ON INTELLIGENT IMAGE PROCESSING METHODOLOGIES APPLIED TO NAVIGATION ASSISTANCE FOR VISUALLY IMPAIRED

G.SAINARAYANAN
(PS 2000-008- 157(A))

THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (ELECTRICAL & ELECTRONICS ENGINEERING)

**SCHOOL OF ENGINEERING AND INFORMATION TECHNOLOGY
UNIVERSITI MALAYSIA SABAH
KOTA KINABALU**

2002

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS@

JUDUL : ON INTELLIGENT IMAGE PROCESSING METHODOLOGIES APPLIED TO NAVIGATION ASSISTANCE FOR VISUALLY IMPAIRED

IJAZAH : Doktor Falsafah (Kejuruteraan Elektrik dan Elektronik)

SESI PENGAJIAN : 2000 – 2002

Saya, G.SAINARAYANAN mengaku membenarkan tesis Doktor Falsafah ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Malaysia Sabah
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi
4. TIDAK TERHAD

G.L.T

Disahkan oleh

(Penulis: G.SAINARAYANAN)

(TANDATANGAN PUSTAKAWAN)

Alamat Tetap:
56, North Street, Thiruvidaimarudur
Tanjore Dist. Tamil Nadu.
India 612104

(Penyelia: Prof. Dr. R.NAGARAJAN)

Tarikh : 26 December 2002

Tarikh : 15. 01. 2003

CATATAN: @ Tesis dimaksudkan sebagai tesis ijazah Doktor Falsafah dan Sarjana secara penyelidikan atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (LPSM)

DECLARATION

I hereby declare that the research work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

26 December 2002

G.SAINARAYANAN
(PS 2000-008- 157(A))

CERTIFIED BY

Prof. Dr. R. NAGARAJAN
Universiti Malaysia Sabah
SUPERVISOR

Assoc. Prof. Dr. SAZALI YAACOB
Universiti Malaysia Sabah
CO -SUPERVISOR

Prof. Dr. R.K.SUBRAMANIAN
Universiti Sains Malaysia
EXTERNAL EXAMINER

Assoc. ~~Prof. DR~~. ALI CHEKIMA
Universiti Malaysia Sabah
INTERNAL EXAMINER

Prof. Dr. MOHD ZAHEDI DAUD
Chairman, Examining Committee

Assoc. Prof. Dr. SAZALI YAACOB
Dean, School of Engineering and
Information Technology, UMS

ACKNOWLEDGEMENT

The author is highly grateful and indebted to his supervisor Prof. Dr. R.Nagarajan, Professor of Electrical and Electronics Engineering, School of Engineering and Information Technology, Universiti Malaysia Sabah (UMS) for his inspirational guidance, valuable advice and continuous encouragement through out all stages of the author's research and thesis work. His timely suggestions and fruitful discussion with the author helped in improvising the quality of thesis.

The author expresses his sincere gratitude to his Co-supervisor Assoc. Prof. Dr. Sazali Yaacob, Dean, School of Engineering and Information Technology, UMS for his unremitting support and wise counsel for the completion of this work. The author also thanks him for facilities provided in the school. Author has immense contentment in placing on record, his gratitude and thanks to both his supervisor and co supervisor for the completion of this research.

For the facilities and undying support, the author expresses his humble gratitude and deep sense of reverence to Tan Sri Professor Datuk Seri Panglima Dr. Abu Hassan Othman, Vice Chancellor, UMS.

The author wishes to thank Ministry of Science, Technology and Environment for funding the research through Universiti Malaysia Sabah: IRPA code: 03-02-10-0004. The author conveys his sincere appreciation to the blind volunteers, Mr. Marapan (Chairman of Sabah Blind Association) and Mr. Peter Gumba for their patience and Co-operation in every stage of the research.

The author thanks Dr. Peter Meijer, Philips research laboratories, Netherlands and Prof. R.M. Rangayan, University of Calgray, Canada for their constant discussions and comments and for providing the requested materials for literature survey. The author also expresses his heartfelt gratitude to Datuk. Dr. P.Muthusamy, Ophthalmologist for his encouragement and productive thoughts. The author shows his appreciation and express thanks to his Co research students Miss. Farrah Wong, Mr. Kenneth Teo, Mr. Muralidaran and Mr. Pandian for their time and support and to members of Artificial Intelligent Research Group of the school for timely suggestions and comments.

Author thanks The Almighty and his parents for everything provided in his career.

ABSTRACT

The main objective of this thesis is to develop a computer based Navigation Assistance for Visually Impaired (NAVI) as a vision substitutive system. The hardware of the system includes a Vision sensor mounted on a headgear, a set of Stereo earphones and a Single Board Processing System (SBPS) with batteries, duly placed in a vest. The Vision sensor is a digital video camera. The video camera captures the image of the environment. The captured image is processed, mapped on to specially structured stereo sound patterns and sent to the earphones. A set of image processing requirements for vision substitution is identified and incorporated in the NAVI system. The image processing, developed in this thesis, is designed to work as a model of the human vision system. To model the human vision system in image processing, two properties of human eye, namely lateral inhibition and domination of the object properties rather than background are incorporated. The image processing methodologies applied in NAVI are developed using artificial intelligent techniques. The property of lateral inhibition is incorporated using neural network based Canny edge filter. In vision substitutive system, definition of objects and background is not easy as compared to industrial object recognition system. Therefore, three methods for object enhancement and background suppression are proposed in NAVI using fuzzy logic and neural network. The edge image and the object enhanced image with background suppressed are integrated to produce a resultant image. The resultant image is sonified to produce stereo acoustic patterns. Blind volunteers were trained with the developed NAVI system and they were tested to identify the environment. They were able to understand the logic behind the sound in discriminating the object from background. It was also verified that the discrimination of objects by the blind through the proposed image processing methodologies is effective and easier than that of earlier efforts in this direction.

ABSTRAK

Objektif utama tesis ini adalah untuk merekacipta alat bantuan navigasi berasakan komputer bagi mereka yang cacat penglihatan atau NAVI 'Navigation Assistance for Visually Impaired' sebagai satu sistem pengganti pengalihatan. Sistem perkakasan yang telah dihasilkan merangkumi penderia penglihatan yang dipasang pada 'headgear', fontelinga stereo dan sistem pemprosesan papan tunggal ('single board processing system'). Bateri disimpan dalam baju yang direka khas. Penderia penglihatan adalah sebuah kamera video digital yang digunakan untuk merakam imej persekitaran. Imej yang dirakam akan diproses dan ditukarkan kepada isyarat bunyi stereo berstruktur khas dan dihantar kepada fontelinga. Satu set keperluan pemprosesan imej telah dikenal pasti dan digunakan dalam system NAVI ini. Pemprosesan imej yang dibangunkan dalam tesis ini berfungsi sebagai satu model sistem penglihatan manusia. Untuk memodelkan sistem penglihatan manusia dari segi pemprosesan imej, dua ciri mata manusia iaitu penekanan untuk mengenalpasti bahagian hujung dan dominasi sifat-sifat objek berbanding dengan latarbelakang telah digunakan. Dalam tesis ini, kaedah pemprosesan imej adalah berasaskan teknik-teknik kecerdikan buatan. 'Canny Edge Filter' berasaskan rangkaian neural digunakan untuk mengenalpasti bahagian hujung dan sifat objek. Di dalam sistem pengganti penglihatan, definisi sistem pengesan objek dan latar belakang adalah tidak semudah untuk dilakukan berbanding dengan industri. Jadi, tiga kaedah untuk menguatkan paparan objek and mengurangkan latarbelakang dengan menggunakan kaedah fuzzy logik and rangkaian neural buatan telah dicadangkan. Gabungan bahagian tepi imej ("edge image") dengan kesan objek yang dikuatkan dan latarbelakang yang telah dikurangkan membentuk imej yang lebih menonjol. Imej yang dihasilkan ini ditukar kepada bentuk isyarat bunyi stereo. Sukarelawan-sukarelawan yang cacat penglihatan telah dilatih dan diuji untuk mengenalpasti persekitaran dengan menggunakan NAVI. Mereka berupaya memahami logik di sebalik bunyi yang dihasilkan untuk membezakan objek daripada latarbelakang. Di samping itu, diskriminasi objek menggunakan kaedah pemprosesan imej yang dicadangkan ini adalah lebih berkesan dan mudah berbanding dengan kaedah-kaedah sebelum ini.

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

NOMENCLATURE

(The main nomenclature are listed below, however, they are also explained in the text)

A_i : Hard c-partition:

B : Band width frequency of sound (F_H - F_L)

BL, DG, LG,WH : Gray Levels in the Preprocessed image

B_o : Gray value of background

B_l : Gray level of background

C_j : Class represented by the j^{th} output unit

c : Number of clusters

d_{ik} : Euclidean distance measure

E_t : Termination measure

FFNN : Feed Forward Neural Network

F_L : Lowest frequency of the sound produced

F_H : Highest frequency of the sound produced

F_D : Frequency difference between adjacent pixels in vertical direction

F_{image} : Input to FFNN

F_j : j^{th} element of F_{image}

$F_{A_i}(x_k)$: Characteristic function

f_i : Frequency of sine wave for pixels in row 'i'

G : Number of gray level in the image I

G(x) : Gaussian function

G'(x) : First derivative of Gaussian function

G_{obj} : Gray level of object in FLIPS

G_o : Gray level of object in pattern clustering

G_b : Gray level of background in pattern clustering

G_x : First derivative of Gaussian function in x direction

G_y : First derivative of Gaussian function in y direction

H_i : Monochrome of 4 levels

H_{in} : Input to FLIPS; this is the normalized histogram of preprocessed image.

h_1 : Monochrome value of BL

h_2 : Monochrome value of DG

h_3 : Monochrome value of LG

h_4 : Monochrome value of WH

I : Preprocessed image

I_1 : Edge Image

I_2 : Object enhanced and background suppressed image

I_3 . Image with edge and object enhanced with background suppressed.

I_{BS} : Background suppressed image matrix

I_x : x component of image

I_y : y component of image

I_L : Left half of image I

I_R : Right half of image I

J : Objective function in clustering

K_1, K_2 : Chosen scalar constants

K_G : Constant gain.

k : Updation parameter

LVQ : Learning Vector Quantization

M(x,y) : Magnitude of pixel value in edge detection

M_c: Hard partition space of X

M_{fc} : Fuzzy partition matrix

M : Number of rows in the image I

N : Number of columns in the image I

n_1 and n_2 : image dependent constants

n : Number of data

q : Slope parameter

R_T : Ratio of the lower to higher thresholds

S(j) : Sound pattern for column j of the image

S_L : Sound pattern to the left earphone.

S_R : Sound pattern to the right earphone

s : Standard deviation of image.

T : Class of the training vector

T_h : High threshold

T_l : Low threshold

t : iteration count

U* : Optimum partition

v^* : Final cluster center

v_i : Cluster center

w_j : Weight vector for j^{th} output unit

X_1, X_2, X_3 : Object enhancement gains

$X_{BL}, X_{DG}, X_{LG}, X_{WH}$: Feature vector from BL, DG, LG and WH gray levels

X : Training vector

$[x_1, x_2, x_3, x_4]$: Feature vector.

z : weighting parameter

z_0 : Initial z

z_f : Final z

α : initial learning rate in LVQ

α_t : Learning rate, where t is iteration number in LVQ.

β : A chosen parameter to distinguish background as light or dark color

δ : Object occurrence factor

ε : Termination criterion

μ : Mean of image

μ_{ik} : Membership of k^{th} data point in the i^{th} cluster

μ_r : Mean of iris area

θ_1, θ_2 and θ_3 : Enhancement decision factors

σ : Gaussian spread parameter

τ : Threshold of image

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Orientation, Navigation and Mobility are perhaps three of the most important aspects of human life. Most aspects of the dissemination of information to aid navigation and cues for active mobility are passed to human through the most complex sensory system, the vision system. This visual information forms the basis for most navigational tasks and so with impaired vision an individual is at a disadvantage because appropriate information about the environment is not available. The loss of eyesight is one of the most serious misfortunes that can befall a person. The term blindness refers to people who have no sight at all as well as to those whose sight is so seriously impaired that their vision cannot be corrected to what is generally considered normal. Approximately three-quarters of those considered as blind have limited vision, which cannot be corrected to normal vision with standard eyeglasses or contact lenses. These people are said to be severely visually impaired, (WHO, 1998). The major causes of blindness are age-related macular degeneration, cataracts, glaucoma, diabetic retinopathy, trachoma, onchocerciasis, by birth, lack of eye care and accident (Times of India, 2000).

Mobility is an ability of movement within the local environment. It is also the ability to move with the knowledge of objects and obstacles in front. Blind individuals find their mobility difficult and hazardous, because they cannot easily identify the obstacle for a comfortable navigation. The autonomous navigation without collision and with discrimination of objects becomes the major task for them to face their daily life requirement.

1.2 BLIND POPULATION - AN OVERVIEW

Visual impairment is one of the most common disabilities worldwide. WHO reported that due to the lack of epidemiological data, especially from the developing and under developed countries, the exact number of blind persons in the world is not known. In 1994, WHO estimated that it was around 38 million with a further 110 million cases of low vision, that are at risk of becoming blind. In 1998, the total population of visual impairment was more than 150 million people (WHO, 1998). Currently, there is a total of about 45 million blind people in the world and a further 135 million have low vision and this number is expected to double by 2020 (Times of India, 2000). The number of people who become blind each year is estimated to be 7 million. Over 70% of the people with vision problem receive treatment and their vision is restored. Thus, the number of blind persons worldwide is estimated to increase by up to 2 million per year (WHO, 1997). Eighty percent of these cases are ageing-related. In most countries of Asia and Africa, it accounts for over 40% of all blindness. It is also estimated that, currently, there are approximately 15 million blind people in South East Asia Region or one-third of the blind population of the world. China accounts for about 18% of the world's blind and is estimated to have the largest number of blind people in the world. There are a quarter of a million people in the UK who are registered as visually impaired. However, the UK actually has nearly one million people entitled to register as a visually impaired person, and 1.7 million with the vision difficulty. This represents over three percent of the UK population (NFB, 2002). In Britain, more than twenty thousand children grow up with visual impairment, and there are two hundred vision-related accidents per day in the UK alone (Leonard and Gordon, 1999; Viisola, 1995). There are approximately 10 million visually impaired people in the United States (AFB, 2001). In addition, statistics state that for every seven minutes, someone in America is becoming visually impaired (Blasch, 1999). In Malaysia, alarming increment in blind population is noted with about 46.9 % from 1990 to 1999. By September 2000, there were about 13,835 registered in Blind associations and it is predicted that, it might be less than 50 % of the total blind population in the country (JKM, 2000; ERM, 2001).

The largest number of visually impaired people falls into the senior citizen category; in fact sixty-six percent of people with impaired vision are over seventy-five year old (Papenmeier, 1997; Lacey and Dawson-Howe, 1998; WHO, 1997a).

1.3 ELECTRONIC TRAVEL AIDS

Orientation and mobility are two of the main confront that visually impaired individuals face every day. Basic independent mobility is vital throughout all sections of society. Mobility, the ability to navigate in a complex environment, enables human to accomplish many different physical goals. Electronic Travel Aids (ETA) are the electronic equipment that help to present visual information to visually impaired people, so that they can have interaction with the environment. Many devices exist to assist visually impaired people in navigation (Duen, 1998). A number of research institutes and software companies are working on solutions to the problems of navigational information for visually impaired people.

REFERENCES

Advantech, 2001, Embedded PCs: Manual, Drivers and Utilities, Manual of Advantech Version 1.2.

AFB : American Foundation for Blind. 2001. http://www.afb.org/info_documents.asp?collectionid=15

Altman, J. A. 1984. Role of the higher par ts of the auditory system in the location of a moving sound source. *Journal of Neuroscience and Behavioral Psychology*, 14(3), 200-205.

Andrews and Mark. 1996. Migrating to Windows 95: Programmer's Guide to What's new. Boston: AP Professionals.

Arkenstone. 2000. Atlas Speaks. Arkenstone, USA, http://www.arkenstone.org/atlas.htm.

Baldwin. 1998. Research: Who's Doing What and Where, http://isd.saginaw.k12.mi.us/~mobility/reshhome.htm and The Future Of Blind Navigation, http://isd.saginaw.k12.mi.us/~mobility/navigation.htm

Ballard, D. H. and Brown, C. M. 1982. Computer vision, New Jersery, Prentice Hall.

Bantz, E.J. 2000. Getting started with Video for Windows and Visual basic http:/www.videosforwindows.com

Baraldi A. and Blonda P. 1998. A survey of fuzzy clustering algorithms for pattern recognition- Parts I and II. *IEEE Trans. on Systems, Man and Cybernetics*, Vol 29, no. 6, pp 778-785, 786-801.

Baraldi, A., Blonda, P., Parmiggiani, F., Satalino, G. 1998. Image segementation through contextual clustering. International Computer Science Institute, Berkeley, CA, *Technical report-98-009*.

Baraldi, A. and Parmiggiani, F. 1998. SAR image segmentation exploiting no background knowledge on speckled radiance: A feasibility study. International Computer Science Institute, Berkeley, CA, *Technical report - 98-018*.

Bell, D., Borenstein, J., Levine, S., Koren, Y. and Jaros, A. 1994. The NavChair: An assistive navigation system for wheelchairs, based on mobile robot obstacle avoidance. *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*, San Diego, CA, pp. 2012-2017.

Benjamin, J. M., 1973. The new C-5 laser cane for the blind. *Proceedings of Carnahan Conference on Electronic Prosthetics*, Univ. Kentucky Eng. Experiment Station, pp. 104-106.

Bentzen, B.L. and Mitchell, P. A. 1995. Audible signage as a wayfinding aid: comparison of "Verbal Landmark®" with "Talking Signs®". The Smith-Kettlewell Eye Research Institute, California, USA, http://www.ski.org/rerc/WCrandall/ACBPAPER.HTM

Bergholm. 1987. Edge focusing. *IEEE Trans. Pattern Anal. and Machine. Intel.*, Vol. 9, pp 726-741

Besag, J. 1986. On the statistical analysis of dirty pictures. *J. R. Statistic Society*. Vol. 48. pp 259-302

Bezdek, J.C., Keller, J., Raghu, K. and Pal, N.R. 1999. Fuzzy models and algorithms for pattern recognition and image processing. Boston: Kluwer Academic Publishers

Bezdek, J.C. and Pal, N.R. 1995. Two soft relative of learning vector quantization, *Neural Networks*, Vol. 8(5), pp 729-743.

Biggs, L.J. 1996. Headphone-delivered three dimensional sound in NPSNET. Mater Degree Thesis, Naval Postgraduate School, USA

Blasch, B. 1999. An overview of wayfinding issues and technology. *Proceedings of Wayfinding Technology Workshop*. Virginia: Preface.

Borenstein, J. 1990. The NavBelt - a computerized multi-sensor travel aid for active guidance of the blind. *Proceedings of the CSUN's Fifth Annual Conference on Technology and Persons with Disabilities*, Los Angeles, California, pp. 107-116.

Borenstein, J. and Ulrich, I. 1997. The GuideCane – A computerized travel aid for the active guidance of blind pedestrians. *Proceedings of IEEE International Conference on Robotics and Automation*, Albuquerque, NM, pp. 1283-1288.

Boring, E. G. 1986. Auditory theory with special reference to intensity, volume, and localization. *American Journal of Psychology*, 37(2), 157-188

Boudaoud, N. and Masson, M.H. 1997. On line adaptive fuzzy diagnosis system: a fuzzy pattern recognition approach. *Proceedings of IFAC SAFEPROCESS'97*, Hull.

Bouman, C. and Liu, B. 1991. Multiple resolution segmentation of texture images. IEEE Trans. Pattern Anal. Machine Intelligence. Vol. 13 (2), pp -99-113.

Brabyn, L. and Brabyn, J. 1982. Speech intelligibility of the talking signs. *Journal of Visual Impairment and Blindness*, Vol. 76, pp. 77-78.

Brabyn, I. and Brabyn, J. 1983. An evaluation of talking signs for the blind. *Human Factor*, Vol. 25, No. 1, pp. 49-53.

Bush, S. 1998. Talk-to-walk guide for the blind. Electronics Weekly, Reed Business Information,UK.http://www.electronicsweekly.co.uk/issue/articleview.asp?vpath=/articles/1998/06/17/story24.htm&mode=archive

CALL Centre. 2000. CALL Smart Wheelchair. CALL Centre, University of Edinburgh, Scotland,UK.,http://callcentre.education.ed.ac.uk/Smart_WheelCh/smart_wheelch.html

Cannon, R.L., Dave, J. and Bezdek, J. 1986. Efficient implementation of the fuzzy c-means clustering algorithm. *IEEE Trans on PAMI*, Vol.16, pp 855 -861.

Canny,J. 1986. A Computaional approach to edge detection. *IEEE Trans. Pattern Anal. and Machine. Intel.*, Vol 6, pp 679-698.

Capelle, C. and Trullemans, C. 1998. A real-time experimental prototype for enhancement of vision rehabilitation using auditory substitution. *IEEE Trans. on Biomedical Engineering*, Vol 45, No. 10, pp 1279-1293.

Carvalho, B.M., Gau, C. J., Herman, G.T. and Kong, T. Y. 1999. Algorithm for fuzzy segmentation. International Conference on Advances in Pattern Recognition: *Proceedings of ICAPR 98,* London: Springer: pp 154 – 163.

Carterette, E. 1978. Historical notes on research in hearing. E. Carterette, & M. Friedman (Editors), Handbook of Perception Vol. IV, (pp. 187- 242). New York, NY: Academic Press, Inc

Chen, C.W., Luo, J and Parker, K.J. 1998. Image segmentation via adaptive K-mean clustering and knowledge based morphological operation with biomedical application. *IEEE Trans. on Image Processing*, Vol. 7. pp 1673 -1683.

Churchland, P.S. and Sejnowski, T.J. 1998. Perspective on cognitive neuroscience. *Science*, Vol. 242, pp 741-745.

Clark, F.O. 2000. Adaptive-scale filtering and feature detection using range data. *IEEE Transactions on PAMI*, 22(9): pp 983-991.

Cosic, D. and Loncaric, S. 1996. New methods for cluster selection in unsupervised fuzzy clustering. *Automatika*, vol. 37, pp. 133-137.

Cracraft, D. 2000. Seeing sound. *Soundworks*. Vol. 7 Issue 4:10-13

Dallas, Jr. S., Portland, E. and Aubrey, J. 1983. Sound pattern generator. US Patent No. 4378569.

Dana, P. H. 1999. Global positioning system overview. The Geographer's Craft Project, Department of Geography, The University of Texas, http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html

Dewhurst, D. 1999. The Vuphonics home page. http://ourworld.compuserve.com/homepages/DavidDewhurst/Vuphonics.htmi

Dobelle Ins. 2000. Artificial vision system for the blind announced by The Dobelle Institute. Dobelle Ins News, New York, pp. 1-2.

Dobelle, W. H. 2000. Artificial vision for the blind by connecting a television camera to the visual cortex. *ASAIO Jounal,* 2000, Vol. 46, No. 1, pp. 1-7.

Doulamis, A.D., Doulamis, and Kollias, D. 2000. On-Line retainable neural network: Improving the performance of neural network in image analysis problems. *IEEE Trans. on Neural Networks*, Vol. 11. pp 137-155.

Duen, H. Y. 1998. Electronic travel aids for the blind, http://www.noogenesis.com/eta/current.html and Currently available Electronic Travel Aids for the Blind, http://www.noogenesis.com/eta/current.html

Duen H. Y. 1998a. Some electronic travel aid patents. http://www.ibm.com/link/www.patents.ibm.com/

Eastman Kodak Company. 1999. KODAK DVC325 Digital Camera User Guide.

ERM : Ethnologue Report for Malaysia. 2001. http://www.ethnologue.com/show_country.asp?name=Malaysia+%28Peninsular%29

Faussent, L. 1994. Fundamentals of neural networks. New Jersecy: Prentice Hall

Fish, R. M. 1974. Auditory display for the blind. US Patent No. 3800082.

Francioni, J. M., Albright, L. and Jackson, J. A. 1991. The sounds of parallel programs. *Proceedings of the Sixth Distributed Memory Computing Conference*, IEEE Computer Society Press.

Frysinger, S. P. 1990. Applied research in auditory data representation. *Proceedings of the SPIE, Conference* 1259, Extracting Meaning from Complex Data: Processing, Display, Interaction, pp. 130 - 139.

Fu, L.M. 1984. Neural network for computer intelligence. New York: McGraw Hill,.

Gaver, W. W. 1989. The Sonicfinder: An interface that uses auditory icons. *Human Computer Interaction* (4), 67 - 94.

Geman, S. and Geman. D. 1984. Stochastic relaxation distributions, and the Bayesian restoration of images. *IEEE Trans. PAMI*, Vol.6 pp 721-741.

Gourgey, K. 1999. Audio/Tactile Kiosks for Transportation Terminals. Presentation summary from the Wayfinding Technology Workshop, Interagency Committee on Disability Research, Arlington, Virginia, USA, http://www.ncddr.org/icdr/icdr_wayfind.html

Granrath, D.J. 1981. The role of human visual model in image processing. *Proc. IEEE*, Vol. 69, No. 5, pp 552-561.

Grantham, D. W. 1986. Detection and discrimination of simulated motion of auditory targets in the horizontal plane. *Journal of the Acoustical Society of America*, 79(2), 1939-1949.

Gupta, Madan M. and Knopf, George K. 1993. Neuro-vision systems principles and applications. New York: IEEE Press.

Hall, C.F. and Hall, E.L. 1977. A non linear model for the spatial characteristics of the human visual system. *IEEE Trans. Syst., Man, Cybern.,* Vol. SMC-7, pp 161-170.

Hanselman, D. 1997. MATLAB: The language of technical computing, computation, visualization, programming. New Jersey: Prentice-Hall.

Hanselman, D. and Field, B.L. 1997. Mastering MATLAB 5. Prentice-Hall.

Haralick R. M., 1993. Computer and robot vision. Massachusetts: Addison Wesley.

Haralick, R.M., Shanmugam, K. and Dinstein, I. 1973. Texture features for image classification. *IEEE Trans. on System, Man and Cybernetics*, pp 610-617.

Heyes, T. 1984. Sonic pathfinder. *Wireless World*: 26 – 29

Heyes, T. 1999. The Sonic pathfinder, Perceptual alternatives. Melbourne, Australia, http://ariel.ucs.unimelb.edu.au/~heyes/pf_blerb.html

Hojjatolesalami, S.A. and Kitter, J. 1998. Region growing: A new approach. *IEEE Trans. on Image Processing*, Vol. 7. pp 1079-1084.

Huntsberger, T and Ajimarangee, P. 1990. Parallel seft-organizing feature maps for unsupervised pattern recognition. *International Journal of Gen. System*, Vol. 16, pp 357-372.

ICAD (International Community for Auditory Display). 1997. Sonification report: status of the field and research agenda prepared for the National Science Foundation. http://www.santafe.edu/~icad/

Jain, R., Kasturi, R. and Schunck, B.G. 1995 , Machine Vision, New York: McGraw Hill.

Jawahar, C.V., Biswas, P.K. and A.K. Ray. 2000. Analysis of fuzzy thresholding schemes. *Pattern Recognition* , 33: 1339-1349.

JKM : Jabatan Kebajikan Masyarakat. 2000. Buletin Perangkaan Kebajikan 1999. Kuala Lumpur: Percetakan Nasional Malaysia Berhad.

Johnson, C R. 2000. Sound plays first note in visual recognition. *EE Times*.

Johnson, V. 1998. The MoBIC Project, Sensory Disabilities Research Unit, Psychology Department, University of Hertfordshire, http://phoenix.herts.ac.uk/SDRU/MOBIC/mobic.html

Kaczmarek, Webster, Bach-y-Rita and Willis J.T. 1991. Electrotactile and vibrotactile displays for sensory substitution system. *IEEE Trans. on Biomedical Engineering*, Vol 38, No. 1, pp 1-16

Karayiannis, N.B. and Pai, P. 1999. Segmentation of magnetic resonance image using fuzzy algorithm for learning vector quantization. *IEEE Trans. on Medical Imaging*, Vol. 18, pp 172-180

Katevas, N. 1998. The PAM-AID project. Sensory Disabilities Research Unit, Department of Psychology, University of Hertfordshire, UK, http://phoenix.herts.ac.uk/SDRU/PAM-AID.htm

Klette, R. and Zamperoni, P. 1996. Handbook of image processing operators. England: John Wiley & Sons.

Kohonen, T. 1990. The self organizing map. *Proceeding of IEEE*, Vol. 78(9), pp 1464-1480.

Krishnan, S., Rangayyan, R.M., Bell, G.D. and Franl, C.B. 2001. Auditory display for knee-joint vibration signal. *The Journal of Acoustical Society of America.*

Lacey, G. and Dawson-Howe, K. M. 1998. Evaluation of robot mobility aid for the elderly blind. *Robotics and Autonomous Systems*, Elsevier, 23, pp 245-252.

Lacey, G. 1997. Personal adaptive mobility AID for the frail visually impaired. http://www.cs.tcd.ie/PAMAID/

Leonard, R. and Gordon, Arlene R. 1999. Statistics on vision impairment: A resource manual. New York: Lighthouse Int.

Livingstone, M. and Hubel, D.1988. Segregation of form, color, movement and depth: anatomy, physiology and perception. *Science*, Vol. 240, pp 740-749.

Löfving, S. 1998. Extending the cane range using laser technique. Proceedings of 9th International Orientation and Mobility Conference, Atlanta, http://www.reab.se/lofving/lhfs/index.html

Loughborough, W. 1979. Talking lights. *Journal of Visual Impairment and Blindness*, Vol. 73, pp. 243.

Lunney, D., and Morrison, R. C. 1990. Auditory presentation of experimental data. *Proceedings of the SPIE*, Conference 1259, Extracting Meaning from Complex Data: Processing, Display, Interaction, pp. 140 - 146.

May, M. 1998. A Case Study of Strider~ A talking portable satellite navigation system. *Presented at The Wearable Computer Conference*, Fairfax Virginia, USA, http://www.arkenstone.org/strider.htm.

Martins, A.C.G., Rangayyan, R.M. and Ruschioni, R.A. 2001. Audification and sonification of texture in image. *Journal of Electronic Imaging*.

Meijer, P.B.L. 1992a. An experimental system for auditory image representations. *IEEE Transactions on Biomedical Engineering*, Vol. 39, No. 2, pp. 112-121.

Meijer, P.B.L. 1992b. Image-audio transformation system. US Patent No. 5097326.

Meijer, P.B.L. 2000. Sensory Substitution. http://ourworld.compuserve.com/homepages/Peter_Meijer/sensub.htm

Merusi and Donald. 1995. Software implementation Techniques: Writing Software in Open VMS,OS/2, Unix and Windows NT. 2nd Edition, Boston: Digital.

Mestel, R. 1994. Hearing pictures, seeing sounds. *New Scientist*, pp. 20-23.

Mingquan, B. 1999. Classification of multi-temporal SAR images and INSARcoherence images using adaptive neighborhood model and simulated annealing approach. *Proceedings of Asian Conference on Remote Sensing* 1999,

Molton, N. S. S., Brady, Lee, D. and Probert, P. 1998. A stereo vision-based aid for the visually impaired. *Journal of Image and Vision Computing*, Elsevier, Vol.16, pp 251–263.

Murthy, C.A. and Pal, S.K. 1990. Fuzzy thresholding: mathematical framework, bound functions and weighted moving average technique. *Pattern Recognition Letters,* vol. 11, no. 3: 197- 206.

National Federation of the Blind (NFB). 2002. http://www.nfb.org/default.htm

Nevin, A. M., Mohamed N.A., Aly A. F. 1999. Modified Fuzzy c mean in medical image segmentation. *Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing 99,* vol. 6, pp. 3429-3432

Odor, P. 1995. The CALL centre smart wheelchair. CALL Centre, University of Edinburgh, UK, pp. 1-30.

O'Hea, A. R. 1994. Optophone design: optical-to-auditory vision substitution for the blind. PhD Thesis, The Open University, United Kingdom.

Oldfield, S. and Parker, S. 1984. Acuity of sound localisation: A topography of auditory space. I: Normal listening conditions. *Perception*, 13, 581-600.

Pal, N.R. and Pal, S.K. 1993. A review on image segmentation techniques. *Pattern recognition*, Vol. 26, pp 1277-1293.

Pal, S.K. and Majumder, D. D. 1986. Fuzzy mathematical approach to pattern recognition. New Delhi: Wiley Eastern Ltd.: 137-141.

Pal, S.K., King, R.A. and Hashim, A.A. 1983. Automatic gray level thresholding through index of fuzziness and entropy. *Pattern Recognition Letters,* vol. 1: 141-146.

Pan, J., Pack, D.J., Kosaka, A. and Kak, A.C. 1995. FUZZY-NAV: A vision -based robot navigation architecture using fuzzy inference for uncertainty -reasoning. *Processing of the World Congress on Neural Networks,* Washington D.C, Vol. 2. pp 602-607.

Papenmeier. 1997. Mobility of the blind and elderly people interacting with computers. Papenmeier Reha Technology, Germany, http://www.papenmeier.de/reha/research/mobice.htm

Pappas, T.N. 1992. An adaptive clustering algorithm for image segmentation. *IEEE on Signal Processing*, Vol. 40. pp 901-914.

Park, W.E., Hoffman, E.A., and Sonka, M. 1998. Segmentation of intrathoracic airways trees: a fuzzy logic approach. *IEEE Trans. on Medical imaging*. Vol. 17. pp 489-497

Parker, J.R. 1997. Algorithms for image processing and computer vision. USA: Wiley Computer Publishing.

Perrott, D. 1984. Discrimination of the spatial distribution of concurrently active sound sources: Some experiments with stereophonic arrays. *Journal of the Acoustic Society of America*, 76(6), 1704-1712.

Picton, P. and Capp, M. 2000. The Optophone: Some question and answer, School of Technology and Design. Nene – University College Northampton, http://194.81.105.205/~demos/Public/optophone.html

Pulsedata, 1999, Mowat Sensors: Orientation aid. Pulse Data Co., http://www.pulsedata.com.au/mobi.html

Quick thinking. 2000. *New Scientist Magazine*.

Ramar, K. 2000. A fuzzy neuro approach: some studies and its applications in computer vision system. Ph.D. Thesis. Manonmaniam Sundaranar University, India.

Regan, D. 1977. Auditory-visual interactions and the correspondence between perceived auditory space and perceived visual space. *Perception* (6), 133-138.

Reid, H. 1998. Sonic Eye. USA, http://www.chaospark.com/inventions/sonic.htm

Rigby and William, H. 1995. Computer interfacing: A practical approach to data acquisition and control. New Jersey: Prentice-Hall.

Ritter, G. X and Wilson, J.N. 1996. Handbook of computer vision algorithms in image algebra. New York: CRC Press.

Robotron. 2000. Columbus Talking Compass. http://www.robotron.net.au/columbus.htm

Rose, T. J. 1995. Fuzzy logic with engineering application. New York: McGraw-Hill

Rosenfeld, A. 1989. Computer Vision: A source of models for biological visual process. *IEEE Trans. Biomedical Engg.*, Vol. 36, No:1, pp 93-96.

Rybak, I.A.S., Natalia, A.P. and Golovan,A. 1991. Visual cortex domain model and its use for visual information processing neural networks. Vol. 4, England: Pergamon Press Ltd.

Sainarayanan, G., Nagarajan,R. and Yaacob, S. 2001. Interfacing vision sensor for real time application in MATLAB", *Proceedings of Scored 2001* , Malaysia, Paper Number 156.

Sejnowski, T.J., Koch, C. and Churchland, P.S. 1998. Computational neuro science. *Science*, Vol. 241, pp 1299-1306.

Setnes, M. 2000. Supervised fuzzy clustering for rule extraction. *IEEE Trans. On Fuzzy Systems*, Vol. 8. No. 4: 416 – 424.

Shammas and Clement, N. 1994. Visual C++ generic programming. New York: McGraw Hill

Shammas and Clement, N. 1996. Mathematical algorithm in visual basic for scientists and engineers. New York: McGraw Hill.

Shoval, S., Borenstein, J. and Koren, Y. 1998. The NavBelt - A computerized travel aid for the blind based on mobile robotics technology. *IEEE Trans. Biomedical Engineering*, Vol. BME-45, pp. 1376-1386.

Simpson, R. C., Levine, S. P., Bell, D. A., Jaros, L. A., Koren, Y. and Borenstein, J. 1998. NavChair: An assistive wheelchair navigation system with automatic adaptation. V. O. Mittal et. al. (Eds.): Assistive Technology and AI, LNAI 1458. Berlin: Springer: 235 – 255.

Smith-Kettlewell Ins. 1999. Source material on remote infrared signage. The Smith-Kettlewell Eye Research Institute, California, USA, http://www.ski.org/rerc/WCrandall/intro.htm

Snaith, M., Lee, D. and Probert, P. 1998. A low- cost system using sparse vision for navigation in the urban environment. *Journal of Image and Vision Computing*, Elsevier, Vol. 16, pp 225–233.

Sonic Vision. 1999. History. http://www.sonicvision.co.nz/history.html

Squire, D. M. and Pun, T. 1998. Assessing agreement between human and machine clusterings of image databases. *Pattern Recognition*, 31(12).

Sum, J. and Chan, L.W. 1994. Alternative membership function for sequential fuzzy clustering. *Proceedings of FUZZ-IEEE'94*, Florida, Vol.III, 1846-1851.

Stcokham, T.G.Jr. 1972. Image processing in the context of a visual model. *Proc. IEEE*, Vol. 60, pp 828-842.

Stonick and Virginia, L. 1996. Labs for signal and systems using MATLAB. Boston : PWS,

Talbot-Smith, M. 1994. Audio recoding and reproduction- practical measures for audio enthusiasts. England: Clays Ltd.

Tal-Mec Ltd. 1999. Sonar vision, TAL-MEC Ltd. Hungary, http://www.elender.hu/~tal-mec

Tan, H. Z. and Pentland, A. 1997. Tactual displays for wearable computing, Technical Report No. 431. Massachusetts Institute of Technology, pp. 1- 5.

The MathWorks Inc. 1997. Image processing toolbox user's guide.

The Math Works, Inc., 1999a. MATLAB C Math Library, User's Guide for Version5.3.

The MathWorks Inc. 1999b. Using MATLAB Version 5.

Times of India. 2000. Blind population to touch 90 m by 2020.

Trahanias, P.E., Lourakis, M.I.A., Argyros, A.A. and Orphanoudakis, S.C.1996. Vision-based assistive navigation for robotic wheelchair platforms. *Technical Report FORTH-ICS/Tr-178*, pp. 1.

Tizhoosh, H. R. 1997. Fuzzy image processing: introduction in theory and practice. Springer-Verlag.

Tizhoosh, H. R. 2000. Fuzzy image segmentation. http://ipe.et.uni-magdeburg.de/~hamid/FuzzyImageProcessing.htm

Umbaugh, S, E. 1998. Computer vision and image processing. New Jersery, Prentice Hall.

Viisola, M. 1995. Statistics on children and visual impairments. Lighthouse Int., New York: 4.

Wallach, H., Newman, B., and Rosenzweig, M. 1949. The precedence effect in sound localization. *American Journal of Psychology*, 62, 315-336

Watkinson, J. 1998. The art of sound reproduction. MA, Butterworth - Heinemann Ltd.

Wasserman, P.D. 1990. Neural computing theory and practice. Van Nostra and Reinhold, New York.

Wenzel, E. M., Wightman, F. L., and Foster, S. H. 1988. A virtual display system for conveying three-dimensional acoustic information. *Proceedings of the Human Factors Society*, pp. 86 - 90.

WHO : World Health Organization. 1998. *World Health Report 1998*.

WHO : World Health Organization. 1997. Blindness and visual disability, part i of vii: general information. *Fact Sheet 142*.

WHO : World Health Organization. 1997a. Population ageing-a public health challenge, part i of vii: general information. *Fact Sheet 135*

Wong, F., Nagarajan, R., Yaacob, S., Chekima, A. and Belkhamza N-E. 2000. Electronic travel aids for visually impaired – A guided tour. *Proceedings of Conference in Engineering in Sarawak*, Malaysia, pp 377-382.

Wong. F. Nagarajan, R. Yaacob, S., Chekima, A. and Belkhamza N-E. 2001. An image segmentation method using fuzzy-based threshold. *Proceedings of*

Sixth International Symposium on Signal Processing and its Applications (IEEE ISSPA), Kuala Lumpur.

Yager, R. R. 2000. On the entropy of fuzzy measures. *IEEE Transactions on Fuzzy Sets and Systems*, 8: 453 – 461.

Zimmermann, H.J. 1996. Fuzzy set theory and its application. 2nd Ed. New Delhi: Allied Publishers Ltd and Kluwer Academic Publishers.

Zingaretti, P. and Carbonaro, A. 1999. On increasing the objectiveness of segmentation results. International Conference on Advances in Pattern Recognition: *Proceedings of ICAPR 98*, London: Springer pp 103-112.

Zurada, J.M. 1992. Introduction to artificial neural system. Bombay: Jaico Publishing House.