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Effective Method For Detecting Multi Planes From Depth Maps

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Abstract: In the field of visual stereo image processing, plane detection aims to assist in the movement of the mobile vehicle or mobile robot. This paper has carried out the plane detection problem based on depth map by using a new Neighbor Grouping algorithm and a rational Filter (NGaF). The main advantage of this proposed method is the simplicity while it still ensures the reliability of the results. A concise and clear hypothetical concept of the plane is built in the depth map. Then the plane extracting algorithm is applied based on some strong characteristics of the plane. The results of the applied method are considered positive in terms of both visual assessment and evaluation parameter. Then, the NGaF approach is also be evaluated more superior than the RANSAC algorithm, powerful PPDFDM and FPDIDM methods. The proposed method's computation time is reduced 33 times compared to the improved RANSAC algorithm (HSBSR). Meanwhile, the result in number of found planes is greater than and PPDFDM, FPDIDM method about 8% percentage. Last, the percentage of calculated valid points is larger than compared methods 2%. It certainly has the ability to implement on common hardware with limited resources as well as to ensure the real-time applications which processes stereo video signal.

Keywords: Detection, plane, depth map, depth difference, neighbor point.

1. Introduction

In the field of computer vision, plane detection is one of basic applications in order to mine visual data deeply including 3D architectural reconstruction, and robot navigation. Recent studies show some interesting results with difference algorithms. These approachs also use many kind of input such as 3D point cloud, single color image or disparity map. In [1], the authors combine an improved Hough transform with clustering to search many targets in the image base on edge of objects. These are able to detect multiple objects with round shape or straight shapes. However, the structure of extracted objects is quite simply. So the applied algorithms could not adapt for the natural environment in which most thing is formed by planes. Work [2] has an approach more realistically by solving the problem of plane finding based on 3D Hough transformation algorithm applied to 3D point cloud. The major outstanding contribution is to

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improve the complexity of Hough transformation in the coordinate system of three-dimensional space. The experienced results are positive optimistic but it is clear that the aim of real-time matching still is not met. Manuscripts [3-5] present a new approach to detect the planes by coordinating RANSAC algorithm with MDL algorithm in order to improve the reliability of the tested results. There are some encouraging results on both synthetic and real-world data. The method could avoid detecting wrong planes due to the complex geometry of the 3D data. But then the complexity of the structure's data is not taken care. Even with the work [6], the horizontal plane is detected from clues of vanishing points of visual images or from the border detection of 3D point data. However, these methods are not suitable for most types of building structures, actually. The solution of the plane finding presented in [7] bases on Particle Swarm Optimization (PSO) with Region Growing (RG) to extract small planes. It should need to discuss more about the ability of reducing computational costs and improving the accuracy. The approaches mentioned above all select the complex 3D input. Paper [8] concentrates on a major step of VDEMs by grouping of 3D point clouds optimally. So there is a set of underlying surface which may represent the into planar regions, whenever possible. However, article [8] presents a capable of plane extracting based on a disparity map. This 2D input has a main advantage of simplicity but it is easily taken large tolerances in real scenes because the depth and the disparity are not linearly proportional. The authors have not addressed this difficulty thoroughly in order to enhance the reliability of the results

More recently, articles [9-11] refer to the detection of any type of surface without camera calibration by assuming a linear motion cameras. The flat surfaces are parameterized by transforming them into a parabola of c-velocity space [9]. The author proposed a detection method which exploits binding iso-velocity curve after estimating an optical flow and voting for the accumulations. C-velocity function depends on two variables x and y with the square root relationship so it is too high complexity. The manuscript [11] presents some fantastic results and they should be developed further.

An interesting applied method [12-13] could rapidly detect multi planes based on a depth map obtained from the Kinect camera. The applied algorithm calculates the local normal vector of the group four adjacent points in the depth map. Then process of coplanar verification is implemented for each point in 3D cloud data base on normal vector criteria. The advantage of this method is able to detect multiple planes simultaneously with improving the speed of the plane detection process except in [13]. Experimental results show that the rate of proposed method is faster than some previous methods such as 3D Hough transformation algorithm and RANSAC algorithm. It is also able to works in real time. But besides that, the reliability of the results is not as good as expected because the local normal vectors are only calculated exactly in case of the perfect depth map. This situation rarely is met by a compact handset sensor cause of its limited hardware resources. In addition, the common prioritized aim is performing well in real time.

In this manuscript, the proposed method retains the advantages of the approaches [4, 5, 8] by introducing a simple hypothesis of the plane concept in the depth map in order to simplify the calculation more base on the same input data. The rest of the paper is organized as follows: Section 2 describes in detail mathematical fundamentals, introducing stereo camera system and some useful basic concepts. In the third section, this work presents the system architecture to perform searching of the flat area as well as applied algorithms. The fourth section is the obtained results and some important discussions to improve outcomes in different environments. The fifth section shows several conclusions and the needed future work.

2. Basic of planes mathematics and system architecture

a) The basic mathematics of the plane in the depth map

Mathematically, if a plane exists, it is a set of adjacent consecutive points and satisfies an represented plane equation defined as follows:

$$Ax + By + Cz + D = 0 \quad (1)$$

Obviously, (1) has to satisfy the condition $A^2 + B^2 + C^2 > 0$. From (1), z is drawn on a side of the (1) and z becomes a function of two variables x, y is written as follows:

$$z = -\frac{A}{C}x - \frac{B}{C}y - \frac{D}{C} \quad (2)$$

Taking partial derivatives of the function (2) with respect to x variable and y variable respectively:

$$\frac{\partial z}{\partial x} = -\frac{A}{C} \quad (3)$$

$$\frac{\partial z}{\partial y} = -\frac{B}{C} \quad (4)$$

Thus, the gradient vector is defined:

$$\nabla z = \left(\frac{\partial z}{\partial x}, \frac{\partial z}{\partial y}\right) = \left(-\frac{A}{C}, -\frac{B}{C}\right) \quad (5)$$

From (5), the depth gradient of a predetermined plane is constant along with both x axis and y axis directions. As such, the adjacent points have the same depth gradient values they belong to the same plane. This is a reliable characteristic for the object in the image is considered to be planar.

b) Maintaining the integrity of the specifications

Figure 1 illustrates the architecture of visual stereo camera system which is modularization of three function blocks. The first one consists of two vision cameras these are installed horizontally as same as a human eyes system. The selection of these two cameras has to ensure that they are identical to the focal length f and other technical parameters.

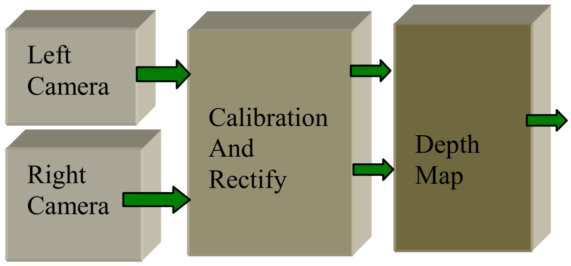


Fig. 1. The block diagram of stereo vision camera system.

The distance T between the left camera center O_L and center of the right camera O_R is fixed. The line through the two center points of cameras creates a baseline. P_L and P_R are the projections of the object P in the left and the right image respectively. Then x_L and x_R are denoted horizontal coordinates of the projections P_L and P_R respectively. z is indicated the depth of the object P in the frame that is calculated based on the method of triangular geometry (Fig. 2).

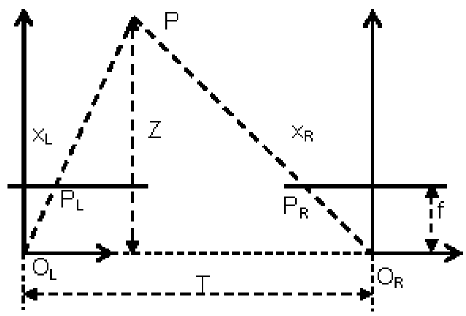


Fig. 2. Principle of stereo vision.

The depth value z is calculated by the following formula:

$$z = \frac{f.T}{|x_L - x_R|} \quad (6)$$

c) Some of the basic concept

The depth map is one of the data outputs of the stereo camera system, such as Microsoft's Kinect device. Typically the depth map is stored as a gray scale image with the value of each point within range of 8-bit or 11-bit representation. Each point p in a depth map has up to four neighboring points vertically and horizontally which were named *Top*, *Bottom*, *Left*, *and Right* corresponds to the position relationship with *p* point shown in Fig. 3. Each nearby point of *p* point will be considered as the neighbor of *p* point if it meets the conditions of depth differences with the central point that must be less than a predetermined threshold θ.

A plane is structured by a set of pixels. When a pixel is regarded as belonging to a plane, the improbable event that it also lays on a different flat surface. We could base on mathematical and intuitive geometric to give some properties of pixels of flat surface. A pixel is said to be attached to a flat surface area if it fully satisfies the following conditions:

♦ Pixel must be adjacent to the considered flat area.

♦ A pixel belongs to only one plane.

The depth disparity of the pixel is equal to or less than an identified threshold.

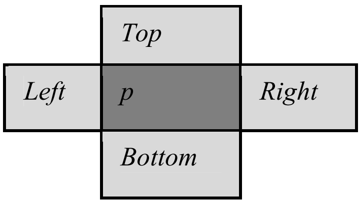


Fig 3. Principle of stereo vision.

3. The system implementation

a) Architecture of processing system

The proposed NGaF system includes three successive stages as shown in Fig. 4. The first functional block is responsible for enhancing the quality of depth image that it receives from the Kinect. The main objective of this group is to minimize noise in an image depth. The task of the second function block is creating a set of neighbors point groups with proposed Neighbor Grouping algorithm. These groups are not overlapping each other and the sum of all the groups is smaller than the size of original depth image. Each group will become a candidate for selection by the last function block. This block will retain the trust planes which meet a set of binding conditions.

Fig 4. Block diagram of plane detection system.

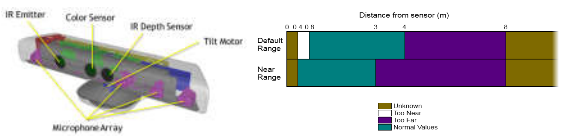
b) Map Enhancing

This study uses two sources of input data corresponding to two different test cases. In the first case, the implementation of the program on nearly perfect data including disparity maps from a library that shares across site http://vision.middlebury.edu/stereo/data/. It is not necessary to improve their quality (Fig. 5).

Fig 5. Illustration of data from Middlebury.
(a): Color Image; (b): Disparity map.

In the second test case, the process of reducing the noise in input cannot be ignored. The program collects depth data from Microsoft's Kinect sensor [14] (Fig. 6). Quality of depth maps is usually not ideal (Fig. 7). The appearing noise phenomenon occurs regularly in each frame of the depth stream. The main reason is the reflection of the uneven surface caused by micro roughness structure. To decrease this type of the noise, it is easy to see that if a review of the scope of a window *W* is small enough, they should always receive the correct values and the variability of depth value is not too strong. Thus, in the reviewed window, if it contains some points with unreasonable depth value then we can put them on the average value of the actual value of the points as shown in Fig. 7. The result is the number of black points is greatly reduced. If the ratio between wrong value points and size of window W is more than *50%*, the repair work is not effective because of lack of average value information. However, if this work reference experience from observing the actual depth data, this kind of error mostly occurs in regions which are far from the location of the camera. So it has a less important role than the near zone from camera's position.

A Kinect streams out color, depth, and skeleton data one frame at a time (Fig. 6). This section briefly describes the coordinate spaces for each data type and the API support for transforming data from one space to another. The APIs are designed to convert data from one coordinate space to the other.



(a) (b)

Fig 6. (a): Kinect's Windows Sensor Components and (b): Depth Space Range

(a) (b) (c)

Fig 7. Illustration of captured data from Kinect and improving result. (a): Color Image; (b): Depth map; (c): Enhanced depth map.

c) Neighbor grouping

The task of this step is to provide set of the candidates for the selection of worthy planes. Each candidate including the points neighbors that their order form connected planar area. Assuming for a set of identified point S includes points with its valid depth (Fig. 8). Neighbors grouping algorithm starts with the selection of center point p_i in S and consider its four nearby points. A nearby point that has a depth value difference Δz from the depth value of center point p_i less than or equal threshold value θ will become a neighbor of p_i (see Section C, Part II.) And it is added to candidate set P_k. One point that has been recognized as a neighbor also has its neighbor points so it should be considered as a central point later. Each point is evaluated its relationship only once with the role as a central point or as a neighbor point. So after a point is concerned, it will certainly be marked. The range of threadhold θ is dependent on the quality of input. If the program uses nearly perfect depth maps it executes with fixed $\theta = 1$. Other cases, the threadhold is get higher by *2*. The algorithm stops when the set S becomes empty.

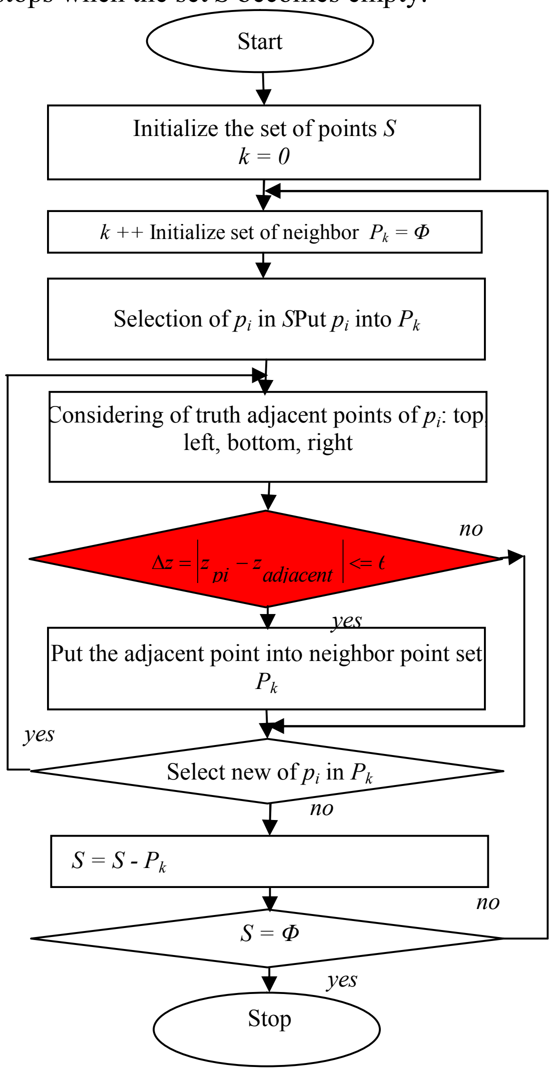


Fig. 8. Algorithm of neighbor grouping.

d) Planes selection

The results of step 2 include groups that each pair of points in which are neighbors each other and they cover most valuable depth points. Now, they can be considered as candidates for voting planes. The task of this step is to select the candidates that satisfy a number of conditions in practice to generate a real set of planes.

This leads to a common situation that we might to accept. That's not all the elements of the neighbor are planes. One of the important filter conditions related to the minimum size of the plane *min*. A candidate's point number must be greater than the determined minimum threshold to ensure that a significant number of small cluster interference is discarded successfully. The minimum threshold *min* will surely be affected in each case a specific scene, so this program will experiment with some different thresholds to check the number of the flat zones and avoid skipping a few pieces of planes in the set of real plane.

4. Experiences results and discussions

The program is written in C # tool in Visual Studio 2012 environment, and implement on a laptop with the configuration includes Core i5-2520 processor, maximum clocked 2.5Ghz, Windows 7 Ultimate 64-bit SP1 (Fig. 10.).

In this section, the authors describe the experimental results using the proposed method. The experiment was conducted on two different types of disparity map. The first input data set consists of five disparity maps collected from the common database with the link http://vision.middlebury.edu/stereo/data/ as illustrated in Fig. 9. The purpose of this test is to implement the applied algorithm in case of perfect disparity maps. To test the stability of the proposed algorithm, the program is executed with non-perfect depth maps as shown in Fig. 11. This second case was happened more frequently than the first case. Quality of depth maps are not often ideal due to the depth computing devices generally use some algorithms with low complexity to achieve the maximum gain in computation time. The detected planes as illustrated in the last column are shown to be smoothly matched with the real scenes in both of two cases.

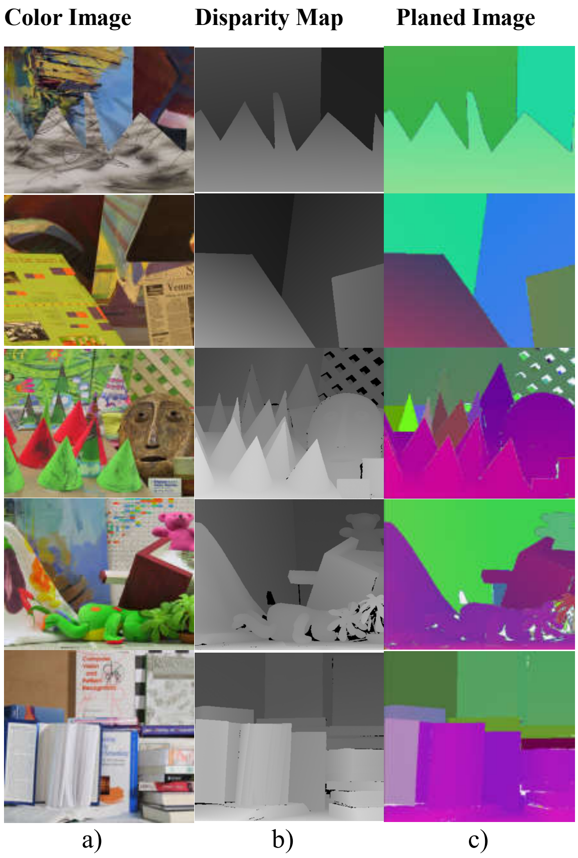
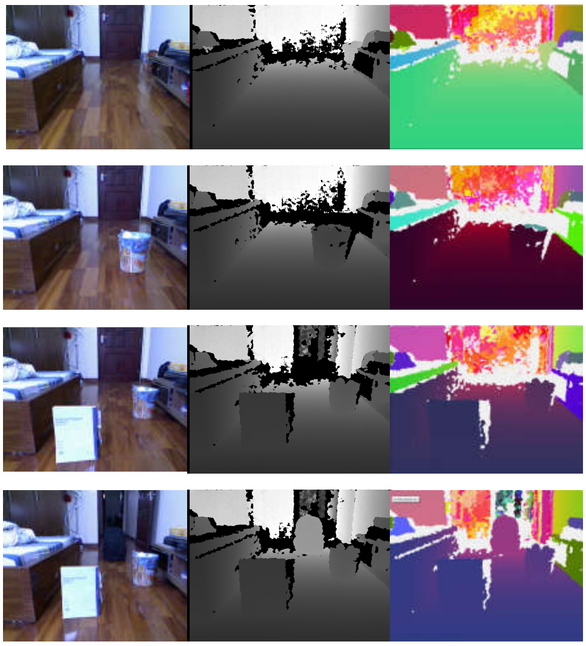


Fig. 9. The results of the tested images in the plenty of environment.

Note: a) color image, b) disparity maps, c) images with the planes are marked in different colors. From top to bottom, the first row is the Sawtooth image, the second row is the Venus image, the third row is the Cones image, the fourth is the Teddy image, and the last row is the Books image, respectively;

Fig. 10. The practicing system for tested images.



a) b) c)

Fig. 11. The results of the tested images capturing from Microsoft's Kinect sensor.

Note: a) color images, b) depth maps, c) images with the planes are marked in different colors. From top to bottom, the first row is the Non Obstacle image, 1- Obstacle image, 2- Obstacle image and 3- Obstacle image, respectively;

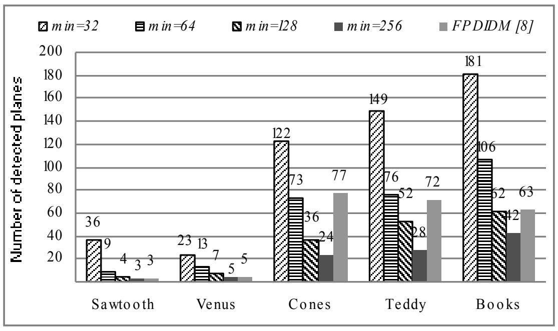


Fig. 12. Comparisions between the number of detected planes according to some difference minimum thresholds *min* and FPDIDM method [8] for disparity maps from Midlebury library.

Figure 12 shows a comparison of the number of planes detected between the applied approach and FPDIDM method [8]. For Sawtooth and Venus images, the results of the FPDIDM method corresponds to result of the proposed method applying a filtering threshold *min=256*. For Cones and Teddy pictures, result of the FPDIDM algorithm corresponds to the applied work with filtering threshold *min=64*. The FPDIDM's number of detected plane's in Books corresponds to the applied method using threshold *min =128*.

Figure 13 demonstrates the number of the detected planes with the minimum threshold *min* from 32 to 256 with depth maps from the Kinect. Obviously, as well as Fig.12, the threadhold *min* is greater the number of detected planes is less because of some plane pieces such as spot noises were discarded. The reduction rate of quantity plane is near 50% while *min* jumps from 32 to 64 and from 64 to 128 but this reduction rate keeps small when the minimum threshold increased from 128 to 256 in all tested cases. Also the number of detected planes depends on the objects in the scenes greatly.

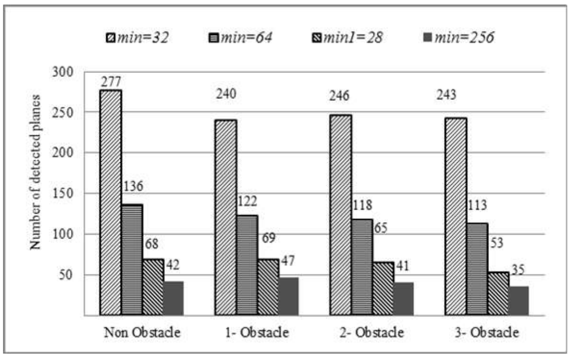
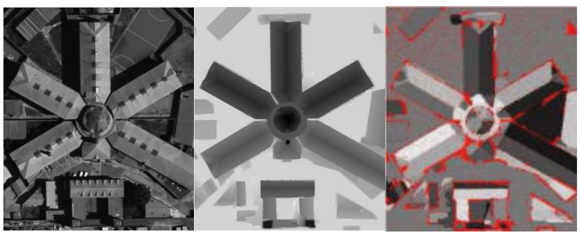
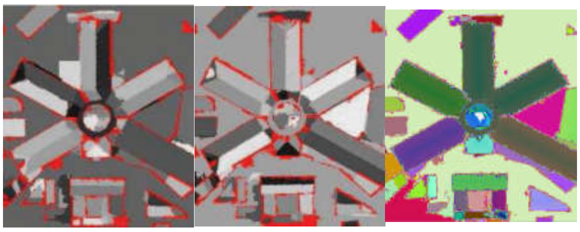


Fig. 13. The number of detected planes according to some difference minimum thresholds *min* with depth maps from Kinect.



(a) (b) (c)



(d) (e) (f)

Fig. 14. The results of HSBSR [4], PPDFDM [5], FPDIDM [8] methods and the proposed algorithm on Toulouse's St-Michel Jail disparity map.

Note: (a): reference image, (b): disparity map, (c): Planar patch classification of [4], (d): Planar patch classification of [5], (e): Planar patch classification of FPDIDM [8] method. Each gray level corresponds to a different plane. The red parts are defined as non planar according to the validation theory of [4], (f): Planar patch classification of proposed method. Each color corresponds to a different plane.

Figure 15, 14 illustrate a comparison among the proposed method and three others approachs consisting HSBSR, PPDFM, FPDIDM. The experienced results is evaluated on three common parameters including the computation time, the number of planes detected and percentage rate of valid points (Fig. 15). Processing time of proposed approach is lowest. Even the proposed method's computation time is reduced 33 times compared to the improved RANSAC algorithm (HSBSR). Meanwhile, the result in number of found planes is greater than and PPDFDM, FPDIDM method about 8% percentage. Last, the our results in percentage rate valid point is better than others approach 2% at least.

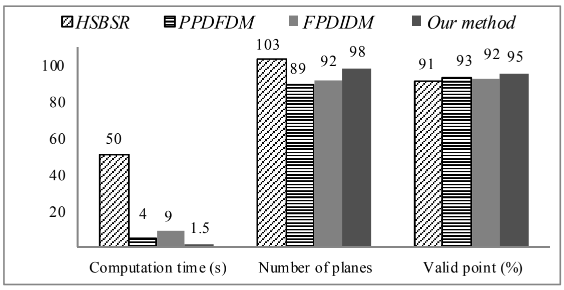


Fig. 15. Comparisons of three parameters among HSBSR, PPDFDM, FPDIDM and the proposed approach on Toulouse's St-Michel Jail disparity map.

5. Conclusions

In this work, we proposed a Neighbor Grouping and Filtering (NGaF) algorithm to detect the planar and semi-planar surfaces from only one depth map or disparity map. This manuscript shows a various of tested results which demonstrate the robust proposed method. By comparing of three common parameters among interesting methods, the applied algorithm illustrates a high performance certainly. In future work, this project should be improved by using real-time depth video.

Acknowledgments

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Phương pháp hiệu quả phát hiện đa mặt phẳng từ bản đồ độ sâu

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Tóm tắt: Trong lĩnh vực xử lý hình ảnh thị giác stereo, phát hiện mặt phẳng nhằm mục đích hỗ trợ sự di chuyển của phương tiện giao thông hay robot di động. Bài viết này thực hiện giải quyết vấn đề phát hiện mặt phẳng dựa trên bản đồ độ sâu bằng cách sử dụng một thuật toán phân nhóm hàng xóm mới và bộ lọc hợp lý (NGaF). Ưu điểm chính của phương pháp đề xuất này là sự đơn giản trong khi vẫn đảm bảo độ tin cậy của các kết quả. Đầu tiên, một giả thuyết về mặt phẳng trong các bản đồ độ sâu được xây dựng ngắn gọn và rõ ràng. Sau đó các thuật toán trích mặt phẳng được áp dụng dựa trên một số đặc trưng chắc chắn của mặt phẳng. Kết quả của phương pháp áp dụng được đánh giá là tích cực trên cả hai mặt trực quan và qua các thông số quan trọng. Phương pháp tiếp cận NGaF cũng đang được đánh giá vượt trội hơn so với các phương pháp sử dụng thuật toán kinh điển RANSAC, thuật toán mạnh PPDFDM và FPDIDM. Thời gian tính toán của phương án đề xuất giảm 33 lần so với các thuật toán RANSAC được cải thiện (HSBSR). Trong khi đó, số lượng mặt phẳng được tìm thấy là lớn hơn khoảng 8% so với kết quả của phương pháp PPDFDM và FPDIDM. Cuối cùng, tỷ lệ phần trăm các điểm có giá trị được xử lý lớn hơn 2% so với các phương pháp được so sánh. Phương pháp đề xuất chắc chắn có khả năng thực hiện trên phần cứng thông thường với nguồn lực hạn chế cũng như đảm bảo cho các ứng dụng thời gian thực về xử lý tín hiệu video.

Từ khóa: Mặt phẳng, phát hiện, bản đồ độ sâu, sự khác biệt độ sâu, điểm hàng xóm.