

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent of: Meadow et al.

U.S. Patent No.: 8,078,396

Attorney Docket No.: 19473-0325IP1

Issue Date: December 13, 2011

Appl. Serial No.: 12/035,423

Filing Date: February 21, 2008

Title: METHODS FOR AND APPARATUS FOR GENERATING A CONTINUUM OF
THREE DIMENSIONAL IMAGE DATA

DECLARATION OF DR. HENRY FUCHS

I, Dr. Henry Fuchs, of Chapel Hill, NC, declare that:

1. I am currently the Frederico Gil Distinguished Professor of Computer Science and an Adjunct Professor of Biomedical Engineering at the University of North Carolina at Chapel Hill. My qualifications for formulating my analysis on this matter are summarized here and are addressed more fully in my curriculum vitae, which is attached hereto as Appendix A.

2. I received my Bachelor of Arts degree in Information and Computer Science from the University of California at Santa Cruz in 1970. In 1975, I received a Ph.D. in Computer Science from the University of Utah.

3. From 1975 to 1978, I was an assistant professor in Computer Science at the University of Texas at Dallas. I have been on the faculty at the University of North Carolina at Chapel Hill since 1978. As a professor of Computer Science, I have also taught courses in graphics, virtual reality, telepresence, computer organization, and robotics.

4. I am a member of the National Academy of Engineering, a fellow of the American Academy of Arts and Sciences, and the recipient of the 1992 ACM-SGGRAPH Achievement Award, the 1992 Academic Award of the National Computer Graphics Association, and the 1997 Stava Award of the Medicine Meets Virtual Reality Conference. In 2013, I received the IEEE-VGTC Virtual Reality Career Award for my contributions to research and practice in virtual environments, telepresence, and medical applications.

5. Since the 1970s, I have been involved with research related to virtual and augmented reality. I have contributed to many of the technologies needed to enable virtual and augmented reality, including automatic construction of 3D models and scenes, fast rendering algorithms (BSP Trees), graphics hardware (Pixel-Planes), large-area tracking systems (HiBall), and optical and video see-through head-mounted displays. Many of these advances were inspired by demanding applications such as augmenting visualization for surgical assistance (by merging real and virtual objects) and teleimmersion for remote medical consultation.

6. A complete list of my publications is included in my *curriculum vitae*, which is attached as Appendix A to this declaration. I have published over 190 journal articles, book chapters, conference papers, and workshop papers in the areas related to virtual and augmented reality. I have given numerous presentations at various conferences and universities worldwide on these topics. I am a named inventor on several U.S. patents and patent applications, also listed in my *curriculum vitae*.

7. One of the research efforts that I have been involved with at UNC-Chapel Hill was a medical visualization technology involving real-time three-dimensional ("3D") ultrasound. In that project, we created a system that allowed a physician to see a 3D projection of an ultrasound projected on a patient during a real-time examination. This involved simultaneously recording images from differently-oriented cameras and ultrasound imagery, and combining ultrasound imagery registered in the appropriate position with the actual images of the patient being examined. Aspects of that project are described in M. Bajura, H. Fuchs, and R. Ohbuchi, "Merging Virtual Objects with the Real World: Seeing Ultrasound Imagery within the Patient," *Computer Graphics*, vol. 26, pp. 203 - 210, 1992. I am a co-founder of InnerOptic Technology, Inc., which was launched in 2003 to commercialize the medical visualization technology developed at the University of North Carolina-Chapel Hill.

8. My opinions set forth in this declaration are informed by my experience in the fields of computer science and virtual reality. Based on my above-described 40 plus years of experience in computer science and virtual reality, I believe that I am considered to be an expert in the field.

9. In writing this Declaration, I have considered the following: my own knowledge and experience, including my work experience in the fields of computer science, computer engineering, and computer graphics systems, including virtual reality systems; my

experience in teaching those subjects; and my experience in working with others involved in those fields. In addition, I have analyzed the following publications and materials:

- The disclosure and claims of U.S. Patent No. 8,078,396 (“the ’396 patent”);
- The prosecution history of the ’396 patent;
- “An Automated Method for Large-Scale, Ground-Based City Model Acquisition” by Früh et al. (October 2004) (“Fruh”);
- “Towards Urban 3D Reconstruction From Video” by Akbarzadeh et al. (June 14, 2006) (“Akbarzadeh”);
- U.S. Patent No. 6,895,126 to Di Bernardo et al. (“Di Bernardo”);
- U.S. Patent 7,389,181 to Meadows et al. (Application No. 11/216,465) (“the ’465 application”);
- U.S. Patent 7,929,800 to Meadows et al. (Application No. 11/702,708) (“the ’708 application”);
- U.S. Publication No. 2008/0189031 to Meadows et al. (Application No. 11/702,707) (“the ’707 application”); and
- Other background references, of which I had previously been aware, not cited herein that a POSITA would have recognized as being related to the subject matter of the ’396 patent.

10. Although this Declaration refers to selected portions of the cited references for the sake of brevity, it should be understood that one of ordinary skill in the art would view

the references cited herein in their entirety and in combination with other references cited herein or cited within the references themselves. The references used in this Declaration, therefore, should be viewed as being incorporated herein in their entirety.

11. I am not, and never was, an employee of Google Inc. I have been engaged in the present matter to provide my independent analysis of the issues raised in the petition for *inter partes* review of the '396 patent. I received no compensation for this declaration beyond my normal hourly compensation based on my time actually spent studying the matter, and I will not receive any added compensation based on the outcome of this *inter partes* review of the '396 patent.

OVERVIEW OF CONCLUSIONS FORMED

12. This expert Declaration explains the conclusions that I have formed based on my analysis. To summarize those conclusions:

- Based upon my knowledge and experience and my review of the prior art publications listed above, I believe that claims 1, 2, 5, and 8-13 of the '396 patent are anticipated by Fruh.
- Based upon my knowledge and experience and my review of the prior art publications listed above, I believe that claims 1, 2, 5, and 8-13 of the '396 patent are rendered obvious in light of Fruh alone.

- Based upon my knowledge and experience and my review of the prior art publications listed above, I believe that claims 1, 2, 5, 8-13, and 16 of the '396 patent are rendered obvious in light of Fruh in view of Di Bernardo.
- Based upon my knowledge and experience and my review of the prior art publications listed above, I believe that claims 1, 2, 5, and 8-10 of the '396 patent are anticipated by Akbarzadeh.
- Based upon my knowledge and experience and my review of the prior art publications listed above, I believe that claims 1, 2, 5, and 8-10 of the '396 patent are rendered obvious in light of Akbarzadeh alone.
- Based upon my knowledge and experience and my review of the prior art publications listed above, I believe that claims 1, 2, 5, 8-13, and 16 of the '396 patent are rendered obvious in light of Akbarzadeh in view of Di Bernardo.

BACKGROUND KNOWLEDGE ONE OF SKILL IN THE ART WOULD HAVE HAD PRIOR TO THE FILING OF THE '396 PATENT

13. The technology in the '396 patent at issue generally relates to a method for creating a continuum of image data by receiving two or more 2D image data sets of a subject captured from disparate points on a continuum, generating a composite image of the subject from aligned portions of two or more of the 2D image data sets, receiving data descriptive of a location of features in the image data sets, tracking the position of at least one feature in two or more of the images, generating a point cloud array for the feature,

converting the point cloud array into a polygon based model, and associating a location for the polygon based model relative to the portions of the image data sets and based on the location of the features in the image data sets. (See '396 patent at 2:32-54.)

14. I have been informed that the '396 patent is a continuation-in-part of App. No. 11/216,465 ("the '465 application") filed August 31, 2005, a continuation-in-part of App. No. 11/702,707 ("the '707 application") filed February 6, 2007, and a continuation-in-part of App. No. 11/702,708 ("the '708 application") filed February 6, 2007, which I have also reviewed.

15. Prior to the August 31, 2005 filing date of the '465 application (and certainly before the February 21, 2008 filing date of the '396 patent), there existed numerous products, publications, and patents that implemented or described the functionality claimed in the '396 patent. Based upon my knowledge and experience and my review of the prior art publications listed above, I believe that a person of ordinary skill in the art would have recognized—before August 2005, and especially before a date as late as February 2008—that the methodology described in the '396 patent was well-known in the prior art. Further, to the extent there was any problem to be solved in the '396 patent, a person of ordinary skill in the art would have known that such a problem had already been solved in the prior art systems before August 31, 2005 (and thus, well before the February 21, 2008 filing date of the '396 patent).

16. Based upon my experience in this area, a person of ordinary skill in the art in this field at the relevant time frame ("POSITA") would have had a combination of experience

and education in computer science, computer graphics, and imaging technology. This typically would consist of a minimum of a bachelor degree in computer science or a related engineering field plus 2-5 years of work and/or research experience in the field of computer science and its subfield of imaging technology. For purposes of my analysis of the '396 patent in this IPR proceeding, I will presume that the relevant time was before February 21, 2008, the filing date of the '396 Patent. However, even if the '396 patent claims are deemed to be entitled to the earlier August 31, 2005 priority date, it would not alter my analysis or conclusions with respect to Fruh and Di Bernardo, and the above-mentioned obviousness combinations thereof because, among other things, those references were all published or filed as patent applications before August 31, 2005. Also, if the '396 patent is deemed to be entitled to its filing date of February 21, 2008, the Akbarzadeh reference was published on June 14, 2006, and thus was published well before the February 21, 2008. Based on my experiences, I have a good understanding of the knowledge and skill possessed by a POSITA. Indeed, I have taught, participated in organizations, and worked closely with many such persons over the course of my career.

17. I have been informed that, for the '396 patent claims to receive the benefit of the filing date of any of its continuation-in-part parent applications (described above), the continuation-in-part parent application must provide written description support for the claim elements (that is, it must reasonably convey to a person of ordinary skill in the art that the inventors had possession of the claimed method at the time of the filing of the continuation-

in-part parent application). Based upon my knowledge and experience in this field and my review of the '396 patent and its continuation-in-part parent applications at issue here (i.e., the '465 application, the '707 application, and the '708 application), I believe that a person of ordinary skill in the art would have concluded that none of the continuation-in-part parent applications – individually or collectively – provide such written description support for all of the elements of independent claim 1 of the '396 patent. In one example, claim 1 of the '396 patent requires the method steps of “generating a point cloud array for the at least one of the plurality of features” and “converting the point cloud array to a polygon based model.” In particular, the person of ordinary skill in the art at the time would have understood that none of the earlier-filed '465 and '708 applications describe generating point clouds and processing the point clouds to generate polygon based models. See U.S. Patent 7,389,181 (the earlier-filed '465 application); U.S. Patent 7,929,800 (the earlier-filed '708 application). Further, although the earlier-filed '707 application generally discloses polygons overlaid on images, it also does not contain a description of generating point clouds and processing the point clouds to generate polygon based models, as recited in claim 1 of the '396 patent. See U.S. Publication No. 2008/0189031 (the earlier-filed '707 application) at ¶ [0026], [0028], [0033], [0035], [0038]-[0041], [0044], [0046], [0060]. Rather, to the extent these two method steps in claim 1 of the '396 patent are described at all in this patent family, the first such possible disclosure occurred when the new and different specification was filed by the inventors on the filing date of the '396 patent—February 21, 2008.

INTERPRETATIONS OF THE '396 PATENT CLAIMS AT ISSUE

18. I understand that, for purposes of my analysis in this *inter partes* review proceeding, the terms appearing in the patent claims should be interpreted according to their “broadest reasonable construction in light of the specification of the patent in which it appears.” 37 C.F.R. § 42.100(b). In that regard, I understand that the best indicator of claim meaning is its usage in the context of the patent specification as understood by a POSITA. I further understand that the words of the claims should be given their plain meaning unless that meaning is inconsistent with the patent specification or the patent’s history of examination before the Patent Office. I also understand that the words of the claims should be interpreted as they would have been interpreted by a POSITA at the time the invention was made (not today). I have used February 21, 2008, the filing date of the ’396 patent, as the point in time for claim interpretation purposes. I have been asked to provide my interpretation of the following terms and phrases of the ’396 patent set forth below.

19. Claims 1 recites “a continuum of image data,” which under the broadest reasonable interpretation standard, is interpreted to mean two or more images captured along a path. The specification of the ’396 patent describes that “According to the present invention, image data is captured from disparate points along a continuum. Referring now to FIG. 1, in some embodiments the continuum 100 includes the path of a vehicle carrying a

digital camera, or other image data capturing device.” (’396 patent at 3:14-18.) Also, the specification of the ’708 application to which the ’396 patent claims priority describes a “continuum of image data” as providing “a two dimensional ribbon of street level views of geographic areas” and that “[t]he ribbons are created by capturing two or more images of a subject, wherein each of the two or more images are captured from disparate points on a continuum. For example, each of the two or more images can be captured from a different position on a street as a vehicle drives down the street.” (’708 application at 2:5-11.) Based upon my knowledge and experience in this field, I believe that a POSITA would have understood that this interpretation is consistent with the plain meaning of these terms under the broadest reasonable interpretation and is consistent with the ’396 patent specification and the ’708 application specification.

20. Claim 1 recites “point cloud array,” which under the broadest reasonable interpretation standard, is interpreted to mean a set of points corresponding to locations of features. The specification of the ’396 patent describes that “In general, point clouds are generated utilizing the location of feature points present in multiple image sets in combination with the position and orientation of a camera capturing the image data set.” (’396 patent at 2:41-44.) Based upon my knowledge and experience in this field, I believe that a POSITA would have understood that this interpretation is consistent with the plain meaning of these terms under the broadest reasonable interpretation and is consistent with the ’396 patent specification.

21. Claim 1 recites “polygon based model,” which under the broadest reasonable interpretation standard, is interpreted to mean a model using polygons to represent 3D structure of objects. The specification of the '396 patent describes that “The point clouds can in turn be processed to generate three-dimensional polygon based models representative of objects.” ('396 patent at 2:44-46.) The specification of the '396 patent further describes that “point cloud arrays can be converted to three-dimensional polygon based models of artifacts present in the image data sets. The three-dimensional polygon based models are based upon physical attributes.” ('396 patent at 6:50-53.) Based upon my knowledge and experience in this field, I believe that a POSITA would have understood that this interpretation is consistent with the plain meaning of these terms under the broadest reasonable interpretation and is consistent with the '396 patent specification.

22. Claim 2 recites “spraying image data onto the polygon based model,” which under the broadest reasonable interpretation standard, is interpreted to mean mapping image data on to the polygon based model. The specification of the '707 application to which the '396 patent claims priority describes that “implementations of the present invention can include a continuum of image data 1001-1004 sprayed as a texture map on a polygon surface 1005-1008. FIG. 10 illustrates a profile, cutaway view which indicates the shape of a surface 1005 onto which image data 1001-1004 can be mapped.” ('707 application at ¶ [0060].) Based upon my knowledge and experience in this field, I believe that a POSITA would have understood that this interpretation is consistent with the plain

meaning of these terms under the broadest reasonable interpretation and is consistent with the '396 patent specification.

23. Claim 12 recites “associating the composite image with a particular portion of the subject,” which under the broadest reasonable interpretation standard, is interpreted to mean associate the composite image with a particular parcel of a geographic area. The specification of the '396 patent describes that “[p]hotographs . . . are easily associated with a particular real estate parcel.” ('396 patent at 1:33-34.) The '396 patent further describes that particular portions of a motion picture are “correlate[ed] with a particular real estate parcel.” (*Id.* at 1:42-44.) The '396 patent also describes that the system “correlates a ribbon of geographic image data with geospatial designations to facilitate identification of a particular geographic area.” (*Id.* at 7:42-44.) Based upon my knowledge and experience in this field, I believe that a POSITA would have understood that this interpretation is consistent with the plain meaning of these terms under the broadest reasonable interpretation and is consistent with the '396 patent specification.

ANALYSIS OF FRUH (CLAIMS 1, 2, 5, and 8-13)

24. Fruh is one of many prior art examples that, much like an embodiment described in the '396 patent, describes a method for ground-based acquisition of large-scale 3D city models. (Fruh at Abstract.) Fruh discloses using cameras and ground-based laser scanners to continuously obtain geometry and texture data for generating 3D city models.

(*Id.* at Abstract and p. 6.) Fruh's system generates a 3D point cloud for a city block from vertical laser scans, transforms the point cloud into a triangular mesh by connecting adjacent vertices, and maps texture onto each mesh triangle to create textured models of the buildings that the acquisition vehicle drove by. (*Id.* at p. 6, 16, 19, and 20.)

25. As set forth in more detail below, all of which is based upon my knowledge and experience in this art and my review of Fruh, I believe that Fruh discloses every element recited in claims 1, 2, 5, and 8-13 of the '396 patent.

[1.P] A method for creating a continuum of image data, the method comprising: [1.1] a) receiving multiple two-dimensional image data sets of a subject, wherein each image data set is captured from a disparate point on a continuum and each image data set comprises a plurality of features;

26. The Fruh reference discloses a method for creating a continuum of image data and receiving multiple 2D image data sets of a subject, where each image data set is captured from a disparate point on a continuum and each image data set comprises a plurality of features. For example, Fruh discloses using laser scanners and a digital camera to continuously acquire ground-level 3D geometry and texture image data and then generating 3D city models. (*Id.* at Abstract and p. 6.) This is depicted in Figure 1 of Fruh below.

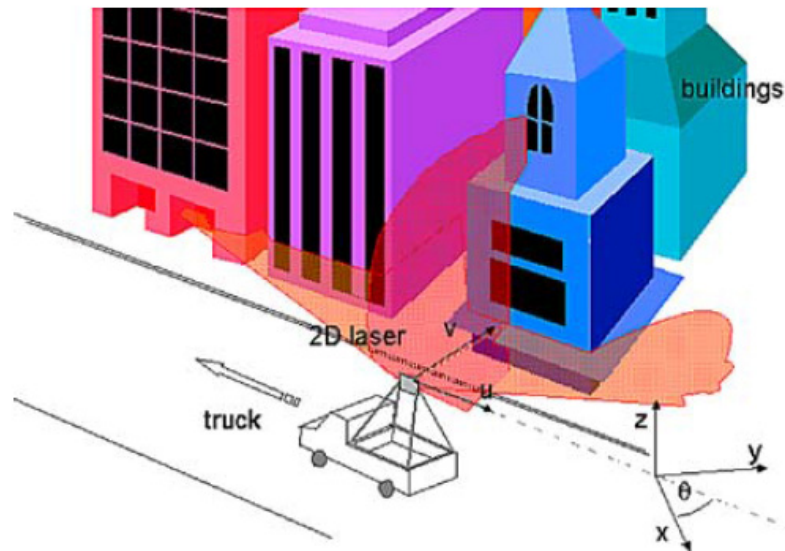


Figure 1. Experimental setup.

Figure 5 of Fruh below shows that the digital camera and laser scanners capture multiple images and multiple scans as the vehicle travels on a path.

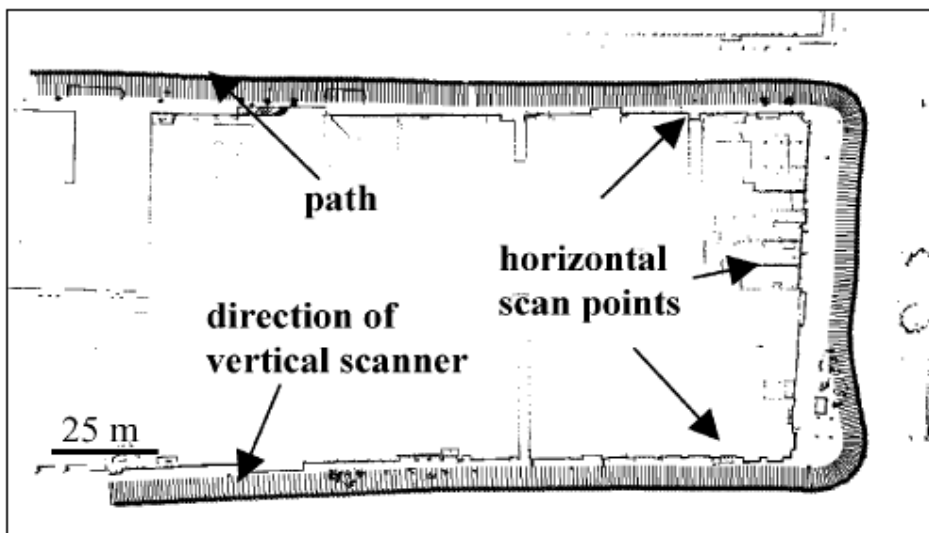


Figure 5. Reconstructed initial path from scan-to-scan matching, and superimposed horizontal scan points for each position.

[1.2] b) generating a composite image of the subject from portions of two or more of the multiple two-dimensional image data sets, wherein the portions are aligned in a dimension consistent with the continuum, and [11] wherein the

composite image comprises a single vertical slice of each of the two or more images;

27. The Fruh reference discloses generating a composite image of the subject from portions of two or more of the multiple 2D image data sets, where the portions are aligned in a dimension consistent with the continuum and the composite image comprises a single vertical slice of each of the two or more images. For example, Fruh discloses acquiring 3D geometry and 2D texture image data using laser scanners and a digital camera. (Fruh at p. 6.) Fruh discloses that “due to its regular structure, the processed point cloud can easily be transformed into a triangular mesh by connecting adjacent vertices.” (*Id.* at p. 16.) Fruh further discloses that the camera and laser scanners are synchronized and calibrated in the 3D coordinate system so that for every arbitrary 3D point, the corresponding image coordinate can be computed and the texture can be mapped onto each mesh triangle to result in textured façade models of the buildings that the acquisition vehicle drove by. (*Id.*) A POSITA would have recognized that texturing a 3D model includes extracting a single vertical strip of a camera image corresponding to a regular structure of the point cloud and aligning vertical strips in adjacent images corresponding to adjacent vertices.

[1.3] c) receiving data descriptive of a location of the plurality of features;

28. The Fruh reference discloses receiving data descriptive of a location of the plurality of features. For example, Fruh discloses acquiring successive ground-based horizontal scans and matching the scans to an aerial photograph or a global map. (*Id.* at

Abstract.) Fruh also discloses that GPS may be used for estimating position of a scanner. (*Id.* at p. 6).

[1.4] d) tracking the position of at least one of the plurality of features in two or more of the two-dimensional images;

29. The Fruh reference discloses tracking the position of at least one of the plurality of features in two or more of the 2D images. For example, Fruh discloses that the camera and laser scanners are synchronized and calibrated in the 3D coordinate system, and an image coordinate is computed for every 3D point. (*Id.* at p. 16.) Fruh also discloses matching successive horizontal scans with each other to determine an estimate of the vehicle's motion and to determine a pose of successive scans and camera images. (*Id.* at Abstract and p. 6.) A POSITA would have understood that doing so would include tracking the position of objects in the successive horizontal scans and that tracking the position of objects in the successive horizontal scans results in tracking the position of the same objects in successive 2D images captured by the camera corresponding to the successive horizontal scans because the camera and laser scanners are synchronized and calibrated in the 3D coordinate system.

[1.5] e) generating a point cloud array for the at least one of the plurality of features;

30. The Fruh reference discloses generating a point cloud array for at least one of the plurality of features. For example, Fruh discloses generating a 3D point cloud for a city

block from vertical laser scans. (*Id.* at p. 16 and 19.) The structured point cloud for a city block is shown below in Figure 19.

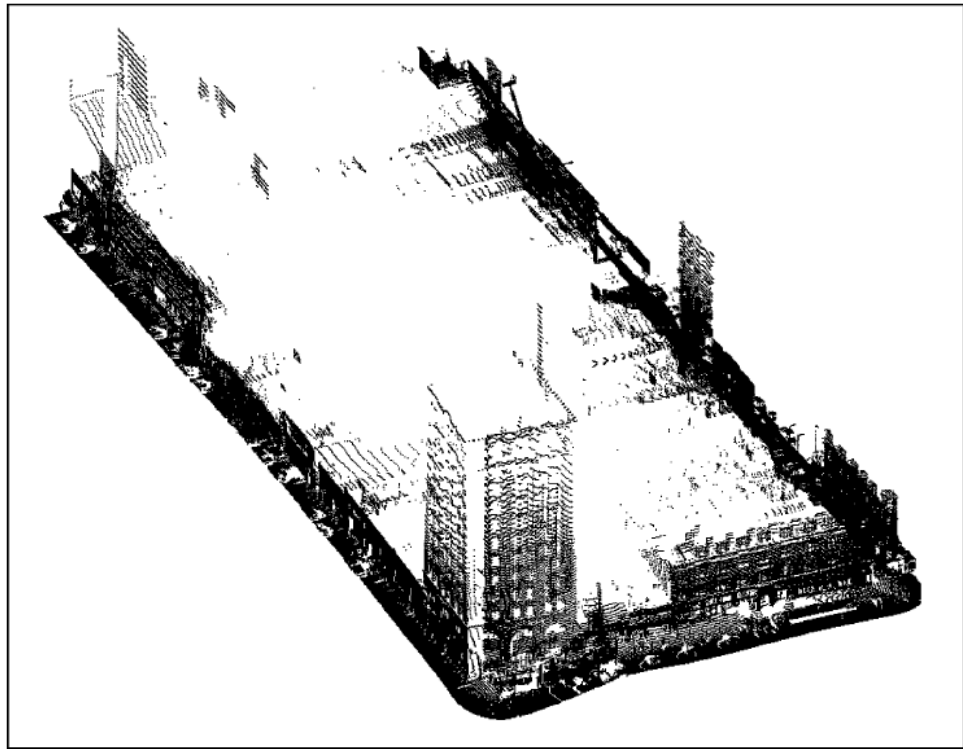


Figure 19. Structured point cloud for a city block.

[1.6] f) converting the point cloud array to a polygon based model; and

31. The Fruh reference discloses converting the point cloud array to a polygon based model. For example, Fruh discloses transforming the point cloud into a triangular mesh by connecting adjacent vertices, as shown below in Figure 21. (*Id.* at p. 16 and 20.)



Figure 21. Surface mesh by triangulating the point cloud.

[1.7] g) associating a location for the polygon based model relative to the portions of the image data sets and based upon the location of the plurality of features.

32. The Fruh reference discloses associating a location for the polygon based model relative to the portions of the image data sets and based upon the location of the plurality of features. For example, Fruh discloses determining the pose of successive laser scans and camera images in a global coordinate system using an aerial photograph or a

global map, calculating 3D coordinates of vertical scan points in the global coordinate system, and computing the corresponding image coordinate for every arbitrary 3D point to create textured façade models of the buildings that the acquisition vehicle drove by. (*Id.* at Abstract and p. 6, 16, and 20.) Fruh further discloses that the façade models have been brought into perfect registration with either an aerial photo or a global map. (*Id.*) A POSITA would have understood that in Fruh, the locations of features in the façade models is associated with locations in the 2D camera images, and for a façade model to be constructed properly, the images and the associated horizontal laser scans would have to be registered to the aerial photo or the global map based on the locations of the features.

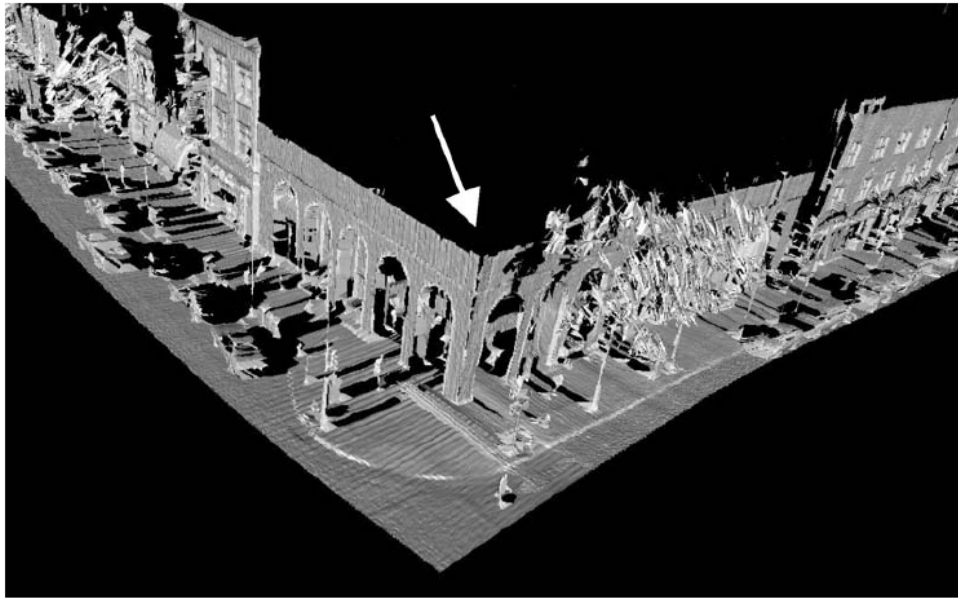
[2] The method of claim 1 additionally comprising the step of spraying image data onto the polygon based model, wherein the polygon based model comprises at least one three dimensional polygon based model and wherein the image data sprayed onto the polygon based model is based upon two-dimensional image data sets and the location of the polygon based model and [5.2] spraying image data onto the each polygon based model, wherein the image data sprayed onto the each polygon based model is based upon two-dimensional image data sets and the location of each respective polygon based model.

33. The Fruh reference discloses spraying image data onto the polygon based model, where the polygon based model comprises at least one 3D polygon based model, and where the image data sprayed onto the polygon based model is based upon 2D image data sets and the location of the polygon based model, and spraying image data onto the each polygon based model, where the image data sprayed onto the each polygon based model is based upon 2D image data sets and the location of each respective polygon based

model. For example, Fruh discloses acquiring texture data using a digital camera. (*Id.* at p. 6.) Fruh's system computes the corresponding image coordinate for every arbitrary 3D point and maps the texture onto each mesh triangle to create textured models of the buildings that the acquisition vehicle drove by. (*Id.* at p. 6 and 16).

[5.P] The method of claim 1 additionally comprising the steps of: [5.1] repeating steps a) through f) multiple times each from disparate points along the continuum; and

34. The Fruh reference discloses repeating steps a) through f) multiple times each from disparate points along the continuum. For example, Fruh discloses continuously acquiring 3D geometry and texture data of an entire city. (*Id.* at p. 6.) Textured façade models of the buildings that the acquisition vehicle drove by are created from the acquired data. (*Id.* at p. 16.) Multiple facade models for a geographic area, e.g., the downtown Berkeley, California area, are aligned with each other to create large-scale 3D city models. (*Id.* at Abstract and p. 20). Figure 22 of Fruh shows the alignment of two independently acquired façade models.



[8] The method of claim 1 wherein the data descriptive of a location comprises a Cartesian coordinate.

35. The Fruh reference discloses that the data descriptive of a location comprises a Cartesian coordinate. For example, Fruh discloses using a Cartesian world coordinate system for vertical scan points. (*Id.* at p. 6, 8, and 16.)

[9] The method of claim 8 wherein the data descriptive of a location of the plurality of features comprises a latitude and longitude coordinate.

36. The Fruh reference discloses that the data descriptive of a location of the plurality of features comprises a latitude and longitude coordinate. For example, Fruh discloses that GPS can be and is often used for position estimates in outdoor environments. (*Id.* at p. 6, 8, and 16.)

[10] The method of claim 1 additionally comprising the step of associating metadata with a polygon based model.

37. The Fruh reference discloses associating metadata with a polygon based model. For example, Fruh discloses that the textured façade models have been brought into perfect registration with either an aerial photo or a global map. (*Id.*) A POSITA would have understood that registering the textured façade models with an aerial photo or a global map provides the claimed associating metadata with the polygon based model.

[12] The method of claim 11, additionally comprising the steps of: recording positional data descriptive of a respective location of each of the multiple two-dimensional image data sets of a subject: and associating the composite image with a particular portion of the subject based upon the positional data and [13] The method of claim 12 wherein the subject comprises a geographic area and the positional data comprises a geospatial designation.

38. The Fruh reference discloses recording positional data descriptive of a respective location of each of the multiple 2D image data sets of a subject and associating the composite image with a particular portion of the subject based upon the positional data, where the subject comprises a geographic area and the positional data comprises a geospatial designation. For example, Fruh discloses acquiring 3D geometry and 2D texture image data using laser scanners and a digital camera. (*Id.* at p. 6.) Fruh discloses matching horizontal laser scans to an aerial photograph or global map to determine the final global pose of the acquisition vehicle. (*Id.* at Abstract.) Fruh further discloses that the camera and laser scanners are synchronized and calibrated in the 3D coordinate system so that for every arbitrary 3D point, the corresponding image coordinate can be computed and

the texture can be mapped onto each mesh triangle to result in textured façade models of the buildings that the acquisition vehicle drove by. (*Id.* at p. 16.) A POSITA would have recognized that matching horizontal laser scans to an aerial photograph or a global map would result in recording of positional data descriptive of a respective location of each of the multiple 2D image data sets of a subject and that the composite texture image is associated with a particular portion of a subject based on the matching of the horizontal laser scans with the aerial photo or the global map. Fruh also describes previous systems where localization of a car-based laser scanner is based on GPS. (*Id.* at Abstract and p. 6 (“GPS is by far the most common source of global position estimates in outdoor environments.”).)

39. In summary, based upon my knowledge and experience in this field and my analysis of Fruh, all elements recited in claims 1, 2, 5, and 8-13 are expressly disclosed by the Fruh reference. Moreover, to the extent the Patent Owner argues that any element of claims 1, 2, 5, and 8-13 is not expressly disclosed by the Fruh reference, the great amount of similarity between Fruh’s teaching and the method of the ’396 patent would have been noticed by a POSITA, and any such element would have been recognized as being rendered obvious in view of the disclosures of the Fruh reference and in light of the knowledge of a POSITA. Indeed, especially by a date as late as February 2008, a POSITA would have plainly understood the fact that Fruh provides a method for creating a continuum of image data, which is highly similar to that of the ’396 patent and that achieves the same or equivalent result as the preferred embodiment of the ’396 patent.

ANALYSIS OF FRUH IN VIEW OF DI BERNARDO (CLAIMS 1, 2, 5, 8-13, and 16)

40. As stated above, I believe that Fruh discloses each and every element of claims 1, 2, 5, and 8-13 or otherwise renders those claims obvious. I have also been asked to assess the combination of Fruh with Di Bernardo with respect to claims 1, 2, 5, 8-13, and 16. To that extent, I believe that a POSITA would have recognized that the resulting combination of Fruh and Di Bernardo discloses all elements of claims 1, 2, 5, 8-13, and 16. For example, Di Bernardo discloses vehicle mounted cameras for capturing image data, and a system for generating composite images of a location from captured images and associating geographic location information with the images. (See Di Bernardo at 2:16-21; 3:39-4:1; 4:26-33; 10:22-33; 12:61-67.)

41. As set forth in more detail below, all of which is based upon my knowledge and experience in this art and my review of Fruh and Di Bernardo, I believe that the combination of Fruh and Di Bernardo discloses every element recited in claims 1, 2, 5, 8-13, and 16 of the '396 patent. I have already addressed claims 1, 2, 5, and 8-13 of the '396 patent with respect to Fruh, and will therefore limit my additional analysis regarding Fruh and Di Bernardo to specific elements recited by claims 1, 11-13, and 16.

[1.P] A method for creating a continuum of image data, the method comprising:

42. In addition to the teachings of Fruh with respect to this claim element (discussed above), a POSITA would have recognized that systems and methods for

creating a continuum of image data were commonly practiced in the prior art. For example, Di Bernardo discloses synthesizing images of a geographic location to generate composite images of the location. (*Id.* at 2:16-21, 3:40-48.) The geographic location may be a particular street in a geographic area with the composite images providing a view of the objects on each side of the street. (*Id.*)

[1.2] b) generating a composite image of the subject from portions of two or more of the multiple two-dimensional image data sets, wherein the portions are aligned in a dimension consistent with the continuum, and [11] wherein the composite image comprises a single vertical slice of each of the two or more images.

43. In addition to the teachings of Fruh with respect to these claim elements (discussed above), a POSITA would have recognized that systems and methods for generating a composite image of the subject from portions of two or more of the multiple 2D image data sets, where the portions are aligned in a dimension consistent with the continuum, and where the composite image comprises a single vertical slice of each of the two or more images were well known in the prior art. For example, Di Bernardo teaches that composite images are formed by extracting image data from selected image frames and combining the image data. (*Id.* at 5:67-6:15.) The image data extracted from each image frame is an optical column that consists of a vertical set of pixels. (*Id.*) The composite image is created on a column-by-column basis by extracting corresponding optical columns from each image frame. (*Id.*) The columns of pixels are stacked side by side to generate a single image forming the composite image that includes portions from

different image frames captured along a camera path. (*Id.* at 5:67-6:25, 9:34-43.) For example, as shown in Figure 2 below, portions of images captured at time t_1 , t_i , and t_N are combined into the wider composite image 40.

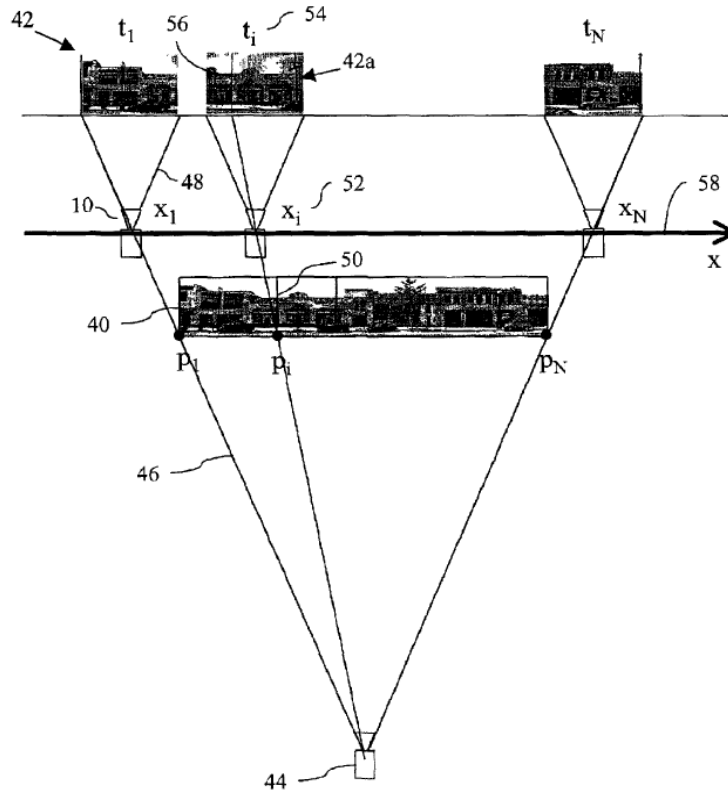


Fig.2

[12] The method of claim 11, additionally comprising the steps of: recording positional data descriptive of a respective location of each of the multiple two-dimensional image data sets of a subject; and associating the composite image with a particular portion of the subject based upon the positional data, and [13] wherein the subject comprises a geographic area and the positional data comprises a geospatial designation.

44. In addition to the teachings of Fruh with respect to these claim elements

(discussed above), a POSITA would have recognized that systems and methods for

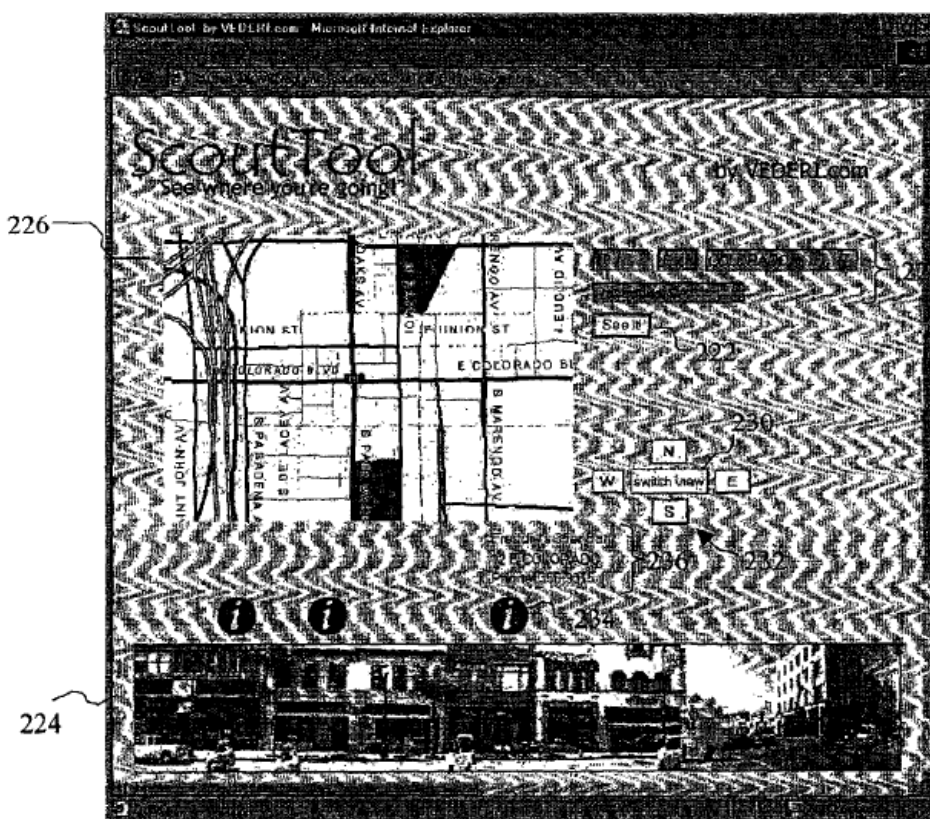
recording positional data descriptive of a respective location of each of the multiple 2D image data sets of a subject were well known in the prior art. For example, Di Bernardo teaches that an image recording device moves along a path recording images of objects along the path while a GPS receiver or inertial navigation system provides position information of the image recording device as the images are acquired. (Di Bernardo at 2:22-28.) The GPS receiver computes latitude and longitude coordinates indicating the position of the recording device during the recording of a particular image frame. (*Id.* at 5:17-23.) The image and position information is provided to the computer to associate each image with the position information. (*Id.* at 2:22-28.) Di Bernardo also teaches tracking the GPS position of landmarks in captured images. (*Id.* at 6:60-65, 7:6-12.)

45. A POSITA would have also recognized that systems and methods for associating the composite image with a particular portion of the subject based upon the positional data, where the subject comprises a geographic area and the positional data comprises a geospatial designation were well known in the prior art. For example, Di Bernardo discloses computing latitude and longitude coordinates as the camera moves along a path and records object in its view. (*Id.* at 5:17-23.) The trajectory taken by the recording device is segmented into street segments using the position information and associating each street segment with identifying information about the street segment, such as a street name and number range. (*Id.* at 6:38-49.) The computer generates a series of composite images depicting a portion of each street segment and stores each composite

image in an image database along with the identifying information of the street segment with which it is associated. (*Id.*)

[16] The method of claim 12 wherein the method additionally comprises the steps of overlaying metadata on the composite image descriptive of the composite image.

46. A POSITA would have recognized that systems and methods for overlaying metadata on the composite image descriptive of the composite image were well known in the prior art. For example, Di Bernardo discloses overlaying metadata on the composite image descriptive of the composite image. The system of Di Bernardo includes “an object information database with information about the objects being depicted in the composite images” and “the host computer searches the object information database to retrieve information about the objects depicted in the composite image.” (*Id.* at 10:26-33; 12:36-39.) Di Bernardo further discloses that a “user may obtain information about the objects being visualized in the composite image by actuating one of the information icons 234 above the image of a particular object.” (*Id.* at 12:49-58.) As Figure 16 below shows, Di Bernardo discloses that icons are displayed relative to objects in the composite image.



47. Di Bernardo discloses overlaying the metadata over the composite image in that information associated with a particular location “is preferably displayed each time the user terminal’s cursor or pointing device is passed above the icon.” (*Id.* at 12:59-67.) Di Bernardo further discloses that “[i]f the objects are business establishments, the information displayed upon actuating the information icons 234 may include the name, address, and phone number 236 of the establishment.” (*Id.*) A POSITA would have understood that, even though the example shown in Figure 16 shows the information icons 234 displayed above the composite image 224, it would have been an obvious design choice to display the information icons 234 superimposed on top of the composite image 224.

48. There are several reasons that would have prompted a POSITA to combine Di Bernardo's teachings with Fruh's system for creating 3D models of a geographic area. For example, a POSITA would have been prompted to modify Fruh's system to incorporate Di Bernardo's teachings regarding overlaying metadata so that the resulting system would provide context to the objects being depicted (as suggested by Di Bernardo). (*Id.* at Abstract, 2:6-8.)

49. Furthermore, a POSITA would have been prompted to modify Fruh's system with Di Bernardo's teachings because doing so would be merely the use of known techniques (e.g., generating a composite image of a geographic area, recording positional data descriptive of the geographic area, or both) to improve similar devices (e.g., Fruh's system for generating 3D models from 2D scans and images) in the same way. Here, both Fruh and Di Bernardo disclose similar systems for generating visualizations from multiple 2D images. A POSITA would have recognized that applying Di Bernardo's suggestions to Fruh's system would have led to predictable results, and that such a modification would not significantly alter or hinder the functions performed by the system of Fruh, but would instead provide the additional benefits conferred by practicing the functions described in Di Bernardo.

50. In summary, based upon my knowledge and experience and my analysis of Fruh and Di Bernardo, all elements recited in claims 1, 2, 5, 8-13, and 16 of the '396 patent are expressly disclosed by the combination of Fruh in view of Di Bernardo. Moreover, to the

extent the Patent Owner argues that any element of claims 1, 2, 5, 8-13, and 16 is not expressly disclosed by the combination of Fruh and Di Bernardo, the overwhelming similarity between the combination of Fruh and Di Bernardo and the method of the '396 patent would have been noticed by a POSITA, and the POSITA would have recognized that any such element would have been obvious in view of the disclosures of Fruh and Di Bernardo and in light of the knowledge of a POSITA.

ANALYSIS OF AKBARZADEH (CLAIMS 1, 2, 5, and 8-10)

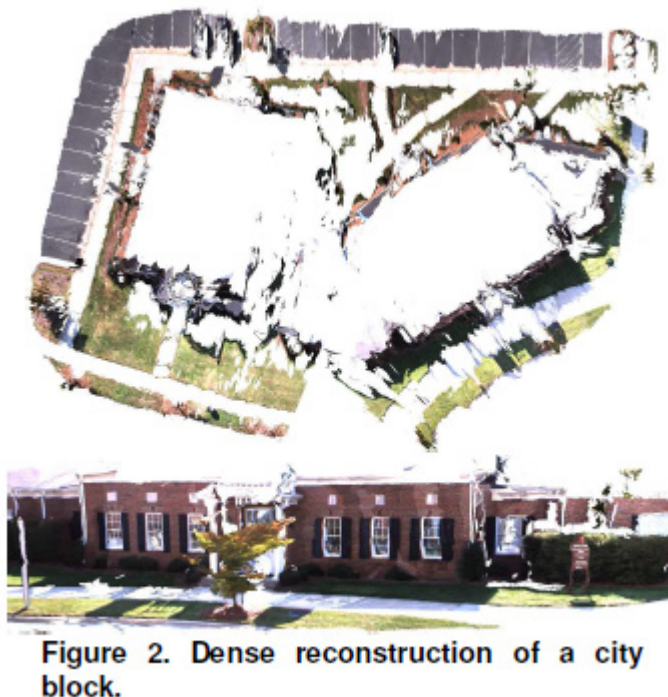
51. Akbarzadeh is one of many prior art examples that, much like the embodiment described in the '396 patent, describes a method for 3D reconstruction of urban scenes from multiple video streams captured by an on-vehicle acquisition system. (Akbarzadeh at Abstract and p. 2 and 5.) Akbarzadeh discloses collecting multiple video streams using a multi-camera system while driving through streets. (*Id.* at Abstract and p. 1 and 3.) Ground-level 3D models of urban scenes are generated from the video data captured by the multi-camera system. (*Id.* at p. 1.)

52. As set forth in more detail below, all of which is based upon my knowledge and experience in this field and my review of Akbarzadeh, I believe that Akbarzadeh discloses every element recited in claims 1, 2, 5, and 8-10 of the '396 patent.

[1.P] A method for creating a continuum of image data, the method comprising:

53. The Akbarzadeh reference discloses a method for creating a continuum of image data. For example, Akbarzadeh discloses a method for reconstructing 3D models of urban scenes from multiple video streams captured by an on-vehicle acquisition system.

(*Id.* at Abstract and p.2 and 5.) Figure 2 of Akbarzadeh below shows the dense reconstruction of a city block.



Thus, Akbarzadeh's method for creating a continuum of image data is like the preferred method of the '396 patent in that the 3D models created from the multiple video streams captured by an on-vehicle acquisition system provides the claimed continuum of image data.

[1.1] a) receiving multiple two-dimensional image data sets of a subject, wherein each image data set is captured from a disparate point on a continuum and each image data set comprises a plurality of features;

54. The Akbarzadeh reference discloses receiving multiple two-dimensional image data sets of a subject, wherein each image data set is captured from a disparate point on a continuum and each image data set comprises a plurality of features. For example, Akbarzadeh discloses collecting multiple video streams using a multi-camera system while driving through streets. (*Id.* at Abstract and p. 1 and 3.)

[1.2] b) generating a composite image of the subject from portions of two or more of the multiple two-dimensional image data sets, wherein the portions are aligned in a dimension consistent with the continuum;

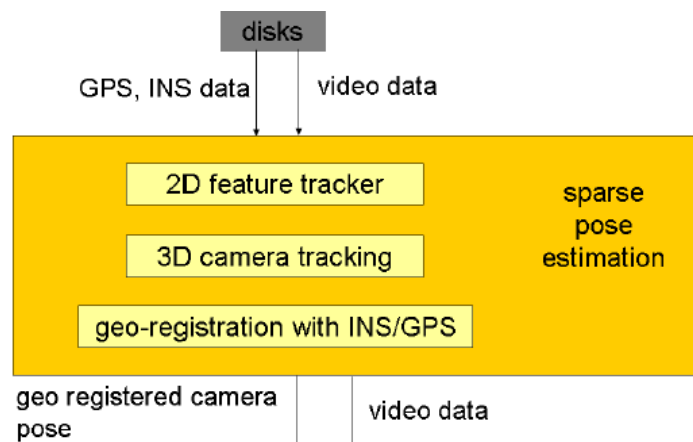
55. The Akbarzadeh reference discloses generating a composite image of the subject from portions of two or more of the multiple two-dimensional image data sets, wherein the portions are aligned in a dimension consistent with the continuum. For example, Akbarzadeh discloses generating ground-level 3D models of urban scenes from video data captured by a multi-camera system. (*Id.* at p. 1.) To generate the 3D models, Akbarzadeh generates depth maps for each video frame by performing stereo matching on the input images and fuses the depth maps to enforce consistency between them. (*Id.* at p. 3.)

[1.3] c) receiving data descriptive of a location of the plurality of features, [8] wherein the data descriptive of a location comprises a Cartesian coordinate, and [9] wherein the data descriptive of a location of the plurality of features comprises a latitude and longitude coordinate;

56. The Akbarzadeh reference discloses receiving data descriptive of a location of the plurality of features, where the data descriptive of a location comprises a Cartesian coordinate, and where the data descriptive of a location of the plurality of features comprises a latitude and longitude coordinate. For example, Akbarzadeh discloses collecting GPS and INS measurements to determine the geo-registered coordinates of features in the 3D model. (*Id.* at p. 4.)

[1.4] d) tracking the position of at least one of the plurality of features in two or more of the two-dimensional images;

57. The Akbarzadeh reference discloses tracking the position of at least one of the plurality of features in two or more of the two-dimensional images. For example, Akbarzadeh discloses a “2D feature tracker” (see portion of Figure 3 below) that determines correspondence between 3D feature points in consecutive image frames. (*Id.* at 3-4.)



[1.5] e) generating a point cloud array for the at least one of the plurality of features; [1.6] f) converting the point cloud array to a polygon based model; and

58. The Akbarzadeh reference discloses generating a point cloud array for the at least one of the plurality of features and converting the point cloud array to a polygon based model. For example, Akbarzadeh discloses determining 2D-2D point correspondences in consecutive video frames by tracking 1000 feature points in a 1024 x 768 image. (*Id.* at p. 3.) Akbarzadeh also discloses producing a depth map for each video frame that provides a depth estimate for each point in a frame. (*Id.* at p. 4 and 5.) A triangulated, texture-mapped, 3D model of a scene is generated from the depth maps. (*Id.* at 5; FIG. 23.)

[1.7] g) associating a location for the polygon based model relative to the portions of the image data sets and based upon the location of the plurality of features, and [10] associating metadata with a polygon based model.

59. The Akbarzadeh reference discloses associating a location for the polygon based model relative to the portions of the image data sets and based upon the location of the plurality of features and associating metadata with a polygon based model. For example, Akbarzadeh discloses that the 3D reconstruction of urban scenes are geo-registered. (*Id.* at Abstract.) To determine geo-registered coordinates of the features in the 3D model, Akbarzadeh uses geo-registered poses of the cameras estimated from the video and INS/GPS data. (*Id.* at p. 4.) The '396 patent explicitly describes metadata of images as including geospatial data from a GPS receiver unit. ('396 patent at 5:17-22.)

[2] The method of claim 1 additionally comprising the step of spraying image data onto the polygon based model, wherein the polygon based model

comprises at least one three dimensional polygon based model and wherein the image data sprayed onto the polygon based model is based upon two-dimensional image data sets and the location of the polygon based model and [5.2] spraying image data onto the each polygon based model, wherein the image data sprayed onto the each polygon based model is based upon two-dimensional image data sets and the location of each respective polygon based model.

60. The Akbarzadeh reference discloses spraying image data onto the polygon based model, wherein the polygon based model comprises at least one 3D polygon based model and wherein the image data sprayed onto the polygon based model is based upon 2D image data sets and the location of the polygon based model and spraying image data onto the each polygon based model, where the image data sprayed onto the each polygon based model is based upon 2D image data sets and the location of each respective polygon based model. For example, Akbarzadeh discloses generating a 3D model of a scene in geo-registered coordinates and providing texture for the surfaces of the 3D model using the video data. (*Id.* at p. 2 and 5.) Akbarzadeh discloses “sparse reconstruction during which the geo-registered poses of the cameras are estimated from the video and the INS/GPS data; and dense reconstruction during which a texture-mapped, 3D model of the urban scene is computed from the video data and the results of the sparse [reconstruction] step” and “The dense reconstruction stage also provides texture for the surfaces using the video input.” (*Id.* at p. 2.)

[5.P] The method of claim 1 additionally comprising the steps of: [5.1] repeating steps a) through f) multiple times each from disparate points along the continuum; and

61. The Akbarzadeh reference discloses repeating steps a) through f) multiple times each from disparate points along the continuum. For example, Akbarzadeh discloses capturing and processing large amounts of video data and reconstructing 3D models of urban scenes from several hours of video data. (*Id.* at p. 1.) Akbarzadeh discloses a fully automatic system that operates in continuous mode to post-process large video datasets. (*Id.* at p. 3.) In particular, Akbarzadeh discloses “an approach for fully automatic 3D reconstruction of urban scenes from several hours of video data captured by a multi-camera system.” (*Id.*)

62. In summary, based upon my knowledge and experience and my analysis of Akbarzadeh, all elements recited in claims 1, 2, 5, and 8-10 are expressly disclosed by Akbarzadeh. Moreover, to the extent the Patent Owner argues that any element of claims 1, 2, 5, and 8-10 is not expressly disclosed in the Akbarzadeh, the high degree of similarity between Akbarzadeh’s teaching and the method of the ’396 patent would have been noticed by a POSITA, and any such element would have been recognized as being rendered obvious in view of the disclosure of Akbarzadeh and in light of the knowledge of a POSITA. Here, especially by a date as late as February 2008, a POSITA would have plainly understood the fact that Akbarzadeh provides a method for creating a continuum of image data, which is highly similar to that of the ’396 patent and that achieves the same or equivalent result as the preferred embodiment of the ’396 patent

ANALYSIS OF AKBARZADEH IN VIEW OF DI BERNARDO (CLAIMS 1, 2, 5, 8-13, and 16)

63. As stated above, I believe that Akbarzadeh discloses each and every element of claims 1, 2, 5, and 8-10 or otherwise renders those claims obvious. I have also been asked to assess the combination of Akbarzadeh with Di Bernardo with respect to claims 1, 2, 5, 8-13, and 16. As previously described above in ¶¶ 40-47, Di Bernardo discloses elements [1.P] and [1.2] of claim 1, and each and every element of claims 11-13 and 16. To that extent, I believe that a POSITA would have recognized that the resulting combination of Akbarzadeh and Di Bernardo discloses all elements of claims 1, 2, 5, 8-13, and 16. I have already addressed claims 1, 2, 5, 8-10 of the '396 patent with respect to Akbarzadeh, and will therefore limit my additional analysis regarding Akbarzadeh and Di Bernardo to specific elements recited by claims 12 and 13.

[12] The method of claim 11, additionally comprising the steps of: recording positional data descriptive of a respective location of each of the multiple two-dimensional image data sets of a subject; and associating the composite image with a particular portion of the subject based upon the positional data, [13] wherein the subject comprises a geographic area and the positional data comprises a geospatial designation.

64. The Akbarzadeh reference discloses recording positional data descriptive of a respective location of each of the multiple 2D image data sets of a subject and associating the composite image with a particular portion of the subject based upon the positional data, where the subject comprises a geographic area and the positional data comprises a geospatial designation. For example, Akbarzadeh discloses collecting GPS and INS

measurements while collecting video data of an urban scene. (Akbarzadeh at Abstract and p. 2.) The GPS and INS measurements are used to estimate a geo-registered camera pose for each frame of the video stream and to place the reconstructed models in georegistered coordinates. (*Id.* at Abstract and p. 3.)

65. For reasons similar to those described in ¶¶ 48 and 49, a POSITA would have been motivated to combine the teachings of Di Bernardo with Akbarzadeh's system for creating 3D images of a scene.

66. In summary, based upon my knowledge and experience and my analysis of Akbarzadeh and Di Bernardo, all elements recited in claims 1, 2, 5, 8-13, and 16 are expressly disclosed by the combination of Akbarzadeh and Di Bernardo. Moreover, to the extent the Patent Owner argues that any element of claims 1, 2, 5, 8-13, and 16 is not expressly disclosed by the combination of Akbarzadeh and Di Bernardo, the similarity between the combination of Akbarzadeh and Di Bernardo and the method of the '396 patent would have been noticed by a POSITA, and the POSITA would have recognized that any such element would have been obvious in view of the disclosures of Akbarzadeh and Di Bernardo and in light of the knowledge of a POSITA.

LEGAL PRINCIPLES

Anticipation

67. I have been informed that a patent claim is invalid as anticipated under 35 U.S.C. § 102 if each and every element of a claim, as properly construed, is found either explicitly or inherently in a single prior art reference. Under the principles of inherency, if the prior art necessarily functions in accordance with, or includes the claimed limitations, it anticipates.

68. I have been informed that a claim is invalid under 35 U.S.C. § 102(a) if the claimed invention was known or used by others in the U.S., or was patented or published anywhere, before the applicant's invention. I further have been informed that a claim is invalid under 35 U.S.C. § 102(b) if the invention was patented or published anywhere, or was in public use, on sale, or offered for sale in this country, more than one year prior to the filing date of the patent application (critical date). And a claim is invalid, as I have been informed, under 35 U.S.C. § 102(e), if an invention described by that claim was described in a U.S. patent granted on an application for a patent by another that was filed in the U.S. before the date of invention for such a claim.

Obviousness

69. I have been informed that a patent claim is invalid as "obvious" under 35 U.S.C. § 103 in light of one or more prior art references if it would have been obvious to a POSITA, taking into account (1) the scope and content of the prior art, (2) the differences between the prior art and the claims, (3) the level of ordinary skill in the art, and (4) any so

called “secondary considerations” of non-obviousness, which include: (i) “long felt need” for the claimed invention, (ii) commercial success attributable to the claimed invention, (iii) unexpected results of the claimed invention, and (iv) “copying” of the claimed invention by others. For purposes of my analysis above, I have applied a date of February 21, 2008, as the date of invention in my obviousness analyses, although in many cases the same analysis would hold true even at an earlier time than February 21, 2008.

70. I have been informed that a claim can be obvious in light of a single prior art reference or multiple prior art references. To be obvious in light of a single prior art reference or multiple prior art references, there must be a reason to modify the single prior art reference, or combine two or more references, in order to achieve the claimed invention. This reason may come from a teaching, suggestion, or motivation to combine, or may come from the reference or references themselves, the knowledge or “common sense” of one skilled in the art, or from the nature of the problem to be solved, and may be explicit or implicit from the prior art as a whole. I have been informed that the combination of familiar elements according to known methods is likely to be obvious when it does no more than yield predictable results. I also understand it is improper to rely on hindsight in making the obviousness determination. *KSR Int’l Co. v. Teleflex Inc.*, 550 U.S. 398, 421 (2007).

ADDITIONAL REMARKS

71. I currently hold the opinions set expressed in this declaration. But my analysis may continue, and I may acquire additional information and/or attain supplemental insights that may result in added observations.

72. I hereby declare that all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true. I further declare that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of the Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patents issued thereon.

Dated: Aug. 20, 2014 By: 

Dr. Henry Fuchs, Ph.D. of Chapel Hill, NC

Henry FUCHS

Federico Gil Distinguished Professor of Computer Science
Adjunct Professor in Department of Biomedical Engineering
University of North Carolina at Chapel Hill



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Citizenship: USA

Education

1975	Ph.D Computer Science, University of Utah
1970	B.A. Information and Computer Science, University of California at Santa Cruz

Position(s) Held

1978- present	UNC Chapel Hill Adjunct Professor of Biomedical Engineering (2000-) Federico Gil Distinguished Professor (1988-) Adjunct Professor of Radiation Oncology (1988-2008) Professor of Computer Science (1983-) Associate Professor of Computer Science (1978-83)
1975-82	University of Texas at Dallas Adjunct Associate Professor of Medical Computer Science, Southwestern Medical School, The University of Texas Health Science Center (1979-82) Adjunct Associate Professor, Programs in Mathematical Sciences (1978-82) Computer Science Coordinator, Programs in Mathematical Sciences (1977-78) Assistant Professor, Mathematical Sciences (1975-78)
1970-74	University of Utah Research Assistant and Teaching Fellow, Computer Science Department

1976- Present	Consultant or Member of Technical Technical Advisory Board, Mersive Technologies External Advisory Board, Harvard Neuroimage Analysis Center Former consulting and advisory board memberships: Mitsubishi Electric Research Lab, Thomson, Digital Equipment Corp., Fraunhofer CRCG, General Electric, Lockheed-Georgia, RAND Corp., Research Triangle Institute, ShoGraphics, Stellar Computer, Xerox Palo Alto Research Center, others
1968-74	Engineer and Consultant, Image Processing Laboratory of Jet Propulsion Laboratory of the California Institute of Technology (summers)
1968-70	Programmer and Consultant, Computer Center, University of California at Santa Cruz

Honors

- The 2013 IEEE VGTC Virtual Reality Career Award ("In recognition of his lifetime contributions to research and practice of virtual environments, telepresence and medical applications").
- Fellow, the American Academy of Arts and Sciences, 1997.
- Member, the National Academy of Engineering, 1997.
- The 1997 Satava Award, Medicine Meets Virtual Reality Conferences. "For your commitment to the transformation of medicine through visionary applications of interactive technology."
- ACM Fellow, 1994. "For distinguished contributions in the field of computer graphics."
- The 1992 Computer Graphics Achievement Award, ACM/SIGGRAPH. "In recognition of his outstanding contribution to high-performance, parallel display architecture."

- The 1992 National Computer Graphics Association (NCGA) Academic Award.
"For his outstanding leadership in the development and promotion of computer graphics applications in the academic community."

Patents and Patents Pending

15. Frahm J., H. Fuchs, M. Marathe, B. Mauchly, "System and Method for providing depth adaptive video conferencing," US App. #12/873,100 United States Patent Pending.

14. Fuchs H., K. Keller, R. Schubert, A. State, G. Welch, "Concepts for real and apparent deformation and motion of physical virtual objects," US App. #616/648,384, United States Patent Pending.

13. Bishop G., M. Dou, J. Frahm, H. Fuchs, G. Welch, "Unified scene acquisition, head and hand tracking in a wearable display," US App. #61/648,552 United States patent pending.

12. H. Fuchs, P. Lincoln, M. Marathe, B. Mauchly, A. Nashel, H. Towles, G. Welch, "System and method for depth perspective image rendering," 12/366,593, February 5, 2009. United States patent pending.

11. H. Fuchs, P. Lincoln, A. Nashel, A. State, G. Welch, "Methods, systems, and computer readable media for shader-lamps based physical avatars of real and virtual people," PCT/US2010/026534, March 8, 2010. International patent pending.

10. H. Fuchs, L. McMillan, A. Nashel, "Methods, systems, and computer readable media for generating autostereo three-dimensional views of a scene for a plurality of viewpoints using a pseudo-random hole barrier," PCT/US2010/026537, March 8, 2010. International patent pending.

9. A. Bulysheva, H. Fuchs, T. Peck, A. State, H. Yang, "Methods, systems, and computer readable media for image guided ablation," US App. #12/842,261, July 23, 2010. United States patent pending.

8. Fuchs, H., K. Keller, L. McMillan, "Methods, systems, and computer program products for full spectrum projection," US Patent #8,152,305, April 10, 2012.

7. Fuchs, H., D. Cotting, M. Naef and M. Gross, "Methods, systems and computer program products for imperceptibly embedding structured light patterns in projected color images for display on planar and non planar surfaces," US Patent #7,182,465, February 27, 2007.

6. Keller, K., J. Ackerman, M. Rosenthal, H. Fuchs and A. State, "Methods and systems for real-time structured light depth extraction, and endoscope using real—time structured light depth extraction," US Patent 6,503,195, January 7, 2003.
5. Fuchs, H., M.A. Livingston, T.G. Bishop, and G.F. Welch, "Dynamic generation of imperceptible structured light for tracking and acquisition of three dimensional scene geometry and surface characteristics in interactive three dimensional computer graphics applications," US Patent #5,870,136, February 9, 1999.
4. Fuchs, H., "Image buffer having logic-enhanced pixel memory cells and method for setting values therein." US Patent #4,827,445, May 2, 1989.
3. Fuchs, H. and J. Poulton, "VLSI Graphic Display Image Buffer Using Logic Enhanced Pixel Memory Cells," US Patent #4,783,649, November 8, 1988.
2. Fuchs, H. and S. M. Pizer, "A 3-D Display Based on Conventional 2-D Graphics Equipment," US Patent #4,607,255, August 19, 1986.
1. Fuchs, H., "Graphics Display System Using Logic-Enhanced Pixel Memory Cells," US Patent # 4,590,465, May 20, 1986.

Grants & Contracts (Within past three years)

1. National Science Foundation: "Eyeglass-Style Multi-Layer Optical See-Through Displays for Augmented Reality" (PI)
2. Cisco Systems, Inc.: "Telepresence Wall" (PI)
3. National Science Foundation: "CRI:IAD Integrated Projector-Camera Modules for the Capture and Creation of Wide-Area Immersive Experiences" (PI)
4. NAVAIR: SBIR Phase 2: Deployable Intelligent Projections Systems for Training" Renaissance Science Corporation, Prime; (PI of UNC subcontract)
5. Office of Naval Research: 3D Display and Capture of Humans for Live-Virtual Training (joint PI with Greg Welch)
6. Office of Naval Research: "Behavioral Analysis and Synthesis for Intelligent Training" (joint UNC PI with Greg Welch; Project lead by Naval Postgraduate School, A. Sadagic, PI)

OTHER FORMER GRANTS AND CONTRACTS from Defense Advanced Research Projects Agency; National Institutes of Health, National Cancer Institute; National Science Foundation; , U.S. Air Force; U.S. Dept. of Energy.

Professional Activities (Selected)

- Member, Editorial Advisory Board, Computers & Graphics, 2013
- Member, External Advisory Board, Harvard's Neuroimage Analysis Center, 2004-2012.
- Member, External Advisory Board, Mersive Technologies. ~2008-present.
- Member, Steering Committee, ISMAR, International Symposium on Mixed and Augmented Realities, 2008 – present.
- Member, Dept. of Energy Blue Ribbon Panel for Evaluation of ASCI Program, 1998-1999.
- UNC Delegate, New Vistas in Transatlantic Science and Tech Cooperation, Washington D.C., 1998.
- Member, Information Science and Technology Study Group, Advanced Research Projects Agency, 1994.
- Member, Computer Science and Telecommunications Board, National Research Council, 1993-1997.
- Co-Director (with Gary Bishop), NSF Invitational Workshop on Research Directions in Virtual Environments, Chapel Hill, NC, March 1992.
- Co-Director (with K.H. Höhne and Steve Pizer), NATO Advanced Research Workshop in 3D Imaging in Medicine, Travemünde, Germany, June 1990.
- Chairman, 1986 Workshop on Interactive 3D Graphics, UNC Chapel Hill, Oct. 1986.
- Distinguished Visitor, IEEE Computer Society, 1985-1986.
- Chairman, 1985 Chapel Hill Conference on VLSI, May 1985. (7th Annual. All previous ones held at Caltech and MIT). Conference now called S.I.S.
- Chairman, Tutorial on VLSI and Computer Graphics, SIGGRAPH'83, SIGGRAPH'84, SIGGRAPH'85.
- Associate Editor, ACM *Transactions on Graphics*, 1983-1988.
- Guest Editor, ACM *Transactions on Graphics*, Vol.1, No. 1, January 1982.

- Technical Program Chairman, SIGGRAPH'81.
- Member, Advisory Committee, National Science Foundation, Division of Microelectronic Information Processing Systems.
- Member, Special Study Sections, National Institutes of Health; Review Panels and Site Visit Committees, National Science Foundation: 1978-Present.

Program Committee Memberships (Selected)

- [ACM-SIGGRAPH Asia \(2013\)](#)
- ACM-SIGGRAPH (1979, 1980, 1981, 1985-1992, 1998-2001, 2005)
Annual Conferences on Computer Graphics and Interactive Techniques
- Symposium on Interactive 3D Graphics, 2001 in Chapel Hill, N.C.
- Symposium on Interactive 3D Graphics, 1990 at Snowbird, Utah
- Workshop on Volume Visualization, 1989 at UNC-Chapel Hill
- Conference on Advanced Research in VLSI (1986 at MIT, 1987 at Stanford, 1988 at MIT, 1989 at Caltech)
- EUROGRAPHICS, 1997
- International Electronic Image Week (CESTA, SIGGRAPH) FRANCE (1986 and 1987)
- Computer Graphics International (1987 in Japan; 1988 in Switzerland)

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11. Kedem Z. and H. Fuchs, "On Finding Several Shortest Paths in Certain Graphs," Eighteenth Annual Allerton Conference on Communication, Control, and Computing, Champaign-Urbana, IL, 1980.
10. Barros J. and H. Fuchs, "Generating Smooth 2-D Monocolor Line Drawings on Video Displays," SIGGRAPH '79, Chicago, IL, 1979.
9. Fuchs H. and B. W. Johnson, "An Expandable Multiprocessor Architecture for Video Graphics (Preliminary Report)," 6th Annual ACM-IEEE Symposium on Computer Architecture, 1979.
8. Fuchs H., Z. M. Kedem, and B. Naylor, "Predetermining Visibility Priority in 3-D Scenes (Preliminary Report)," SIGGRAPH '79, Chicago, IL, 1979.
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6. Fuchs H., J. Duran, B. Johnson, and Z. M. Kedem, "Acquisition and Modeling of Human Body Form Data," 1978 NATO Symposium on Applications of Human Biostereometrics, Paris, France, 1978.
5. Fuchs H. and Z. M. Kedem, "The "Highly Intelligent" Tablet as an Efficient Pointing Device for Interactive Graphics (Preliminary Report)," 1978 Annual ACM Conference, 1978.
4. Fuchs H. "Distributing a Visible Surface Algorithm over Multiple Processors," 1977 ACM Annual Conference, 1977.

3. Fuchs H., J. Duran, and B. Johnson, "A System for Automatic Acquisition of Three-Dimensional Data," 1977 National Computer Conference, 1977.
2. Fuchs H., Z. M. Kedem, and S. P. Uselton, "Optimal Surface Reconstruction from Planar Contours," *Communications of the ACM*, vol. 20, pp. 693-702, 1977. One of only two papers from Siggraph'77 Conference selected to be published in CACM.
1. Fuchs H., "The Automatic Sensing and Analysis of Three-Dimensional Surface Points from Visual Scenes (Ph.D. Dissertation)," in Department of Computer Science. Salt Lake City, UT: University of Utah, 1975.

Technical Reports (Selected)

- D. Bandyopadhyay, R. Raskar, A. State, and H. Fuchs, "Dynamic Spatially Augmented 3D Painting," University of North Carolina at Chapel Hill Department of Computer Science, Chapel Hill, NC 2001.
- R. Raskar, H. Fuchs, G. Welch, A. Lake, and M. Cutts, "3D Talking Heads: Image Based Modeling at Interactive Rates Using Structured Light Projection," University of North Carolina at Chapel Hill Department of Computer Science, Chapel Hill, NC 1998.
- W. J. Dally, L. McMillan, G. Bishop, and H. Fuchs, "The Delta Tree: An Object-Centered Approach to Image-Based Rendering," Massachusetts Institute of Technology Artificial Intelligence Laboratory, Technical Memo 1604, Cambridge, MA, May 1996.
- U. Neumann, A. State, H. Chen, H. Fuchs, T. J. Cullip, Q. Fang, M. Lavoie, and J. Rhoades, "Interactive Multimodal Volume Visualization for a Distributed Radiation-Treatment Planning Simulator," University of North Carolina at Chapel Hill Department of Computer Science, Chapel Hill, NC 1994.

Invited Talks (Selected)

46. Keynote, BEAMING Workshop, Barcelona, Spain, June 2011, "Toward Improved Telepresence: BeingThere International Research Center for Telepresence and Telecollaboration...and related work."
45. Keynote, Japan VR, Tokyo, Japan, December 2010.
44. Keynote, ISMAR 2010, Seoul, Korea, October 2010.

43. Keynote, IEEE International Symposium on Multimedia (ISM2010), Taichung, Taiwan, December 2010, "Physical and Digital Media of Telepresence."
42. ISMAR Symposium Workshop, Orlando, Florida, October 2009.
41. AMI-ARCS Workshop, London, England, September 2009.
40. NAIST, Japan, July 2009.
39. Keynote, NOSSDAV, Williamsburg, Virginia, June 2009, "Experiences Building Telepresence Systems."
38. University of Pennsylvania, Franklin Institute Symposium, RoboFest: A Celebration of Robotics at the GRASP Laboratory, April 2009.
37. NASA Langley Research Center, Initiated the Speaker Series on Virtual Worlds, April 2009.
36. 9th Marconi Research Conference, Office Ergonomics Research Committee (OERC), Marconi Center, Marshall, CA, January 2009.
35. Keynote, Graphics Hardware 2008, Sarajevo, Bosnia and Herzegovina June 20, 2008.
34. Keynote, PROCAMS 2008, Los Angeles, CA, August 9, 2008.
33. Keynote (1 of 2), Eurographics 2004, Grenoble, France, September 2004.
32. J. Barkley Rosser Distinguished Lecture, University of Wisconsin, Madison, WI, March 2001.
31. Distinguished Lecture, National Science Foundation (NSF), February 2001.
30. Address, Sesquicentennial Anniversary, University of Rochester, October 2000 (1 of 2 in Computer Science).
29. Distinguished Lecture, Stanford University Department of Computer Science, June 2000.
28. Keynote Address, VRST '99, London, England, December 1999.
27. Keynote, 1st International Symposium on Mixed Reality (ISMR'99), Yokohama, Japan. Mar. 9, 1999.

26. University of Utah Department of Computer Science Distinguished Lecture, December 8, 1998.
25. Invited Paper, Advanced Multimedia Content Processing (AMCP'98), Osaka, Japan. Nov. 9, 1998.
24. Keynote, Advanced School for Computing and Imaging (ASCI'98), Lommel, Belgium. June 11, 1998.
23. Fraunhofer Inauguration Symposium, Virtual Environments Panel, Darmstadt, Germany, Oct. 30, 1997.
22. Keynote, Eurographics '97, Budapest, Hungary, September 6, 1997.
21. Keynote, Computer Graphics International'97, Hasselt, Belgium, June 25, 1997.
20. Keynote, 2nd Visualization Conference, Technicon, Haifa, Israel, June 30, 1996.
19. Keynote, 1995 Symposium on Interactive 3D Graphics, Monterey, CA, April 10-12, 1995.
18. University of Southern California Department of Computer Science Distinguished Lecture, Los Angeles, CA, Dec. 2, 1994.
17. Invited talk, The London VR User Show, VR in Medicine Workshop, London, England, September 1994.
16. IEEE EMBS 1994 International Summer School on Three-Dimensional Biomedical Imaging, to teach course on Virtual Reality in Medical Imaging, July 7-8, 1994.
15. Invited talk, ATR Workshop on Virtual Space Teleconferencing Systems, Kyoto, Japan, Dec. 3, 1993.
14. Invited talk, Computer Graphics International '92 (CGI '92), Tokyo, Japan, June 24, 1992.
13. NATO Advanced Research Workshop, Travemünde, Germany, June 26, 1990.
12. Keynote, First Conference on Visualization in Biomedical Computing, Atlanta, Georgia, May 23, 1990.
11. Keynote Address, Computer Graphics International, Leeds, UK, June 1989.
10. World Congress on Medical Physics and Biomedical Engineering, San Antonio, Texas, August 1988.

9. Member of panel on "Parallel Processing for Computer Vision and Display" at SIGGRAPH'88, August 1988.
8. Member of panel on "3D Imaging in Medicine: Pitfalls and Possible Remedies" at the National Computer Graphics Association annual conference, Anaheim, California, March 1988.
7. International Conference and Exhibition on Parallel Processing for Computer Vision and Display (sponsored by IBM - UK Labs, Univ. of Leeds, British Computer Society, Computer Graphics Society, Eurographics), University of Leeds, UK (January 1988).
6. NATO International Advanced Study Institute on Theoretical Foundations of Computer Graphics and CAD, Il Ciocco, Lucca, Italy (July 1987).
5. NATO International Advanced Study Institute on Mathematics and Computer Science in Medical Imaging, Il Ciocco, Lucca, Italy, (September 1986).
4. International Summer Institute (British Computer Society), State of the Art in Computer Graphics, Stirling, Scotland (June 1986).
3. NATO International Advanced Study Institute on Fundamental Algorithms for Computer Graphics, Ilkley, England (April 1985).
2. Eurographics'85, Nice, France (September 1985) (1 of 4 keynotes).
1. NATO International Advanced Study Institute on Microarchitecture of VLSI Computers, Urbino, Italy (July 1984).