DEFENCE R&D ORGANISATION
MINISTRY OF DEFENCE

AN INTRODUCTION TO NIGHT VISION TECHNOLOGY

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NEW DELHI – 110 011
2002

DRDO Monographs/Special Publications Series

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ISBN: 81–86514–10–4

Printed and published by Director, DESIDOC, Metcalfe House, Delhi-110 054.

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PREFACE

Vision during the night has been one of the interesting ambitions of the humankind and for quite sometime it was considered to be within the realm of unattainability. Yet in the early twentieth century the scientific community did think of its possibilities. The importance of light-gathering by a relatively aberration-free optical system was well realized. In fact a 7×50 binocular with an aperture of 50 mm and an exit pupil of 7 mm to match the human scotopic eye-pupil size was referred to as a night-vision binocular in earlier literature. These did perform well at dusk and dawn though not during the night and helped in early morning assaults by an infantry column. Modern interest in the field arose with an explanation of the photoelectric effect by Einstein in 1905, discovered earlier by Hertz in 1887. Though attempts to develop suitable photocathodes based on photoelectric effect for image intensification began in early 1930s, yet the first success with an instrument system fabricated around near-infrared sensitive *Ag-O-Cs* photocathode, came in 1950s only. This resulted in 'O' Generation night vision instrumentation wherein the night scene had to be irradiated with near infrared radiation cutting out the visible and the reflections thereof made visible on the phosphor screen of an image converter tube. The tube itself was the result of a composite effort which brought together the photocathode technology, electron-optics for the amplification of weak electrons through an electro-optical system and phosphor screen development, all in a vacuum envelope besides suitable entrance and exit surfaces. It was by now clear that what is required is the development of better and better photocathodes corresponding to the natural illumination in the night-sky, better methods of amplification of energy and number of weak electrons and more suitable phosphors for ultimate viewing besides suitable input and output windows for the vacuum tube that may ultimately be designed. This development was further accelerated as by then the upcoming television industry was also looking for suitable phosphors and photocathodes to suit their requirements. It was hence logical that the next generation of instruments developed for night vision were passive in nature, i.e., where imaging was based on the night sky illumination itself thus dispensing with any artificial irradiation.

Generation I image intensifier tubes were the first to appear which involved a major contribution in terms of its fibre optics input and output windows and a photocathode much more sensitive to the overall spectral distribution of the night sky. The earlier photocathodes had a lower quantum efficiency and hence three such tubes had to be coupled to give an adequate light amplification for vision without losing on the resolution. It was only a matter of time before Generation II image intensifier tubes appeared with photocathodes on the *military scene* by introducing electron energy amplification and electron multiplication through microchannel plates (hollow-fibre matrix) to enable adequate light amplification to be achieved with only one tube. Developments have since continued both in evolving more and more sensitive photocathodes and better and better designs for the microchannel plates. Understanding of the functioning of a photocathode resulted in the evolution of modern day *negative electron affinity* photocathodes. Nevertheless it can be stated that scope still exists in *engineering* newer and newer photocathodes with still higher quantum detection efficiencies with matching electron-optics and microchannel plates with better and better signal-to-noise ratio.

This monograph has been organised in nine chapters. The first chapter on *Vision and the Human Eye* discusses the background against which all vision including night-vision instrumentation has to be ultimately assessed. The next chapter *Search and Acquisition* relates to the parameters that contribute towards establishing a visual line to an object of interest. The criteria for detection, orientation, recognition and identification are examined as also the relationship of contrast to help search and acquisition. Chapter III discusses the environment that is mainly the atmosphere (intervening medium), its attenuation of the optical signal and thereby the effect on contrast and visibility. The next chapter examines night-illumination in detail as also reflectance from surfaces of interest and from the background.

After familiarizing with all the factors that affect instrument design for night vision applications, it is but natural to consider various design aspects such as those related to optical parameters, the evolution of photocathodes and the development of phosphors before one goes into the details of the image intensifier tubes which form the mainstay of night vision systems based on image intensification. Chapters V, VI, VII are therefore devoted to each of the factors, i.e., Optics, Photocathodes and Phosphors. Chapter VIII on *Image Intensifier Tubes* includes discussion on electron-optics and fibre optics that is relevant to the making of intensifier tubes. Chapter IX then concludes by drawing attention to overall considerations for instrument design for night vision systems. Photographs and illustrations of some interesting systems designed and developed by Defence R&D Organisation also find a place in this final chapter.

This monograph is limited to night vision based on image intensification. Though references in the text to 'thermal imaging' do find a place here and there, this text does not include the contemporary development in night vision based on *thermal imaging*. Obviously that should form the subject matter of an independent volume.

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ACKNOWLEDGEMENTS

The author's thanks are primarily due to Dr APJ Abdul Kalam who initiated this idea of a monograph on night vision technology. Many thanks are certainly due to Dr SS Murthy, former Director, DESIDOC, and the present Director Dr Mohinder Singh for their persistence and patience and to the group of scientists who helped me in literature search and in consolidating the contents of this volume. Thanks are also due to a few scientists at IRDE, Dehradun, who helped me in obtaining some specific literature and by way of discussions. Particularly, my thanks are due to Shri E David who helped me with various figures and photographs that have been included herein. I am also indebted to Shri M Srinivasan of BeDelft, Pune, for the photographs referred to in Chapter VIII, and to the Director, IRDE, for all the other photographs.

Finally, I like to record my sincere thanks to Shri KK Vohra who provided me with working space and to Shri Swaroop Chand an Ex-Soldier working with Shri Vohra, for his diligent day-to-day assistance.

R Hradaynath

CHAPTER 1

VISION & HUMAN EYE

1.1 INTRODUCTION

Vision entails perception—by the eye-brain system, of the environment based on reflectance of the static or changing *observable scene* illuminated by a light source or a number of sources, and that of the sources themselves. In most cases, the illumination is natural and due to sun, moon and stars along with possible reflectance of these sources by clouds, sky, or any land or water mass. These days artificial illumination is also of significance. The ability of a *living species* to recognize and represent sources, objects, their location, shape, size, colour, shading, movement and other characteristics relevant to its planning of action or interaction defines its *observable scene*. The *observable scene* would thus be limited by the capability of a *species* and the information sought by it. Sustained vision would further require large steady-state sensitivity to properly react to amplitude and wavelength changes in the illuminating sources. Thus perception of a given scene should not get distorted by observation from sunlight at noontime to starlight at night, or under a wide range of coloured or white artificial sources or by facing away or towards the sun.

Vision as perceived above would therefore call for processing of the input visual signal to attain what has been stated. For instance location of objects in space or their movement may be helped by

(a) Stereopsis, i.e., using cues provided by the visual input in two spatially separated eyes.

(b) Optic flow, i.e., by using information provided to the eye from moment to moment (i.e., separated in time)

(c) Accommodation, i.e., by determining the focal length which will best bring an object into focus, and

(d) Segmentation, i.e., the process of extracting information about areas of the image (called regions or segments) that are visually distinct from one another and are continuous in some feature, such as colour, depth or motion.

As these are processes that can take place all over the image, parallel processing by the visual system would be quite in order. Likewise, the variable reflected optical signal received by the eye is processed by the visual system over a wide range for constancy of luminance, colour and contrast by appropriate networking of the individual signals from each photoreceptor. However, recognition of a source either by direct viewing or by specular reflection would need a different type of processing for its brightness.

1.2 OPTICAL PARAMETERS OF HUMAN EYE

This monograph is restricted to the optical and processing aspects of the human eye and retina, though in actual practice the entire biological processes of the eye-retina-brain combination needs to be discussed and understood as far as presently known.

It was Helmholtz[1] who suggested a *schematic eye* which is a close representation of the living eye with fairly accurate characteristics as defined by the first-order theory of geometric optics.

Figure 1.1 shows a cross-section through such an eye

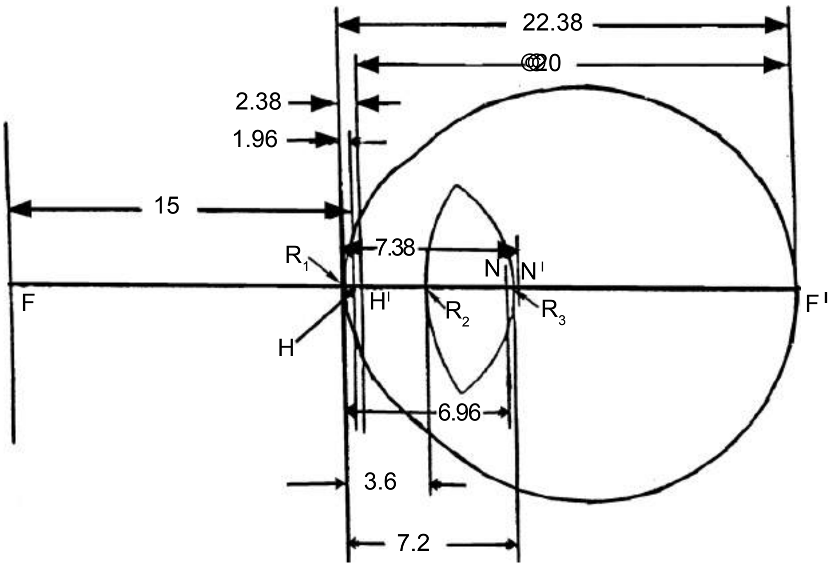

Figure 1.1. Optical constants of Helmholtz's schematic eye (all dimensions are in mm).

About the Author

The author who rose to the level of a Distinguished Scientist in the Defence R&D Organisation and superannuated as Director, IRDE, Dehradun continued later for quite a few years as Scientist Emeritus both with his parent Department and with the Council of Scientific & Industrial Research besides being responsible for the creation of a Photonics Laboratory at one of the Research Centres of the Department of Electronics.

During his tenure as Director and even earlier, he involved himself and his colleagues in research, development and successful transfer of technology to various new and established production agencies. Thus for the first time in India, it was possible to produce a series of night vision and laser devices in significant numbers, competitive to the best in the world.

The author has extensively lectured at various centres of learning and has over seventy publications in scientific journals both in India and abroad apart from quite a significant contribution to classified documents for the Defence R&D in the field of optics, optronics and electro-optics. He has also authored a text on 'Optical Workshop Technology' and edited a milestone volume for the SPIE (USA) pertaining to 'Mirrors and Prisms'.

About the Book

This monograph is intended to familiarize a reader with the relevant factors and technologies that lead to the development of a night vision system based on image intensification in the visible and the near infrared regions of the electro-magnetic spectrum. The first four chapters discuss the human and external limitation due to restrictions of human observation by the environment and night illumination conditions, besides its ability for search and acquisition. The next set of chapters is devoted to optical, material and electro-optical technologies that resulted in the image intensifier tubes for their use in the night vision systems. Finally, the monograph concludes with a chapter bringing out the range and performance limitations and requirements with illustrations of some of the state-of-the-art instrument systems.

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ISBN: 81-86514-10-4

Price : Rs. 270, US $18, UK £13