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Comparison of 3D Reconstruction Methods based on Aerial Images of Traffic Accident

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***Abstract*—Image-based 3D(three dimensional) reconstruction technology has been widely used in many fields. Aiming at the specific scene of road traffic accident, relevant 3D reconstruction materials based on UAV(Unmanned Aerial Vehicle) aerial photography accident scene images have been collected. Moreover, the most popular open source and commercial 3D reconstruction methods are studied and compared. Then the simulated accident images acquired by UAV are reconstructed with the above methods, and the dense point cloud model of the accident site is obtained. Finally, each reconstruction result is evaluated in terms of geometric accuracy. The experimental results show that COLMAP, Altizure and PIX4D methods are more suitable for traffic accident scene reconstruction.**

I. Introduction

The traditional traffic accident scene survey is mainly conducted by means of taking photos, measuring and manually drawing sketches, etc. It is inevitable that there are omissions and deficiencies in the collection of accident scene information, which may cause difficulties in subsequent accurate accident analysis, liability identification or relevant scientific research. 3D reconstruction technology based on UAV aerial photography can provide a fast and convenient method to obtain comprehensive and complete visual information of the accident site to establish 3D real scene model, which will be an effective way to solve the above problems.

When checking again based on the 3D model of the traffic accident, the most important thing is to ensure the accuracy, especially the geometric accuracy, and completeness of the model. As different 3D reconstruction techniques have different emphasis, it is necessary to evaluate and compare the results of different 3D reconstruction schemes by using traffic accident datasets, so that the reconstruction method which has the best geometric accuracy can be referred and applied in traffic accident analysis.

II. Related Work

A. Research on 3D Reconstruction of Traffic Accident Scene

Reference [1] shows that in September 2014, the Royal Canadian Mounted Police used Draganfly X4-ES UAV and Pix4Dmapper software to reconstruct a simulated traffic accident scene in 3D. The data generated by this project is directly compared with the data obtained by traditional accident investigation tools such as tape measure, total station instrument and laser scanner. The experiment proves that the former has great advantages in road traffic accident investigation as it takes less time, the results can be preserved for a longer time, and the reconstructed scene can be checked and measured in any direction.

Reference [2] is a serious minibus accident in Maryland, USA in June 2016. The Anne Arundel County Police used DJI Phantom 3 UAV to take aerial photos of the accident scene, and used Pix4Dmapper software to reconstruct the accident scene and generate the quality report. Meanwhile, orthomosaic generated by Pix4D was imported into CAD software to generate the contour map of the damaged vehicle, so as to quantify the damage of the vehicle and infer the information such as the speed of the vehicle. The above results provide evidence for the collision investigation report submitted to the court.

Reference [3] shows that in September 2018, GM6 team in the USA completed 3D reconstruction of the simulated car accident scene by using Altizure development platform. They deeply integrate Altizure's modeling browsing service with road traffic accident-related data in greater depth. Some basic distance information of the accident site can be obtained by measuring the model. The report points out that using 3D models to create electronic files of accident cases can provide a clear picture of the situation at the time of the accident, even if the case is restarted after a long time.

Reference [4] refers to the serial images of traffic accident scene acquired by UAV, 3D sparse point cloud model generated by SfM(Structure from Motion) algorithm, and 3D dense point cloud model generated by MVS(Multi-View Stereo Vision) algorithm. Then the point cloud model is optimized by meshing and texturing, and the DSM(Digital Surface Model) and DEM(Digital Elevation Model) of the accident site are presented. Two evaluation indexes are adopted to evaluate the quality of the accident site reconstruction, and 6 reference objects are selected to measure the reconstruction accuracy. Experimental results show that this method is suitable for accident investigation and reconstruction.

B. 3D Reconstruction Method

At present, the most commonly used 3D reconstruction method is SfM technology in passive visual reconstruction technology, which can carry out sparse reconstruction according to the input sequence images and generate sparse point cloud and camera projection matrix. Since SfM technology can only provide sparse reconstruction, MVS technology, surface reconstruction technology and texture mapping technology of dense point cloud need to be calculated. Most of the existing free and open source algorithms can only complete one or a

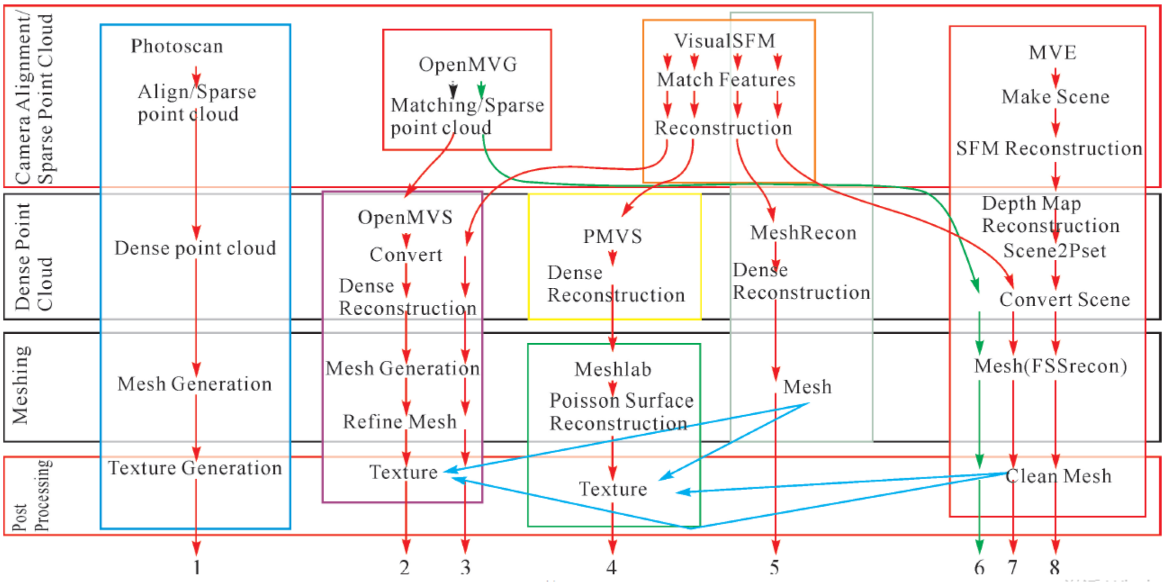

Fig. 1. Combination of 3D reconstruction methods

few intermediate processes in the whole 3D reconstruction, and the combination of SfM+MVS method is required if the complete visual effect of the model is expected to be reconstructed.

Early on, reference [5] shows that Seitz et al. develope-d Bundler, which is an SfM technology that can generate camera posture and sparse point cloud by using disordered image sequences, image features and image matching as input. Reference [6] shows that Furukawa et al. studied the method of diffusion from sparse point cloud to dense point cloud, among which CMVS (Clustering Views for multi-view Stereo) technology and PMVS (Patch based multi-view Stereo) technology can better reconstruct the complete contour of the object, and do not need to initialize data. Earlier 3D reconstruction methods were built with Bundler and PMVS2.

Subsequently, reference [7] shows that Moulon et al. developed OpenMVG, which extends the use of SfM technology and provides a large number of multi-view geometric tools and algorithms. OpenMVG is divided into incremental and global algorithms, often paired with technologies such as PMVS or OpenMVS.

Reference [8] shows that Schonberger et al. summarized the problems and difficulties existing in the reconstruction of SfM, and made corresponding improvements to key points such as robustness, accuracy, integrity and scalability of the reconstruction system. They proposed a new SfM technology, called COLMAP, and published the results as open source code.

Reference [9] shows that Dr. Peter Falkingham from Liverpool John Moores University in the UK specially tested these open source software, trying to complete the whole processing pipeline from image to model by combining multiple open source software. As shown in Fig.1, the whole processing pipeline is divided into sparse point cloud, dense point cloud, 3D mesh and post-processing (mainly texture mapping). Then each method can be more or less combined with other 1-3 software to complete the entire reconstruction. The processes connected by the red arrows in the figure work well with each other, while the processes connected by the green arrows have problems, and the blue ones have not been tried yet. As can be seen from the Fig.1, the open source method MVE [10] can also complete the whole process, while other methods need to be combined in the process, such as OpenMVG + OpenMVS, VisualSFM+PMVS+MeshLab, etc..

In addition to many free and open source technologies, there is a wealth of commercial software available for image-based 3D reconstruction. Such as Pix4Dmapper[11] developed by Pix4D SA in Switzerland, Agisoft PhotoScan develope-d by Agisoft in Russia, Smart3D Capture (also known as Context Capture)[12] developed by Acute3D in France, and Altizure.cn[13], an online 3D reality reconstruction platform developed by the Hong Kong University of Science and Technology.

C. *3D Reconstruction Evaluation Method and Benchmark*

If any 3D reconstruction methods is only evaluated from the subjective aspect of vision, it is insufficient and vulnerable to the influence of environment, observation state and other factors. Therefore, an objective and quantitative evaluation method is needed.

Reference [14] introduces the Middlebury benchmark established by Seitz et al. in 2006. Reference [15] introduces the EPFL benchmark established by Strecha et al. in 2008, and reference [16] introduces the DTU large-scale benchmark data set established by Aanaes et al. in 2016. All the authors selected several popular 3D reconstruction methods at that time for reconstruction and quantitative evaluation of the results. Firstly, the accuracy of 3D reconstruction method is evaluated. They used an ICP algorithm to align the reconstructed point cloud with the point cloud scanned by the standard library with laser or structured light, and calculate the distance difference between the reconstructed data point and the nearest standard library data point. Secondly, the completeness of 3D reconstruction is evaluated. In contrast to the accuracy evaluation method, the distance difference between the data points in the standard library and the nearest reconstructed data points is calculated. In Matlab software, the median and mean of the statistical and visual distance difference are used to represent the accuracy and completeness of different final reconstruction methods.

Reference [17] introduces Knapitsch et al established the benchmark of large-scale scene with Tanks and Temples in 2017. It includes images of sculptures, vehicles, complex indoor environments and large outdoor scenes. In this paper, 15 open source and commercial 3D reconstruction methods are selected and combined to conduct experiments on this benchmark and evaluate the results. Precision quantified the accuracy of reconstruction and Recall the integrity of reconstruction. Precision and Recall are combined to form a comprehensive measure F-score that better reflects the quality of reconstruction results than the arithmetic mean of distance difference. In addition, Rank is obtained according to the comprehensive ranking of F-score in different data sets. The experiment proves that the 3D reconstruction algorithms ranked high are COLMAP, Pix4D, OpenMVG + OpenMVS, MVE and OpenMVG-G + OpenMVS respectively.

Different evaluation methods based on image 3D reconstruction choose different evaluation angles, and the evaluation indexes contain some premises, which limits the scope of application. Most evaluation methods focus on the overall correctness and completeness of the reconstruction results, but ignore the local correctness and geometric correctness.

There are currently a large number of datasets available for image-based 3D reconstruction. However, most of these data sets are small indoor desktop objects, and only a small part are large buildings or other objects. There is a lack of data sets targeting at specific scenes like traffic accidents. As the performance of the algorithm may vary greatly between different scenes [18], it indicates that corresponding datasets are required to test 3D reconstruction methods for specific scenes.

III. Comparison of 3D Reconstruction Method Based on Benchmark

According to the experimental research results of reference [17] and reference [19] on the evaluation of different 3D reconstruction methods, the Rank and F-score optimal top five methods are selected for research on this basis. In addition, two commercial software that have not been used in the above mentioned experiments are relatively popular at the present stage are added for comparison.

First of all, COLMAP, MVE, Pix4D, Smart3D and Altizure have been configured as complete methods, integrating their SfM and MVS methods, and can directly use these complete methods to reconstruct the accident scene. In addition, we use a combination of SfM and MVS methods that provide compatible interfaces, where OpenMVG represents the incremental SfM method and OpenMVG-G represents the global SfM method.

In this experimental test datasets, the Intermediate group in Tanks and Temples was used for online evaluation. As shown in Fig.2, the higher the f-score value, the higher the precision and completeness of reconstruction method. Therefore, it can be obtained that the geometric accuracy of 3D reconstruction method is from high to low: Altizure, COLMAP, PIX4D, OpenMVG + OpenMVS, MVE and OpenMVG-G + OpenMVS. Fig.3 shows the charts for Precision of various reconstruction methods on the M60 dataset.

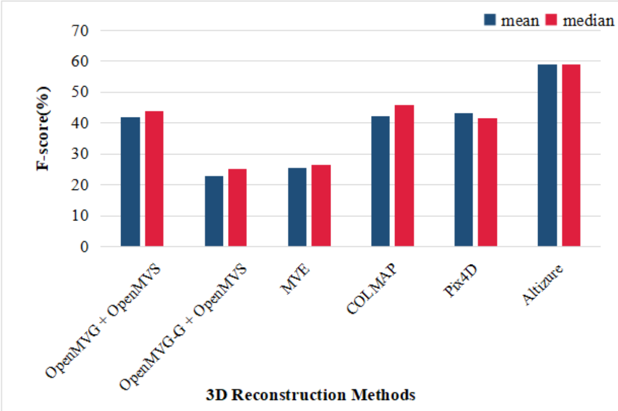

Fig. 2. 3D reconstruction methods F-score score comparison

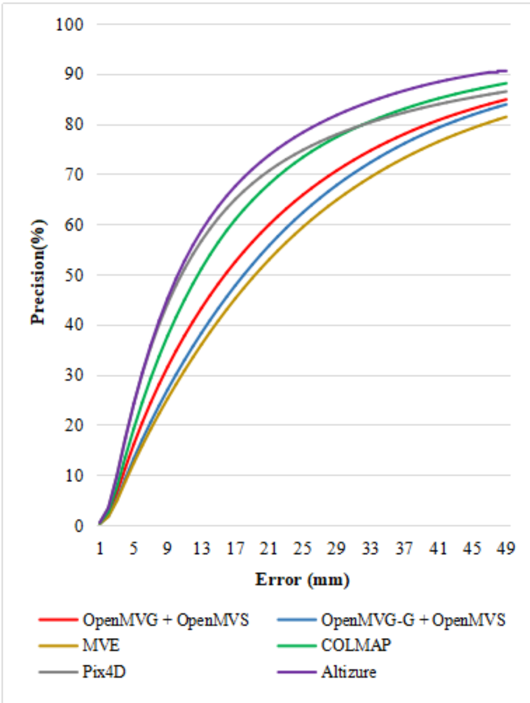

Fig. 3. Charts for Precision and Recall

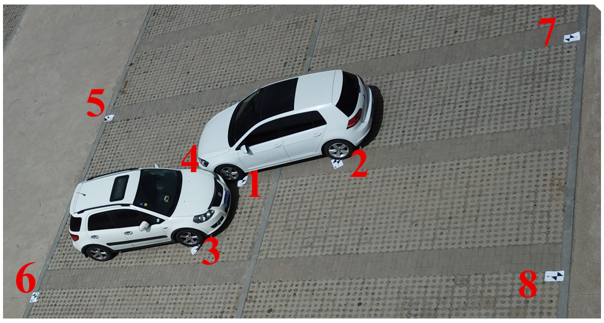

Fig. 4. Check points map

Fig. 5. Check points distance

IV. 3D Reconstruction Experiment

A. Aerial Images Acquisition

At present, there are a large number of benchmarks based on 3D reconstruction of images, but there is a lack of datasets that are specific to traffic accidents. For this reason, this paper designed to simulate a traffic accident in which two white cars (SUZUKI SX4 and Volkswagen Golf) collided. As shown in Fig.4, eight CPs(Check Points) are set around the accident site. As shown in Fig.5 and TABLE I, the distance between CPs is measured by tape measure, which is taken as the prior information of reconstruction, so as to objectively and quantitatively evaluate each reconstruction result according to the reconstruction error in the later stage.

In this paper, DJI Mavic Pro equipped with cradle head and camera is adopted as aerial UAV system. The remote control is connected with the mobile terminal software DJI GO 4 to fly and take photos by means of interest point circling. The flight altitude is between 10 meters and 20 meters, the center of the accident site is taken as the interest point, and the flight radius is about 12 meters. A total of 88 images with GPS information are taken, and the resolution of each image is 4000*3000 pixels.

B. Comparison based on Aerial Photography Datasets

In this experiment, aerial images of simulated road traffic accidents collected by DJI Mavic Pro were used as verification datasets, and the above 3D reconstruction methods were used for reconstruction. The obtained dense point cloud model was imported into Meshlab software to achieve visualization, and the effect of intercepting the same perspective was shown in Fig.6. The most visually appealing models are simply labeled and imported into Altizure(https://planets.altizure.cn/viewer?sid=5d2fe01c13938c0f164c834a).

V. Evaluation Method

In this paper, the distance error between the real CPs distance and the measured CPs distance is calculated. Mean and median respectively represented the quality of reconstruction results. The smaller the mean and median, the smaller the geometric error of the reconstruction.

TABLE I records the distance between CPs measured by tape measure at the simulated accident site. A total of seven distances in different directions are counted, which serve as the reference standard for the distance between them. Then, the point cloud model built by each 3D reconstruction method was used by the software Could Compare to measure the distance between its CPs.

As shown in Fig.7, the errors of various 3D reconstruction methods are statistically analyzed. That is, the smaller mean and median, the smaller the geometric error, and the higher the geometric accuracy of the reconstruction method. Therefore, it can be concluded that the geometric accuracy of 3D reconstruction methods from high to low are: COLMAP, Altizure, PIX4D, MVE, OpenMVG + OpenMVS, Smart3D and OpenMVG-G + OpenMVS.

VI. Conclusions

It is found that the geometric accuracy of 3D reconstruction methods from high to low are: COLMAP, Altizure, PIX4D, MVE, OpenMVG+ OpenMVS, Smart3D and OpenMVG-G + OpenMVS. The results of our reconstruction evaluation from geometric accuracy are similar to the research results of Knpaitsch et al. [17], and the geometric errors of COLMAP, PIX4D and MVE reconstruction are relatively small.

Altizure, a new addition to the discussion, is just as accurate as COLMAP. As can be seen from the previous discussion, Altizure is the best reconstruction in the Tanks and Temples

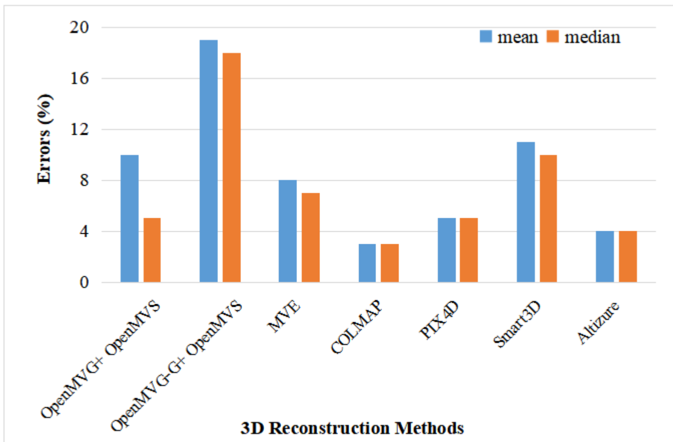

Fig. 7. Distance error between CPs

TABLE I
DISTANCE BETWEEN REAL CPS AND MODEL CPS

Start point	Terminal point	Actual value(m)	OpenMVG+ OpenMVS(m)	OpenMVG-G+ OpenMVS(m)	MVE(m)	COLMAP(m)	PIX4D(m)	Smart3D(m)	Altizure(m)
1	2	2.31	2.43	2.72	2.22	2.43	2.17	2.08	2.21
1	4	1.14	1.55	1.45	1.32	1.18	1.07	1.00	1.05
2	4	3.42	3.75	3.96	3.48	3.46	3.25	3.07	3.32
4	5	5.09	5.22	6.07	4.42	5.29	4.89	4.51	4.84
5	6	6.12	6.43	7.05	5.65	6.39	5.82	5.52	5.92
5	7	11.95	12.39	13.87	11.17	12.22	11.45	10.62	11.48
7	8	5.98	6.24	7.14	5.66	6.17	5.71	5.42	5.76
mean(%)	-	-	10	19	8	3	5	11	4
median(%)	-	-	5	18	7	3	5	10	4

data set, but COLMAP is more accurate in our aerial accident data set.Obviously, different 3D reconstruction methods have different reconstruction effects among different scenes due to the influence of algorithm performance. In terms of geometric accuracy, COLMAP, PIX4D and Altizure are more suitable for 3D reconstruction of road traffic accident sites.

Through the experimental comparison between OpenMVG and OpenMVG-G, it is found that the incremental SfM method has better performance than the global SfM method. The incremental SfM method reconstructed the accident field model with fewer and more complete holes in dense point clouds. The most important thing is that the geometric accuracy of the incremental SfM method is better than the global SfM method.

In addition, it can be found from the experimental results that Smart 3D reconstruction model is particularly good in terms of completeness, with the largest number of points in dense 3D reconstruction, but its geometric accuracy is slightly worse than other methods.

The contribution of this research is to reconstruct the specific scene of road traffic accident. The most popular image reconstruction methods based on the image data collected by UAV to simulate the accident scene are verified, and the best methods of reconstruction geometric accuracy are ranked. The research results will contribute to the introduction of advanced UAV application technology, computer vision and 3D reconstruction technology and other new methods and technologies in the field of road traffic accidents.

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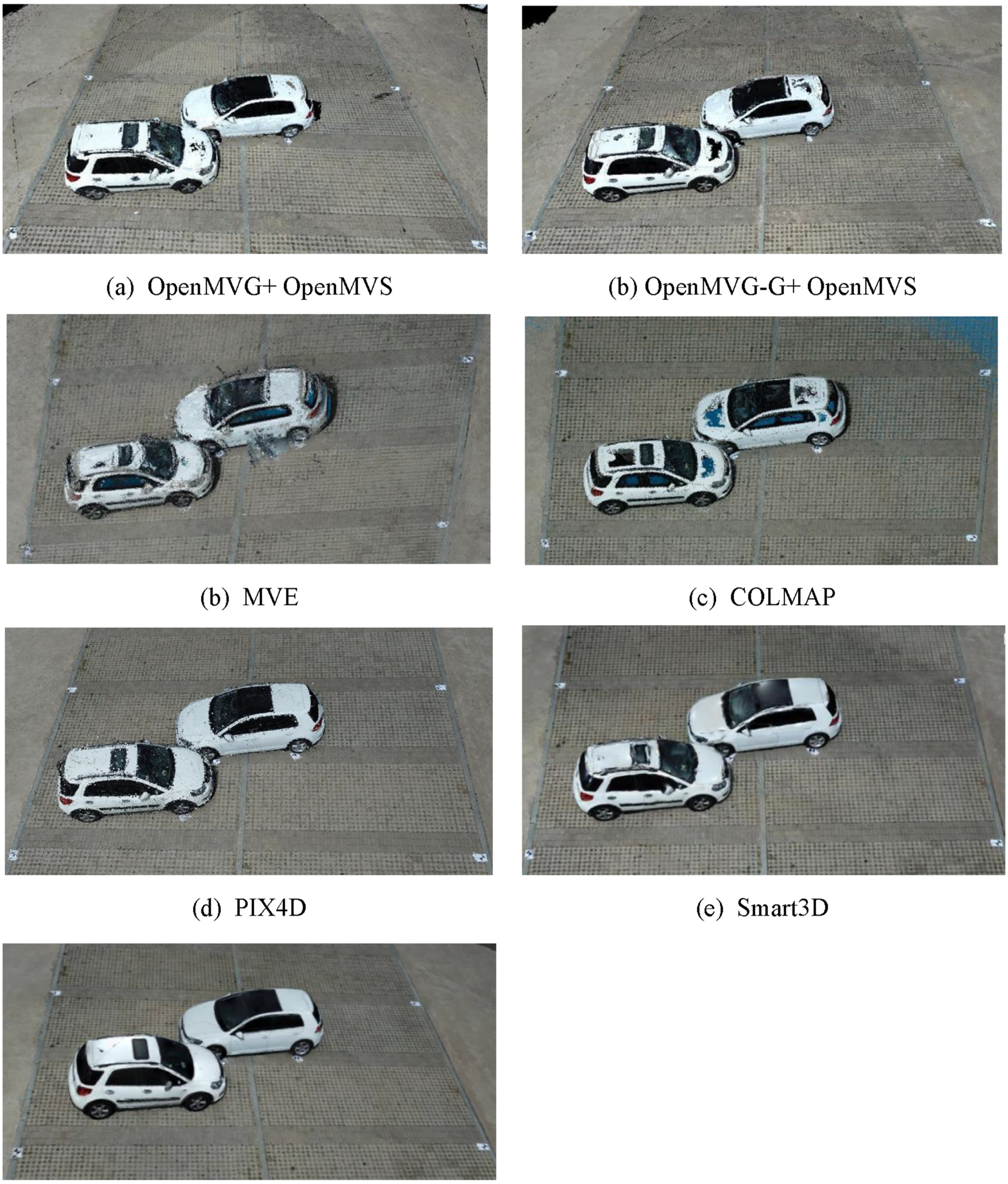

(a) OpenMVG+ OpenMVS

(b) OpenMVG-G+ OpenMVS

(b) MVE

(c) COLMAP

(d) PIX4D

(e) Smart3D

(f) Altizure

Fig. 6. Reconstruction results