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3D visualization of 2D/360° image and navigation in virtual reality through motion processing via smartphone sensors

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Abstract

The 360° images or regular 2D images look appealing in Virtual Reality yet they fail to represent depth and how the depth can be used to give an experience to the user from two dimensional images. We proposed an approach for creating stereogram from computer generated depth map using approximation algorithm and later use these stereo pairs for giving a complete experience on VR along with forward and backward navigation using mobile sensors. Firstly the image is being segmented into two images from which we generated our disparity map and afterwards generate the depth image from it. After the creation of the depth image, stereo pair which is the left and right image for the eyes were created. Acquired image from the previous process then handled by Cardboard SDK for VR support used in the Android devices using Google Cardboard headset. With the VR image in the stereoscopic device, we use the accelerometer sensor of the device to determine the movement of the device while head mounted. Unlike the other VR navigation systems offered (HTC Vibe, Oculus) using external sensors, our approach is to use the built-in sensors for motion processing. Using the accelerometer reading from the movement, the user will be able to move around virtually in the constructed image. The results of this experiment are the visual changes of the image displayed in VR according to the viewer's physical movement.

Introduction

Previously, numbers of researchers worked on 3D visualization and VR navigation separately. Their approached models are either have bulky systems, complex setup and high costs [1]. These approaches limit their uses on versatile environment due to lack of portability. Besides, for 3D visualization most of the models either use sensors like Kinect sensor to achieve the depth information of the object [2]. According to the sensor based approaches the distance of the object plays a vital role. If the distance of the object is increased from the camera plane the error in finding the depth image increases. The percentage on an average of the Absolute Mean Percentage Error is 3.6% compared with the depth distance and the actual distance of the object from the camera plane [2]. In our model we have taken a more liberal approach to overcome this limitation by providing the computer generated depth image for creating a more accurate virtual stereogram. Another thing we take into account is that, for VR device navigation our proposed model uses Google's 'Cardboard' platform to provide the structure for Head Mounted Display. Along with that, for the movement in the VR plane our model proposes a more cost effective approach which handles the linear movement via the accelerometer of the smartphone devices. All in all, our proposed approach, we integrated the 3D visualization technique to create a computer generated depth image. For 3D visualization model of stereo pairs we integrated it with the Google's Cardboard platform for VR device support and mobile's accelerometer for moving on the 3D visualized plane.

Literature Review

The advancement of VR technology has increased 3D content creation. Therefore people are more focused on making 3D contents. The term 3D was first introduced in 1850's.In 1853 W. Rollmann 1st introduced the idea of 3D anaglyph through viewing a yellow blue drawing with red and blue glasses [3]. He also found that with a red and blue drawing the outcome was not as perfect as it is with the yellow and blue drawing because the red and blue line drawing are not visible with the yellow and blue glasses [4,5]. In 1858, Joseph D'Almeida projected the 1st 3D magic lantern where the audience wore green and red goggle to view the 3D lantern [4, 5]. Later on 1953, the anaglyph for 3D visualization of image spread among comics' newspapers and magazines [5]. Humans are able to have 3D effect due to their 3D vision. Human eyes perceive the same scene but from different perception because of the differences of left and right eye the scene is deviated from one to another. This visualization technique results slightly different signal to the brain [6]. Furthermore, the accuracy of the visualization improves through attributes like light, shadow etc. for better depth estimation. Mainly brain accepts horizontal disparities between two images and returns a single image with accurate depth information [6]. Many existing papers, propose techniques that provides creation of image for 3D visualization from single image camera and Kinect sensor [7]. The Kinect sensor and it's in built camera is used for capturing the color of every pixel and depth information. From this they extract the left and right image and then applied the color filtering to achieve the 3D anaglyph [8]. Moreover, there are more complex approach for estimating the depth information. There are methods where depth map is generated through 3D histogram-based segmentation to refine the depth map produced by the learning based method. Another depth extortion from single view 2D image is to measure the focus and defocus cues through higher-order statistics technique through which the foreground and background is segmented. Later on the depth map is refined from the segmented images [9]. Furthermore, high computed data mining techniques such as Knn based learning are introduced for calculating the depth map [10]. The drawbacks of all these methods are they either require great computational power or not well suited for depth generation from 2D images. Depth cues play an important role for visualization of 3D image. The human brain is a very complex system. Our eyes perceive the image from two different positions through left and right eyes. Because of the distance between our eyes which is approximate 6.5cm this displacement of images is created which results in the stereo vision also known as stereogram [11]. Diffusion in the signals in brain gives us a 3D visualization. Recreating this visualization on computer the red cyan techniques has been introduced for stereo images where the left eye image is filtered in red color and the right eye image is filtered in cyan and imposed on each other to recreate the 3D anaglyph. Besides, rendering one image from observer's side and applying the horizontal offset to create the stereoscopy. This offset is known as Base in stereoscopy which is assumed as 6.5cm [12]. Furthermore this method is executed when there is a pair of stereo image and depth information either collected via stereo camera and complex depth map generation techniques. For generating stereoscopic 3D from 2D video image stitching through fundamental matrix is proposed with higher computing cost. The Homography matrix generation is considered for better result [13]. It is known that Homographies induced by the plane $n^TX + d = 0$ under coordinates $\Pi_E = (n^T, d)^T$ is [14] :

$$H_{ij} = K_i[R - tn^T/d]\,K_j^{-1} \tag{1}$$

Again depending on the rotation of the camera the homographies may undergo different equation such as [15]

$$H_{ij}=K_iR_iR_j^TK_j^{-1} \tag{2}$$

Furthermore, stereo images are the basis for stereoscopes. A stereoscopic device is prepared for displaying stereo pair images. Stereoscopes can either be glass oriented which was explained earlier or they can be high-end headsets. Low cost solution for this headsets are available too where they use the mobile devices as the display, with the stereoscopic image being created by two replaceable lenses. Mainly the stereo images are the basis for the headsets that provides a 3D visualization using our 3D vision. Virtual Reality technology has been popular for a while. Therefore many products have taken over the market with new techniques on VR along with other integrated features. Navigation techniques and supports have been offered in some of the products out there in market such as Oculus Rift and HTC Vive. Oculus Rift uses a pair of Oculus Sensors which tracks constellations of IR LEDs to translate movements in VR [16].

Similarly but with different technology HTC Vive offers a pair of base stations as their motion detectors. Each base station scans the room with a laser beams 50 times a second, alternating between horizontal and vertical sweeps [17]. Therefore, it has been a popular approach for navigation in VR to use external sensors to map movements and position of the head-mounted display. However, in mobile devices the only few options of VR is provided by Samsung Gear VR, Google Cardboard, and Google Daydream which do not provide navigation movement systems with their devices but through external devices it provides the navigation [18]. Though mobile devices have sensors such as accelerometer, gyro-sensor, low range IR sensor and other sensors which can be involved in motion tracking, the services do not provide us direct access to it for movement in Virtual Space. Only the gyro-sensor is used for a head-rotating experience in VR in all the mobile. Still the lack of navigation and movement exists in mobile VR. Researches on movement in real world using mobile sensors has been done using the mentioned motion sensors [19].

Since our research is based on images in VR and through navigation we will interact with image as if it is 3D, our goals are more or less alike. Smartphone accelerometers can take readings of the device's acceleration over the 3 dimensional axis which can have many applications [20]. Accelerometer readings are not usually accurate since the gravity is always a factor when the reading is taken. Therefore, in order to take linear acceleration reading the gravity must be cancelled out [21].Therefore,

linear acceleration = acceleration - acceleration due to gravity

Motion processing from noisy data can be inaccurate and therefore can be solved using different techniques such as removal of noise and even integrating the noise data. But the results can drift having a large margin of error, so the results are not always promising yet it shows a possibility of making new assumptions [22]. According to the motion readings from the smartphone, the image can be processed to be given a closer view when physically moved forward and relatively further view if move backwards in a VR environment. The visual results will feel like as if it was in 3D and the objects in the 2D image will seem interactive. In the mainstream VR systems such as HTC Vive and Oculus Rift external sensors are used for navigation and virtual movements [23]. Multiple long range IR sensors, showed in Figure 1, are used track the movements of the wearer of the VR headset. Thus the navigation in virtual space can be done.

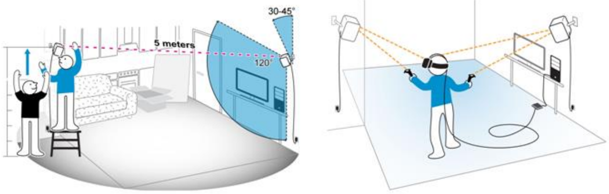

Figure 1. *HTC Vive setup and navigation using base stations [24]*

In our research, we are trying to create a model that gives us similar navigation results using internal sensors of smartphones rather any external sensors.

Proposed Method

The proposed model consists for several different phases analyzing a 2D image to create a stereo pair that will be ported to the head mounted display. The basic work flow of our model is outlined on the Figure 2.

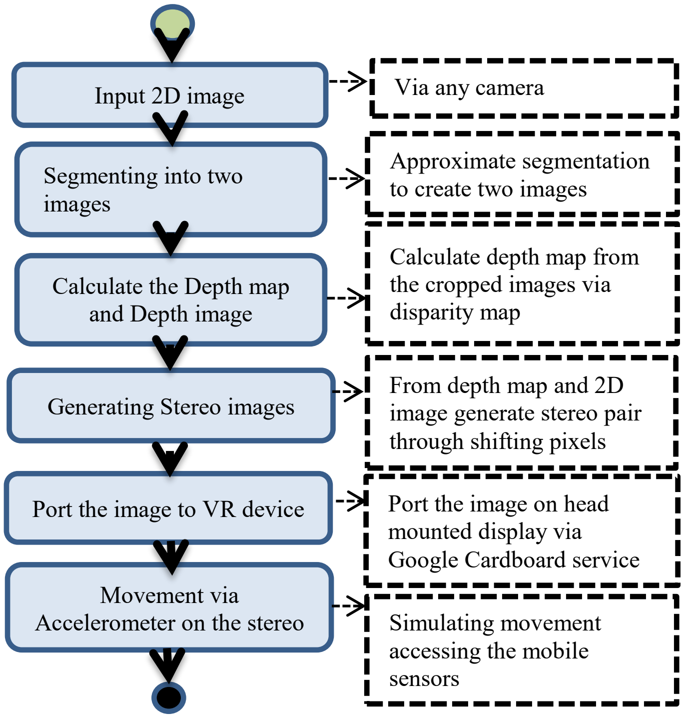

Figure 2. *Proposed model work flow*

In the 2D image the Z axis remain constant because eyes have the same Z direction. But due to the displacement of one eye to right the horizontal (positive X axis) is displaced by the distance T_x, where T_x is the base of the eye pair. So, the image is having (X_0, Y_0, Z_0) coordinates values than, the segmented new pair's coordinate can be expressed as below [25].

$$N_R = (X_0 - T_x, Y_0, Z_0) \tag{4}$$

After cutting the horizontal width of the image, the image needs to be resized as the ideal image. For resizing the image, the deducted width will be converted by making each pixel of the image's x and y coordinate to color value zero.

The next step in the proposed model, is calculating and generating the depth image. For that the new generated image and the ideal image will be taken so that the disparity can be calculated from them. Disparity happens due to the displacement of our eyes. As we are taking only a 2D image, on our previous step we created a computer generated two images depending on human physical environment. Therefore the difference between the horizontal x-axis will be the binocular disparity, D.

$$D = X_{\text{idealImage}} - X_{\text{NewImage}} \tag{5}$$

Based on the information above the disparity map will be calculated through Semi global block matching algorithm.

The Semi Global Block Matching algorithm which is also known as SGBM aims to minimize global energy function to obtain the disparity map. The Energy function E for disparity image, D with $P_2 >= P_1$ is calculated by the following equation [26],

$$A = \sum_p (C(\mathrm{p}, \mathrm{Dp}) \sum_{q \in Np} P1\, I\, [|Dp - Dq| = 1]$$

$$B = \sum_{q \in Np} P1\, I\, [|Dp - Dq| > 1]$$

$$E\,(D) = \quad A + B \tag{6}$$

Where

E (D) is the energy for disparity image, D
p, q represent indices for pixels in the image
Np is the neighborhood of the pixel p
C (p, D_p) is the cost of pixel matching with disparity in Dp.

The cost function C (p, D_p) is computed in the following manner [26]

$$C(p,d) = \min(d(p, p-d, I_L, I_R), d(p-d, p, I_R, I_L)) \tag{7}$$

Where,

I_L and I_R are left and right rectified images, respectively [26]

$$d\,(p, p-d, I_L, I_R) = \min_{p-d-0.5 \leq p-d+0.5} | I_L(p) - I_R(q) | \tag{8}$$

Furthermore, the SGBM algorithm generates the disparity. From the disparity the depth image is generated by given formula [27]

$$Z = f * \left(\frac{T}{d}\right) \tag{9}$$

Where, Z is the depth to be calculated, f is the focal length, T is the baseline & d is the disparity.

For synthesizing the left and right images, the model proposes computing each of the pixel's parallax value from the estimated depth map. After that shift each pixel by the corresponding parallax values in an input image. The parallax value at (x, y), Parallax (x, y) is computed from the depth map as follows [28, 9].

$$\text{Parallax}(x, y) = M * \left(1 - \frac{depth(x,y)}{255}\right) \tag{10}$$

Where, M denotes the maximum parallax value and depth (x, y) is the estimated depth value at (x, y).

For every pixel of the input image, the parallax is calculated from the estimated depth map. Considering the input image as the virtual central view from which the left and right image are obtained (Figure 3) by shifting the input pixels by a value equal to the parallax/2 for each view [28, 9].

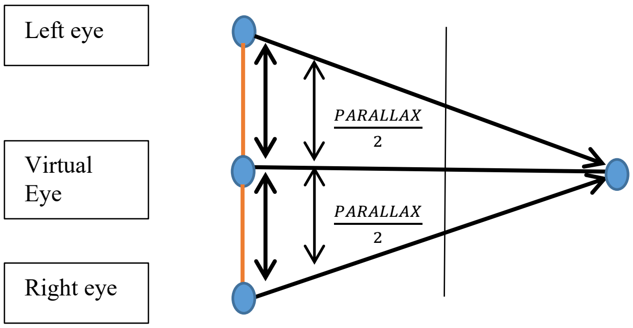

Figure 3. *Stereo-pair generation*

Experimental Results and Analysis

The computer generated stereo pair then will be implemented in the mobile device using Google Cardboard SDK and Android Studio or Unity3D. Figure 4, is our sample 360^0 image.

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Figure 4. *Sample 360^0 image*

Accelerometer reading of mobile, for the entire three axis x, y and z can be fetched and used.
The three elements of the rotation vector are expressed in Figure 5

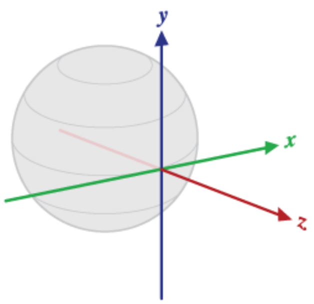


Figure 5. *Coordinate system used by the rotation vector sensor*

The equation the follows these rotation vectors are

$$x.\sin(\frac{\theta}{2}) \quad (13)$$

$$y.\sin(\frac{\theta}{2}) \quad (14)$$

$$z.\sin(\frac{\theta}{2}) \quad (13)$$

Since our target is to get linear movement in forward and backwards, we will be taking acceleration over z-axis
Therefore,

$$al_{inearZ} = A - g - Noise \quad (17)$$

$$Noise = A - g \text{ (at rest)} \quad (18)$$

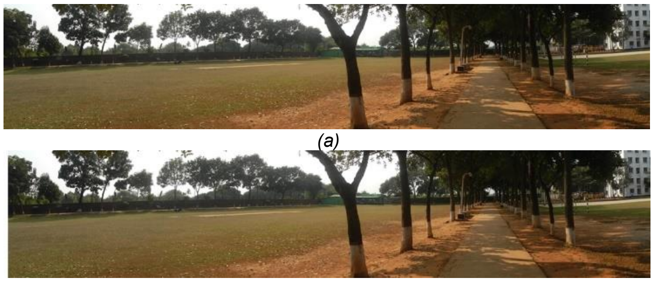
Where,

$$A = ax + ay + az \quad (19)$$

$$g = 9.8\ ms^{-2}, \quad Noise \sim 2\ ms^{-2}\text{(experimental)}$$

Using the equation we can estimate the linear acceleration over z-axis to determine the amount of movement on forward and backward.

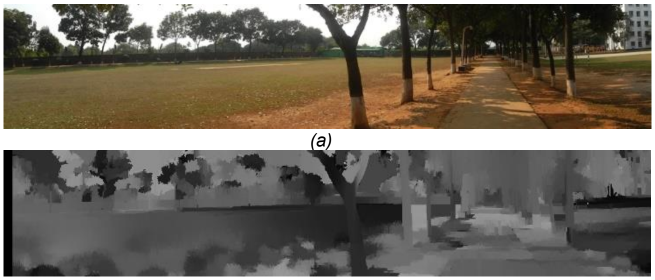
Because of the VR navigation, the 360^0 image was captured via a camera (Figure 6. (a)) and then it is segmented with the white space in it (Figure 6. (b)).


(a)

(b)

Figure 6. *(a) 3600 ideal image (b) segmented image*

The 360^0 segmented ideal image goes through the SGBM algorithm and the depth map equation (10) to produce the depth image (Figure 7).


(a)

(b)

Figure 7. *(a) 360^0 image (b) Depth Image*

After the generation of computer generated depth image, based on the ideal image and the depth image, the stereo pairs, that is the left eye image and right eye image is generated by the equation (10).

Figure 8, represents the stereo image of the 360^0 image (Figure 10 & 12) that has been created from the proposed methods.


(a)

(b)

Figure 8. *Stereo Pair (a) Left eye image (b) Right eye Image*

The acceleration reading using a mobile device was taken to plot a graph (Figure 9) to show the behavior of the acceleration on the three axis. The accelerometer reading may differ from device to device. The smart phone device was in landscape mode while determining the acceleration movement. After plotting the values of the accelerometer sensor reading in respect of time, it shows a graph of forward movement acceleration (Figure 9).

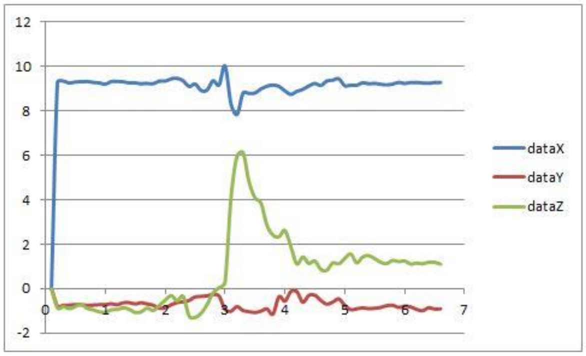


Figure 9. *Forward movement acceleration on graph*

The spike on the Z-axis on Figure 9 data indicates the physical forward movement of the headset. Therefore for each forward movement there will be a positive spike on the Z-axis.

Also, with a 360^0 image of Figure 19, the navigation will feel more natural and moving forward physically will give a sense of moving forward in the virtual space as well showed in Figure 10.

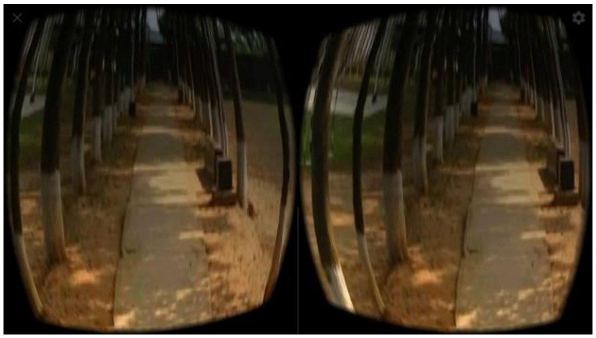


Figure 10. *360 Sample Image in VR view navigating forward*

For backward movement we took similar data via sensor manager on every axis and plotted graph in Figure 11 to analyze the behavior change.

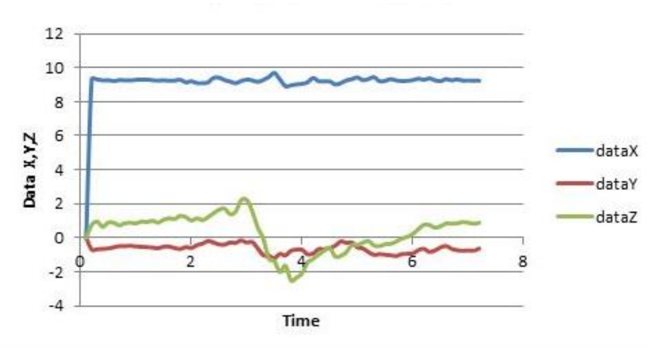


Figure 11. *Backward movement acceleration on graph*

The Z-axis data showed in Figure 11 a negative value spike and therefore signifies the backward movement of the device. For each negative value spike there can be sensed a backward movement.

In the Figure 12, backward movement physically will give the sense of going backwards in the pseudo-space virtually.

Figure 12. *360 Sample image in VR view navigating backward*

Conclusion and Discussion

In our proposed model, the depth image is generated through computer and the navigation part is done without the help of external sensors. If we compare the computer generated depth image model with the Kinect sensors depth image, the depth will be more diverse. The RGB-D sensors, such as Microsoft Kinect, are 3D sensors from which the depth image is created by calculating the distortion of the IR lights. [29]. But the sensors that are in use also has some limitation regarding the distance of the object from the sensor. The distance starts from millimeters to at max up to 4cm [30]. The standard deviation at different distances of plane to the sensors provides a similar type of quadratic curve in precision (Figure 38) [31]. The limited range for Microsoft SDK is above 800 millimeters for default range and go down to 500 millimeters for nearer range [32]. However, from Figure 38 we can see that it provides measurement range starting at 500 millimeters until 4000 millimeters which is better range but after that it starts to deviate [31]. Whereas in the proposed model the depth image created via computer, for which the distance limitation is not found in our model. Though we face error for the focal length of the camera from which the 2D image is collected and also with the baseline by which the image is segmented.

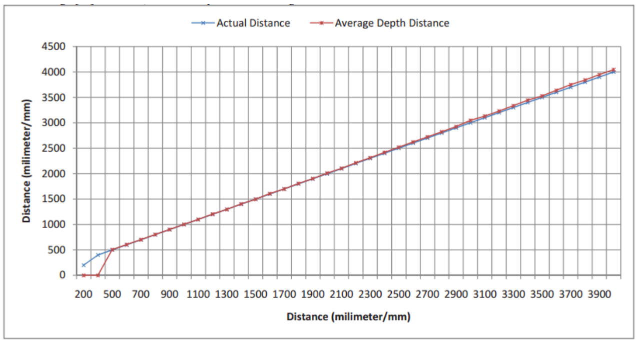


Figure 13. *Comparisons between Average Depth Distances vs. Actual Depth Distance [31]*

The navigation system that we proposed is inexpensive than the available systems due to less use of sensors. Besides, using of the Google Cardboard platform made it more cost effective [33]. The existing system such as Oculus and HTC Vive etc. uses external sensors such as long range IR sensors which is why the system becomes more expensive. Again, these existing system reads axis values therefore, it takes three dimensional movement reading. But in our system, it takes reading only in one axis as we are working on 2D image. All in all, our proposed model roughly gives a better experience for 2D image which is converted for 3D visualization.

References

[1] S. LaValle, A. Yershova, M. Katsev and M. Antonov, "Head tracking for the Oculus Rift", 2014 IEEE International Conference on Robotics and Automation (ICRA), 2014.

[2] A. Sabale and Y. Vaidya, "Accuracy measurement of depth using Kinect sensor", 2016 Conference on Advances in Signal Processing (CASP), 2016.

[3] W. Rollmann, "Zwei neue stereoskopische Methoden", Annalen der Physik und Chemie, vol. 166, no. 9, pp. 186-187, 1853.

[4] C. Boletsis, "The New Era of Virtual Reality Locomotion: A Systematic Literature Review of Techniques and a Proposed Typology", Multimodal Technologies and Interaction, vol. 1, no. 4, p. 24, 2017.

[5] Gemshein, H., & Gemshein, A. (1969). The History of Photography from the Camera Obscura to the Beginning of the Modern Era. NY, McGraw-Hill J. Smith, "Sample Conference Paper," in Twenty First Color and Imaging Conference: Color Science and Engineering Systems, Technologies, and Applications, Albuquerque, New Mexico, 2013.

[6] W. Zuiderbaan, B. Harvey and S. Dumoulin, "Image identification from brain activity using the population receptive field model", PLOS ONE, vol. 12, no. 9, p. e0183295, 2017.

[7] S. Izadi, A. Davison, A. Fitzgibbon, D. Kim, O. Hilliges, D. Molyneaux, R. Newcombe, P. Kohli, J. Shotton, S. Hodges and D. Freeman, "KinectFusion", Proceedings of the 24th annual ACM symposium on User interface software and technology - UIST '11, 2011.

[8] Makhzani Niloufar, Kok-Why Ng, and Babaei Mahdi, "DEPTH-BASED 3D ANAGLYPH IMAGE MODELING," International Journal of Scientific Knowledge, vol. 4, Mar. 2014.

[9] J. Ko, M. Kim, and C. Kim, “2D-to-3D stereoscopic conversion: depth-map estimation in a 2D single-view image,” Applications of Digital Image Processing XXX, 2007.

[10] Z. Ganatra and R. Chavda, International Journal of Innovations & Advancement in Computer Science. 2014.

[11] Ke Lu, Xiangyang Wang, Zhi Wang and Lei Wang, "Binocular stereo vision based on OpenCV", IET International Conference on Smart and Sustainable City (ICSSC 2011), 2011.

[12] Arts.rpi.edu,2018.[Online].Available:http://www.arts.rpi.edu /~ruiz/steeo_history/Howtomake3D.htm. [Accessed: 19- Jul- 2018].

[13] Z. Lu, S. Rehman, M. Khan and H. Li, "Anaglyph 3D Stereoscopic Visualization of 2D Video Based on Fundamental Matrix", 2013 International Conference on Virtual Reality and Visualization, 2013.

[14] R. Hartley and A. Zisserman. Multiple View Geometry in ComputerVision. Cambridge University Press, New York, NY, USA, 2003.

[15] M. Brown and D.G. Lowe. Automatic panoramic image stitching using invariant features. Int. J. Computer. Vision, 74(1):59–73, 2007.

[16] "The Teardown: Oculus Rift 3D gaming head-mounted display", Engineering & Technology, vol. 8, no. 5, pp. 88-89, 2013.

[17] A. Ng, L. Chan and H. Lau, "A low-cost lighthouse-based virtual reality head tracking system", 2017 International Conference on 3D Immersion (IC3D), 2017.

[18] P. Wozniak, O. Vauderwange, A. Mandal, N. Javahiraly and D. Curticapean, "Possible applications of the LEAP motion controller for more interactive simulated experiments in augmented or virtual reality", Optics Education and Outreach IV, 2016.

[19] K. Arai, H. Tolle and A. Serita, "Mobile Devices Based 3D Image Display Depending on User’s Actions and Movements", International Journal of Advanced Research in Artificial Intelligence, vol. 2, no. 6, 2013.

[20] K. Fujinami, "On-Body Smartphone Localization with an Accelerometer", Information, vol. 7, no. 2, p. 21, 2016.

[21] "Motion sensors", Android Developers, 2018. [Online]. Available: https://developer.android.com/guide/topics/sensors/sensors_motion. [Accessed: 20- Jul- 2018].

[22] D. Sachs, “Sensor Fusion on Android Devices: A Revolution in Motion Processing”, 2010, Available: http://youtu.be/C7JQ7Rpwn2k . [Accessed: 20- Jul- 2018].

[23] G. Llorach, A. Evans, J. Agenjo and J. Blat, "Position estimation with a low-cost inertial measurement unit", 2014 9th Iberian Conference on Information Systems and Technologies (CISTI), 2014.

[24] "Tips for setting up the base stations", Vive.com, 2018. [Online]. Available: https://www.vive.com/eu/support/vive/category_howto/tips-for-setting-up-the-base-stations.html. [Accessed: 02- Aug- 2018].

[25] Depth map from stereo pair", Forums.ni.com, 2018. [Online]. Available: https://forums.ni.com/t5/Machine-Vision/Depth-map-from-stereo-pair/td-p/1488176. [Accessed: 01- Aug- 2018].

[26] "Semi-Global Block-Matching Algorithm - NI Vision 2012 Concepts Help - National Instruments", Zone.ni.com, 2018. [Online]. Available: http://zone.ni.com/reference/en-XX/help/372916M-01/nivisionconceptsdita/guid-53310181-e4af-4093-bba1-f80b8c5da2f4/. [Accessed: 20- Jul- 2018].T. Jones, "Sample Journal Article," Jour. Imaging Sci. and Technol., vol. 53, no. 1, pp. 1-5, 2009.

[27] A. Pradhan, A. Kr. Singh and S. Singh, "An Approach to Calculate Depth of an Object in a 2-D Image and Map it into 3-D Space", International Journal of Computer Applications, vol. 119, no. 15, pp. 27-32, 2015.

[28] Battiato, S.; Capra, A.; Curti, S.; and La Cascia, M, “3D Stereoscopic Image Pairs by Depth-Map Generation”, in Proc.of 2nd International Symposium on 3D Data Processing Visualization and Transmission, 3DPVT ,2004.

[29] Alhwarin F., Ferrein A., Scholl I. (2014) IR Stereo Kinect: Improving Depth Images by Combining Structured Light with IR Stereo. In: Pham DN., Park SB. (eds) PRICAI 2014: Trends in Artificial Intelligence. PRICAI 2014. Lecture Notes in Computer Science, vol 8862. Springer, Cham.

[30] K. Khoshelham and S. Elberink, "Accuracy and Resolution of Kinect Depth Data for Indoor Mapping Applications", Sensors, vol. 12, no. 2, pp. 1437-1454, 2012.

[31] L. Chin, S. Basah, S. Yaacob, M. Din and Y. Juan, "Accuracy and reliability of optimum distance for high performance Kinect Sensor", 2015 2nd International Conference on Biomedical Engineering (ICoBE), 2015.

[32] T. G. and P. A. M.R. Andersen, T. Jensen, P. Lisouski, A.K. Mortensen, M.K. Hansen, “KINECT DEPTH SENSOR EVALUATION FOR COMPUTER VISION APPLICATIONS,” 2012

[33] "GVRPanoramaView Class", Google Developers, 2018. [Online]. Available:https://developers.google.com/vr/ios/reference/interface_g_v_r_panorama_view. [Accessed: 20- Jul- 2018].

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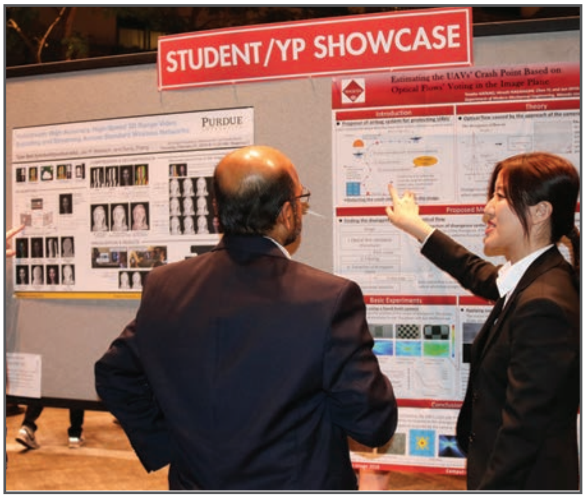
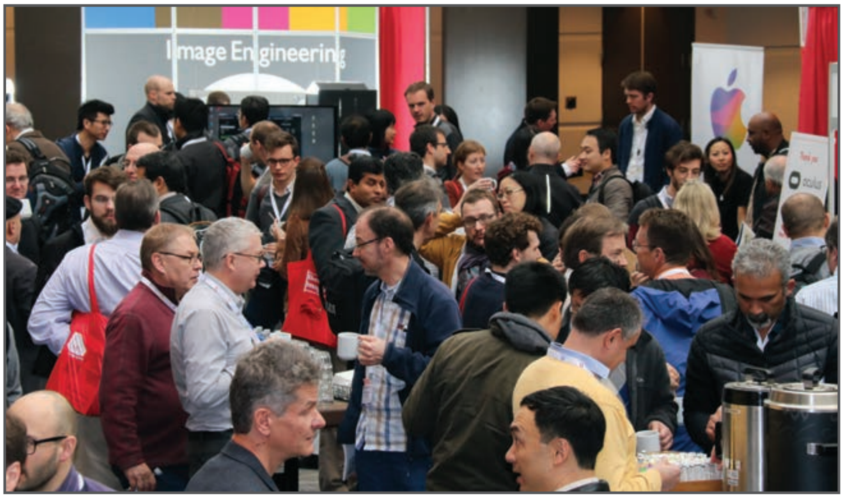
Shitab Mushfiq-ul Islam completed his B.Sc. in Computer Science and Engineering from BRAC University (2018) with a goal to become a game concept developer. Started working with Unity3D, he grew fond of game development and visual content creation. Associated with Computer Vision and Intelligent Systems (CVIS) Research Lab, BRAC University he currently works on Virtual Reality and Augmented Reality applications.





AR is a fundamental and transformative interface and platform.

20+ years from my initial working demo to today's AR displays

Optimistic that it won't take another 20 to reach ubiquitous consumer AR!