



Real Time Depth Hole Filling using Kinect Sensor and Depth Extract from Stereo Images

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Abstract

The researcher have suggested real time depth based on frequency domain hole filling. It get better quality of depth sequence generated by sensor. This method is capable to produce high feature depth video which can be quite useful in improving the performance of various applications of Microsoft Kinect such as obstacle detection and avoidance, facial tracking, gesture recognition, pose estimation and skeletal. For stereo matching approach images depth extraction is the hybrid (Combination of Morphological Operation) mathematical algorithm. There are few step like color conversion, block matching, guided filtering, minimum disparity assignment design, mathematical perimeter, zero depth assignment, combination of hole filling and permutation of morphological operator and last nonlinear spatial filtering. Our algorithm is produce smooth, reliable, noise less and efficient depth map. The evaluation parameter such as Structure Similarity Index Map (SSIM), Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE) measure the results for proportional analysis.



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Introduction

Kinect sensor is able to generate color and depth images at the equal time at a speed of thirty frames per Second. Depth data are used in 3-D vision

and robotic applications. These applications are 3-D television, 3-D communication, object detection, gaming industry and gesture recognition for controlling devices. The attractiveness of the Kinect

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camera can be qualified to its lower cost and the real-time depth map making capacity. Kinect sensor is also known as RGB-D camera. This camera is suffering with some problems while producing depth maps. In this map large number of noise and holes are present. Therefore our algorithm is efficient explanation to develop the sensor outcomes. Stereo matching algorithms are reconstructed 3D scenes through matching multiple images taken from slightly different viewpoints. The important task in machine vision field is defining of 3D data from images. Stereo matching algorithms are important to decide correspondences between the two views.^{1,2} In this

research we have developed two algorithms namely real time depth hole filling and stereo matching method. Fig. 1 shows functional block diagram of the research contribution. Objectives of the research are as under;

- To fill the hole for real time depth from video sequences captured by Kinect sensor
- To obtain depth map for multi view images based on stereo matching algorithm
- To analyze the results with the use of qualitative parameters such as PSNR, MSE, SSIM.

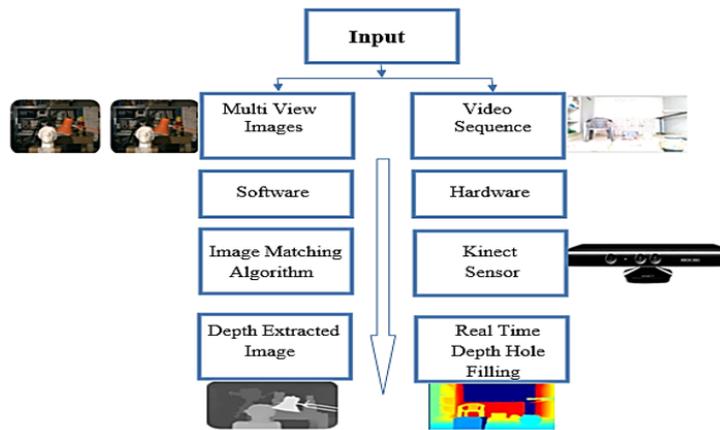


Fig. 1: Research contribution of depth extract from video and images

Hole Filling using Kinect Sensing Device

Kinect camera consists of a RGB camera which gives the RGB arrays output. The depth camera and the four microphone array are capable to give the depth data and audio signal at the same time. Depth image, color image, and audio streams are synchronized on primesense PS1080 System on Chip-SoC. Depth is calculated from IR camera and IR projector. Infrared- IR projector transmits the IR light in the form of speckle dot on the scene and the IR camera captures the reflected IR speckles. One camera and one IR transmitter provides input for the depth map 320x240 pixels resolution while the third camera detects the human visual spectrum at 640x480 pixels resolution.^{3,4}

The input to the kinect map is raw depth sequences. The filling of holes, object boundary rectification and alignment of the pixel with color image is the vision of improvement of the depth map. First step

of implementation is image registration known as depth video preprocessing. We set the trigger repeat, frame grab interval, total number of frame acquired, resize the frame and continuously update the real time result. It constructs a video sequence as an input object from the device and set the port number. Color and depth cameras are available through specific port number 1 and 2 respectively. The frame grab interval identify how frequently to obtain frame from video sequences. It is used to specify the interval so synchronize the frame with mathematical process. It is measured in number of frames not in time. If we define the interval value of five then every fifth frame is acquired from video sequence. Trigger repeat property is executed every time until the stop function or error occurs.

Depth renovate as a frequency domain environment and morphological transformation to recover the boundaries and smoothness of the object in

series. Depth enhancement and holes filling are finished by the mixture of filling holes and spatial filtering function with arbitrary noise riddance. The numbers of frames acquired from Kinect sensor are three hundred that include both colored and depth sequences. The number of frame sequence functions and resize are essential for filtering operation and revamp. Combination of morphological operators are erosion, dilation, closing and opening with structuring element having definite matrix 1's and 0's. The results of the spatial filtering are method for frequency domain.

The filtering method is bring out in frequency domain uses Fast Fourier Transform (FFT). The FFT is limber to design and implement filter. Smoothness the image in the frequency domain means attenuating a precise range of high frequency element in the image. The filtering step has modified the transformation of the image through filtering task and obtained inverse transformed results. The input image is converted in 2D Discrete Fourier Transform (DFT). This DFT is calculated with an FFT algorithm.^{5,6} The component of the frequency domain is moving to zero frequency element in the middle of the spectrum. The 2D DFT of $f(u, v)$ can be expressed by (1).

$$F(u, v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) e^{-j2\pi(\frac{ux}{M} + \frac{vy}{N})} \quad \dots(1)$$

Where $v, u = 0, 1, 2, 3 \dots M-1$ and $y, v = 0, 1, 2 \dots N-1$. This filtering function $H(u, v)$ is multiply by $F(u, v)$ as showing in equation (2). $F(u, v)$ has real, imaginary parts.

$$G(u, v) = H(u, v) F(u, v) \quad \dots(2)$$

Where, $H(u, v)$ - Gaussian Transfer Function can be expressed by (3).

$$H(u, v) = e^{-D^2(u,v)/2\sigma^2} \quad \dots(3)$$

σ is the standard deviation as a calculate for spread gaussian curve. Author assume $\sigma = D0$, in the expression (4).

$$H(u, v) = e^{-D^2(u,v)/2D0^2} \quad \dots(4)$$

Where $D0 =$ cutoff frequency. The filter is down 0.607 to the maximum. Distance from any location (point) to the origin of the Fourier Transform is expressed by (5).

$$D(u, v) = \{(u-M/2)^2 + (v-N/2)^2\}^{1/2} \quad \dots(5)$$

$D(u, v)$ is the distance from the origin of the Fourier Transform. The output of the filter function to apply 2-D Inverse DFT of $f(x, y)$ is expressed by (6).

$$f(x, y) = \frac{1}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} f(u, v) e^{j2\pi(\frac{ux}{M} + \frac{vy}{N})} \quad \dots(6)$$

The make utilize of Gaussian filters no ringing effects are produced. Increasing the cutoff frequency smoothens the image output. In this method we have used the cutoff frequency at 3 radii of 90, 190 and 250. The results are more suitable and smoother while the radii are increased. Nonlinear spatial filter also known as rank filter is used to decrease the noise and improves the output of the depth as a grayscale image is applied at the last stage. Order statistic or median filter is valid the size of mask 3, 7, 9, 11 etc.

Depth Extract from Images

Depth extraction basically proceeds in 4 steps as similarity measure cost calculation, Cost aggregation, Disparity calculation and Disparity refinement. This flow of algorithm is to apply color conversion, block matching, guided filtering, minimum disparity assignment design, mathematical perimeter, zero depth assignment, the combination of hole filling and permutation of a morphological operator and last nonlinear spatial filtering.⁷

We have used block based horizontal pixel matching technique and zero depth assignment process. Construction of raw depth matrix for every disparity can be expressed by (7).

$$d(s, t, Hsm) = \frac{1}{3 \cdot r \cdot c} \sum_{s=it}^{i+r} \sum_{j=k}^{j+c} \sum_{k=1}^3 (I(s, t, k) - IR(s, t - Hsm, k))^2 \quad \dots(7)$$

Where $Hsm =$ Maximum shifting at horizontal; $k =$ Number of image plane component having value 1, 2, 3 respectively; $r, c =$ number of row and column respectively.

To set a horizontal shift value to measure, how dissimilar pixel analogous to the point t in left image compared among the pixel match with right image. Guided filter is a neighborhood operation; it calculates the output value of pixels statistics of a region in the equivalent spatial neighborhood using guidance image.⁸ It is used to reduce sharp

transitions, de-noising, and incorrect matching in images. Square window size $N \times N$ of guided filtering is applied to d (s, t, Hsm). Guided filter is the fast edge-preserving non-approximate linear time filter. The guided filter output gfo_i at a pixel i is denoted as a weighted average in (8).

$$gfo_i = \sum_j w_{ij}(I) p_j \quad \dots(8)$$

Where, I and j are pixel indexes. This filter kernel w_{ij} is a function of the guidance image, I and independent of p . The filter is linear with respect to p . This guided image filter assumes linear transformation in a local or centered window W_k the relation between guidance image I and filtering output gfo can be expressed by

$$gfo_i = a_k I_i + b_k, \forall_i \in W_k \quad \dots(9)$$

Where I_i indicates gray cost of the pixel i in the guidance image I . This linear coefficient a_k, b_k are constant and $i \in W_k$ defines pixel I is in window w_k . In eq. (9) $\nabla gfo = a \nabla I$, and ∇ signifies the gradient therefore gfo has an edge if Image I has an edge.

To establish the linear coefficients (a_k, b_k) we require restriction from the filter input p . The linear output gfo as the input p mathematically subtract some surplus components n like noise or textures expressed by

$$gfo_i = p_i - n_i \quad \dots(10)$$

The w_k cost function expressed by (11) for minimizing difference of image p and gfo .

$$E(a_k, b_k) = \sum_{i \in W_k} ((a_k I_i + b_k - p_i)^2 + \epsilon a_k^2) \quad \dots(11)$$

Where ϵa_k^2 is regularization term and ϵ is preclude large a_k . The linear coefficient a_k and b_k mathematical calculation as expressed by (12) and (13).

$$a_k = \frac{\frac{1}{|w|} \sum_{i \in W_k} (I_i p_i - \mu_k \bar{p}_k)}{\sigma_k^2 + \epsilon} \quad \dots(12)$$

$$b_k = \bar{p}_k - a_k \mu_k \quad \dots(13)$$

σ_k^2 and μ_k are the variance and mean respectively of guidance image I in w_k , $|w|$ is the number of pixels in w_k . \bar{p}_k is the mean of p in w_k . By applying guided filter W_{ij} kernel in eq. (14) can be expressed by,

$$w_{i,j}(I) = \frac{1}{|w|^2} \sum_{k:(i,j) \in W_k} \left(1 + \frac{(I_i - \mu_k)(I_j - \mu_k)}{\sigma_k^2 + \epsilon} \right) \quad \dots(14)$$

Where μ_k and σ_k^2 are mean and variance of w_k in I . ϵ is a smooth parameter, $|w|$ is the number of pixels in window with fixed dimension.

For proper horizontal shift value, the minimum starting value is zero. The maximum horizontal shift Hsm is the maximum cost of the pixel in the ground truth divided by the scale factor. Mathematical expressed is shown in (15).

$$Hsm = B f / N x \quad \dots(15)$$

Where Hsm is the specified range of the object, B is the baseline means the distance among the centers of the cameras, f is focal length of the sensor, x pixel size, N maximum disparity value. The window is only shifted along the x direction define as Hsm. To compute the difference, a window is placed fixed at left images, while Hsm is a shift over a finite range in the right image. Further guided filtering outputs the minimum difference value assignment function with a minimum error for each disparity. The minimum error energy g (s, t, Hsm) as the reliable depth estimation for pixel (i, j) of raw depth map is as follow by (16).

$$Dr(s, t) = \min \{g(s, t, Hsm)\} \quad \dots(16)$$

The perimeter is the total length of the scene boundary. It can be measured by tracing the boundary of the object and adding all the steps of length.

For zero depth map assignment, we count the disparity map whose disparity is not defined shows flow chart in fig. 2. For that, we create a map in which the disparity is calculated by its neighbor pixel in the same column which lies above the said reference pixel. Similarly, we create another map to compute disparity of said pixel in a downward direction along the same column. After this process, we get two different disparity maps among one in above direction and one along the downward direction. Finally, we compute the finishing disparity map which compares the prior two different disparities which we obtained earlier.

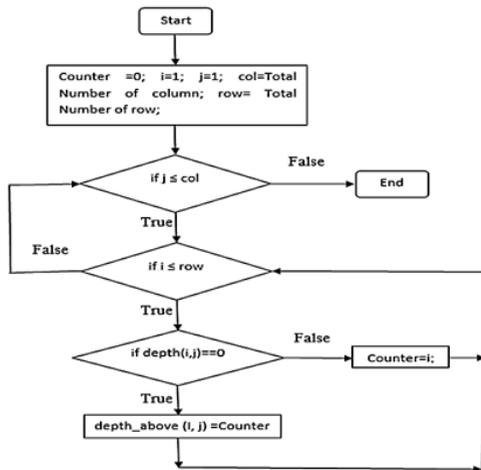


Fig. 2: Flow chart of zero depth map assignment

The filling phase is the key part of our algorithm and completes the final result. Region fill process is based on a set of intersections, dilations and complementation to fill the holes in the image. 'I' is the region and connected components. The form an array X_k the similar size as the array include 'I' whose elements are 0 (background value), except at each location known to correspond point in every connected component in I, which we set to one foreground value. The purpose is to start with X_0 and locate all the linked components by iterative procedure in equation (17)

$$X_k = (X_{k-1} \oplus B) \cap I^c, k = 1, 2, 3 \dots (17)$$

Where, B - structuring element, $X_k = X_{k-1}$ with X_k containing all the connected components of I.

The hybrid (combination of morphological operators) is erosion, opening, closing and dilation operation by structuring element neighborhood with precise matrix 1's and 0's. In this algorithm we are using random structure $[1 \ 1; 0 \ 0]$ and $[1 \ 1 \ 0; 0 \ 1 \ 0; 0 \ 0 \ 1]$ etc. Nonlinear spatial filter known as rank filter is used to decrease the noise and get better the output of the depth as a grayscale image is applied at the last stage.⁴²

The perimeter measuring process is the next step to trace the boundary of the scene and adding all the steps of length. In the map, some pixels have not been assigned value yet so next step is to assign the value. With the help of perimeter, function assigns the values embedded at zero value in the map. Here dissimilar pixels are set to unknown. At the end these are filled using hole filling operation. Depth maps are generated using 3, 5, 7 and 9 neighborhood size (N x N) of the median filter at the last of the stage. The median filter reduces the noise and black specks around the border.⁹

Results and Discussion

The results of depth are measured for a range of object located at different distance. Kinect camera has maximum range of near about four meter and we have calculated different parameter values for 3, 3.5 and 4 meter and the value of cutoff frequency at 3 different radii of 90, 190 and 250 shows in table 1.

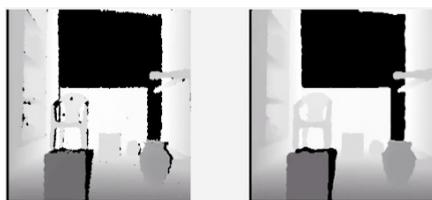
Table 1: Experimental results of the qualitative parameters for real-time Kinect depth sequences

Distance from Kinect (Meter)	Cutoff frequency set at radii value	SSIM	MSE	PSNR
4	90	0.8414	0.0093	68.44
	190	0.8979	0.0026	74.02
	250	0.8983	0.0024	74.27
3.5	90	0.8633	0.0099	68.16
	190	0.9311	0.0015	76.32
	250	0.9331	0.0012	77.49
3	90	0.8414	0.0093	68.43
	190	0.8979	0.0026	74.01
	250	0.8983	0.0024	74.40

The object is sets at various sizes and shapes, so we can confirm the improved efficiency of Kinect based algorithm. Value of PSNR of the resultant image increases with an increase in cutoff frequency radii value. The value of MSE decreases with an increase in cutoff frequency radii value. SSIM value increases with an increase in cutoff frequency radii value. Results are more appropriate and smooth when the cutoff frequency radii are increased.¹⁰

The better values of SSIM and PSNR are obtained when the set of radii is 250. The most of the information in the image will be enclosed in the output at the distance 3.5 meter. Gaussian low pass filter has capacity to pass lower frequency component also it will chunk the higher frequency element. Table 1 show that for lower cutoff frequency and the cost of statistical parameters is very small as the pass band is very low. It also shows that as the cutoff frequency increases, the processed image contains more information and this lead to better values of PSNR, MSE and SSIM.¹¹

The speed of processing the algorithm diverges with the numbers of invalid pixels and numbers of acquired frames. The average time of the algorithm is 35 seconds per 300 frames. This estimated time of one frame is 0.11 second per frame-SPF. This method generates visibly clear and accurate filling of hole. The post-processing step corrects and sharpens the boundary of the objects of the depth map and makes sure local depth smoothness the object. Experimental result shows that the random error of depth measurement increases when the distance between the scene and the sensor increases, ranging from a few millimeters to about 4 meter.¹⁴ Stereo matching algorithm uses different number of windows of different sizes to make a fair evaluation shown in fig. 7 and 8. The computation of time of the algorithm increases with an increase in window size.¹¹⁻¹³



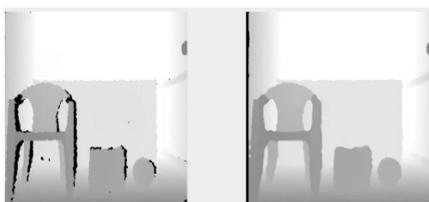
(a) (b)

Fig. 3: Video sequences captured by Kinect Sensor at 4 m distance (a) Gray scale raw depth sequence (b) Refined gray scale depth sequence (Radii value-250)



(a) (b)

Fig. 4: Video sequences captured by Kinect Sensor at 3.5 m distance (a) Gray scale raw depth sequence (b) Refined gray scale depth sequence (Radii value-90)



(a) (b)

Fig. 5: Video sequences captured by Kinect Sensor at 3 m distance (a) Gray scale raw depth sequence (b) Refined gray scale depth sequence (Radii value-190)



(a) (b)

Fig. 6: Video sequences captured by Kinect Sensor (a) Gray scale raw depth sequence (b) Refined gray scale depth sequence (Radii value-90)

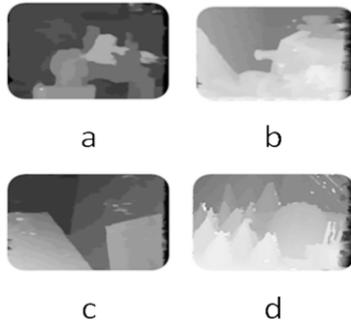


Fig. 7: The results of cone image (a to d).
Horizontal Shifting - Hsm of values (a) 30,7 x 7, 384 x 288, rgb2lab (b) 50, 3 x 3, 450 x 375, rgb2lab (c) 30, 3 x 3, 484 x 383, rgb2lab (d) 60, 5 x 5, 450 x 375, rgb2lab

Conclusion

The depth quality is enhanced by depth renovation in frequency domain technique, fills the holes in depth sequences, 2-D spatial filtering and combination of morphological operation. An experiment result demonstrates the quality of our projected method is better than preceding research work. Our algorithm generates noiseless, efficient, reliable and smooth depth sequence. This algorithm with Kinect sensor works in dark region.

We conclude that for upper window sizes the performance of the filter deteriorates as compared with lower window sizes it is because in low window size the number of elements in windows is dedicated and the filter costs are near which gives a mean value remove the noise. But filter window increases the elements of filter also increase that gives a degree of noise remove but additional a value of noise in the filtered image. Guided and nonlinear spatial filters decrease the noise and improve the results of the depth images. The experimental results show that guided and nonlinear spatial filters give optimum

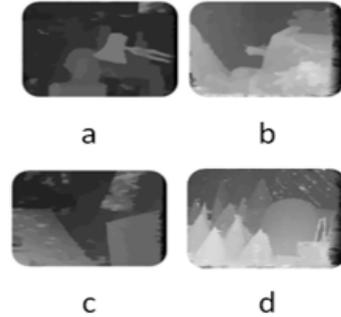


Fig. 8: The results of cone image (a to d).
Horizontal Shifting - Hsm of values (a) 30,7 x 7, 384 x 288, rgb2xyz (b) 50, 3 x 3, 450 x 375, rgb2xyz (c) 30, 3 x 3, 484 x 383, rgb2xyz (d) 60, 5 x 5, 450 x 375, rgb2xyz

and best quality results for all noise mass in 3 x 3 window size.

As window size increases the SSIM increases. The values of SSIM are better in quality in rgb2xyz conversion as compared to rgb2lab. The depth maps recovered by our algorithm are closed to the ground truth data.

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Conflict of Interest

All authors the authors declare that there is no conflict of interest.

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