A New Depth and Disparity Visualization Algorithm for Stereoscopic Camera Rig

Rohit Ramesh, Heung-Sub Shin, Shin-Il Jeong, Wan-Young Chung, *Member, KIMICS*

Abstract—**In this paper, we present the effect of binocular cues which plays crucial role for the visualization of a stereoscopic or 3D image. This study is useful in extracting depth and disparity information by image processing technique. A linear relation between the object distance and the image distance is presented to discuss the cause of cybersickness. In the experimental results, three dimensional view of the depth map between the 2D images is shown. A median filter is used to reduce the noises available in the disparity map image. After the median filter, two filter algorithms such as 'Gabor' filter and 'Canny' filter are tested for disparity visualization between two images.**

The 'Gabor' filter is to estimate the disparity by texture extraction and discrimination methods of the two images, and the 'Canny' filter is used to visualize the disparity by edge detection of the two color images obtained from stereoscopic cameras. The 'Canny' filter is better choice for estimating the disparity rather than the 'Gabor' filter because the 'Canny' filter is much more efficient than 'Gabor' filter in terms of detecting the edges. 'Canny' filter changes the color images directly into color edges without converting them into the grayscale. As a result, more clear edges of the stereo images as compared to the edge detection by 'Gabor' filter can be obtained. Since the main goal of the research is to estimate the horizontal disparity of all possible regions or edges of the images, thus the 'Canny' filter is proposed for decipherable visualization of the disparity.

Index Terms— **Binocular cues, Stereoscopic or 3D image, Depth, Disparity.**

I. INTRODUCTION

RECENTLY, advancement in the stereo vision technology has given a new pinnacle in the arena of three dimensional imaging systems. In the industrial field of 3D, stereoscopic imaging technology has been extensively used in many applications ranging from Augmented Reality to Virtual Reality [1].

In this paper, we demonstrate two camcorder cameras which are placed on a horizontal platform. This leads to form a "Parallel-axis stereoscopic camera rig" system. These two stereoscopic cameras work in resemblance with the human stereo vision. When we see an object, our visual mechanism, vergence and focus, changes to fix the location of the object [2]. Also, focus of eye lens changes to acquire clear images of the object. In the same fashion, the focus of the camera lenses is adjusted to view the object distinctly.

To obtain a clear stereoscopic image, zero vertical shift between the two cameras is considered. Binocular stereo vision brings the well known correspondence problem. Until now, many researches has been done to undertake the stereo-matching problem (also known as correspondence problem) taking either 'area-based' or 'feature-based' approach. Area based approach mainly includes 'cross-correlation' method while feature based includes 'edge-detection' and 'texture extraction' methods. Even though, viewing from different aspects, feature based algorithm are considered as most pragmatic way to implement stereo vision algorithms [3]. So, in this paper, feature based stereo algorithm is taken up to perform the binocular stereo image visualization.

By edge detection and texture extraction methods, binocular cues of the depth perception and disparity estimation between 2D images of the same scene taken at slightly different positions is presented.

The rest of the paper is organized as follows: In section II, we review the related work. In section III, the geometry of a lens system and also the linear relation between object distance and image distance is described. In section IV, detailed specifications of "parallel-axis stereoscopic camera rig" model is introduced. In section V, binocular cues for depth perception between two images in three-dimensional view is presented. In section VI, the modified approach for estimating the horizontal shift or disparity between stereoscopic images is discussed. In section VII, the experimental results with others found in the literatures are compared. In section VIII, we conclude the binocular cues visualization.

II. RELATED WORKS

In this section, we review the related works for perception of depth and disparity estimation between two images taken from stereoscopic camera rig system.

Clark et al. [4] describes a stereo vision approach to depth perception in which a set of programs was developed. Position and orientation of cameras in 3-space has been considered. Using two pictures, loci of point

Manuscript received October 11, 2010; revised November 8, 2010; accepted November 18, 2010.

Wan-Young Chung is with the Department of Electronics Engineering, Pukyong National University, Busan, 608-737, Korea (Email: wychung @pknu.ac.kr)

pairs are found. Each point pair is computed in 3-space. Resultant depth information is extracted.

Pascal et al. [5] proposed a simple and parallel technique to achieve the dense depth maps. Both feature based and area based approach is considered by correlation followed by interpolation techniques.

Xiaodong et al. [6] presents disparity estimation method combining phase based and energy based algorithm using gabor filter by fourier transform. A set of quadrature-pair gabor filters are used to estimate the disparity from the local phase correlation.

M. Ali et al. [7] propose the feature or texture extraction method by using canny edge detection based on computing the squared gradient magnitude. The main motive of using ‘Canny’ edge detection was to derive an ‘optimal’ operator for detecting the edges and finding their accurate localization. The accuracy of detecting the edges is found to be inversely proportional to their localization. The more accurate the detector is, the less accurate the localization.

S. Yong et al. [8] presented the development of a parallel-axis stereoscopic imaging camera (SIC) for depth measurement. In this, SIC is considered as main device for capturing stereo images for further use in the field of virtual reality. Different mechanism of human visual system like fixation, vergence and focus control are considered for the effective design of SICs.

K. C. Kwon et al. [9] proposed a binocular stereoscopic camera vergence control method for getting horizontal disparity information. The key-object in left and right images are extracted by labeling the centre area of image and then the disparity information is calculated.

III. LINEAR RELATION BETWEEN OBJECT DISTANCE AND IMAGE DISTANCE

Human stereo vision changes focus of the eye lens to fixate the object. As a result, the clear images of the object are obtained. Also, vergence angle between left and right eyes changes in order to fixate different object distances [10]. However, sometimes a troublesome problem occurs with Virtual Reality when users suffer from motion sickness-like symptoms popularly called as cybersickness [11]. This symptom is mainly occurred when there is difference in the virtual distance comprehended by horizontal disparity and focus, causes eyestrain or headache. Another important reason of cybersickness is the object distance. If object distance of a stereoscopic image is very near to the eye lenses then it brings eyestrain to the viewers. Therefore, in the procedure of forming a stereoscopic still or motion image, it becomes requisite to take proper care of the object distance in order to avoid cybersickness to the viewers.

Here, a linear relation between the object distance and the image distance with the help of geometry of a stereoscopic camera lens system is presented. The diagram of the geometry of camera lens system is shown in Fig. 1 [8]. The operation of a stereo camera mainly depends on the vergence and focus of the camera. To reduce the problem of cybersickness, as mentioned before, it is inevitable to know the position of the CCD sensors with respect to the lens because it only determines the distance to an object through the lens equation.

Let us consider an object to be placed at ‘p_d’ distance from the camera lens in the Fig. 1. ‘f’ be the focal length and ‘i_d’ be the image distance of the object. The equation of the camera lens is represented as:

$$\frac{1}{f} = \frac{1}{i_d} + \frac{1}{p_d} \qquad (1)$$

Finally, on manipulating the lens equation, the linear relationship between the object distance and the image distance with respect to focal length of the camera lens is represented as:

$$i_d = \frac{p_d * f}{p_d - f} \qquad (2)$$

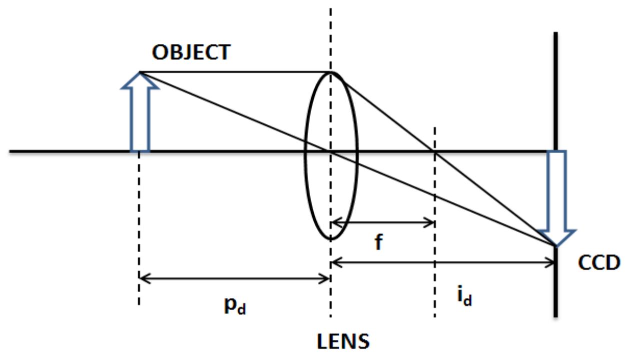


Fig. 1. Geometry of a stereoscopic camera lens system.

Taking f1 = 25 mm, f2 = 35 mm, and f3 = 50 mm respectively, we can obtain the corresponding graph in MATLAB 7.4.0 as shown in fig. 2.

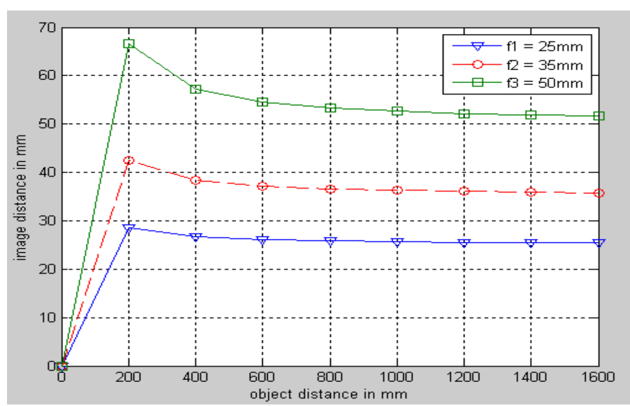


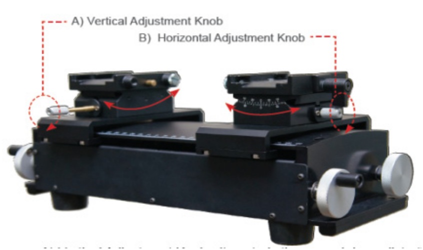
Fig. 2. Graph between object distance and image distance.

IV. 3D CAMERA RIG SPECIFICATIONS

To obtain a stereoscopic 3D image, two digital cameras which can be placed on a horizontal platform called as ‘rig’ are required. The motion of the cameras in horizontal directions controls the vergence and focus of the lens. Moving both cameras in opposite directions increases the disparity and decreases the depth between the two images. On bringing the cameras close to each other decreases the disparity and develop more depth. Higher the depth, more clear the stereoscopic image.

Fig. 3(a) shows the front view of parallel-axis stereoscopic camera rig model developed by “Redrover Ltd. Co.” in Korea. Fig. 3(b) shows the front and back view of the display system where a 3D image can be seen with depth-of-field graphics on the screen. Fig. 3(c) is the base model of the stereoscopic camera rig system on which two digital cameras are placed and depending on their horizontal movement vergence and focus are controlled.

(a) (b)



(c)

Fig. 3. 3D Camera system: (a) two cameras mounted on the 3D camera rig, (b) monitoring viewfinder, and (c) 3D camera rig.

V. DEPTH VISUALIZATION BETWEEN STEREOSCOPIC CAMERA IMAGES

The visual ability to view the distance between two stereoscopic images which is formed by imbricating the left image over the right image is known as depth. In the past few years, various strategy for 3D reconstruction based on the analysis of 2D images was proposed. Nowadays, reconstruction of a detailed depth map between two stereoscopic images which is taken from the cameras has become a wider area of interest due to increasing number of applications, both in 3D stereo vision and 3D graphics. The horizontal movement of two digital cameras on a stereoscopic camera rig platform is majorly responsible for building up clear depth between the 2D images.

The movements are also significant for forming a decent 3D image on the screen in real time virtual reality applications. This technique of producing three dimensional images with depth brings greater flexibility in the field of reconstruction.

In this paper, depth map visualization directing a high quality binocular stereo reconstruction is presented. Here, MATLAB 7.4.0 is used for the image processing of stereoscopic images and also utilized for acquiring the 3D depth map image. A simple parallel-axis technique of camera rig system is employed to achieve the goal of dense depth map estimation in the world of 3D imaging.

TABLE I
SPECIFICATIONS OF DIGITAL CAMERAS

Digital camera properties	Specifications
Model	SONY-PMW EX3
Focal length	½ inch
CMOS Sensor Size	½ inch
Pixel Resolution	1920*1080 (HQ Mode)
Signal to Noise Area	54 dB
Wide angle view	5.8 mm
Shutter Angle	180 degree

VI. OUR APPROACH: HORIZONTAL DISPARITY ESTIMATION USING ‘CANNY’ FILTER

The differences in the position of two images is foremost the canonical step for 3D reconstruction of the images from two-dimensional projections. This horizontal shift between left and right images taken from stereoscopic cameras creates a horizontal disparity. Usually, the disparity estimation is classified into either ‘area-based’ or ‘feature-based’ methods. Considering all the previous disparity estimation techniques, mostly area-based methods are used. By this method, at first a rectangular area of one image is chosen and by correlation method, matching is done between the selected rectangular area and all the corresponding positions of the other image. The best matching correlation found is then used to calculate the disparity [12]. Disparity is computed when the filter is totally inside the image area. For this purpose, ‘Gabor’ filter is regarded as a useful filter for binocular disparity estimation [13]. While considering ‘feature-based’ method also, ‘Gabor’ filter is regarded as most appropriate for texture extraction, representation and finally discrimination between two images [14]. Texture extraction method for disparity estimation involves the following procedure: The left and right color images are converted into grayscale. The ‘Gabor’ filter is applied to both images for texture extraction. The horizontal shift or disparity is estimated between the two images. The drawback of using texture extraction method for visualizing stereo disparity is that it is not useful for estimating disparities for every corresponding point of edges in the respective 2D images.

Therefore, in this paper, an approach to estimate disparity between two stereoscopic images is made to make every corresponding point or the edges apparently visible. For this purpose, ‘Canny’ filter is used for color edge detection of the images through image processing. Canny et al. [15] proposed a computational theory of optimal edge detection algorithm which originally implies good detection, better localization of the edges and also achieved to get minimal response of the edges. On the images obtained from stereoscopic camera rig model, the purpose of using ‘Canny’ filter is to reduce the computation time and increase the effectiveness for estimating the horizontal disparity in comparison to the disparity estimation using ‘Gabor’ filter.

VII. EXPERIMENTAL RESULTS

The two color images obtained from left camera and right camera when imbricate together forms a single synthesized image. The disparities between the two create an illusion of depth between the images. Here, samples of two images are taken of the same scene and depth map between them is computed by image processing in MATLAB 7.4.0. In Fig. 4, the depth map as well as the disparity map is obtained by first converting color images into the grayscale. Fig. 4(c) shows the illusion of depth map of two images Fig. 4(a) and (b). It is observed that the darker shades means object is closer and lighter shades means object is farther away. Hence, a depth is estimated between them. Fig. 4(d) is obtained as distorted disparity map containing noises due to some unavoidable environmental conditions. Therefore, a median filter is used to reduce the noises and the corresponding median filtered disparity map is obtained as shown in Fig. 4(e). In Fig. 4(f), z-axis shows the depth between two images in three-dimensional view.

Let us consider another scene i.e. Fig. 5 to estimate the horizontal disparity between the two images. In Fig. 5, texture extraction method is done by converting color images into grayscale and then ‘Gabor’ filter is applied in both the grayscale images. Fig. 5(c) and (d) are obtained by using ‘Gabor’ filter. In both images, the back portion of the ‘head’ is taken so as to estimate the horizontal disparity between the two images. It can be easily found that in both Fig. 5(c) and (d), it is only possible to choose those regions for estimating the disparity which are visible to us. So, using ‘Gabor’ filter is not the precise way for estimating the horizontal disparity between the stereoscopic images.

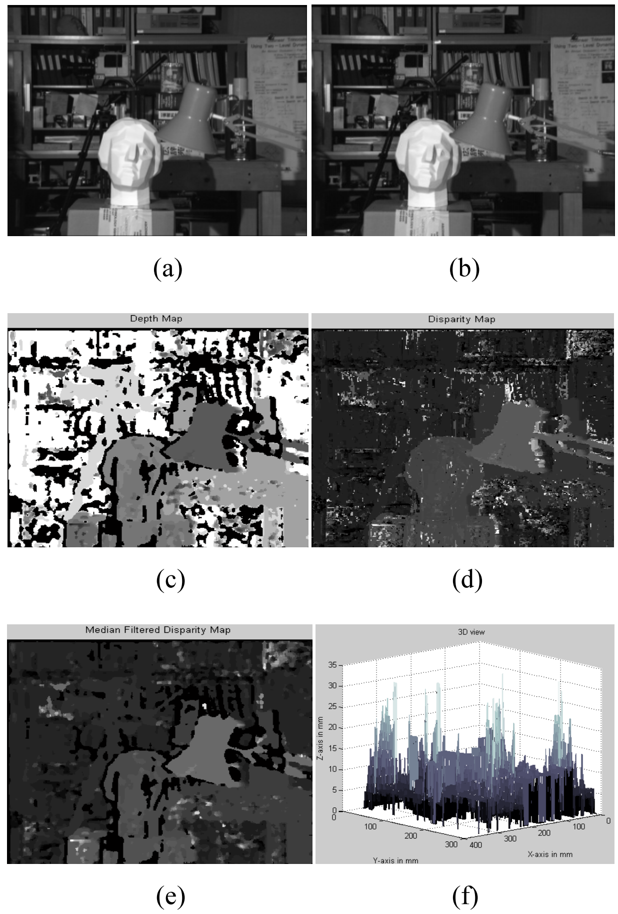


Fig. 4. The grayscale camera images from left camera and right camera respectively: (a) left camera image, (b) right camera image, (c) the depth map of single image obtained by overlying the left and right images, (d) the disparity map, (e) the median filtered disparity map, and (f) the depth map between two images in 3D view.

Therefore, we made an approach to estimate the disparity between the two images in more robust way. For this reason, ‘Canny’ filter is used to detect the edges of both color images obtained from left camera and right camera respectively without any need to convert color images into grayscale. From Fig. 5(e) and (f), it is observed that the resulting edge detection is also obtained in color. To show the disparity, many regions can now be easily selected as most of the corresponding points of edges or areas are visible to us. In Fig. 5(e) and (f), the ‘handle’ of the vessel in both images is taken to show the horizontal disparity.

One major advantage of using ‘Canny’ filter for estimating the disparity is that it greatly reduces the computation time. The reason is that the conversion of the color images which is being obtained by stereoscopic cameras into grayscale images is not required. Another advantage is that efficiency as well as clarity for recognizing the edges by ‘Canny’ filter is increased as compared to detecting edges through ‘Gabor’ filter.

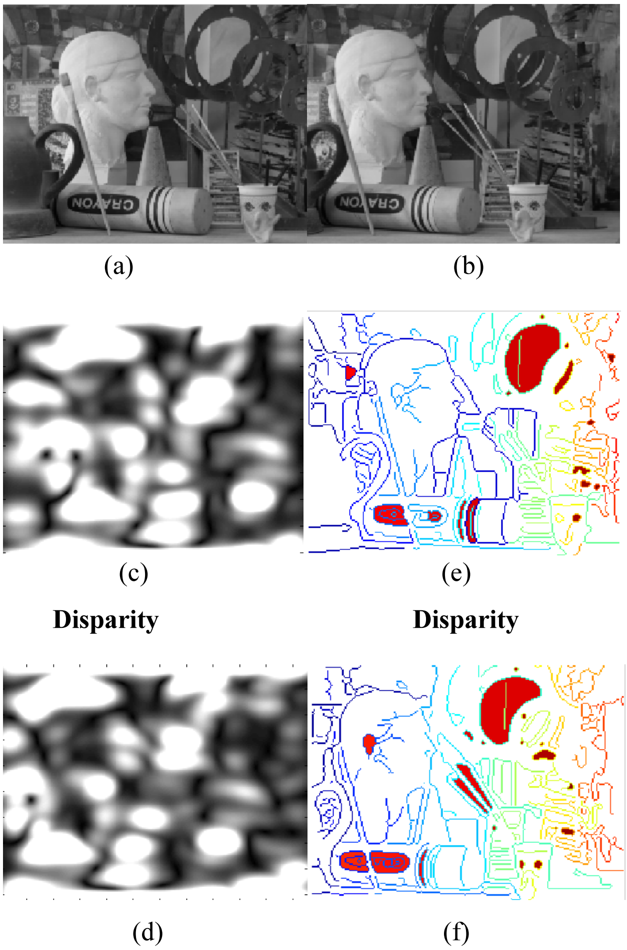


Fig. 5. The grayscale camera images by left and right cameras: (a) left camera image, (b) right camera image, (c) and (d) the edge detections of (a) and (b) respectively obtained by using ‘Gabor’ filter. (e) and (f) the edge detections of (a) and (b) respectively obtained by using ‘Canny’ filter.

VIII. CONCLUSIONS

In most of the 3D imaging applications, edge detection method act as a preprocessing stage for feature extraction. The extraction of features such as edges and curves from an image is useful for many purposes like texture analysis, 3D reconstruction of surfaces, image segmentation and stereo-matching of the images.

In this paper, depth and horizontal disparity estimation between the two images is presented with the help of stereoscopic camera rig model. Disparity estimation is being performed by using ‘Gabor’ filter through texture extraction method. The disparity visualization technique by using ‘Gabor’ filter brings few drawbacks like for each corresponding edges or regions we cannot able to estimate the disparity between the images effectively. This problem is being sorted out by using ‘Canny’ edge detection method. Finally, our attempt of using ‘Canny’ filter is to estimate the horizontal disparity between two images with more clarity, higher effectiveness and less computation time.

ACKNOWLEDGEMENT

This work was supported by the Culture Technology Joint Research Center Project of the Korea Creative Content Agency.

REFERENCES

[1] N. Lee, J. Moon and S. Y. Park, “Microscopic Stereo Camera with Simultaneous Vergence and Focus Control,” *The 23rd International Technical Conference on Circuits/Systems, Computers and Communications* (ITC-CSCC), 2008, pp.1637-1640.

[2] G. Lee, N. Hur and C. Ahn, “Parallel-Axis Stereoscopic Camera with Vergence Control and Multiplexing Functions,” *Stereoscopic Displays and Virtual Reality Systems*, X, 5006, 2003.

[3] R. A. Lane and N. A. Thacker, “Tutorial: Overview of Stereo Matching Research,” [online] Available: www.tina-vision.net. Tina Memo No. 1994-001.

[4] C. Thomson, “Depth Perception in Stereo Computer Vision,” A report submitted to Computer Science Department, Stanford University. Research Report Number STAN-CS-75-521, 1975.

[5] P. Fua, “A Parallel Stereo Algorithm that produces Dense Depth Maps and Preserves Image Features,” Inria Research Labs. France. Research Report Number 1369, 1991.

[6] X. Huang and E. Dubois, “Disparity Estimation for the Intermediate View Interpolation of Stereoscopic Images,” *IEEE International Conference on Acoustics, Speech, and Signal Processing*, vol. 2, 2005, pp. 881-884.

[7] M. Ali and D. Clausi, “Using the Canny Edge Detector for Feature Extraction and Enhancement of Remote Sensing Images,” *IEEE International Geoscience and Remote Sensing Symposium* (IGARSS), 2001, pp. 2298-2300.

[8] S. Y. Park and N. Lee, “Stereoscopic Imaging Camera with Simultaneous Vergence and Focus Control,” *Society of Photo-Optical Instrumentation Engineers*, 43(12), 2004, pp. 3130- 3137.

[9] K. C. Kwon, Y. T. Lim and N. Kim, “Vergence Control of Binocular Stereoscopic Camera Using Disparity Information,” *Journel of the Optical Society of Korea*, vol.13, no. 3, September 2009, pp. 379-385.

[10] D. Coombs and C. Brown, “Cooperative Gaze Holding in Binocular Vision,” *IEEE Control System*, 1991, pp. 24-33.

[11] J. J. L. JR., “A Discussion Cybersickness in Virtual Environments,” *SIGCHI Bulletin*, vol. 32, no.1, Jan.2000, pp. 47-56.

[12] D. Bakin, “Stereoscopy on Complex Scenes and Edge Detection,” [online] Available: http://www.okob.net/texts/mydocuments/stereoscopy.

[13] M. H. Ouali, D. Ziou and C. Laurgeau, "Dense Disparity Estimation Using Gabor Filters and Image Derivatives," *2nd International Conference on 3D Digital Imaging and Modeling*, 1999, pp. 483-489.
[14] V. S. N. Prasad and J. Domke, "Gabor Filter Visualization," [online] Available: http://www.cs.umd.edu/class/spring2005/cmsc 838S/assignment- projects / gabor-filter-visualization / report.pdf.
[15] J. Canny, "A Computational Approach to Edge Detection," *IEEE Transactions on Pattern Analysis and machine Intelligence* vol. PAMI-8, no. 6, Nov. 1986.

Rohit Ramesh is a Master degree student at department of Telecommunication Engineering in Pukyong National University, Busan, South Korea. He received his B.E. degree in Electronics and Instrumentation Engineering from Sathyabama University, Chennai, India, in 2009. His current research interest is in Stereoscopic Camera's Image Processing.

Heung-Sub Shin is a Master degree student at department of Electronic Engineering in Pukyong National University, Busan, Korea. He received his B.S. degree in Electronic Engineering from Dongseo University, Busan, Korea, in 2009. His areas of interest are Ubiquitous Healthcare, Wireless Sensor Networks, Analog Circuit, and Automobile Application.

Shin Il Jeong is a full Professor of Department of Information and Communication Engineering at Pukyong National University, Korea from March, 1981. He received Ph.D. degree in Electronic Engineering from Kyungpook National University, Daegu, Korea in 1988. Before he joined Pukyong National University he worked for ETRI and KIST as a research engineer on fiber optics from 1977. His current areas of interest include Fiber Optics and Ubiquitous Sensor Networks.

Wan-Young Chung is a full Professor of Department of Electronic Engineering at Pukyong National University, Korea from September, 2008. He earned B.S. and M.S. degrees in Electronic Engineering from Kyungpook National University, Daegu, Korea in 1987 and 1989, respectively and a Ph.D. degree in Sensor Engineering from Kyushu University, Fukuoka, Japan in 1998. From 1999 to 2008 he was an associate professor at Dongseo University. His areas of interest include Ubiquitous Healthcare, Wireless Sensor Networks and Embedded Systems.