Tapei, Taiwan.
3. Seraphim N. Efstratiadis, Ph. D. degree awarded Dec. 1991 (defense date Oct. 1991); Thesis title: *Adaptive Constrained recursive Displacement Field and Image Sequence Estimation*; current position: Professor, Technological Education Institute of Thessaloniki, Thessaloniki, Greece.
4. Cheuk L. Chan, Ph.D. degree awarded Dec. 1993 (defense date July 1993; co-advisor); Thesis

title: *Image Sequence Filtering and Displacement Field Estimation Under Quantum-Limited Imaging Conditions*; positions: PAR Government Systems Corporation, La Jolla, CA; Packet Video, San Diego, CA.

5. James C. Brailean, Ph.D. degree awarded Dec. 1993 (defense date July 1993); Thesis title: *Recursive Displacement Field Estimation with Application to Image Sequence Processing*. positions: CEO, Packet Video, San Diego, CA.

6. Moon Gi Kang, Ph. D. degree awarded June 1994 (defense date Feb. 1994); Thesis title: *Adaptive Iterative Image Restoration Algorithms*; Position: Assistant Professor, University of Minnesota, Duluth, MN; current position: Professor, Yonsei University, Seoul, Korea.

7. Mark Banham, Ph. D. degree awarded June 1994; Thesis title: *Wavelet-Based Image Restoration Techniques*; positions: Packet Video, San Diego, CA.

8. John A. Goyette, Ph. D. degree awarded Dec. 1994 (co-advisor); Thesis title: *Evaluation of the Point Spread Function for Restoration of Autoradiographic Images*; current position: XiTec, Inc., Windsor Locks, CT.

9. Taner Ozcelik, Ph.D. degree awarded June 1995 (defense date Dec. 1994); Thesis topic: *A Very Low Bit Rate Video Codec*; positions: SONY, San Jose, CA; President and CEO of MobileSmarts, Palo Alto, CA.

10. Brian C. Tom, Ph.D. degree awarded Dec. 1995 (defense date June 1995); Thesis topic: *Reconstruction of a High Resolution Image from Multiple Degraded Mis-Registered Low Resolution Images*; current position: MRI, Evanston, IL.

11. Guido M. Schuster, Ph.D. degree awarded June 1996; Thesis topic: *A Video Compression Scheme with Optimal Bit Allocation among Segmentation, Displacement Vector Field, and Displaced Frame Difference*; positions: US Robotics (3COM), Skokie, IL; Professor, HSR Hochschule fur Technik Rapperswil, Switzerland.

12. Min-Cheol Hong, Ph.D. degree awarded Dec. 1997; Thesis topic: *Adaptive Iterative Image and Video Recovery Approaches*; positions: LG, Seoul, Korea; Assistant Professor, Soongsil University, Seoul, Korea.

13. Damon Tull, Ph.D. degree awarded June 1998; Thesis topic: *Regularized Restoration of Partial-Response Distortions in Sporadically Degraded Images*; positions: Assistant Professor, University of Wisconsin, Madison, WI; CEO- DVIP Multimedia, Rockville, MD., Evanston, IL.

14. Javier Mateos, Ph.D. degree awarded summer 1998 (co-advisor, University of Granada); Thesis topic: *Hierarchical Bayesian Estimation for the Removal of Blocking Artifacts in Block-Compressed Images*; current position: Assistant Professor, University of Granada.

15. Chun-Jen Tsai, Ph.D. degree awarded Dec. 1998; Thesis topic: *Disparity and Motion Field Estimation in Bi-channel Video Sequences*; positions: Packet Video, San Diego, CA; Professor, National Chiao Tung University, HsinChu, Taiwan.

16. Lisimachos P. Kondi, defense date June 1999; Thesis topic: *Low Bit-Rate SNR Scalable Video Coding and Transmission*; current position: Assistant Professor, State University of New York, Buffalo, NY.

17. Faisal Ishtiaq, defense date June 1999; Thesis topic: *H.263 Scalable Video Coding and Transmission at Very Low Bitrates*; current position: Senior Director Machine Learning, Comcast

18. Gerry Melnikov, defense date May 2000; Thesis topic: *Boundary Encoding for Multimedia Communications*; positions: XR Trading, Chicago, IL.
19. Jay J. Williams, defense date May 2000; Thesis topic: *Speech-to-Video Conversion for Individuals with Impaired Hearing*; positions: Ingenient Technologies, Chicago, IL; Motorola, Schaumburg, IL.
20. Laura Drake, defense date June 2001; Thesis topic: *Sound Source Separation via Computational Auditory Scene Analysis (CASA)-Enhanced Beamforming*.
21. Carlos E. Luna, Ph. D. awarded June 2002; Thesis topic: *Video Quality and Network Efficiency Trade-Offs in Video Streaming Applications*; current position: Boeing, CA.
22. C. Andrew Segall, Ph. D. awarded June 2002; Thesis topic: *Framework for the Post-Processing, Super-Resolution and Deblurring of Compressed Video*; current position: Sharp Labs, WA.
23. Antonio Lopez Fernandez, Ph.D. degree awarded summer 2002 (co-advisor, University of Granada); Thesis topic: *Parameter Estimation in Bayesian Reconstruction of SPECT Images using Gauss Markov Models*; current position: Assistant Professor, University of Granada.
24. Javier Abad Ortega, Ph.D. degree awarded summer 2003 (co-advisor, University of Granada); Thesis topic: *Bayesian Image Restoration and Reconstruction Using Multichannel Decomposition*; current position: Assistant Professor, University of Granada.
25. Fan Zhai, Ph.D. degree awarded June 2004 Thesis topic: *Cross-layer Resource Allocation for Video Transmission over Packet Lossy Networks*; current position: Texas Instruments, TX.
26. Yiftach Eisenberg, Ph.D. degree awarded June 2004; Thesis topic: *Optimal Resource Allocation in Stochastic Video Communication Systems*; current position: Program Manager, DARPA, Washington, DC.
27. Petar Aleksic, Ph.D. degree awarded June 2004; Thesis topic: *Audio-Visual Interactions in Multimodal Communications Using Facial Animation Parameters*; current position: Google, NY, NY.
28. Haohong Wang, Ph.D. degree awarded June 2004; Thesis topic: *Optimal Resource Allocation in Object-Based Video Encoding*; current position: TCL-Thomson Electronics, San Jose, CA.
29. Zhilin Wu, Ph.D. degree awarded June 2004; Thesis topic: *Feature Extraction for Audio-Visual Interactions*; current position: University of Wisconsin, WI.
30. James Li, Ph.D. degree awarded June 2004; Thesis topic: *Rate-Distortion Based Video Summarization*; current position: Samsung, TX.
31. Sotirios Tsaftaris, Ph. D. degree awarded June 2006; Thesis topic: *DNA Computing*; current position: Assistant Professor, IMT Lucca, Italy.
32. Peshala Pahalawata, Ph. D. degree awarded Dec. 2007; Thesis topic: *Downlink Packet Scheduling and Resource Allocation for Multiuser Video Transmission Over Wireless Networks*; current position: Senior Research Engineer, Dolby Laboratories.
33. Stefanos Belekos, Ph.D. degree awarded June 2009; Thesis topic: *Bayesian Techniques for*

Super-Resolution of Compressed and Uncompressed Video; current position: Vodafone, Greece.

34. Sevkett Derin Babacan, Ph. D. degree awarded Dec. 2009; Thesis topic: *Bayesian Techniques for Image Recovery*; current position: Google, Mountain View, CA.

35. Ehsan Maani, Ph. D. degree awarded Dec. 2009; Thesis topic: *Scalable Video Transmission*; current position: Sony, San Jose, CA.

36. Passant Karunaratne, Ph. D. awarded June 2010; Thesis topic: *Pre-Processing and Post-Processing Methods for Video Compression*; current position: Microsoft, Seattle, WA.

37. Glafkos Stratis, Ph. D. awarded June 2010; Thesis topic: *Quantization of Polarization States through Scattering Mechanisms*; current position: Ryttheon, Tucson, AZ (co-advised with Prof. Taflove).

38. Fan Jiang, Ph. D. awarded Dec. 2010; Thesis topic: *Anomalous Event Detection from Surveillance Video*; current position: Amazon, Seattle, WA.

39. Eren Soyak, Ph. D. awarded March 2011; Thesis topic: *Tracking Optimized Video Compression*; current position: Director, Systems Engineering, AirTies Wireless Networks, Istanbul, Turkey.

40. Louis Terry, Ph. D. awarded March 2011; Thesis topic: *Audio-Visual Asynchrony Modeling and Analysis for Speech Alignment and Recognition*; current position: Quantitative Trader, Chopper Trading, Chicago, IL.

41. Xiaoming Yin, Ph. D. awarded June 2011; Thesis topic: *Exponential Signal Models for Gradient Echo Imaging in MRI*; current position: Citigroup, NY, NY.

42. Martin Luessi, Ph. D. awarded August 2011; Thesis topic: *Bayesian Approaches to Inverse Problems in Functional Neuroimaging*; current position: Postdoctoral Research Fellow, Massachusetts General Hospital and Harvard Medical School.

43. Bruno Amizic, Ph. D. awarded June 2014; Thesis topic: *Bayesian Blind Image Restoration*; current position: The Boeing Company, CA.

44. Li Gao, Ph.D. awarded June 2014; Thesis topic: *Use of Global and Local Features for Fast Video Search*; current position: Quantum Data Inc, IL.

45. Xin Xin, Ph.D. awarded June 2014; *Compact Descriptors for Visual Search*; current position: Microsoft, Seattle, WA.

46. Zhaofu Chen, Ph.D. awarded June 2014; *Multidimensional Signal Processing for Sparse and Low-Rank Problems*; **EECS Best Thesis Award**; current position: Google, Mountain View, CA.

47. Bao Wang, Ph.D. awarded June 2015; current position: Microsoft, Seattle, WA.

48. Pablo Ruiz, Ph.D. awarded September 2015; *Bayesian Modeling and Inference in Image Recovery and Classification Problems*; current position: University of Granada, Spain.

49. Jeremy Watt, Ph. D. awarded December 2015; *Feature Learning: Novel Algorithms and Unifying Perspectives*; current position: Northwestern University.

50. Michael Iliadis, Ph. D. awarded June 2016; *Sparse Representation and Deep Learning for*

Image and Video Reconstruction; current position: Sony, CA.

51. Leonidas Spinoulas, Ph. D. awarded June 2016; *Design and Analysis of Coded Mask Imaging Systems*; current position: USC/ISI, CA.

52. Reza Borhani, Ph. D. awarded June 2016; current position: University of Chicago, IL.

53. Armin Kappeler, Ph. D. awarded June 2016; *Deep Neural Networks with Applications in Image and Video Classification and Recovery*; current position: Yahoo, CA.

54. Matthew Woods, Ph. D. awarded August 2016; current position: Northrop-Grumman, IL.

55. Evaggelia Tsiliogianni, Ph. D. awarded June 2016; current position: University of Ioannina, Greece.

56. Qiqin Dai, Ph. D. awarded June 2017; *Solution of Inverse Problems using Learning*; current position: Zoloz, CA.

57. Seunghwan Yoo, Ph. D. awarded June 2018; *3D Image Reconstruction from Multi-Focus Microscopy*; current position: Motorola Mobility, Chicago, IL.

58. Neda Rohani, Ph.D. awarded Dec. 2018; *Machine Learning for Multi-Sensory Data*; current position: Microsoft Research, WA.

59. Arun Sankisa, Ph. D. awarded Dec. 2018.

60. Juan Gabriel Serra Perez, Ph. D. awarded June 2019.

61. Alice Lucas, Ph.D. awarded June 2020.

62. Arjun Punjabi, Ph. D. awarded June 2020.

63. Sara Bahaadini, Ph. D. awarded Dec. 2019; current position: Microsoft, San Francisco, CA.

64. Yanran Wang, Ph.D. awarded June 2019.

65. Pablo Morales-Alvarez, Ph.D. awarded June 2020; current position: University of Granada.

66. Santiago Lopez Tapia, Ph. D. awarded June 2021; current position: Northwestern University.

67. Semih Barutcu, Ph. D. awarded June 2022; current position: Uber, NY, NY.

68. Emanuel Azcona, Ph. D. awarded June 2022; current position: Nike, Seattle, WA.

69. Srutarshi Banerjee, Ph. D. awarded June 2022; current position: Argonne National Laboratory, Chicago, IL.

70. Miguel López-Pérez, Ph.D. awarded June 2022; current position: Northwestern University.

71. Fernando Pérez Bueno, Ph.D. awarded June 2022; current position: University of Granada, Spain.

72. Henry Chopp, Ph. D. awarded June 2023; current position: Northwestern University.

73. Xijun Wang, Ph.D. awarded June 2024; current position: Purdue University.
74. Yunan Wu, Ph. D. awarded June 2024.
75. Peng Kang, Ph. D. awarded June 2024.
76. Shamal Lalvani, Ph.D. awarded Aug. 2024.
77. Xinyi Wu, Ph. D. awarded Aug. 2024.

GRADUATE STUDENT SUPERVISION

Pre-Doctoral Visitor Supervision

1. Javier Mateos, Universidad de Granada, Spain, Fall 1997, Winter 1998.
2. Luis D. Alvarez, Universidad de Granada, Spain, 2003-2004.
3. Reto Ansorge, Hochschule fur Technik Rapperswil, Switzerland, Fall 2004.
4. Erwin Kirchmeier, Hochschule fur Technik Rapperswil, Switzerland, Fall 2004.
5. Martin Luessi, Hochschule fur Technik Rapperswil, Switzerland, Fall 2005.
6. Marco Eichmann, Hochschule fur Technik Rapperswil, Switzerland, Fall 2005.
7. Roger Merz, Hochschule fur Technik Rapperswil, Switzerland, Fall 2006.
8. Rolf Haller, Hochschule fur Technik Rapperswil, Switzerland, Fall 2006.
9. Valentin Andermatt, Hochschule fur Technik Rapperswil, Switzerland, Fall 2007.
10. Andr Schlegel, Hochschule fur Technik Rapperswil, Switzerland, Fall 2007.
11. Stefanos Belekos, National and Kapodistrian University of Athens, Greece, Spring 2008.
12. Haomian Zheng, Hong Kong Polytechnic University, Fall 2009.
13. Fang Liu, Hong Kong University of Science and Technology (HKUST), April-Sept. 2010.
14. Miguel Tallon, Universidad de Granada, Spain, Fall 2010.
15. Kevin Trmpi, Hochschule fur Technik Rapperswil, Switzerland, Fall 2010.
16. Marc Vettiger, Hochschule fur Technik Rapperswil, Switzerland, Fall 2010.
17. Lasya Priya Kotu, University of Stavanger, Stavanger, Norway, Fall 2011-Winter 2012.
18. Lei Song, Northwestern Polytechnical University, Xi'an, China, 2010-2012.
19. Li Tao, Beijing Institute of Technology, 2011-2013.
20. Pablo Ruiz Mataran, Universidad de Granada, Spain, Fall 2013, Fall 2014.
21. Thomas Niederberger, Hochschule fur Technik Rapperswil, Switzerland, Sept. 2013-

Jan. 2014.

22. Lukas Schmid, Hochschule fur Technik Rapperswil, Switzerland, Febr. 2014-Aug. 2014.
23. Roman Koller, Hochschule fur Technik Rapperswil, Switzerland, Febr. 2014-Aug. 2014.
24. Ali Bahrami Rad, University of Stavanger, Stavanger, Norway, Summer-Fall 2014.
25. Huyen Vu, University of Stavanger, Stavanger, Norway, Spring-Summer 2015.
26. Juan Gabriel Serra Perez, Universidad de Granada, Spain, Fall 2017.
27. Aris Chimariotis, Aristotle University of Thessaloniki, Fall 2017, Spring 2017.
28. Patrick Koller, Hochschule fur Technik Rapperswil, Switzerland, Fall 2023.

Post-Doctoral Supervision

1. Moongi Kang, Northwestern University, 1994.
2. Lisimachos Kondi, Northwestern University, 1999.
3. Laurent Mugnier, Office national d'études et de recherches aérospatiales (ONERA), Paris, France, 1995.
4. Derin Babacan, Northwestern University, 2010.
5. Jin Qi, University of Electronic Science & Technology of China, Chengdu, China, March 2012-February 2013.
6. Chenghao Liu, Tampere University of Technology, Tampere, Finland, Winter 2014.
7. Marina Alterman, Technion-Israel Institute of Technology, Summer 2015-Summer 2017.
8. Pablo Ruiz Mataran, Universidad de Granada, Spain, Jan. 2017-2020.
9. Yudong Yao, Chinese Academy of Sciences, Summer 2017-2020.
10. Juan Gabriel Serra Perez, Universidad de Granada, Spain, Sept. 2018-Aug. 2021.
11. Santiago Lopez Tapia, Universidad de Granada, Spain, Sept. 2021-now.
12. Hasan Asyari Arief, Norce Norway, March 2022-Sept. 2023.
13. Henry Chopp, Northwestern University, June 2023-now.
14. Asami Odate, Northwestern University, Aug. 2023-now.

Visiting Professors

1. Prof. Rafael Molina, Universidad de Granada, Spain, Fall 2005.
2. Prof. Ian T. Young, Delft University of Technology, 2000.
3. Prof. Nicolas Maglaveras, Aristotle University of Thessaloniki, Fall 2016-Fall 2020.

4. Prof. Christoph Wursch, Hochschule fur Technik Rapperswil, Switzerland, Sept. 2023-Feb. 2024.

Current Students

Deanna Dimonte, Ph. D. expected June 2025.
Amit Adate, Ph. D. expected June 2025.
Hui Lin, Ph. D. expected June 2025.
Charilaos Apostolidis, Ph.D. degree expected June 2027.
Lawrence Chillrud, Ph.D. degree expected June 2027.
Jiaqi Guo, Ph.D. degree expected June 2027.
Ugur Demir, Ph.D. degree expected June 2027.
Manuel Ballester Matito, degree expected June 2026.
Shinjan Dutta, degree expected June 2027.

SERVICE TO ACADEMIC COMMUNITY

Departmental Committees

EE PhD Qualifying Exam Committee (85/86) Colloquium Committee (87/88-90/91) Laboratory Budget Committee (87/88, 88/89) EE Program Committee (87/88, 88/89)
Faculty Search Committee, Communications Area (87/88, 98/99, 01/03) Faculty Search Committee, Signal Processing Area (98/99, 01/02) Curriculum Committee (89/90, 90/91, 92/present)
Computer Resources Committee (90/91, 91/92)
Teaching Assistant Counselor (90/91, 91/92, 92/93, 93/94) Laboratory Committee (91/92, 92/93, 93/94)
EE Junior Advisor (87/88, 91/92, 95/96, 99/00, 03/04, 07/08, 14/15), Senior Advisor (88/89, 92/93, 96/97, 00/01, 04/05, 09/10), Freshman Advisor (89/90, 93/94, 97/98, 01/02, 05/06, 09/00, 12/13), Sophomore Advisor (90/91, 94/95, 98/99, 02/03, 06/07, 10/11, 13/14)
Graduate Committee (92/93; chair: 93/94; 2010-present) Group Coordinator (92-05)
ECE Executive Committee Chair (96/98)
ECE Member of the Promotions, Tenure, Recruitment and Improvement Committee (1998-2001)
EE Undergraduate Curriculum Committee (2008-present)
Publicity, Alumni and Industrial Relations Committee (2008-15; Chair: 2015-present)
Teaching and External Awards Committee (2008-present)

McCormick Committees

Tech Library Resource Committee (90/91)

Academic Standing Committee (91/92, 92/93, 96/99, 00/03)

Center for Information and Telecommunication Technology (1988-1992) Tech Corporate Partner Liaison: US Robotics (89-94), Ameritech (95-99) Promotion and Tenure Committee (1997-99, 2001-03, 2005-07, 2013-15)

Promotion and Tenure Ad Hoc Committee Member (2003, 2004, 2008, 2009, 2010, 2011, 2012)

Cooperative Engineering Education (2009-10)

Computer Resources Committee (2005-2015)

Global McCormick Ambassador for Spain (2014-present)

NAISE Fellow (2018-present)

University Committees

Medical School ad hoc Promotion and Tenure Committee (2000-2001) Nicholson Fellowship Committee (1998-2003)

Steering Committee Member, Language, Music, and Communications Group, Northwestern Institute on Complex Systems (2006-present)

Member, Standing Advisory Limited Submissions Committee (2008-2010)

Academic Advisory Board Member, Center for Advanced Molecular Imaging (2009-present)

Advisory Board Member, Center for Interdisciplinary Exploration and Research in Astrophysics (2014-present)

PROFESSIONAL ACTIVITIES

Editor-in-Chief, *IEEE Signal Processing Magazine* (1997-2002)

Member, Board of Governors, IEEE Signal Processing Society (1999-2001) Member, Publication Board, IEEE Signal Processing Society (1997-2002) Member, IEEE TAB Magazine Committee (1998-2002)

Member, IEEE Signal Processing Society Awards Board (2014-2016)

Member of Scientific Board, Centre for Research and Technology Hellas-CE.R.T.H. (2000)

Member, Advisory Board, International Graduate School in Information and Communication Technology, Trento, Italy (2004-present)

Editorial Board Member of Academic Press (1998-present)

Editorial Board Member of Marcel Dekker, Signal Processing Series (1998-present) Editorial

Board Member of *Applied Signal Processing* (2001-2007)

Editorial Board Member of *Computer Journal* (2001-2007) Editorial Board Member of *IEEE Proceedings* (2002-2007)

Editorial Board Member of *IEEE Signal Processing Magazine* (2002-2006)

Editorial Board Member of *EURASIP Journal on Image and Video Processing* (2006-present)

Editorial Board Member of *Advances in Multimedia* (2006-present)

Steering Committee Member, *IEEK Transactions on Smart Processing & Computing (IEEK SPC)* (2012-present)

Associate Editor, *IEEK Transactions on Smart Processing & Computing (IEEK SPC)* (2012-present)

Associate Editor, *IEEE Transactions on Signal Processing* (1990-1992) Area Editor, Graphical Models and Image Processing (1992-1995)

Guest Editor, *Journal of Visual Communications and Image Representation*, special issue on *Image Restoration*, Nov. 1992

Guest Editor, *IEEE Transactions on Image Processing*, Special issue on *Application of Artificial Neural Networks to Image Processing*, Aug. 1998.

Editorial Board Representative, *Applied Signal Processing*, special issue on *Applied Visual Inspection*, 2002.

Editorial Board Representative, *Applied Signal Processing*, special issue on *Multimedia Human-Computer Interface*, 2002.

Guest Editor, *EURASIP Journal on Applied Signal Processing*, special issue on “*Signal Processing Technologies for Ambient Intelligence in Home-Care Applications*”, 2007.

Guest Editor, *Computer Journal*, special issue on *Super-resolution of Images and Video*, 2008.

Member, Editorial Advisory Board, *Visual Speech Recognition: Lip Segmentation and Mapping*, Information Science Reference, 2008.

Member, Advisory Board, *Journal of Communications*, Academy Publishers (2008-present).

Member, European Commission, *Future Media and 3D Internet Task Force (FM3DI-TF)*, (May 2008-present).

Participant, Cost Action 283 and Cost Action 292

Invited Member, 2008 Research and Development Exchange Workshop, President’s National Security Telecommunications Advisory Committee, Sept. 2008.

Lead Guest Editor, *IEEE Transactions on Multimedia*, Special Issue on *Quality-Driven Cross-Layer Design for Multimedia Communications*, Oct. 2009.

Member, IEEE Connexions Lensing Oversight Committee (2007-present)

Advisory Board Member, Knowledge Space of Shared Technology and Integrative Research to Bridge the Semantic Gap, European Network of Excellence, 2005-2008.

Advisory Board Member, 3D Life, European Network of Excellence, 2010-2013. Advisory Board

Member, REVERIE, European Network of Excellence, 2012-2015. Advisor, Image, Video and Mesh Coding Interest Group (IMVIMEC-IG), 2012-present

Member, Senior Editorial Board, *IEEE Journal of Selected Topics in Signal Processing* (2009-present)

Editorial Board Member, *ICT Academy of Tamil Nadu, ICTACT Journals* (2011-present)

Member, Steering Committee, *IEEE International School of Imaging* (2013-present) Editorial Board Member, *Journal of Imaging* (2014-present)

Member of SPIE

Member of the IEEE-SP Technical Committee on Image and Multidimensional Signal Processing (IMDSP) (1990-1998)

Founding Member of the IEEE-SP Technical Committee on Multimedia Signal Processing (MMSP) (1996-present)

Member of the IEEE-CAS Technical Committee on Visual Signal Processing and Communications (1989-present)

Member of the Steering Committee of the IEEE Transactions on Medical Imaging as a representative of the IEEE Signal Processing Society (1990-1999)

Member of the Steering Committee of the IEEE Transactions on Image Processing as a representative of the IEEE Control Systems Society (1991-1997)

Member of the Executive Committee of SPIE Chicago Regional Chapter (1988-1991; chaired the Nominating Committee 1990-1991)

Member of the Steering Committee of Visual Communications and Image Processing Conference (1988-present)

Member of the Executive Committee of Visual Communications and Image Processing Conference (1994-present)

Member of the Organizing Committee of Optical Engineering Midwest Conference (1989-1994)

Chairman of the IEEE-MDSP Technical Subcommittee for the establishment of an IEEE Digital Image Database

Registration Chairman, 1992 American Control Conference, Chicago, IL, June 1992.

Publicity Chairman, IEEE 1993 International Conference on Acoustics, Speech, Signal Processing, Minneapolis, MN.

Publicity Chairman, 1993 European Signal Processing Conference, Edinburgh, Scotland, Sept. 1994.

General Chairman, 1994 SPIE Conference on Visual Communications and Image Processing, Chicago, Illinois, Sept. 1994

General Co-Chairman, SPIE Conference on Artificial Neural Networks for Image Processing, San Jose, CA, 1995-present.

Member of Program Committee, International Workshop on Stereoscopic and Three-Dimensional Imaging, Santorini, Greece, Sept. 6-8, 1995.

Member of International Program Committee, IASTED International Conference on Signal and Image Processing, SIP-95, SIP-96, SIP-97

General Co-Chairman, 1996 Conference on Digital Compression Technologies and Systems for Video Communications, Berlin, Germany, Oct. 1996.

Member of Program Committee, International Workshop on Synthetic-Natural Hybrid Coding and Three-Dimensional Imaging (IWSNHC3DI'97), Rhodes, Greece, Sept. 7-9, 1997.

Technical Program Co-Chair, IEEE 1998 International Conference on Image Processing, Chicago, IL, Oct. 1998.

Member of Technical Program Committee, Erlangen Workshop '99, "Vision, Modeling, and Visualization," Nov. 17-19, 1999, Erlangen, Germany.

Member of Technical Program Committee, Int. Workshop on Synthetic-Natural Hybrid Coding and 3D Imaging, Sept. 15-17, 1999, Santorini, Greece.

Member of Technical Program Committee, Packet Video Workshop (PV2000), Cagliari, Sardinia, Italy, May 1-2, 2000.

Member of Technical Program Committee, Workshop on Vision, Modeling, and Visualization 2000, Max-Planck-Institut fuer Informatik, Saarbruecken, Germany, Nov. 22-24, 2000.

Advisory Committee Member, International Symposium on Multimedia Information Processing, Dec. 13-15, 2000, Sydney, Australia.

Member of Program Committee, EUROIMAGE 2001, International Conference on Augmented, Virtual Environments and 3D Imaging, Mykonos, Greece, May 30-June 1, 2001.

Member of Technical Program Committee, IEEE International Conference on Multimedia and Expo (ICME 2001), Tokyo, Japan, Aug. 2001.

Member of Technical Program Committee, IEEE Workshop on Multimedia Signal Processing 2001, Cannes, France, Oct. 3-5, 2001.

Member of Program Committee, IEEE 2001 International Conference on Image Processing, Thessaloniki, Greece, Oct. 2001.

Member International Technical Program Committee, 14th International Conference on Digital Signal Processing, Santorini, Greece, July 1-3, 2002.

Member International Technical Program Committee, IEEE Intl. Conf. on Multimedia and Expo (ICME 2002), Lausanne, Switzerland, August 2002.

Member Technical Program Committee, 4th International Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS-03), London, England, April 9-11, 2003.

Member Technical Program Committee, 1st Iberian Conference on Pattern Recognition and Image Analysis (IbPRIA 2003), Puerto de Andratx, Mallorca, Spain, June 4-6, 2003.

Member, Steering Committee, International Workshop Very Low-Bit Video (VLBV03), Madrid, Spain, September 18-19, 2003.

Member Technical Program Committee, 5th International Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS-04), Lisboa, Portugal, April 21-23, 2004.

Panelist, *Image and Video Analysis: Trends and Challenges*, 5th International Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS-04), Lisboa, Portugal, April 21-23, 2004.

Member Technical Program Committee, 3rd International Symposium in Sensor Networks (IPSN'04), Berkeley, CA, April 26-27, 2004.

Member Technical Program Committee, IEEE International Workshop on Multimedia Signal Processing (MMSP-04), Siena, Italy, Sept. 29 - Oct. 1, 2004.

Member Technical Program Committee, 6th International Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS-05), Montreux, Switzerland, April 13-15, 2005.

Member Technical Program Committee, IEEE Int. Workshop on Genomic Signal Processing and Statistics (GENSIP-05), Newport, Rhode Island, May 22-24, 2005.

Member Technical Program Committee, OSA Computational Sensing and Imaging, Charlotte, NC, June 6-9, 2005.

Member Technical Program Committee, 2nd Iberian Conference on Pattern Recognition and Image Analysis (IbPRIA 2005), Estoril, Portugal, June 7-9, 2005.

General Co-Chairman, First International Conference on Multimedia Services Access Networks (MSAN 2005), Orlando, FL, June 13-15, 2005.

Member Technical Program Committee, IEEE International Conference on Multimedia and Expo (ICME 2005), Amsterdam, The Netherlands, July 6-8, 2005.

Member International Program Committee, 12th Int. Workshop on Systems, Signals and Image Processing, Chalkida, Greece, Sept. 22-24, 2005.

Member Technical Program Committee, Intern. Workshop on Multimedia Signal Processing (MMSP-05), Shanghai, China, Oct. 30 - Nov. 2, 2005.

Member Technical Program Committee, Pacific-Rim Conference on Multimedia (PCM2005), Jeju, Korea, Nov. 13-16, 2005.

Member Scientific Committee, X Iberoamerican Congress on Pattern Recognition, Havana, Cuba, Nov. 15-18, 2005.

Member Technical Program Committee, 2nd European Workshop in the Integration of Knowledge, Semantic, and Digital Media Technologies (EWIMT2005), London, UK, Nov. 30 - Dec. 1, 2005.

Member Technical Program Committee, 7th International Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS-06), Incheon, Korea, April 19-21, 2006.

Member Technical Program Committee, IEEE Int. Workshop on Genomic Signal Processing and Statistics (GENSIP-06), College Station, TX, May 28-30, 2006.

Member Technical Program Committee, 2nd Int. Symposium of Multimedia over Wireless (IWCMC 2006), Vancouver, Canada, July 3-6, 2006.

Member Technical Program Committee, 14th European Signal Processing Conference (EUSIPCO 2006), Florence, Italy, Sept. 4-8, 2006.

Member International Program Committee, 13th International Conference on Systems, Signals and Image Processing, Budapest, Hungary, Sept. 21-23, 2006.

Member Technical Program Committee, IEE Conference on Visual Information Engineering, Bangalore, India, Sept. 26-28, 2006.

Member Technical Program Committee, Pacific-Rim Conference on Multimedia (PCM2006), Hangzhou, China, Nov 2-4, 2006.

Member Technical Program Committee, 11th Iberoamerican Congress on Pattern Recognition, Cancun, Mexico, Nov. 14-17, 2006.

Member Technical Program Committee, International Conference on Semantic and Digital Media Technologies (SAMa06), Athens, Greece, Dec. 7-8, 2006.

Member Technical Program Committee, International Workshop on Advanced Multimedia Technology and Applications (AMTA2006), Korea, 2006.

Member International Program Committee, International Workshop on Telecommunications (IWT07), Santa Rita do Sapucaí, Brazil, Feb. 12-15, 2007.

Member Technical Program Committee, 8th International Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS-07), Santorini, Greece, June 6-8, 2007.

Member International Steering Committee, Computational Optical Sensing and Imaging, Vancouver, Canada, June 18-20, 2007.

Member Technical Program Committee, IEEE International Conference on Multimedia and Expo (ICME 2007), Beijing, China, July 2-5, 2007.

Member Technical Program Committee, 15th European Signal Processing Conference (EUSIPCO 2007), Poznan, Poland, Sept. 3-7, 2007.

Member International Steering Committee, Picture Coding Symposium (PCS 2007), Lisbon, Portugal, Nov. 7-9, 2007.

Member Technical Program Committee, 12th Iberoamerican Congress on Pattern Recognition, Via del Mar-Valparaíso, Chile, Nov. 13-16, 2007.

Member Technical Program Committee, Int. Conf. on Advanced Engineering Computing and Applications in Sciences (ADVCOMP 2008), Valencia, Spain, Sept. 29 - Oct. 4, 2008.

Special Sessions/Workshops Co-Chair, Int. Conf. on Image Processing (ICIP 2008), San Diego, CA, Oct. 12-15, 2008.

Member Technical Program Committee, Mosharaka Int. Conf. on Communications, Networking and Information Technology (MIC-CNIT 2008), Amman, Jordan, Dec. 4-6, 2008.

Member Technical Program Committee, 7th ACM SIGGRAPH Int. Conf. on Virtual-Reality Continuum and its Applications in Industry (VRCAI 2008), Biopolis, Singapore, Dec. 8-9, 2008.

Technical Program Co-Chair, Int. Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS-09), London, UK, May 6-8, 2009.

Technical Program Co-Chair, Picture Coding Symposium (PCS-09), Chicago, IL, May 6-8, 2009.

Member, Technical Program Committee, IEEE International Workshop on Genomic Signal Processing and Statistics (GENSIPS 2009), Minneapolis, Minnesota, May 17-21, 2009.

Member International Program Committee, Int. Symposium on Programming and Systems (ISPS 2009), Algiers, Algeria, May 18-20, 2009.

Member, Program Committee, International Workshop on Content-Based Multimedia Indexing (CBMI 2009), Chania, Crete, Greece, June 3-5, 2009.

Member, Technical Program Committee, Int. Conf. on Digital Signal Processing (DSP 2009), Santorini, Greece, July 5-7, 2009.

General Co-Chair, Int. Conf. on Computer Communications and Networks (ICCCN 2009), San Francisco, CA, Aug. 2-6, 2009.

Member, Technical Program Committee, IEEE Workshop on Multimedia Computing and Communications, San Francisco, CA, Aug. 2-6, 2009.

General Co-Chair, Latin-American Conference on Networked and Electronic Media (LACNEM 2009), Bogota, Colombia, Aug. 4-6, 2009.

Reviewer for the Department of Energy of the Large Scale Geospatial Image Indexing and Retrieval Program, Oak Ridge National Laboratory, Oak Ridge, TN, March 23, 2010.

Member Technical Program Committee and US Liaison, 11th International Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS-10), Desenzano de Garda, Italy, April 12-14, 2010.

General Co-Chair, 1st Int. ICST Conf. on User Centric Media - UCMedia 2009, Venice, Dec. 9-11, 2009.

Member International Advisory Committee, 5th IEEE Int. Conf. on Industrial Electronics and Applications (ICIEA 2010), Taichung, Taiwan, June 15-17, 2010.

Member Technical Program Committee, Visual Communications and Image Processing, Huang Shan, China, July 11-14, 2010.

Technical Program Co-Chair, Latin-American Conference on Networked and Electronic Media (LACNEM 2010), Cali, Colombia, Sept. 8-10, 2010.

Member, International Advisory Committee, Sensor Signal Processing for Defense Conference, London, UK, Sept. 29-30, 2010.

Member, Best Paper Award Committee, IEEE Global Communications Conference (GLOBECOM 2010), Miami, FL, Dec. 6-10, 2010.

Member, International Steering Committee, Picture Coding Symposium, Nagoya, Japan, Dec. 7-10, 2010.

Member, Program Committee, ACM SIGGRAPH Int. Conf. on Virtual-Reality Continuum and its Applications to Industry (VRCAI 2010), Seoul, Korea, Dec. 12-13, 2010.

Member, Technical Program Committee, Workshop on Future Media Networks and IP-based TV (FMN-IPTV), Shanghai, April 10-15, 2011.

Member, Technical Program Committee, 12th International Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS-11), Delft, The Netherlands, April 13-15, 2011.

Member, Technical Program Committee, Int. Conf. on Digital Signal Proc. (DSP 2011), Corfu, Greece, July 6-8, 2011.

Member, Technical Program Committee, IEEE Int. Conf. on Multimedia and Expo (ICME 2011), Barcelona, Spain, July 11-15, 2011.

Area Chair and Member, Technical Program Committee, Int. Conf. on Image Processing (ICIP 2011), Brussels, Belgium, Sept. 11-14, 2011.

Member, International Advisory Committee, Sensor Signal Processing for Defense Conference, London, UK, Sept. 28-29, 2011.

Member, Technical Program Committee, Int. Visual Communications and Image Processing (VCIP2011) Conference, Tainan City, Taiwan, Nov. 6-9, 2011.

Panelist, "Future of 3D Media Industry," EMC² Industry Day, Berlin, Germany, Nov. 14, 2011.

Member, Technical Program Committee, The 16th Iberoamerican Congress on Pattern Recognition, Pucon, Chile, Nov. 15-18, 2011.

Technical Program Co-Chair, Latin-American Conference on Networked and Electronic Media (LACNEM 2011), San Jose, Costa Rica, Nov. 17-19, 2011.

Member, Technical Program Committee, 10th Int. Conf. on Virtual Reality Continuum and Its Applications in Industry (ACM SIGGRAPH VRCAI 2011), Hong Kong, Dec. 11-12, 2011.

Site reviewer at Trinity College Dublin, for the Science Foundation Ireland, Dublin, Ireland, Jan. 30-31, 2012.

Member, Technical Program Committee, Int. Conf. on Computing, Networking and Communications, Multimedia Computing and Communications Symposium (ICNC-12), Maui, Hawaii, Jan. 30 - Feb. 2, 2012.

Member, Technical Program Committee, 8th Int. Conf. on Networking and Services (ICNS 2012), St. Maarten, The Netherlands Antilles, March 25-29, 2012.

Member, Technical Program Committee, Int. Conf. on Systems, Signals and Image Processing (IWSSIP 2012), Vienna, Austria, April 11-13, 2012.

Member, Technical Program Committee, IEEE Southwest Symposium on Image Analysis and Interpretation (SSIAI), Santa Fe, NM, April 22-24, 2012.

Member, International Steering Committee, Picture Coding Symposium (PCS-12), Krakow, Poland, May 7-9, 2012.

Member, Technical Program Committee, 19th Int. Packet Video Workshop, Munich, Germany, May 10-11, 2012.

US Liaison, 13th Int. Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS-12), Dublin City University, Ireland, May 23-25, 2012.

Member, Technical Program Committee, The IET Image Processing Conference (IPR-12), London, UK, July 3-4, 2012.

Member, Technical Program Committee, Int. Conf. on Advances in Computing, Communications and Informatics (ICACCI-2012), Chennai, India, August 3-5, 2012.

Member, Technical Program Committee, IEEE Statistical Signal Processing (SSP) Workshop, Ann Arbor, MI, Aug. 5-8, 2012.

Member, Technical Program Committee, The 17th Iberoamerican Congress on Pattern Recognition, Buenos Aires, Argentina, Sept. 3-6, 2012.

Member, Regional Chair, Latin-American Conference on Networked and Electronic Media (LACNEM 2012), Santiago de Chile, Chile, Oct. 17-19, 2012.

Member, Technical Program Committee, Int. Conf. on Digital Signal Processing (DSP 2013), Santorini, Greece, July 1-3, 2013.

Member, Technical Program Committee, International Conference on Systems, Signals and Image

Processing (IWSSIP 2013), Bucharest, Romania, July 7-9, 2013.

Member, Technical Program Committee, First IEEE Workshop of GREEN Multimedia: Energy-efficient Multimedia Computing, Communication and Presentation, San Jose, CA, July 15 - 19, 2013.

Member, International Steering Committee, Latin-American Conference on Networked and Electronic Media (LACNEM 2013), Manizales, Colombia, Sept. 2-5, 2013.

Member, Technical Program Committee, 8th International Symposium on Image and Signal Processing and Analysis (ISPA 2013), Trieste, Italy, Sept. 4-6, 2013.

Member, International Program Committee, The 2013 Intern. Conf. on Systems, Control and Informatics, Venice, Italy, Sept. 28-30, 2013.

Member, International Program Committee, The 2013 Intern. Conf. on Applied Mathematics and Computational Methods, Venice, Italy, Sept. 28-30, 2013.

Member, International Program Committee, The 2013 Intern. Conf. on Electronics, Signal Processing and Communication Systems, Venice, Italy, Sept. 28-30, 2013.

Member, Technical Program Committee, Picture Coding Symposium (PCS-13), San Jose, CA, Dec. 8-11, 2013.

Member, Technical Program Committee, Packet Video Workshop, San Jose, CA, Dec. 12-13, 2013.

Member, Program Committee, International Conference on Educational Technologies and Education, Interlaken, Switzerland, February 22-24, 2014.

Member, Technical Program Committee, IEEE Southwest Symposium on Image Analysis and Interpretation (SSIAI), San Diego, CA, April 6-8, 2014.

Member, Scientific Committee, SIAM Conference on Imaging Science (SIAM-IS14), Hong Kong Baptist University, Hong Kong, May 12-14, 2014.

Member, Technical Program Committee, International Conference on Systems, Signals and Image Processing (IWSSIP 2014), Dubrovnik, Croatia, May 12-15, 2014.

Member, International Scientific Committee, 18th Intern. Conf. on Circuits, Systems, Communications and Computers (CSCC 2014), Santorini Island, Greece, July 17-21, 2014.

Member of International Program Committee, IEEE Int. Conference on Digital Signal Processing (DSP 2014), Hong Kong, Aug. 20-23, 2014.

Member Technical Program Committee, European Conference on Computer Vision (ECCV 2014), Workshop on "Video Event Categorization, Tagging and Retrieval Towards Big Data," Zurich, Switzerland, Sept. 6, 2014.

General Co-Chair, IEEE International Conference on Imaging Systems and Techniques, Santorini, Greece, Oct. 14-17, 2014.

Member Technical Program Committee, IEEE International Conference on Image Processing (ICIP 2014), Paris, France, Oct. 27-30, 2014.

Member Technical Program Committee, Int. Conf. on Signal Processing and Integrated Networks, Noida, India, Feb. 19-20, 2015.

Member, Technical Program Committee, The Seventh International Conferences on Advances in

Multimedia (MMEDIA 2015), Barcelona, Spain, April 19-24, 2015.

Member, International Steering Committee, Picture Coding Symposium (PCS-15), Cairns, Australia, May 31-June 3, 2015.

Member of Technical Program Committee, Packet Video Workshop (PV 2015), Sydney, Australia, June 4-5, 2015.

Member of Technical Program Committee, IEEE Intern. Conference on Multimedia and Expo (ICME2015), Torino, Italy, June 29-July 3, 2015.

Member of International Program Committee, IEEE Int. Conference on Digital Signal Processing (DSP 2015), Singapore, July 21-24, 2015.

Member of Technical Program Committee, 9th Int. Symposium on Image and Signal Processing and Analysis (ISPA 2015), Zagreb, Croatia, Sept. 7-9, 2015.

General Co-Chair, IEEE International Conference on Imaging Systems and Techniques, Macau, China, Sept. 16-18, 2015.

Member of Technical Program Committee, IEEE Southwest Symposium on Image Analysis and Interpretation (SSIAI), Santa Fe, NM, March 6-8, 2016.

Member of Organizing Committee, 2nd Global Summit and Expo on Multimedia and Applications, London, UK, Aug. 15-16, 2016.

General Co-Chair, IEEE International Conference on Image Processing (ICIP), Phoenix, Arizona, Sept. 25-28, 2016.

Co-Chair, Special Session, IEEE Int. Conference on Acoustics Speech and Signal Proc. (ICASSP), New Orleans, LA, March 5-9, 2017.

Member, Advisory Board, IEEE International Conference on Image Processing (ICIP), Athens, Greece, Oct. 7-10, 2018.

Co-Chair, Plenary Sessions, IEEE International Conference on Image Processing (ICIP), Abu Dhabi, UAE, Oct. 25-28, 2020.

Member, Technical Program Committee, International Conference on Mathematics and Computers in Science and Engineering (MACISE), Madrid, Spain, 2020.

Member, Steering Committee, PCS 2021, Bristol, June 29 - July 2, 2021.

Co-Chair, Special Session, IEEE Int. Conference on Acoustics Speech and Signal Proc. (ICASSP), Rhodes, Greece, June 4-10, 2023.

Co-Chair, Plenary Sessions, IEEE International Conference on Image Processing (ICIP), Abu Dhabi, UAE, Oct. 27-30, 2024.

Organizer, Northwestern Machine Learning Meetup

Reviewer, National Science Foundation; IEEE Press; IEEE Transactions on Signal Processing, Image Processing, Multimedia Signal Processing, Circuits and Systems for Video Technology; Circuits, Systems and Signal Processing; Signal Processing; Signal Processing: Image Communications; Computer Vision, Graphics and Image Processing; Journal of the Optical Society of America; Optical Engineering; Journal of Visual Communications and Image Processing.

Selected Sessions Organized and Chaired

Session Chairman: *Image Restoration and Modeling*, IEEE International Conference on Acoustics, Speech and Signal Processing, New York City, N.Y., April 11-14, 1988.

Session Chairman: *Image Analysis*, SPIE Conference on Visual Communications and Image Processing, Philadelphia, PA, Nov. 5-10, 1989.

Session Chairman: *3-D Image Processing*, SPIE Conference on Visual Communications and Image Processing, Lausanne, Switzerland, Oct. 1-4, 1990.

Organizer and Session Chairman: *Image Restoration*, Conference on Information Sciences and Systems, Johns Hopkins University, April 1991.

Session Chairman: *Image Restoration*, IEEE International Conference on Acoustics, Speech and Signal Processing, Toronto, Canada, May 1991.

Session Chairman: *Motion Estimation and Motion Analysis*, SPIE Conference on Visual Communications and Image Processing, Boston, MA, Nov. 11-13, 1991.

Session Chairman: *Motion Analysis and Video Coding*, SPIE Conference on Visual Communications and Image Processing, Boston, MA, Nov. 18-20, 1992.

Organizer and Session Chairman: *Video Signal Processing for Military Applications*, MILCOM '93, Boston, MA, Oct. 11-14, 1993.

Session Chairman: *Motion Estimation, Compensation II*, SPIE Conference on Visual Communications and Image Processing, Boston, MA, Nov. 9-11, 1993.

Session Chairman: *Multispectral Image Processing*, IEEE International Conference on Image Processing, Austin, TX, Nov. 13-16, 1994.

Session Chairman: *Motion Analysis and Video Coding*, SPIE Conference on Visual Communications and Image Processing, Taipei, Taiwan, May 23-26, 1995.

Organizer and Session Chairman: *Nonlinear Techniques in Image Restoration and Recovery*, 1995 IEEE Workshop on Nonlinear Signal and Image Processing, Neos Marmaras, Greece, June 20-22, 1995.

Organizer and Session Chairman: *Very Low Bit Rate Video Coding*, International Conference on Digital Signal Processing, Limassol, Cyprus, June 26-28, 1995.

Session Chairman: *Restoration/Enhancement*, IEEE International Conference on Image Processing, Washington, D.C., Oct. 23-26, 1995.

Session Chairman: *Video Coding*, SPIE Conference on Visual Communications and Image Processing, Orlando, FL, March 18-20, 1996.

Session Chairman: *Image Enhancement and Restoration*, IEEE International Conference on Acoustics, Speech and Signal Processing, Atlanta, GA, May 7-10, 1996.

Session Chairman: *Region Segmentations*, IEEE International Conference on Image Processing, Lausanne, Switzerland, Sept. 16-19, 1996.

Organizer and Session Chairman: *Multimedia Signal Processing*, International Conference on Digital Signal Processing, Santorini, Greece, July 2-4, 1997.

Session Chairman: *Image Processing*, IEEE International Symposium on Circuits and Systems,

Hong Kong, June 9-12, 1997.

Session Chairman: *Robust Video*, IEEE International Conference on Image Processing, Santa Barbara, CA, Oct. 26-29, 1997.

Organizer and Session Chairman: *Video Compression and Communications*, European Signal Proc. Conference, Rhodes, Greece, Sept. 8-11, 1998.

Session Chairman: *Video Processing*, 1999 IEEE Workshop on Nonlinear Signal and Image Processing, Antalya, Turkey, June 20-23, 1999.

Session Chairman: *Transform Techniques*, IEEE International Conference on Acoustics, Speech and Signal Processing, Phoenix, Arizona, March 15-19, 1999.

Session Chairman: *Motion Estimation*, IEEE International Conference on Image Processing, Kobe, Japan, Oct. 24-28, 1999.

Session Chairman: *Motion Estimation*, IEEE International Conference on Acoustics, Speech and Signal Processing, Istanbul, Turkey, June 5-9, 2000.

Session Chairman: *Face Video Analysis and Synthesis*, IEEE International Conference on Multimedia and Expo, New York, NY, July 30-Aug. 2, 2000.

Session Chairman: *Motion Estimation*, IEEE International Conference on Image Processing, Vancouver, Canada, Sept. 10-13, 2000.

Session Chairman: *Signal Processing for Media Integration*, IEEE International Conference on Acoustics, Speech and Signal Processing, Salt Lake City, Utah, May 7-11, 2001.

Session Chairman: *Image Restoration*, IEEE International Conference on Image Processing, Thessaloniki, Greece, Oct. 7-10, 2001.

Panel Chair: *Wireless, Internet, and Mobile Communications*, Inter. Workshop on Very Low Bit Rate Video Coding, Athens, Greece, Oct. 11-12, 2001.

Session Chairman: *Motion Detection and Estimation*, IEEE International Conference on Image Processing, Rochester, NY, Sept. 22-25, 2002.

Session Chairman: *Robust and Scalable Coding*, IEEE International Conference on Acoustics, Speech and Signal Processing, Montreal, Canada, May 17-21, 2004.

Session Chairman: *Video Object Segmentation and Tracking*, IEEE International Conference on Image Processing, Genova, Italy, Sept. 11-14, 2005.

Special Session Organizer, *Content Aware Video Coding and Communication for Ubiquitous Adaptation*, IEEE Int. Workshop on Multimedia Signal Processing (MMSP), Shanghai, China, Oct. 30 - Nov. 2, 2005.

Session Chairman: *Block Matching-Based Motion Estimation*, IEEE International Conference on Image Processing, Atlanta, GA, Oct. 8-11, 2006.

Panel Organizer and Chair: *Multimedia Communications*, IEEE Int. Conf. on Computer Communications and Networks (ICCCN 2007), Hawaii, Aug. 13-16, 2007

Session Chairman: *Image Restoration*, IEEE International Conference on Image Processing, San Antonio, Texas, Sept. 2007.

Session Chairman: *Descriptors and Metrics*, Sixth Int. Workshop on Content-Based Multimedia Indexing (CBMI), London, UK, June 18-20, 2008.

Panel Organizer and Chair: *The Future of Multimedia Retrieval Research*, Sixth Int. Workshop on Content-Based Multimedia Indexing (CBMI), London, UK, June 18-20, 2008.

Session Chairman: *COST292 Special Session*, 5th Int. Conference on Visual Information Engineering (VIE 2008), Xi'an China, July 29- Aug. 1, 2008.

Session Chairman: *Biomedical Image Processing*, Int. Conf. on Signal Processing, Santorini, Greece, July 5-7, 2009.

Session Chairman: *Image Deconvolution*, IEEE International Conference on Image Processing, Cairo, Egypt, Nov. 2009.

Session Chairman: *Video Transmission*, IEEE International Conference on Image Processing, Honk Kong, Sept. 2010.

Session Chairman: *Image Processing 3*, Int. Technical Conf. on Circuits/Systems, Computers and communications (ITC-CSCC), Gyeongju, Korea, June 2011.

Session Chairman: *Error Resilience and Channel Coding for Image and Video Systems*, IEEE International Conference on Image Processing, Brussels, Belgium, Sept. 2011.

Session Chairman: *Machine Learning: Signal Processing Applications*, European Signal Proc. Conference, Lisbon, Portugal, Sept. 1-5, 2014.

Session Chairman: *Face Recognition*, IEEE International Conference on Image Processing, Paris, France, Oct. 27-30, 2014.

Session Chairman: *Multi-image and Video Super-Resolution and Restoration*, IEEE International Conference on Image Processing, Quebec, Canada, Sept. 27-30, 2015.

SELECTED TALKS

Plenary/Keynote Talks

A Hybrid Object-Oriented Approach to Very Low Bit Rate Coding of Video, 1995 International Conf. on Digital Signal Processing, Limassol, Cyprus, June 26, 1995.

Recent Results on Very Low Bit Rate Video Coding, IEEE Southwest Symposium on Image Analysis and Interpretation, San Antonio, TX, April 9, 1996.

Recent Trends in Image Restoration and Enhancement Techniques, IEEE Asia Pacific Conf. on Circuits and Systems, Seoul Korea, Nov. 21, 1996.

Very Low Bit Rate Video Coding: Some Optimal Results and Some Open Questions, VII National Symposium on Pattern Recognition and Image Analysis, Barcelona, Spain, April 25, 1997.

Recent Advances in Video Compression, IASTED Int. Conf. on Signal and Image Processing, New Orleans, LA, Dec. 5, 1997.

Advances and Challenges in Multimedia Communications, IASTED Int. Conf. on Signal and Image Processing, Las Vegas, NV, Oct. 28, 1998.

Current Issues and Developments in Multimedia Signal Processing, Motorola Science Advisory Board (SABA) Induction meeting, Motorola Galvin Center, Schaumburg, IL, May 11, 1999.

Rate-Distortion Techniques in Image and Video Coding, Norwegian Signal Processing Conference, NORSIG-99, Asker, Norway, Sept. 10, 1999.

Rate-Distortion Techniques in Video Coding and Transmission, Irish Machine Vision and Image Processing Conference, IMVIP 2000, Belfast, UK, Aug. 31 - Sept. 2, 2000.

When Signal Compression Meets Signal Recovery, Workshop on Mathematics in Image Processing, WMIP 2000, Hong Kong, Dec. 14-16, 2000.

Rate-Distortion Techniques in Video Processing and Communications, Distinguished Lecture Series, University of Toronto, Canada, March 6, 2001.

Trends in Information Technology, Conference on "New Developments in Research and Innovative Products in: Information Technologies, Environmental Technologies, Agrobiotechnologies, and Water Management Technologies", Thessaloniki, Greece, June 23, 2001.

Recent Advances in Multimedia Signal Processing and Communications, Keynote Talk, EURASIP-IEEE International Symposium on Video/Image Processing and Multimedia Communications, Zadar, Croatia, June 16-19, 2002.

Audio-Visual Interaction in Multimedia Communications, Plenary talk, International Conference on Telecommunications, Santa Rita, Brazil, Oct. 22, 2002.

Resource Allocation Techniques in Video Coding and Transmission, Plenary talk, International Conference on Telecommunications, Santa Rita, Brazil, Oct. 23, 2002.

Efficient Video Communication over Lossy Channels, Plenary Talk, Workshop on the Computational and Information Infrastructure in the Astronomical DataGrid, Granada, Spain, Feb. 21, 2003.

Audio-Visual Interaction in Multi-Modal Communications, Plenary Talk, 4th European Workshop on Image Analysis for Multimedia Interactive Services, London, UK, April 10, 2003.

Superresolution of Compressed Images and Video, Workshop on Mathematics in Image Processing, WMIP 2003, Singapore, Dec. 17, 2003.

Dynamic Resource Allocation in Video Communications, Virtual observatories: Plate Content Digitization, Archive Mining and Image Sequence Processing, Sofia, Bulgaria, April 28, 2005.

Recent Advances in Video Communications: Challenges and Opportunities, Plenary Talk, IEEE WirelessComm 2005, Maui, Hawaii, June 16, 2005.

When Superresolution Meets Compression, Workshop on Mathematics in Image Processing, WMIP 2005, Hong Kong, Aug. 30, 2005.

Challenges and Opportunities in Video Communications, Plenary Talk, 2005 Pacific-Rim Conference on Multimedia (PCM2005), Jeju, Korea, Nov. 14, 2005.

Image and Video Recovery, IEEE SPS Distinguished Lecture, University of Toronto, Toronto, Canada, May 14, 2007.

Image and Video Recovery, IEEE SPS Distinguished Lecture, Hong Kong Baptist University,

Hong Kong, June 18, 2007.

New Results in Image and Video Recovery, IEEE SPS Distinguished Lecture, Hong Kong Polytechnic University, Hong Kong, June 18, 2007.

Bayesian Image and Video Recovery, IEEE SPS Distinguished Lecture, Universidad Carlos III de Madrid, Madrid, Spain, June 29, 2007.

Challenges and Opportunities in Video Transmission, Plenary Talk, IEEE Int. Conf. on Computer Communications and Networks, Oahu, Hawaii, Aug. 15, 2007.

Recent Results in Video Transmission, IEEE SPS Distinguished Lecture, Universidad Distrital Francisco Jose de Caldas, Bogota, Colombia, Sept. 24, 2007.

Recent Advances in Image and Video Recovery, Plenary Talk, Symposium on Signal and Image Processing and Computer Vision, Barranquilla, Colombia, Sept. 27, 2007.

Recent Advances in Image and Video Recovery, Plenary Talk, Western New York Image Processing Workshop, Rochester, NY, Sept. 28, 2007.

Recent Advances in Image and Video Recovery, IEEE SPS Distinguished Lecture, University of Illinois, Chicago, March 21, 2008.

Recent Advances in Image and Video Recovery, IEEE SPS Distinguished Lecture, Bogazici University, Istanbul, Turkey, March 25, 2008.

Challenges and Opportunities in Video Transmission, IEEE SPS Distinguished Lecture, Santa Clara Valley Chapter, Santa Clara, CA, May 12, 2008.

Challenges and Opportunities in Video Transmission, Plenary Talk, 5th Int. Conference on Visual Information Engineering (VIE 2008), Xi'an China, July 31, 2008.

Video Transmission, Plenary Talk, Cali, Colombia, Oct. 2008.

Challenges and Opportunities in Video Transmission, IEEE SPS Distinguished Lecture, King's College, London, UK, Dec. 2008.

Challenges and Opportunities in Video Transmission, IEEE SPS Distinguished Lecture, De Montfort University, Leicester, UK, Dec. 2008.

Future Content Networks in the US, Invited Talk, European Commission, Future Internet Assembly, Madrid, Spain, Dec. 2008.

Current Advances on Video Transmission, Keynote Speech, 13th WSEAS Multiconference, Rodos Island, Greece, July 23, 2009.

Compressive Sensing, plenary talk, Latin-American Conference on Networked and Electronic Media (LACNEM2009), Bogota, Colombia, Aug. 5, 2009.

Multimedia Content Delivery, plenary talk, Networked and Electronic Media (NEM) Summit, St. Malo, France, Sept. 30, 2009.

Peer-to-Peer Networks, plenary talk, 1st Int. ICST Conf. on User Centric Media - UCMedia 2009, Venice, Dec. 9-11, 2009.

Bayesian Techniques for Image Recovery, plenary talk, IEEE Southwest Symposium on Image Analysis and Interpretation (SSIAI), Austin, TX, May 23-25, 2010.

Sparse Representation for Image Retrieval, plenary talk, Latin-American Conference on Networked

and Electronic Media (LACNEM2010), Cali, Colombia, Sept. 9, 2010.

Video Transmission: Recent Results, Challenges, and Opportunities, plenary talk, IEEE Global Communications Conference (GLOBECOM), Miami, Florida, Dec. 9, 2010.

Sparse Representation and Low-Rank Matrix Recovery, keynote talk, First Huawei Workshop on Multimedia Processing and Computing in Cloud Computing, Bridgewater, NJ, April 4, 2011.

Sparse and Redundant Representations in Signal Processing, plenary talk, 26th Int. Technical Conf. on Circuits/Systems, Computers and Communications (ITC-CSCC), Gyeongju, Korea, June 21, 2011.

Sparse and Redundant Representations: Theory and Applications, plenary talk, IEEE Int. Conf. on Multimedia and Expo (ICME), Barcelona, Spain, July 11-15, 2011.

Recent Results on Compressive Sensing, plenary talk, Latin-American Conference on Networked and Electronic Media (LACNEM2011), San Jose, Costa Rica, Nov. 18, 2011.

Theory and Applications of Sparse and Redundant Representations, plenary talk, EURASIP Second Greek Signal Processing Jam, Thessaloniki, Greece, May 17, 2012.

On Video Surveillance, Video Analytics in the Wild, Big Data Week, Chicago, IL, April 26, 2013.

Compressive Sensing and Blind Image Deconvolution, Computational Optical Sensing and Imaging (COSI), Arlington, VA, June 24, 2013.

Advances in Sparsity-Based Image Processing, plenary talk, Latin-American Conference on Networked and Electronic Media (LACNEM2013), Manizales, Colombia, Sept. 2, 2013.

Recent Advances in Medical Imaging, keynote talk, 10th Int. Symposium on Medical Information Processing and Analysis (SIPAIM 2014), Cartagena, Colombia, Oct. 14, 2014.

Learning for Future Video, keynote talk, 22nd Int. Conference on Systems, Signals and Image Processing (IWSSIP 2015), London, UK, Sept. 12, 2015.

Deep Learning for Video Super-Resolution, plenary talk, Latin-American Conference on Networked and Electronic Media (LACNEM2015), Medellin, Colombia, Sept. 23, 2015.

Learning for Future Video, keynote talk, IEEE Int. Symposium on Multimedia, Miami, FL, Dec. 15, 2015.

Learning for Media Computing, keynote talk, IEEE Int. Conf. on Computing, Networking and Communications, Kauai, Hawaii, Feb. 18, 2016.

Learning for Future Video, plenary talk, IEEE Southwest Symposium on Image Analysis and Interpretation, Santa Fe, NM, March 7, 2016.

Machine Learning Approaches for Solving Inverse Imaging Problems, keynote talk, European Signal Processing Conference (EUSIPCO), Kos, Greece, Aug. 29, 2017.

Hidden Intentions: Hyperspectral Data Fusion of Picasso's Blue Period Paintings, AAAS Annual meeting, Austin, TX, Feb. 17, 2018.

On Label Efficient Learning, ICNC, Big Island, Hawaii, Feb.19, 2024.

Selected Invited Talks/Lectures

University of California, Irvine, CA, March 1985. University of Pennsylvania, Philadelphia, PA, April 1985. Jet Propulsion Laboratories, Pasadena, CA, May 1985.

Polytechnic University, Brooklyn, NY, May 1985.

Institute of Imaging Sciences, Polytechnic University, Brooklyn, NY, October 1986.

New York State Center for Advanced Technology in Telecommunications, Brooklyn, NY, February 1987.

Board of Trustees, Polytechnic University, March 1987.

Iterative Image Restoration, Riverside Research Center, New York, NY, April 1987.

Delft University of Technology, Delft, The Netherlands, August 1987, September 1988, May 1989.

VLSI Implementation of an Iterative Image Restoration Algorithm, 5th MDSP Workshop, Noordwijkerhout, The Netherlands, Sept. 1987.

Simultaneous Identification and Restoration of Images Using Maximum Likelihood Estimation, 1989 IEEE Int. Conf. on Control and Applications, Jerusalem, Israel, April 1989.

Parallel Iterative Image Restoration Algorithms, 32nd Midwest Symposium on Circuits and Systems, Urbana, IL, Aug. 1989.

Maximum Likelihood Blur Identification and Image Restoration, 6th MDSP Workshop, Monterey, CA, Sept. 1989.

Iterative Identification and Restoration of Images, SPIE Conf. on Visual Communications and Image Processing, Philadelphia, PA, Nov. 1989.

GE Medical Systems, Tech Corporate Partners, March 29, 1990.

Technology Reviews: Executive Briefings for Managers of Technology, Northwestern University, April 30, 1990.

Digital Image Processing Research, McCormick Faculty, Northwestern University, May 1, 1990.

Image Identification and Restoration Based on the EM Algorithm, Illinois Institute of Technology, Chicago, IL, May 4, 1990.

Multiple Input Adaptive Image Restoration Algorithms, SPIE Conf. on Visual Communications and Image Processing, Lausanne, Switzerland, Oct. 1990.

Image Blur Identification and Restoration by an Improved Wiener Filter, University of Southern California, Los Angeles, CA, Dec. 27, 1990.

Motorola Inc., Chicago Corporate Research and Development Center, Schaumburg, IL, March 1991.

Pel-Recursive Motion Estimation Algorithms, Rensselaer Polytechnic Institute, Troy, NY, March 28, 1991.

Image Processing Research, Motorola Science Advisory Board Associates Conference, Northwestern University, April 1991.

Recent Advances in Estimating the Motion in Image Sequences, Bell Northern Research, Montreal,

Canada, May 1991.

Ford Glass Company, Tech Corporate Partners, July 1991.

Adaptive Multiple-Input Pel-Recursive Motion Estimation, 7th MDSP Workshop, Lake Placid, NY, Sept. 1991.

Image Processing Research, BIRL, Evanston, IL, Oct. 22, 1991.

Foundations of Image Processing, class lecture, Biomedical Engineering Department, Northwestern University, Spring 1992.

Recent Advances on the Recursive Estimation of Motion, Delft University of Technology, Delft, The Netherlands, Aug. 1992.

Motion Modeling and Estimation, University of Illinois, Chicago, March 2, 1993.

Recursive Motion Estimation, University of Illinois, Urbana, March 3, 1993.

Very Low Bit Rate Coding, Columbia University, July 14, 1993.

Robust Displacement Field Estimation in Noisy-Blurred Image Sequences, 8th Workshop on IMDSP, Nice, France, Sept. 1993.

Adaptive Regularized Restoration Algorithms Applied to HST Images, Space Telescope Science Institute Workshop, Baltimore, MD, Nov. 1993.

Image Restoration of Astronomical Images, University of Granada, Spain, Nov. 1994.

A MAP Approach to Motion Estimation, University of Cataluna, Barcelona, Spain, Nov. 1994.

Digital Restoration of Images: Recent Advances and Future Trends, tutorial, SPIE Digital Signal Processing: Critical Reviews Conference, Orlando, FL, April 17, 1995.

Approaches to Image Restoration, Yonsei University, Seoul, Korea, May 1995.

Stochastic Approaches to Image and Video Restoration, Chung-Ang University, Seoul, Korea, May 1995.

Recent Advances in Video Processing, Samsung Electronics, Suwon, Korea, May 1995.

Recovery Techniques for Compressed Video, SPIE Conf. on Visual Communications and Image Processing, Tapei, Taiwan, May 1995.

A Hybrid Object-Oriented Approach to Very Low Bit Rate Coding of Video, Symp. on Multimedia Comm. and Video Coding, Brooklyn, NY, Oct. 11, 1995.

On Very Low Bit Rate Video Coding, Motorola Inc., Chicago Corporate Research and Development Center, Schaumburg, IL, Nov. 2, 1995.

A Very Low-Bit Video Codec with Optimal Trade-Off among DVF, DFD and Segmentation, Illinois Institute of Technology, Chicago, IL, Feb. 16, 1996.

Rate-Distortion Optimal Video Encoding, University of California, Berkeley, Jan. 1997.

Rate-Distortion Based Video and Boundary Encoding, University of Erlangen, Germany, Aug. 1997.

Optimal Boundary Encoding in the Rate-Distortion Sense, University of Illinois, Urbana-Champaign, Oct. 1997.

Image and Video Recovery, 29th Annual Seminar Day, NU Alumni Association and the NU Alumnae Board, NU Evanston Campus, April 18, 1998.

Multimedia Signal Processing, Distinguished Speaker, Integrated Media Systems Center, University of Southern California, Nov. 23, 1998.

A Paradigm for Recovery and Compression Techniques, Stanford University, Dept. of Electrical Engineering, Feb. 1, 1999.

Current Issues and Developments in Video Coding and Transmission, US Army Research Laboratory, Adelphi, MD, April 9, 1999.

Implementing MPEG7/MPEG7 for Interactive TV Systems, IBM Research Labs, Yorktown, NY, Interactive TV Workshop, August 17, 1999.

Rate-Distortion Optimal Shape Encoding, Cornell University, School of Electrical Engineering, May 2, 2000.

Recent Advances in Multimedia Signal Processing and Communications, University of Granada, Spain, June 12, 2002.

Efficient Video Communication over Lossy Channels, University of Trento, Trento, Italy, June 2004.

Recent Advances in Video Communications, Newcom Network of Excellence, Paris, France, June 25, 2004.

Recent Advances in Video Communications, Soongsil University, Seoul, Korea, Nov. 16, 2005.

Superresolution from Compressed Video, LG Electronics, Seoul, Korea, Nov. 16, 2005.

Video Recovery, Audio-Visual Processing, and Shape Encoding, ETRI, Daejeon, Korea, Nov. 17, 2005.

Recent Results on Video Communications, Yonsei University, Seoul, Korea, Nov. 18, 2005.

Recent Advances on Video Communications, HP Labs, Palo Alto, CA, May 11, 2008.

Recent Results on Video Transmission, Microsoft, China, Beijing, China, July 2008.

Future Content Networks in USA, European Future Internet Assembly, Madrid, Spain, Dec. 9-10, 2008.

Video Transmission for Sensor Networks, ONR/ARO/NSF Workshop on Distributed Video Sensor Networks, UC Riverside, Riverside, CA, May 11, 2009.

On Information Theory, Integrated Modeling Team, Department of Energy, Washington DC, Aug. 27, 2009.

From Image Recovery to Video Transmission, Imperial College, London, UK, Nov. 17, 2009.

Recent Results on Image Recovery, Cambridge University, Cambridge, UK, Nov. 18, 2009.

Recent Results on Image Recovery, Queen Mary, London, UK, Nov. 26, 2009.

Recent Results on Image Recovery, King's College, London, UK, Nov. 27, 2009.

Future Multimedia Applications, Future Media Internet Task Force, Brussels, Belgium, Feb. 5, 2010.

Image and Video Recovery, Hong Kong Polytechnic University, Hong Kong, July 7, 2010.

Recent Advances on Video Transmission, Chinese University of Hong Kong, Hong Kong, July 8, 2010.

Sparse and Redundant Representations in Signal Processing, Yonsei University, Seoul, Korea, June 23, 2011.

Recent Advances in Image Recovery, Chung-Ang University, Seoul, Korea, June 27, 2011.

Sparse and Redundant Representations in Signal Processing, Soongsil University, Seoul, Korea, June 28, 2011.

From Restoration to Super-Resolution, Samsung Electronics, Seoul, Korea, June 28, 2011.

Mobile Visual Search, Telefonica, Barcelona Spain, July 11, 2011.

Experiences with Technology Transfer in the US, EMC² Industry Day, Berlin, Germany, Nov. 14, 2011.

Theory and Applications of Sparse and Redundant Representations, University of Illinois, Urbana-Champaign, Beckman Institute, Urbana, IL, Sept. 26, 2012.

Bayesian Recovery Techniques, Institutions, Markets, Technologies (IMT), Lucca, Italy, March 25, 2013.

Sparse/Low-Rank Recovery Problems in Image Processing and Machine Learning, Universidad Nacional de Colombia, Bogota, Colombia, Oct. 17, 2014.

Recent Results on Computational Imaging, Computational Research Day, Northwestern University, Evanston, IL, April 14, 2015.

Machine Learning and Video Processing, invited talk, Strategic Planning Workshop, YouTube, San Bruno, CA, April 11, 2016.

Compressive Sensing: A Tutorial, invited talk, Video Coding and Emerging Trends, 4th PROVISION Workshop, Fraunhofer HHI, Berlin, Germany, Feb. 9, 2017.

Machine Learning Approaches for Solving Inverse Imaging Problems, invited talk, Huawei Strategy and Technology Workshop, Shenzhen, May 17, 2017.

Selected Conference Presentations

A General Formulation of Adaptive Iterative Image Restoration Algorithms, Conf. Inf. Sciences and Systems, Princeton, NJ, March 1986.

VLSI Implementation of an Iterative Restoration Algorithm, Int. Conf. Sys. Man, and Cybern., Atlanta, GA, October 1986.

Adaptive Iterative Color Image Restoration Algorithms, Conf. Inf. Sciences and Systems, The Johns Hopkins University, Baltimore, MD, March 1987.

Multiple Input Adaptive Iterative Image Restoration Algorithms, Int. Conf. Acoust., Speech, Signal Processing, Dallas, TX, April 1987.

Fast Iterative Image Restoration Algorithms, 25th Annual Allerton Conf. on Commun., Control and Computing, Monticello, IL, Sept. 1987.

Regularized Differentiation for Edge Detection, 25th Annual Allerton Conf. on Commun., Control and Computing, Monticello, IL, Sept. 1987.

A Unified Approach to Iterative Image Restoration, SPIE Symp. on Visual Communications and Image Processing, Cambridge, MA, October, 1987.

A Unified Approach to Iterative Signal Restoration, Int. Conf. Acoust., Speech, Signal Processing, New York, NY, April 1988.

Regularized Edge Detection, Int. Conf. Acoust., Speech, Signal Processing, New York, NY, April 1988.

Iterative Color Image Restoration Algorithms, Int. Conf. Acoust., Speech, Signal Processing, New York, NY, April 1988.

Constrained Iterative Identification and Restoration of Images, EUSIPCO, Grenoble, France, Sept. 1988.

Adaptive Restoration of Regionally Blurred Noisy Images, Conf. Inf. Sciences and Systems, The Johns Hopkins University, Baltimore, MD, March 1989.

Maximum Likelihood Image Identification and Restoration Based on the EM Algorithm, Conf. Inf. Sciences and Systems, The Johns Hopkins University, Baltimore, MD, March 1989.

Parallel Processing Architectures for Iterative Image Restoration, Int. Conf. Acoust., Speech, Signal Processing, Glasgow, Scotland, May 1989.

A Multiple Frame Pel-Recursive Wiener-Based Displacement Estimation Algorithm, SPIE Conf. on Visual Communications and Image Processing, Philadelphia, PA, Nov. 1989.

Spatio-Temporal Filtering of Noisy Image Sequences, SPIE Conf. on Visual Communications and Image Processing, Philadelphia, PA, Nov. 1989.

Image Restoration Using the Hopfield Network with Nonzero Autoconnections, Int. Conf. Acoust., Speech, Signal Processing, Albuquerque, NM, April 1990.

Edge Detection Using a Neural Network, Int. Conf. Acoust., Speech, Signal Processing, Albuquerque, NM, April 1990.

A Model Based Pel-Recursive Motion Estimation Algorithm, Int. Conf. Acoust., Speech, Signal Processing, Albuquerque, NM, April 1990.

Motion Estimation in Digital Angiographic Images Using Skeletons, Optical Engineering Midwest, Sept. 1990.

Distributed Detection Methods for Displacement Estimation, SPIE Conf. on Visual Communications and Image Processing, Lausanne, Switzerland, Oct. 1990.

Optical Methods for Iterative Image Restoration, SPIE Conf. on Visual Communications and Image Processing, Lausanne, Switzerland, Oct. 1990.

Motion Compensated Priority DCT Coding for Image Sequences, SPIE Conf. on Visual Communications and Image Processing, Boston, MA, Nov. 1991.

Adaptive Image Sequence Noise Filtering Methods, SPIE Conf. on Visual Communications and Image Processing, Boston, MA, Nov. 1991.

An Image Restoration Algorithm Based on the Bispectrum, SPIE Conf. on Visual Communications

and Image Processing, Boston, MA, Nov. 1991.

Adaptive Multiple-Input Constrained Pel-Recursive Displacement Estimation, Int. Conf. Acoust., Speech, Signal Processing, San Francisco, CA, March, 1992.

Motion Compensated Recursive Filtering of Noisy Displacement Fields, EUSIPCO, Brussels, Belgium, Aug. 1992.

Frequency Domain Adaptive Iterative Image Restoration and Evaluation of the Regularization Parameter, SPIE Conf. on Visual Communications and Image Processing, Boston, MA, Nov. 1992.

Recursive Displacement Estimation for Use in Multiple Object Tracking, IEEE Military Comm. Conf., Boston, MA, Oct. 1993.

Regularized Iterative Image Restoration Based on an Iterative Updated Convex Smoothing Functional, SPIE Conf. on Visual Communications and Image Processing, Boston, MA, Nov. 1993.

Restoration of Low Bit Rate Compressed Images Using Mean Field Annealing, Int. Conf. Acoust., Speech, Signal Processing, Adelaide, Australia, April 1994.

A General Formulation of the Weighted Smoothing Functional for Regularized Image Restoration, Int. Conf. on Image Processing, Austin, TX, Nov. 1994.

(invited) *A Video Coding Algorithm Based on Recovery Techniques Using Mean Field Annealing*, 1995 SPIE Conf. on Visual Communications and Image Processing, Tapei, Taiwan, May 1995.

Occlusion and Nonstationary Displacement Field Estimation in Quantum-Limited Image Sequences, 1995 SPIE Conf. on Visual Communications and Image Processing, Tapei, Taiwan, May 1995.

(invited) *Prior Models and Methods of Choosing the Unknown Parameters in the Bayesian and Regularization Approaches to Image Restoration*, 1995 IEEE Workshop on Nonlinear Signal and Image Processing, Neos Marmaras, Greece, June 1995.

(invited) *Exploitation of Spatio-Temporal Inter-Correlation Among Motion, Segmentation, and Intensity Fields for Very Low Bit Rate Coding of Video*, Symp. on Multimedia Comm. and Video Coding, Brooklyn, NY, Oct. 1995.

(invited) *Reconstruction of a High-Resolution Image by Simultaneous Registration, Restoration, and Interpolation of Low-Resolution Images*, 1995 IEEE International Conf. on Image Processing, Washington, DC, Oct. 1995.

(invited) *A Hybrid Object-Oriented Very Low Bit Rate Video Codec*, 9th Workshop on IMDSP, Belize City, Belize, March 1996.

An Iterative Algorithm for Improving the Resolution of Video Sequences, 1996 SPIE Conf. on Visual Communications and Image Processing, Orlando, FL, March 1996.

Detection and Encoding of Model Failures in Very Low Bit-Rate Video Coding, 1996 SPIE Conf. on Visual Communications and Image Processing, Orlando, FL, March 1996.

A Hybrid Object-Based Video Codec, 1996 Int. Conf. Acoust., Speech, Signal Processing, Atlanta, GA, May 1996.

An Optimal Segmentation Encoding Scheme in the Rate Distortion Sense, 1996 Int. Conf. Circuits and Systems, Atlanta, GA, May 1996.

(invited) *Resolution Enhancement of Color Video*, European Conf. on Signal Processing, Trieste,

Italy, Sept. 1996.

(invited) *A Very Low Bit Rate Video Codec With Optimal Tradeoff Among DVF, DFD and Segmentation*, European Conf. on Signal Processing, Trieste, Italy, Sept. 1996.

(invited) *Recursive MAP Displacement Field Estimation and its Applications*, 1996 IEEE International Conf. on Image Processing, Lausanne, Switzerland, Sept. 1996.

(invited) *An Optimal Quad-Tree-Based Motion Estimator*, SPIE Conf. on Digital Compression Technologies and Systems for Video Communications, Berlin, Germany, Oct. 1996.

An Iterative Regularized Error Concealment Algorithm, SPIE Conf. on Digital Compression Technologies and Systems for Video Communications, Berlin, Germany, Oct. 1996.

Multiple Candidate Hierarchical Block Matching with Inherent Smoothness Properties, SPIE Conf. on Digital Compression Technologies and Systems for Video Communications, Berlin, Germany, Oct. 1996.

Optical Flow Estimation for Multichannel Video Sequences, 1997 SPIE Conf. on Visual Communications and Image Processing, San Jose, CA, Feb. 1997.

(invited) *Estimating and Transmitting Regularization Parameters for Reducing Blocking Artifacts*, 13th Int. Conf. on Digital Signal Proc., Santorini, Greece, July 2-4, 1997.

Iterative Regularized Image Restoration Using Local Constraints, 1997 IEEE Workshop on Non-linear Signal and Image Processing, Mackinac Island, MI, Sept. 8-10, 1997.

Joint Optimal Object Shape Estimation and Encoding, SPIE Conf. on Visual Communications and Image Processing, San Jose, CA, Jan. 28-30, 1998.

SNR Scalable Video Coder Using Progressive Transmission of DCT Coefficients, SPIE Conf. on Visual Communications and Image Processing, San Jose, CA, Jan. 28-30, 1998.

Disparity Estimation with Modeling of Occlusion and Object Orientation, SPIE Conf. on Visual Communications and Image Processing, San Jose, CA, Jan. 28-30, 1998.

Hierarchical Bayesian Image Restoration from Partially Known Blurs, 1998 Int. Conf. Acoust., Speech, Signal Processing, Seattle, WA, May 12-15, 1998.

Total Least-Squares Disparity-Assisted Stereo Optical Flow Estimation, IEEE Image and Multidimensional Digital Signal Processing Workshop, Alpbach, Austria, July 12-16, 1998.

(invited) *Error Resilience and Concealment in Video Coding*, EUSIPCO-98, Rhodes, Greece, Sept. 8-11, 1998.

Iterative Determination of Local Bound Constraints in Iterative Image Restoration, 1998 IEEE International Conf. on Image Processing, Chicago, IL, Oct. 5-7, 1998.

(invited) *Joint Optimal Boundary Encoding and DPCM Model Selection*, Asilomar Conf. on Signals, Systems, and Computers, Pacific Grove, CA, Nov. 1-4, 1998.

Inter-Mode Vertex-Based Optimal Shape Coding, 1999 Int. Conf. Acoust., Speech, Signal Processing, Phoenix, AZ, March 15-19, 1999.

Context Based Optimal Shape Coding, 1999 IEEE Workshop on Multimedia Signal Processing, Copenhagen, Denmark, Sept. 13-15, 1999.

An Optimal Single Pass SNR Scalable Video Coder, 1999 IEEE International Conf. on Image Processing, Kobe, Japan, Oct. 24-28, 1999.

(invited) *Sequential Construction of 3D-Based Scene Description*, 1999 IEEE International Conf. on Image Processing, Kobe, Japan, Oct. 24-28, 1999.

A Rate-Distortion Optimal Scalable Vertex Based Shape Coding Algorithm, 2000 Int.Conf. Acoust., Speech, Signal Processing, Istanbul, Turkey, June 5-9, 2000.

A Hidden Markov Model Based Visual Speech Synthesizer, 2000 Int. Conf. Acoust., Speech, Signal Processing, Istanbul, Turkey, June 5-9, 2000.

Simultaneous Motion Estimation and Resolution Enhancement of Compressed Low Resolution Video, 2000 IEEE International Conf. on Image Processing, Vancouver, Canada, Sept. 11- 13, 2000.

Shape Approximation Through Recursive Scalable Layer Generation, 2000 IEEE International Conf. on Image Processing, Vancouver, Canada, Sept. 11-13, 2000.

Transmission Energy Minimization in Wireless Video Streaming Applications, Int. Symposium on Telecommunications, Tehran, Iran, Sept. 1-3, 2001.

A Rate-Distortion Optimal Video Pre-Processing Algorithm, 2001 IEEE International Conf. on Image Processing, Thessaloniki, Greece, Oct. 8-10, 2001.

Application of the Motion Vector Constraint to the Regularized Enhancement of Compressed Video, 2001 IEEE International Conf. on Image Processing, Thessaloniki, Greece, Oct. 8-10, 2001.

Bayesian High-Resolution Reconstruction of Low-Resolution Compressed Video, 2001 IEEE International Conf. on Image Processing, vol. 2, pp. 25-28, Thessaloniki, Greece, Oct. 8-10, 2001.

Rate-Distortion Optimal Skeleton-Based Shape Coding, 2001 IEEE International Conf. on Image Processing, Thessaloniki, Greece, Oct. 8-10, 2001.

A Frame-based Rate-distortion Optimal Coding System Using a Lower Bound Depth-first-search Strategy, Nordic Signal Processing Symposium (NORSIG-2002), Hurtigruten, Norway, Oct. 2002.

A recursive shape error concealment algorithm, IEEE International Conf. on Image Processing, Rochester, NY, Sept. 22-25, 2002.

Disparity variation in stereo-panoramic video, IEEE International Conf. on Image Processing, Rochester, NY, Sept. 22-25, 2002.

Joint Source Coding and Packet Marking for Video Transmission over DiffServ Networks, Tyrrhenian Int. Workshop on Digital Communications, Carpi, Italy, Sept. 2002.

Min-max Optimal Shape Coding using Skeleton Decomposition, IEEE Int. Conf. on Multimedia and Expo (ICME), July 2003.

Operational Rate-distortion Optimal Bit Allocation Between Shape and Texture for MPEG-4 Video Coding, IEEE Int. Conf. on Multimedia and Expo (ICME), July 2003.

EM Based Simultaneous Registration, Restoration, and Interpolation of Super-resolved Images, 2003 IEEE International Conf. on Image Processing, Barcelona, Spain, Sept. 14-17, 2003.

Object-Based Video Compression Scheme with Optimal Bit Allocation among Shape, Motion and Texture, 2003 IEEE International Conf. on Image Processing, Barcelona, Spain, Sept. 14-17, 2003.

Approaches for the Restoration of Compressed Video, 2003 IEEE International Conf. on Image Processing, Barcelona, Spain, Sept. 14-17, 2003.

(invited) *Image and Video Analysis: Trends and Challenges*, 5th European Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS 2004), Lisbon, Portugal, April 21-23, 2004.

Fast Video Shot Retrieval Based on a Sequence Trace in the Principal Component Space, 5th European Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS 2004), Lisbon, Portugal, April 21-23, 2004.

Minimax Optimal Video Summarization, 5th European Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS 2004), Lisbon, Portugal, April 21-23, 2004.

Automatic Facial Expression Recognition Using Facial Animation Parameters and Multi-Stream HMMs, 6th European Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS 2005), Montreux, Switzerland, April 13-15, 2005.

Resource-Distortion Optimal Video Coding and Communications, 1st Int. Conf. on Multimedia Services Access Networks (MSAN 2005), Orlando, FL, June 13-15, 2005.

Video Summarization for Multiple Path Summarization, IEEE International Conf. on Image Processing (ICIP 2005), Genova, Italy, Sept. 11-14, 2005.

Comparison of MPEG-4 Facial Animation Parameter Groups with Respect to Audio-Visual Speech Recognition Performance, IEEE International Conf. on Image Processing (ICIP 2005), Genova, Italy, Sept. 11-14, 2005.

A Content Aware Scheduling Scheme for Video Streaming to Multiple Users Over Wireless Networks, EUSIPCO-06, Florence, Italy, Sept. 4-6, 2006.

Pricing Based Collaborative Multi-User Video Streaming over Total Power Constrained Wireless Down Link, IEEE Intern. Conf. on Acoustics, Speech and Signal Processing, Toulouse, France, May 2006.

DNA Hybridization as a Similarity Criterion for Querying Digital Signals Stored in DNA Databases, IEEE Intern. Conf. on Acoustics, Speech and Signal Processing, Toulouse, France, May 2006.

A Content Aware Scheduling Scheme for Video Streaming to Multiple Users Over Wireless Networks, EUSIPCO-06, Florence, Italy, Sept. 4-6, 2006.

Fast Video Shot Retrieval with Luminance Field Trace Indexing and Geometry Matching, IEEE Int. Conf. on Image Processing, Atlanta, GA, Oct. 8-11, 2006.

(invited) *Tracking Motion-Blurred Targets in Video*, special session on *Knowledge-Based Image Processing for Classification and Recognition in Surveillance Applications*, IEEE Int. Conf. on Image Processing, Atlanta, GA, Oct. 8-11, 2006.

(invited) *Robust Video Indexing and Retrieval with Additive Noise and Frame Drops*, IEEE Int. Workshop on Content Based Multimedia Indexing (CBMI), Bordeaux, France, June 25-27, 2007.

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CONSULTING

Tech Consultant, US Robotics, Tech Corporate Partners Program

Tech Consultant, Ameritech, Tech Corporate Partners Program

Lake County Astronomical Society, Lake Forest, Illinois

Space Telescope Science Institute, Baltimore, Maryland

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Packet Video, San Diego, California

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599. H. Lin, S. Lopez-Tapia, F. Schiffers, Y. Wu, H. Yang, N. Iakovlev, B. D. Alle, R. Avery, D. C. Lee, D. Kim, and A. K. Katsaggelos, "Usformer: A Light Neural Network for Left Atrium Segmentation of 3D LGE MRI," *2023 31st European Signal Processing Conference (EUSIPCO)*, pp. 995-999, Helsinki, Finland, Nov. 2023.
600. P. Kang, S. Banerjee, H. Chopp, A. K. Katsaggelos, and O. Cossairt, "Spiking GLOM: Bio-Inspired Architecture for Next-Generation Object Recognition," *Proc. IEEE International Conference on Image Processing (ICIP)*, Kuala Lumpur, Malaysia, pp. 950-954, Oct. 2023.
601. S. López-Tapia, X. Wang, and A. K. Katsaggelos, "Variational Deep Atmospheric Turbulence Correction for Video," *Proc. IEEE International Conference on Image Processing (ICIP)*, Kuala Lumpur, Malaysia, pp. 3568-3572, Oct. 2023.
602. S. López-Tapia, J. Mateos, R. Molina, and A. K. Katsaggelos, "Deep Robust Image

Restoration Using the Moore-Penrose Blur Inverse," *Proc. IEEE International Conference on Image Processing (ICIP)*, Kuala Lumpur, Malaysia, pp. 775-779, Oct. 2023.

603. S. Yang, F. Pérez-Bueno, F. M. Castro-Macías, R. Molina, and A. K. Katsaggelos, "Deep Bayesian Blind Color Deconvolution of Histological Images," *Proc. IEEE International Conference on Image Processing (ICIP)*, Kuala Lumpur, Malaysia, pp. 710-714, Oct. 2023.

AWARDS/RECOGNITION/PUBLICITY

SEIO - Spanish Society of Statistics and Operational Research-Fundación BBVA Award for the Best Applied Contribution in Statistics for the work "Scalable Variational Gaussian Processes for Crowdsourcing: Glitch Detection in LIGO" published in *IEEE Transactions on Pattern Analysis and Machine Intelligence*.

Life Fellow of IEEE (2022)

Fellow of OSA (2018)

Fellow of EURASIP (2017)

First Prize, Computer in Cardiology Challenge 2017, for the paper "Detection of Atrial Fibrillation in ECG Hand-held Devices using a Random Forest Classifier," co-authored by M. Zabihi, A. Bahrami Rad, S. Kiranyaz, and M. Gabbouj.

Runner-up, Computer in Cardiology Challenge 2016, for the paper "Heart Sound Anomaly and Quality Detection using Ensemble of Neural Networks without Segmentation," co-authored by M. Zabihi, A. Bahrami Rad, S. Kiranyaz, and M. Gabbouj.

Third Prize at the International IEEE EMBS Conference for the Brain Computer Interface Challenge at Neural Engineering, Montpellier, France, April 22, 2015, for the paper "A Novel P300-Speller Error Detection Approach in Brain-Computer Interface, co-authored by A. Bahrami Rad, M. Zabihi, S. Kiranyaz, and M. Gabbouj.

Best paper award by European Signal Processing Conference (EUSIPCO), Marrakech, Morocco, September 9-13, 2013, for the paper "Variational Bayesian Compressive Blind Image Deconvolution," co-authored by B. Amizic, L. Spinoulas, and R. Molina.

IEEE Signal Processing Society Technical Achievement Award (2010)

Distinguished Visiting Fellowship, The Royal Academy of Engineering, Imperial College, London, November 2009.

Best paper award by the 6th International Symposium on Image and Signal Processing and Analysis (ISPA) September 16-18, 2009, Salzburg, Austria, for the paper "Bayesian Super-Resolution Image Reconstruction using an l1 prior," co-authored with S. Villena, M. Vega, and R. Molina.

Fellow of SPIE (2009)

IEEE Signal Processing Society Distinguished Lecturer (2007-2008)

Best paper award by the IEEE Int. Conference on Image Processing (ICIP 2007), San Antonio,

TX, Sept. 16-19, 2007, for the paper "Total Variation Image Restoration and Parameter Estimation Using Variational Posterior Distribution Approximation," co-authored with D. Babacan and R. Molina.

Best paper award by the IEEE International Conference on Multimedia and Expo (ICME 2006), Toronto, Canada, July 9-12, 2006, for the paper "Locally Embedded Linear Subspaces for Efficient Video Indexing and Retrieval," co-authored with Zhu Li and Li Gao

IEEE Signal Processing Society 2001 Meritorious Service Award

IEEE Signal Processing Society 2001 Best Paper Award for the paper co-authored with Guido Schuster "An Optimal Polygonal Boundary Encoding Scheme in the Rate-Distortion Sense", IEEE Trans. on Image Processing, Jan. 1998.

IEEE Third Millennium Medal (2000)

Fellow of IEEE (1998)

Senior Member of IEEE (1992-1997)

Greek State Honorary Scholarship (1974, 1975, 1978)

Ameritech Fellow (1989-1990)

Member of the Sigma Xi Honorary Scientific Society, the New York Academy of Sciences, the Illinois Academy of Sciences

Work on the Filtering of Digital Angiograms was featured in *Northwestern Daily*, Jan. 23, 1990.

Work on the Restoration of Hubble Space Telescope Images was featured in the *Chicago Tribune*, Dec. 15, 1991.

Work on the Restoration of Hubble Space Telescope Images was featured in *Constructs*, April 1992.

Work on the Restoration of Hubble Space Telescope Images was featured in *McCormick Dimension*, Fall 1992.

Work on the Filtering of Digital Angiograms was featured in *Partners' Update*, Fall 1992.

Work on the Restoration of Disney Animation was featured in *McCormick Dimension*, Fall 1994.

Images restored in our Lab were accepted for the first time as evidence in the court by Dr. W. R. Oliver, Office of the Armed Forces Medical Examiner, Washington, D.C., Fall 1995.

A profile was presented in the *NU Observer*, 3/9/98.

The Northwestern-Motorola Center on Telecommunications and its Director were featured in the *Chicago Tribune* (9/14/98), *The Daily Northwestern* (9/23/98), and the *Observer* (9/24/98).

Interview given in *Chicago Tonight*, March 20, 2003.

Work on Audio-Visual Speech Processing was featured in the *Chicago Tribune*, May 29, 2004.

Work on the colorization of early photographs of the painting *Bathers by a River* by Matisse was covered by major online and print media outlets, including MIT Technology Review, Arts Section New York Times (the media interactive), MSNBC's Cosmic Blog, Northwestern's FrontPage, McCormick News, TA NEA (Greek Newspaper), PhysOrg (Summer-Fall 2010), Northwestern Daily, McCormick Magazine, Kathimerini (Greek Newspaper).

Results from Cortes, J. M., A. Lopez, R. Molina, and A. K. Katsaggelos, "Variational Bayesian localization of EEG sources with generalized Gaussian priors", *The European Physical Journal Plus*, vol. 127, issue 11, pp. 140-152, Nov. 2012, appeared on the cover of the Journal.

PATENTS

1. Method and apparatus for regenerating a dense motion vector field, US 5,574,663, Nov. 12, 1996 (Ozcelik, Brailean, Katsaggelos)
2. Method and apparatus for detecting occlusion, US 5,612,745, March 18, 1997 (Ozcelik, Brailean, Katsaggelos)
3. Method and system for improved motion compensation, US 5,646,867, July 8, 1997 (Ozcelik, Brailean, Katsaggelos, Levine)
4. Method and system for estimating motion within a video sequence, US 5,717,463, Feb. 10, 1998 (Brailean, Ozcelik, Katsaggelos)
5. Method and apparatus for spatially adaptive filtering for video encoding, US 5,764,307, June 9, 1998 (Ozcelik, Brailean, Katsaggelos, Erdogan, Auyeung)
6. Method, device and microprocessor for selectively compressing video frames of a motion compensated prediction-based video codec, US 5,764,921, June 9, 1998 (Banham, Brailean, Levine, Katsaggelos, Schuster)
7. Method and device for optimal bit allocation between different sources of information in digital video compression, US 5,778,192, July 7, 1998 (Schuster, Katsaggelos, Banham, Brailean)
8. Method and Apparatus for Reduction of Visual Content, US 6,963,378, Nov. 8, 2005 (Li, Gandhi, Katsaggelos)
9. Methods and Structure for Scalability Type Selection in Digital Video, US 6,996,172, Feb. 7, 2006 (Ishtiaq, Katsaggelos)
10. Method and System for Scalable Bitstream Extraction, US 8,170,094, May 1, 2012 (Trandel, Katsaggelos, Babacan, Hsiang, Ishtiaq)
11. Method for Video Segment Matching, filed Nov. 18, 2004 (Gandhi, Katsaggelos, Li)
12. Method and Device for Extracting and Utilizing Additional Scene and Image Formation Data for Digital Image and Video Processing, filed March 17, 2005 (Tull, Katsaggelos)
13. Method and Apparatus for Characterizing a Video Segment and Determining if a First Video Segment Matches a Second Video Segment, filed June 9, 2005 (Li, Gandhi, Katsaggelos)
14. System and Method of Optimized Bit Extraction for Scalable Video Coding, US 2010/0091841, April 15, 2010 (Ishtiaq, Hsiang, Katsaggelos, Maani, Uslubas)
15. Digital Image Compression by Residual Decimation, filed June 7, 2010 (Uslubas, Katsaggelos, Ishtiaq, Hsiang, Maani)
16. Digital Image Compression by Resolution-Adaptive Macroblock Coding, filed June 7, 2010 (Uslubas, Katsaggelos, Ishtiaq, Hsiang, Maani)

17. System and Method for Frame Interpolation for a Compressed Video Bitstream, filed Aug. 12, 2010 (M. Luessi, A. K. Katsaggelos, D. Veselinovic, K. Lengwehasatit, J. Kosmach)
18. Interleaved Indexing for Fast Approximate Nearest Neighbor Keypoint Feature Retrieval for Visual Search, filed 2012 (Z. Li, X. Xin, A. K. Katsaggelos)
19. Laplacian SURF as Compact Descriptor for Visual Search, filed 2012 (X. Xin, Z. Li, A. K. Katsaggelos)
20. System and method for randomized point set geometry verification for image identification, US 9,875,386, Jan. 23, 2018 (X. Xin, Z. Li, A. K. Katsaggelos)
21. Scalable Feature Transmission for Mobile Image Search, filed 2012 (X. Xin, Z. Li, A. K. Katsaggelos)
22. Image Topological Coding for Visual Search, US 8,718,378, May 6, 2014 (Z. Li, X. Xin, A. K. Katsaggelos)
23. System and Method for Compact Descriptor for Visual Search, US 8,755,605, June 17, 2014 (X. Xin, Z. Li, and A. K. Katsaggelos)
24. Scalable Query for Visual Search, US 8,948,518, Feb. 3, 2015 (X. Xin, Z. Li, and A. K. Katsaggelos)
25. Visual Inspection System for Automated Detection of Particulate Matter in Flexible Medical Containers, US 10,878,551, Dec. 29, 2020 (A. Kappeler, A. K. Katsaggelos, G. A. Bertos, K. A. Ashline, and N. A. Zupec)
26. Scalable Query for Visual Search, EP 2710518, Oct. 28, 2020 (X. Xin, Z. Li, and A. K. Katsaggelos)
27. Pattern Analysis based on fMRI Data Collected while Subjects Perform Working Memory Tasks Allowing High Precision Diagnosis, US 10,571,539, Feb. 25, 2020 (R. Hummer, J. R. Booth, R. Borhani, and A. K. Katsaggelos)
28. Hyperspectral Imaging Sensor, US 11,222,422. Jan. 11, 2022 (N. I. Alshurafa, A. K. Katsaggelos, O. Cossairt)
29. System and Method for High-Resolution, High Speed, and Noise Robust Imaging, number 11,303,793, April 12, 2022 (O. Cossairt, B. Shi, Z. Wang, P. Duan, A. K. Katsaggelos, T. Huang)
30. System and Methods for Interferometric Multifocus Microscope, US 11,340,057, May 24, 2022 (K. He, O. Cossairt, A. K. Katsaggelos, N. Scherer, and M. Hereld)
31. Bandwidth Limited Context Based Adaptive Acquisition of Video Frames and Events for User Defined Tasks, US 11,798,254, Oct. 24, 2023 (S. Banerjee, H. H. Chopp, J. G. Serra, Z. Wang, O. Cossairt, A. K. Katsaggelos)
32. Method and system for labeling medical images, US20230078011A1 (V. B. Hill, M. A. Iorga, A. K. Katsaggelos, T. B. Parrish)
33. Enhancement of weak signal for machine training neural network representing a solid-state detector, US20220366232A1 (A. H. Vija, M. Rodrigues, S. Banerjee, A. K. Katsaggelos)
34. Precise slice-level localization of intracranial hemorrhage on head cts with networks trained on scan-level labels, US20230368423A1 (Y. Wu, T. Parrish, A. K. Katsaggelos, V. B. Hill)

Expert Work
Prof. Aggelos K. Katsaggelos
May 24, 2024

The following are cases for which I provided a declaration or testified (client indicated in **boldface**).

Concluded Cases:

- **Cummins-Allison Corp. (plaintiff)** vs. Glory Ltd., et al. Case No. 2-CV-7008, N.D. Ill (2006-2007). This 2-patent case involved currency discrimination and counting technologies. I prepared an expert report on infringement, an expert rebuttal report on invalidity, and gave a deposition. Case settled before trial. Legal Firm: **Winston and Strawn, LLP**.
- ObjectVideo Inc. vs. **Robert Bosch GMBH et al. (respondent)**, Case No. 3:11-CV-217 (E.D. Va), In the Matter of Certain Video Analytics Software, Systems, and Components Thereof, and Products Containing the Same, Inv. No. 337-TA-795 (2011-2012). This 5-patent case involved video surveillance technologies (virtual tripwires, slip-and-fall, video primitives). I prepared an expert report on invalidity, an expert rebuttal report on non-infringement, a direct witness statement, and a rebuttal witness statement. I was deposed for two days and testified at the ITC. Legal Firm: **Kenyon and Kenyon, LLP**.
- **"IPR Group" (Samsung Electronics Co., Ltd, Sony Corp. of America, and Nokia Inc.)** USPTO *Inter Partes Reviews* of U.S. Patent Nos. 6,850,647 and 7,489,824 (2015). This 2-patent case involved digital image decompression. I prepared expert reports on invalidity. Case settled. Legal Firm: **Novak Druce Connolly Bove + Quigg, LLP**.
- Nokia Technologies Oy & Alcatel-Lucent USA Inv. vs. **Apple Inc. (defendant)** (2016-2017). The case involved video compression technologies for certain electronic devices, including mobile phones and tablet computers (8 US Patents and 5 foreign patents). Prepared *Inter Partes* review declaration. The trial was scheduled for the Eastern District of Texas (Civil Action Nos. 2:16-cv-144 and 2:16-cv-1441). Case settled. Legal Firms: **WilmerHale LLP and Morrison & Foerster, LLP**.
- Ramot at Tel Aviv University, Ltd., vs. **Snap Inc. (defendant)** (2017). The case involved the manipulation of videos to be displayed on mobile devices. Trial to occur in the District of Delaware. Prepared IPR declaration. The parties stipulated a dismissal of the case. Legal Firm: **Cooley, LLP**.
- Carl Zeiss AG vs. **Nikon (respondent)** (2017). The case involved two patents on certain digital cameras, software, and components thereof. I prepared expert reports on invalidity and an expert rebuttal report on non-infringement. I was deposed for two days and testified (direct and cross-examination) at the ITC in early March 2018. Legal Firm: **Morrison & Foerster, LLP**.

- Yu et al. vs. **Apple Inc. (defendant)** (2019). *Inter Partes Review* challenges of U.S. Patent No. 6,611,289 to Yanbin Yu and Zhongxuan Zhang. Case CAND-3-18-cv-06181. Provided declaration on claim construction. Legal Firm: **Cooley LLP and Haynes and Boone, LLP.**
- Uniloc 2017 LLC vs. **Netflix, Inc., Hulu, LLC, Roku, Inc. (defendants)** (2019). CASE NO. 8:18-cv-02055-GW-DFM, CASE NO. 8:18-cv-02150-GW-DFM, CASE NO. 8:19-cv-0295-GW-DFM, CASE NO. 8:18-cv-02058-GW-DFM. Provided declaration on claim construction. Legal Firm: **Perkins Coie, LLP.**
- Burley Licensing LLC v. **Micro-star International Co. LTD (defendant)** (2022). Case no. 6:21-cv-00862-ADA. Provided declaration on claim construction. Legal Firm: **Cooley, LLP.**
- **Verkada, Inc. (complainant)** v. Motorola Solutions Inc. et al. (2021). Case No. 3:21-cv-6858 (N.D. Cal.); Certain Video Security Equipment and Systems, Related Software, Components Thereof, and Products Containing the Same, Inv. No. 337-TA-1281. Prepared report on non-infringement and I was deposed and testified at the ITC in June 2022. Case won. Legal Firm: **Quinn Emanuel Urquhart & Sullivan, LLP.**
- **Honeywell International, Inc. (complainant)** v. Zebra Technologies Corp. and Symbol Technologies, LLC, ITC case (2022). Provided declaration on claim construction. Case settled. Legal Firm: **DLA Piper, LLP.**
- Maxell, LTD v. **Lenovo Group Ltd, Lenovo (United States) Inc., and Motorola Mobility LLC, (defendants)** (2022) Civil Action No. 6:21-cv-1169 ADA, filed in the Western District of Texas on November 12, 2021. I prepared IPR declaration, and I was deposed. Legal Firm: **DLA Piper, LLP.**

Active Cases:

- Telefonaktiebolaget LM Ericsson v. **Lenovo (United States) Inc, (respondent)** (2024). In the case of Certain Electronic Computing Devices, and Components and Modules Thereof, ITC Inv. No. 337-TA-1387. Legal Firm: **Covington, LLP.**
- GoPro, Inc v. **Arashi Vision Inc. d/b/a Insta360 and Arashi Vision (U.S.) LLC d/b/a Insta360 (respondent)**. In the case of Certain Cameras, Camera Systems, and Accessories used therewith, ITC Inv. No. 337-TA-1400. Legal Firm: **Morrison & Foerster, LLP.**