

METHODS AND SYSTEMS FOR AUGMENTING DEPTH DATA
FROM A DEPTH SENSOR, SUCH AS WITH
DATA FROM A MULTIVIEW CAMERA SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/963,717, filed January 21, 2020, and titled "METHODS AND SYSTEMS FOR AUGMENTING DEPTH DATA FROM A DEPTH SENSOR, SUCH AS WITH DATA FROM A MULTIVIEW CAMERA SYSTEM," which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present technology generally relates to imaging systems, and more specifically, to imaging systems for generating a virtual perspective of a scene for a mediated-reality viewer.

BACKGROUND

[0003] In a mediated reality system, an image processing system adds, subtracts, and/or modifies visual information representing an environment. For surgical applications, a mediated reality system can enable a surgeon to view a surgical site from a desired perspective together with contextual information that assists the surgeon in more efficiently and precisely performing surgical tasks. Such mediated reality systems rely on image data from multiple camera angles and depth information about the environment to reconstruct an image of the environment.

[0004] Depth information about the environment is typically obtained via a dedicated depth sensor, such as a structured light depth sensor. However, the capture of complex three-dimensional geometries using a structured light depth sensor requires that all surfaces of the environment be exposed to the depth sensor to acquire error-free and complete data. In practice, this is not feasible due to geometries and/or occluded surfaces hidden from the depth sensor.

SUMMARY

[0004a] In a first aspect, the present disclosure provides a method of determining a depth of a surgical scene, the method comprising: capturing depth data of anatomy of a patient within the surgical scene undergoing a surgical procedure with a depth sensor; capturing

image data of the anatomy with a plurality of cameras; generating a point cloud representative of the anatomy based on the depth data from the depth sensor; identifying a missing region of the point cloud in which the point cloud includes no data or sparse data, wherein the missing region corresponds to a portion of the anatomy that is occluded from the depth sensor; determining at least one depth value from the point cloud for an area adjacent to the missing region; processing the image data with a depth processing algorithm to generate depth data for the missing region, wherein processing the image data with the depth processing algorithm includes limiting the depth processing algorithm to determine the depth data for the missing region in a depth range surrounding the at least one depth value; and merging the depth data for the missing region with the depth data from the depth sensor to generate a merged point cloud representative of the anatomy.

[0004b] In a second aspect, the present disclosure provides a system for imaging a surgical scene, comprising: multiple cameras arranged at different positions and orientations relative to the surgical scene and configured to capture image data of anatomy of a patient within the surgical scene undergoing a surgical procedure; a depth sensor configured to capture depth data of the anatomy; and a computing device communicatively coupled to the cameras and the depth sensor, wherein the computing device has a memory containing computer-executable instructions and a processor for executing the computer-executable instructions contained in the memory, and wherein the computer-executable, when executed by the processor, cause the processor to: receive the depth data of the anatomy from the depth sensor; receive the image data of the anatomy from the cameras; generate a point cloud representative of the anatomy based on the depth data from the depth sensor; identify a missing region of the point cloud in which the point cloud includes no data or sparse data, wherein the missing region corresponds to a portion of the anatomy that is occluded from the depth sensor; determine at least one depth value from the point cloud for an area adjacent to the missing region; process the image data with a depth processing algorithm to generate depth data for the missing region, wherein the computer-executable instructions, when executed by the processor, further cause the processor to limit the depth processing algorithm to determine the depth data for the missing region in a depth range surrounding the at least one depth value; and merge the depth data for the missing region with the depth data from the depth sensor to generate a merged point cloud representative of the anatomy.

[0004c] In a third aspect, the present disclosure provides a method of generating an output image of a surgical scene, the method comprising: capturing depth data of the anatomy of a patient within the surgical scene undergoing a surgical procedure with a depth sensor; capturing light field image data of the anatomy with a plurality of cameras; generating a point cloud representative of the anatomy based on the depth data from the depth sensor; identifying a missing region of the point cloud within the field of view of the virtual camera in which the point cloud includes no data or sparse data, wherein the missing region corresponds to a portion of the anatomy that is occluded from the depth sensor; determining at least one depth value from the point cloud for an area adjacent to the missing region; processing the light field image data with a depth processing algorithm to generate depth data for the missing region, wherein processing the light field image data with the depth processing algorithm includes limiting the depth processing algorithm to determine the depth data for the missing region in a depth range surrounding the at least one depth value; merging the depth data for the missing region with the depth data from the depth sensor to generate a merged point cloud representative of the surgical scene; processing the light field image data and the merged point cloud to synthesize the output image of the surgical scene; and transmitting the output image to a display for display to a user.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Many aspects of the present disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale. Instead, emphasis is placed on clearly illustrating the principles of the present disclosure.

CLAIMS

I/We claim:

1. A method of determining a depth within a surgical scene, the method comprising:
capturing depth data of anatomy of a patient within the surgical scene undergoing a surgical procedure with a depth sensor;
capturing image data of the anatomy with a plurality of cameras;
generating a point cloud representative of the anatomy based on the depth data from the depth sensor;
identifying a missing region of the point cloud in which the point cloud includes no data or sparse data, wherein the missing region corresponds to a portion of the anatomy that is occluded from the depth sensor;
determining at least one depth value from the point cloud for an area adjacent to the missing region;
processing the image data with a depth processing algorithm to generate depth data for the missing region, wherein processing the image data with the depth processing algorithm includes limiting the depth processing algorithm to determine the depth data for the missing region in a depth range surrounding the at least one depth value; and
merging the depth data for the missing region with the depth data from the depth sensor to generate a merged point cloud representative of the anatomy.
2. The method of claim 1 wherein identifying the missing region of the point cloud includes determining that the missing region of the point cloud has fewer than a predetermined threshold number of data points.
3. The method of claim 1 wherein identifying the missing region of the point cloud includes identifying a hole in the point cloud that is larger than a user-defined threshold.
4. The method of claim 1 wherein the depth data for the missing region has a greater resolution than the depth data captured with the depth sensor.

5. The method of claim 1 wherein the method further comprises generating a three-dimensional mesh representative of the surgical scene based on the merged point cloud.
6. The method of claim 1 wherein the cameras and the depth sensor are rigidly mounted to a common frame and fixed in position relative to one another.
7. The method of claim 6 wherein the cameras are RGB cameras.
8. The method of claim 1 wherein the image data is light field image data.
9. A system for imaging a surgical scene, comprising:
 - multiple cameras arranged at different positions and orientations relative to the surgical scene and configured to capture image data of anatomy of a patient within the surgical scene undergoing a surgical procedure;
 - a depth sensor configured to capture depth data of the anatomy; and
 - a computing device communicatively coupled to the cameras and the depth sensor, wherein the computing device has a memory containing computer-executable instructions and a processor for executing the computer-executable instructions contained in the memory, and wherein the computer-executable instructions, when executed by the processor, cause the processor to:
 - receive the depth data of the anatomy from the depth sensor;
 - receive the image data of the anatomy from the cameras;
 - generate a point cloud representative of the anatomy based on the depth data from the depth sensor;
 - identify a missing region of the point cloud in which the point cloud includes no data or sparse data, wherein the missing region corresponds to a portion of the anatomy that is occluded from the depth sensor;
 - determine at least one depth value from the point cloud for an area adjacent to the missing region;
 - process the image data with a depth processing algorithm to generate depth data for the missing region, wherein the computer-executable instructions, when executed by the processor, further cause the processor to limit the

depth processing algorithm to determine the depth data for the missing region in a depth range surrounding the at least one depth value; and merge the depth data for the missing region with the depth data from the depth sensor to generate a merged point cloud representative of the anatomy.

10. The system of claim 9 wherein the computer-executable instructions, when executed by the processor, cause the processor to identify the missing region of the point cloud by determining that the missing region of the point cloud has fewer than a predetermined threshold number of data points.

11. The system of claim 9 wherein the computer-executable instructions, when executed by the processor, cause the processor to identify the missing region of the point cloud by identifying a hole in the point cloud that is larger than a user-defined threshold.

12. The system of claim 9 wherein the depth data for the missing region has a greater resolution than the depth data captured with the depth sensor.

13. The system of claim 9 wherein the computer-executable instructions, when executed by the processor, further cause the processor to generate a three-dimensional mesh representative of the surgical scene based on the merged point cloud.

14. The system of claim 9 wherein the cameras and the depth sensor are rigidly mounted to a common frame and fixed in position relative to one another.

15. The system of claim 14 wherein the cameras are RGB cameras.

16. A method of generating an output image of a surgical scene, the method comprising:

capturing depth data of the anatomy of a patient within the surgical scene undergoing a surgical procedure with a depth sensor;
capturing light field image data of the anatomy with a plurality of cameras;
generating a point cloud representative of the anatomy based on the depth data from the depth sensor;

identifying a missing region of the point cloud within the field of view of the virtual camera in which the point cloud includes no data or sparse data, wherein the missing region corresponds to a portion of the anatomy that is occluded from the depth sensor;

determining at least one depth value from the point cloud for an area adjacent to the missing region;

processing the light field image data with a depth processing algorithm to generate depth data for the missing region, wherein processing the light field image data with the depth processing algorithm includes limiting the depth processing algorithm to determine the depth data for the missing region in a depth range surrounding the at least one depth value;

merging the depth data for the missing region with the depth data from the depth sensor to generate a merged point cloud representative of the surgical scene;

processing the light field image data and the merged point cloud to synthesize the output image of the surgical scene; and

transmitting the output image to a display for display to a user.

17. The method of claim 16 wherein the output image is from the perspective of a virtual camera having a field of view corresponding to a portion of the surgical scene.

18. The method of claim 17 wherein the plurality of cameras each have a different perspective relative to the surgical scene, and wherein the perspective of the virtual camera is different from any of the perspectives of the cameras.

19. The method of claim 16 wherein the cameras and the depth sensor are rigidly mounted to a common frame and fixed in position relative to one another.

20. The method of claim 16 wherein the cameras are RGB cameras.