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Night vision monocular - basic elements and development trends

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Abstract. **This article examines the fundamental elements and evolving trends in night vision monocular devices. The topicality of this topic lies in the ongoing advancements in sensor technologies, optics, and digital processing, which continually enhance the performance and accessibility of night vision devices.**

The purpose of this study is to provide a comprehensive overview of the basic components and recent developments in night vision monoculars. The study adopts a comparative analysis approach, examining the key features and functionalities of different generations of night vision technology and investigates emerging trends such as miniaturization, improved image resolution, and integration with digital interfaces.

The methodology involves a thorough review of literature encompassing scientific articles, patents, and technical reports related to night vision technologies. Key aspects studied include image intensifier tubes, infrared sensors, objective lenses, and display systems. Additionally, recent research articles, technical reports, and product specifications are analyzed to identify emerging trends in monocular design and performance, in digital image processing algorithms and the integration of augmented reality functionalities.

The findings underscore the importance of ongoing research and development in improving the performance and accessibility of night vision monoculars. Key conclusions include the growing role of digital imaging in night vision devices, the potential for further miniaturization of components, and the importance of optimizing cost-efficiency without compromising performance.

In summary, this article provides insights into the foundational components and evolving trends of night vision monoculars, emphasizing the technological advancements driving the development of next-generation night vision devices. The findings contribute to a deeper understanding of the current state and future prospects of night vision technology.

Keywords: image intensifier, infrared, monocular, night vision.

I. INTRODUCTION

Night vision technology has significantly advanced over the decades, revolutionizing surveillance, security, and military operations. Among the pivotal devices in this field is the night vision monocular, a compact optical instrument that enables individuals to observe low-light environments with enhanced clarity and detail. This paper delves into the fundamental components and evolving trends of night vision monoculars, exploring their historical progression, underlying principles, and future prospects.

The genesis of night vision technology traces back to the early 20th century, spurred by the imperative for nocturnal visibility during warfare and surveillance. Initial iterations relied on cumbersome infrared light sources and photocathode tubes, gradually evolving into the sophisticated electro-optical systems prevalent today. Central to this evolution is the night vision monocular—a single-eyed viewer compact enough for handheld use, embodying core technologies like image intensification and thermal imaging.

Fundamentally, night vision monoculars function by collecting ambient light or thermal radiation, amplifying the signal through electron multiplication, and presenting a visible image to the observer. This process, facilitated by advanced photonics and semiconductor technologies, has seen exponential refinement, resulting in enhanced image quality, extended detection ranges, and reduced form factors.

The contemporary landscape of night vision monoculars is characterized by a convergence of technological advancements. Miniaturization and integration with digital imaging sensors have facilitated portability and versatility, broadening the applications beyond traditional defense uses to include law enforcement, outdoor recreation, and wildlife observation.

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In this study, we aim to delineate the key components that constitute a night vision monocular, elucidate the underlying physical principles governing their operation, and scrutinize recent trends driving innovation in this domain. By synthesizing historical insights with contemporary developments, we endeavor to furnish a comprehensive understanding of night vision monoculars, illuminating their pivotal role in augmenting human vision under low-light conditions and outlining future trajectories for this transformative technology.

II. MATERIALS AND METHODS

A systematic review of existing literature was conducted to gather foundational knowledge on night vision technology. Various academic databases including PubMed, IEEE Xplore, and Google Scholar were searched using keywords such as "night vision", "night vision monocular"," "infrared imaging" and related terms. Articles, research papers, books, and technical reports published from 1990 to 2024 were analyzed to understand the historical development, fundamental principles, and current trends in night vision monocular technology.

Detailed technical specifications of night vision monoculars from leading manufacturers were collected. Specifications such as sensor types (e.g., image intensifiers, thermal sensors), resolution, magnification, field of view, spectral range, signal-to-noise ration and weight were examined. This data was essential for comparing different generations of night vision devices and identifying trends in performance improvements over time.

Recent advancements in night vision monoculars reported in scientific journals and industry publications were reviewed. This involved studying peer-reviewed papers, conference proceedings, and technical articles focusing on innovations such as digital image enhancement algorithms, miniaturization of components, incorporation of augmented reality features, and advancements in sensor technologies (e.g., quantum dot sensors, multispectral imaging).

Quantitative and qualitative analysis techniques were employed to synthesize findings from the literature review, technical specifications, and recent advancements study. Comparative analysis was used to identify key areas of improvement in night vision monocular design and functionality.

Consultations with experts in the field of night vision technology were conducted to validate findings and gain insights into emerging trends. Discussions with engineers, researchers, and industry professionals provided valuable perspectives on challenges and opportunities in night vision monocular development.

The methodology for synthesizing and integrating diverse sources of information involved a structured approach to data collection, analysis, and interpretation. This rigorous framework ensured the reliability and validity of the study's findings.

This comprehensive approach to reviewing literature, analyzing technical specifications, studying recent advancements, conducting data analysis, and engaging with subject matter experts formed the foundation of this study on night vision monoculars and their development trends. The insights derived from these methods contribute to a deeper understanding of the evolution and future directions of night vision technology.

III. RESULTS AND DISCUSSION

A. Overview of Night Vision Technologies

The primary categories of night vision technologies include light intensification (such as image intensifiers), thermal imaging, and near-infrared illumination. Image intensifiers function by collecting ambient light through an objective lens, converting it into electrons, amplifying these electrons, and then converting them back into visible light to produce a brightened image. In contrast, thermal imaging relies on detecting the heat emitted by objects, transforming thermal radiation into a visible image irrespective of available light.

Night vision devices (NVDs) are divided into two main types depending on the technology used [1]:

- NVDs operating on the principle of ambient light amplification from the visible and near-infrared (NIR) range of the spectrum and using Image Intensifier Tubes (IITs);

- Devices using the thermal radiation of the observed objects (thermal imaging technology) that operate in the IR spectrum range (3-30 μm). These devices detect the temperature difference between the background and the objects in foreground so they are entirely independent of ambient light-level conditions. They also are able to penetrate obscurants such as smoke, fog and haze.

There is no internationally accepted NVDs classification. For this reason, the same types of NVDs may have different names in different literary sources. Over 99% of NVDs available on the world market can be considered as models of the following species [2]:

- Night vision goggles (NVGs);

- Night vision monoculars;

- Night vision sights;

- Night vision binoculars.

The first two groups NVDs have wide Field Of View (FOV) similar to human vision (about and above 40°) and 1x magnification. Two-channel NVGs allow observation with both eyes, which ensures the achievement of stereoscopic (3D) vision.

Night vision monoculars can be treated as a cheaper version of dual-channel NVGs because instead of two observation channels, there is one. Additional advantage is their small size and mass. They are designed primarily for use with one eye, resulting in reduced spatial perception. By offering portability and versatility they play a crucial role in providing enhanced situational awareness and are valued for their effectiveness.

Depending on the configuration (design) NVDs can be classified differently. The differences between the NVGs and binoculars and between monoculars and sights are small. The reason for the difference between them is one module – the optical objective. NVGs can be easily converted into binoculars by adding afocal magnifiers or by changing objectives. Monoculars can be transformed into sights by changing the objective and adding mechanical elements allowing them to be attached to weapons.

From this point of view, NVDs can be classified as follows: bino-channel (binocular); mixed-channel (bi-ocular) and mono-channel (monocular). (Fig. 1)

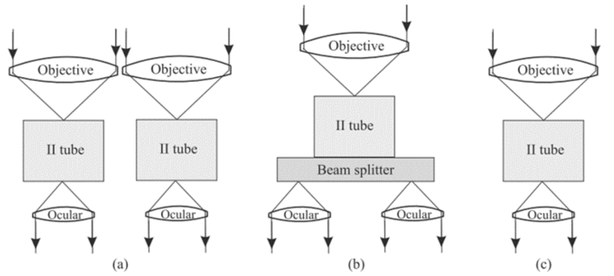


Fig. 1. Block diagrams of three types of NVDs: (a) bino-channel, (b) mixed-channel and (c) mono-channel NVDs [2].

The technical differences between them are significant and it is not possible to easily convert one type of NVDs into another.

The subject of this publication will be mainly the NV monoculars based on image intensifying technology. In fact, image-enhancement systems are normally called night-vision devices (NVDs) [3].

They are widely used in the military field to perform various tasks from nighttime field observation to tracking and surveillance. Due to its compact size and shape, this highly popular type of NVD is ideal for on-the-move target acquisition and covert operations.

B. NV monocular basic elements

The main structural elements of night vision monoculars well as of the other NVDs are objective lens for gathering ambient light, a photocathode tube which converts light into electrons, a microchannel plate to amplify these electrons, a phosphor screen to convert the electrons back into visible light, and an eyepiece lens for magnification and viewing. The housing of the monocular contains these components, often incorporating features like a power supply, controls, and sometimes additional optics for improved performance. These elements work together to enable enhanced vision in low-light conditions, crucial for various applications from military operations to wildlife observation [1].

The technical parameters of the device are determined by the parameters of the opto-electronic channel (objective; IIT and eyepiece). Optical systems – objective and eyepiece, are well known and used in various optical devices (Fig. 2).

Fig. 2. UL PVS-14 (NVD) [8].

a) Optical elements

The major requirement on a lens is a high light-transmitting function of the visible and invisible range of the IR-light. This light-transmitting function is expressed with the figures of the F-numbers (relative aperture), for instance F1.0, F1.4, F2.0, F2.8, F4.0, etc. On increasing of the figure by one, the lens is transmitting 2 times less light. A high relative aperture (lower figure of the F-number) is a very important factor for the night vision devices. The development and the subsequent production of optics with a low F-number (high relative aperture) is a very difficult and expensive task, which any company cannot easily manage. Obviously, the high costs of development and production are increasing the final price. In the race for the uninformed customers many producers are using lenses with a 3,5 up to 5 times magnification, but a low light-transmitting for long distances. It should be noticed that also two identical devices with completely similar tubes, the device with a stronger magnification would produce a lower-quality image than a device with a lower magnification. The range in the near surrounding area (residual light area) is shorter than by using a device with a lower magnification – but with a higher light transmitting.

The construction of the ocular has no impact on the range of the night vision devices, but is very significant for the observation properties. For instance, a simplification of the construction of the ocular leads inevitable to a shape-distortion of the observed object and a low resolution on the edges of the image. The oculars of some manufacturers are able to produce only a part of the whole field of view, although the tube is a major and a most valuable component of a night vision device.

Most NVDs have highly developed glass optics. The quality of devices with plastic optics is much lower than the quality of devices with solid glass optics.

b) Image Intensifier Tube (IIT)

What distinguishes NVDs from other optical instruments is the presence of IIT (“Tube” - Fig. 3).

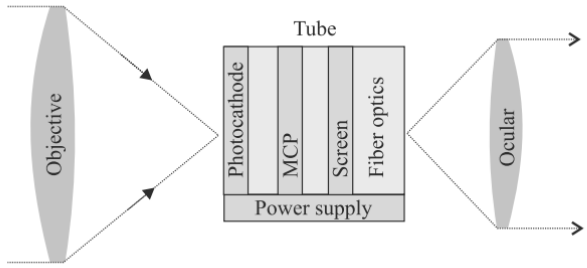


Fig. 3. Block diagram of NV monocular [2].

The objective lens capture ambient light and some near-IR light and focuses it to the photocathode of IIT, which is used to convert the photons of light energy into electrons. As the electrons pass through the tube, similar electrons are released from atoms in the tube, multiplying the original number of electrons by a factor of thousands through the use of a micro channel plate (MCP) in the tube. An MCP is a tiny glass disc that has millions of microscopic holes (micro channels) in it, made using fiber-optic technology. The MCP is contained in a vacuum and has metal electrodes on either side of the disc. Each channel is about 45 times longer than it is wide, and it works as an electron multiplier. When the electrons from the photocathode hit the first electrode of the MCP, they are accelerated into the glass micro channels by the 5,000 V bursts being sent between the electrode pair. As electrons pass through the micro channels, they cause thousands of other electrons to be released in each channel using a process called cascaded secondary emission. Basically, the original electrons collide with the side of the channel, exciting atoms and causing other electrons to be released. These new electrons also collide with other atoms, creating a chain reaction that results in thousands of electrons leaving the channel where only a few entered. An interesting fact is that the micro channels in the MCP are created at a slight angle (about 5° to 8° bias) to encourage electron collisions and reduce both ion and direct-light feedback from the phosphors on the output side [3].

At the end of the IIT, the electrons hit a screen coated with phosphors. These electrons maintain their position in relation to the channel they passed through, which provides a perfect image since the electrons stay in the same alignment as the original photons. The energy of the electrons causes the phosphors to reach an excited state and release photons. The image on the screen can be viewed directly through the ocular lens [3].

The color of the screen depends on the phosphor used. Two types of phosphorus – P20 and P43 – can be cited as the most used in modern EOP due to their high luminous efficiency. They emit light in a green-yellow color, where the sensitivity of the human eye is highest. In recent years, white phosphorus P45 has also been used, for which is claimed that the black-white image it creates is more natural to the human eye. In fact, the fatigue when observing a green-yellow image is less than when observing black and white. This effect is because the light spectrum of P20/P43 corresponds better to the light sensitivity of the human eye compared to the light spectrum of P45. It is also true that in low-light conditions, people see monochromatic images with different levels/shades of gray. In addition, users of typical NVDs generating greenish images see the images in false colors for a certain time after removing them from the eyes. This effect is absent when using NVDs emitting black and white images. The type of phosphorus remains the choice of the user/applicant. [2]

The last element of the structure of the IIT is its output, which can be flat glass or fiber-optic plate. The fiber-optic plate (FOP) contains several million optical fibers arranged parallel to each other. Each optical fiber works on the principle of complete internal reflection. An important advantage of the FOP is that it transmits the image without loss and distortion [1].

C. Generations [3].

NVDs are categorized by generation. Each substantial change in NVD technology establishes a new generation.

Generation 0 - The original night-vision system created by the United States Army and used in World War II and the Korean War, these NVDs use active infrared. This means that a projection unit, called an IR Illuminator, is attached to the NVD. The unit projects a beam of near-infrared light, similar to the beam of a normal flashlight. Invisible to the naked eye, this beam reflects off objects and bounces back to the lens of the NVD. These systems use an anode in conjunction with the cathode to accelerate the electrons. The problem with that approach is that the acceleration of the electrons distorts the image and greatly decreases the life of the tube. Another major problem with this technology in its original military use was that it was quickly duplicated by hostile nations, which allowed enemy soldiers to use their own NVDs to see the infrared beam projected by the device.

Generation 1 - The next generation of NVDs moved away from active infrared, using passive infrared instead. Once dubbed Starlight by the U.S. Army, these NVDs use ambient light provided by the moon and stars to augment the normal amounts of reflected infrared in the environment. This means that they did not require a source of projected infrared light. This also means that they do not work very well on cloudy or moonless nights. Generation-1 NVDs use the same image-intensifier tube technology as Generation 0, with both cathode and anode, so image distortion and short tube life are still a problem.

Generation 2 - Major improvements in image-intensifier tubes resulted in Generation-2 NVDs. They offer improved resolution and performance over Generation-1 devices, and are considerably more reliable. The biggest gain in Generation 2 is the ability to see in extremely low light conditions, such as a moonless night. This increased sensitivity is due to the addition of the micro channel plate to the image-intensifier tube. Since the MCP actually increases the number of electrons instead of just accelerating the original ones, the images are significantly less distorted and brighter than earlier-generation NVDs.

Generation 3 - currently used by the U.S. military. While there are no substantial changes in the underlying technology from Generation 2, these NVDs have even better resolution and sensitivity. This is because the photo cathode is made using gallium arsenide (GaAs), which is very efficient at converting photons to electrons. Additionally, the MCP is coated with an iron barrier, which dramatically increases the life of the tube.

Generation 4 - What is generally known as Generation 4 or "filmless and gated" technology shows significant overall improvement in both low- and high-level light environments. The removal of the ion barrier from the MCP that was added in Generation 3 technology reduces the background noise and thereby enhances the signal to noise ratio. Removing the ion film actually allows more electrons to reach the amplification stage so that the images are significantly less distorted and brighter.

There has been considerable effort expended in developing a Gen 3 tube without the ion barrier film. The effort proved successful, but the manufacturing costs were excessive compared to the performance improvements. For a brief period, the Gen 3 tube without the ion barrier film was termed Gen 4. This terminology, however, was rescinded shortly after it was announced, though some resellers of night-vision tubes still use the nomenclature [5].

In 2001, the United States Government concluded that the "Generation" indicator of an Image Intensifier sensor (IIT), be it Gen 2, Gen 3 or whatever, was not a determinant factor in an image intensifier's performance, confirming the "Generation" indicator as completely irrelevant in determining the performance of an image intensifier. For that matter, the US Government also eliminated the term "Generation" as a base for its export regulations. Instead, the Figure Of Merit (FOM) became key in determining the export feasibility [6].

FOM is easily calculated from known measured values by multiplying the values of SNR and the resolution (lp/mm) of the IIT [4].

The photocathode nowadays mainly consists of either Gallium Arsenide (GaAs), as produced by L3-Harris and ELBIT USA and against all odds still branded as Gen3 or a Hybrid Multi-Alkali (HyMa), as produced by Photonis, branded as 4G.

The main difference between GaAs and HyMa photocathodes is the bandwidth, or spectral range. In other words, the scope of types of light (from UV-blue to IR-red) that the photocathode is able to "absorb" and to transfer into electrons substantially differs. The bandwidth of GaAs is approx. 500 (blue-ish) to 900 (red-ish) nanometers. The bandwidth of HyMa is approx. 350 (UV) to 1100 (IR) nanometers. It is clear that the bandwidth or spectral range of an image intensifier with a HyMa photocathode is significantly wider than that of an image intensifier with a GaAs photocathode.

GaAs was initially thought to be a more efficient material but that was back 30 years ago (transferring light, photons into more electrons). Now it is accepted that the Signal-to-Noise Ratio (SNR) is the parameter describing how efficient the image intensifier deals with low light level. An image intensifier with a better signal to noise ratio will provide a better image in low light level condition than one with a lower SNR, irrespective of the photocathode material or "Generation".

It also became evident that the GaAs material is much more fragile, losing its essential capability quite quickly, reducing the lifetime of the image intensifier drastically. To protect the GaAs photocathode from deteriorating, an ion-barrier film needed to be installed on the MCP (that is not required with a HyMa photocathode; all Photonis tubes are filmless) to protect the GaAs photocathode layer from ion feedback. This results in two operational consequences. First of all, it makes the image intensifiers with a GaAs photocathode extremely susceptible to laser burns, causing irreversible damages.

Secondly, image intensifiers with a GaAs photocathode results in bigger halos. Halos are round bright areas around the brightest spots in a scene, for example streetlights or car headlights, disturbing the overall image quality by 'whiting out' part or the entire image. A halo in an Image Intensifier with a GaAs photocathode would typically be around 1 mm, while the filmless 4G Image Intensifier would typically generate a halo of 0,7 mm. The smaller the halo, the better the capability to identify a possible threat (especially in urban environments). The reduced halo size in the 4G image intensifier provides clearer (less obscured) view on targets in or with light sources.

With each successive generation, the spectral sensitivity of the IIT photocathode has been shifted to an IR spectrum where the spectral density of the natural night illumination is greater than in the visible range. During the transition from the visible to the near-IR range, the transparency of the atmosphere also increases. The signal-to-noise ratio and resolution increase with each generation, as does their lifespan (Mean Time To Failure – MTTF), from 1,000 hours in the first generation to 15,000 hours in the third generation. Although of the same generation, the IITs produced by different companies differ in their parameters – resolution, integral sensitivity, signal-to-noise ratio, weight, image quality, etc. [1].

The addition of an automatic gated power supply system allows the photocathode voltage to switch on and off rapidly, thereby enabling the NVD to respond to a fluctuation in lighting conditions in an instant. This innovative function allows the observer to operate in bright ambient light, or even in daylight operations. By keeping the full capability and performance, this function provides an efficient wear-protection of the device. Furthermore, this electronic solution eliminates the glare of the light source by maintaining the performance. Moreover, this function meets the high tactical requirements - for instance by operating under bright lighting conditions such as military operations in urban terrains, which define many of today's missions. This special control electronic solution prevents blending and shadowing by variant types of light sources or fire and helps to minimize the abrasion of the tube [4].

D. Development trends and innovations

a) Reduction in size and weight.

Ergonomics (size, weight and ease of use) are important considerations. Lightweight devices are more comfortable during extended viewing. Since you will be using the device in the dark, the switches and controls should be positioned logically and be easy to use [7].

The dimensions and weight of IIT are a major factor influencing the same characteristics of NVD/monocular.

IITs differ in the nominal diameter of the photocathode. The most used in NVDs are IITs with a diameter of 18 mm and 16 mm. The weight of the 16 mm IIT is reduced by 35 g compared to a standard 18 mm ANVIS IIT, while its volume is reduced by 40% [2].

The fatigue of the users due to the wearing of heavy NV googles/monoculars attached to the helmet or facemask is always considered a disadvantage of NV technology. The ideal NVD should have a weight comparable to that of human eyes. Ultra-light NVDs or monoculars based on the light 16 mm IITs are a potential solution to this problem.

NV monoculars are usually offered with GEN 2+ or GEN 3 IITs depending on the user's requirements but manufacturers rarely provide information regarding the diameter of IITs used. The information in the table points to two trends – decrease in weight and increase in FOV as only the Thales product (MONIE) achieves both at a significantly shorter length than all other (>30%) (Table 1).

All models have built-in infrared illuminator as well as LED indicators for low battery and active IR illuminator. They allow focus and diopter adjustment. The presence of Manual Gain control, Bright Light cut-off, Automatic shut-off system, Automatic Brightness Control and Auto Gating depend usually depends on the users requirements. Power is provided by one battery AA or CR123 type.

TABLE 1. COMPARISON OF NV MONOCULARS.

Models	**M-40, PVS-14 and similar**	**UL PVS-14** [8]	**NVS-14 3AG** [9]	**MONIE** [10]	**MNVD-51 BRAVO** [11]
Manu-facturers	Optix, AGM, ATN, Optikoelektron, EoTech, L3 Harris,	NVD	Newcon Optik	Thales	Armasight
FOV	40°/42°	40°	40°	51°	51°
Magni-fication	1x				
Weight (g)	300 - 350	235 w/o battery	287 w/o battery	< 280 with battery	310

The reflection of the reduced dimensions and weight of 16 mm IIT on the same parameters of the NV monocular is shown in Table 2.

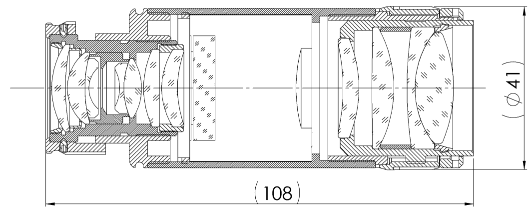
The analyses and prototype specimens show that with the use of 16 mm IIT while preserving the functional parameters of the monocular, the overall dimensions of the same will decrease by about 10% and the weight by almost 20%.

An opportunity to reduce the weight of monoculars can be sought by optimizing the construction and materials for the manufacture of the housing, as well as the optical elements of the objective and the eyepiece.

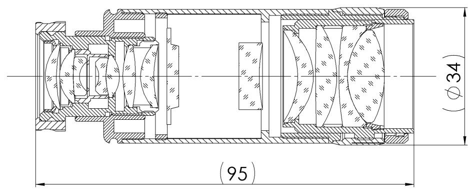
A night vision device is more attractive for the users, the smaller, lighter and the longer range it has. However, these demands are contradictory. A longer range, for instance, can only be achieved by using a device with a larger lens (diameter). The choice is finally left to the user [4].

TABLE 2. COMPARISON OF NV MONOCULARS OF OPTIX - BULGARIA WITH 18 MM AND 16 MM IITS

DIANA M40	**DIANA M40_Pr**
18 mm ANVIS IIT	**16 mm** IIT
- Magnification – 1x; - FOV – 42°; - Resolution > 64 lp/mm; **- Weight – 330 gr.**	- Magnification – 1x; - FOV – 42°; - Resolution > 64 lp/mm; **- Weight – 260 gr.**



DIANA M40



DIANA M40_Pr

b) Adding new functionalities.

Enhanced NVDs (dual sensor NVDs) are probably the most important trend in night vision technology. Both classical NVDs and digital NVDs suffer from the same limitation because both technologies use the same spectral band. Both devices are practically blind in dense fog, smoke, sand storms, or at very low illumination conditions. Next, these devices are also not effective against classical camouflage techniques [2].

Fusion of classical night vision with thermal imaging combines the advantages of both two technologies:

- Ability to generate high contrast images of warm targets of interest at low illumination/poor atmosphere conditions (detection task);

- Ability to generate high-resolution image of both targets and background (identification task).

Enhanced night vision goggle (ENVG) is a helmet-mounted monocular that provides the operator with significantly improved targeting and identification in all battlefield conditions and light levels. Also known mainly by the US military as AN/PSQ-20B, the ENVG uses image intensification technology fused with thermal imagery, thereby bridging the gap in performance and capability for both of these sensors (Fig. 4) [12].

The ENVG uses a proprietary mounting system due to its power supply design. The goggle does not have any onboard power. Instead, power is delivered by attaching the large 4xAA battery pack on backside of the helmet, acting as a counterweight balancing the weight of the device. There is the mounting point for the battery pack. It is a QD design and the anchoring point matches the anchoring point on the goggle itself. ENVG powered helmet shroud has two power contacts that deliver power into the ENVG mount. Because of this, the regular helmet shroud is not usable to mount the ENVG. ENVG mount has brass contacts to deliver power to the goggle. There is one on each side so it's possible to mount the ENVG for right or left eye dominant users. The battery pack can be attached also to the side of the ENVG using the same power mounting points as the ENVG Mount. Due to the design of the housing, it is possible only to attach the battery pack to the right side of the housing. It will not fit on the left side [13][14][15].

Fig. 4. Enhanced night vision goggle (ENVG) AN/PSQ-20B (last version) [12].

Magnification is 1x and the FOV is 40° like the ordinary NV monoculars.

Enhanced Night Vision Goggle (ENVG) AN/PSQ-20 (F6023 - ITT) has high performance 16-mm image tube, 320 X 240 microbolometer, FOV - ≥ 38° (IIT)/≥ 28° Diagonal (IR) [16].

The ENVG also allows Soldiers to rapidly detect and engage targets because it permits use of existing rifle mounted aiming lights. The weight of AN/PSQ-20B is 595 grams which is identical to that of the majority of NVGs used. The system weight is about 900 grams including four AA batteries, helmet mount, and battery pack.

Next step in the development is Enhanced night vision goggle - binocular (ENVG-B) (Fig. 5) [17]. The ENVG-B is a helmet-mounted individual night vision device that has an integrated long-wave infrared (LWIR) thermal sensor and white phosphor dual IITs. The fused IITs and thermal display can be used during low and high light levels, extreme weather and with obscurants. The ENVG-B is interoperable with the Family of Weapon Sights – Individual (FWS-I) for a Rapid Target Acquisition (RTA) that provides the Soldier the ability to accurately engage targets without shouldering the weapon and execute offset shooting. ENVG-B operates on the Intra-Soldier Wireless (ISW) network with Nett Warrior (NW) allowing the Soldier to receive and display navigational, targeting, and situational graphics. It's weight is 2,5 lbs (1,13 kg). 18 mm IITs and 10 µm thermal sensor are used [18].

In fact, it consists of two monoculars - one similar to AN/PSQ-20B and one for night image intensified vision. The significantly increased functionalities of the device in a network environment is impressive, which implies the presence of wireless connectivity.

Fig. 5. Enhanced Night Vision Goggle - Binocular (ENVG-B) [19].

According to the US Army Acquisition program portfolio 2023-2024, the prime contractors for ENVG-B are Elbit Systems of America and L3 Harris Technologies, Inc. [19].

The findings from the research carried out in this field have important implications for the design and development of next-generation night-vision monocular. Simultaneously with the work on reducing the weight and dimensions of the monocular with the use of 16 mm IIT, it is appropriate to examine the possibilities of optimizing the design of the housing, the optical elements of the lens and the eyepiece and the controls (digitalization).

The addition of new functionalities may lead to an increase in the weight and dimensions of the device, which is fully valid in the presence of a thermal imaging channel. In this case, a balance should be sought between operational and ergonomic requirements.

Due to the high weight and too high cost of devices such as AN/PSQ-20B ($20k) and ENVG-B, it will be appropriate to explore the possibility of increasing the functionality of a regular NV monocular by providing the possibility of wireless exchange of tactical information as well as images from other devices (thermal sights or clip-on imagers for example). The cheapest and most easily achievable option is the use of a signal processing unit (SPU), probably attached to the back of the soldier's helmet, which will receive the image from the warfighter's weapon sight/clip-on imager and transmit it to the night-vision device's eyepiece through fiber optic cable. In this case, SPU can be integrated with the power source as well as to perform the role of a counterweight.

c) Integration of AI in Night Vision Systems

AI algorithms have revolutionized night vision by enabling real-time enhancement, analysis, and interpretation of image data. The integration of AI in night vision monoculars involves several key aspects [20][21][22]:

Image Enhancement - AI algorithms can enhance low-light images by reducing noise, sharpening details, and improving overall clarity. Techniques such as denoising, super-resolution, and contrast enhancement play a crucial role in improving image quality.

Object Detection and Recognition - AI-powered object detection algorithms can identify and highlight important objects or targets in the dark. This capability is particularly valuable for military, surveillance, and law enforcement applications.

Scene Understanding - Advanced AI models can analyze night-time scenes to detect patterns, predict movements, and provide situational awareness to the user. This enhances safety and operational effectiveness in various environments.

The future of night vision monoculars is closely intertwined with AI and image processing innovations. Key development trends include:

Integration of Deep Learning Models - More sophisticated AI models, including deep neural networks, will be deployed to handle complex tasks such as semantic segmentation and anomaly detection.

Multi-Sensor Fusion - Night vision systems will leverage multiple sensors (e.g., thermal imaging, LiDAR) combined with AI to provide comprehensive situational awareness.

Real-time Decision Support - AI algorithms will not only enhance images but also provide actionable insights and decision support, aiding users in critical scenarios.

d) Image Processing Algorithms for Night Vision

In addition to AI, image processing algorithms tailored for low-light conditions are essential for optimizing night vision performance [22][23]:

Adaptive Noise Reduction - This algorithm employs advanced filtering techniques to mitigate noise artifacts inherent in low-light imagery captured by night vision monoculars. By adaptively analyzing pixel intensity variations and spatial characteristics, the algorithm effectively reduces noise without sacrificing important image details. This method enhances overall image clarity, particularly in challenging low-light environments.

Low-light Colorization - Addressing the limitations of traditional monochromatic night vision imagery, this algorithm introduces intelligent colorization to enhance visual perception. Through sophisticated color mapping techniques based on contextual analysis and scene understanding, grayscale images are transformed into color-enhanced representations. This process aids in distinguishing objects and improving situational awareness in darkness.

Dynamic Range Expansion - This algorithm extends the dynamic range of captured images, enabling enhanced visualization of both bright and dark regions within a single frame. Leveraging exposure manipulation and pixel intensity remapping, it optimizes contrast and brightness levels to reveal details that would otherwise be obscured in low-light environments. The result is a more comprehensive and realistic depiction of night scenes.

By integrating these cutting-edge algorithms into night vision monoculars, there will be a significant enhance of their effectiveness for military, law enforcement, and surveillance applications.

CONCLUSIONS

In conclusion, this research has provided a comprehensive overview of night vision monocular technology, focusing on its fundamental components and emerging development trends. Through a thorough examination of the optical, electronic, and image intensification elements involved in night vision monoculars, key insights have been gained into the underlying principles and design considerations critical for their performance.

The study has highlighted the significant advancements in night vision technology, including the integration of digital imaging, improved sensor sensitivity, and enhanced ergonomics. These advancements are shaping the future of night vision monoculars, making them more versatile, user-friendly, and capable across various applications from defense and security to outdoor recreation and wildlife observation.

Moreover, the research has underscored the importance of ongoing innovation and research in optimizing night vision monoculars for enhanced performance under challenging low-light conditions. Factors such as resolution, field of view, weight reduction, and power efficiency have emerged as critical focal points for future development efforts.

Additionally, the study has shed light on the growing role of artificial intelligence and image processing algorithms in advancing night vision capabilities, particularly in terms of image enhancement, target recognition, and real-time analysis. AI and image processing algorithms are catalysts for the evolution of night vision monocular technology, enabling unprecedented levels of performance and functionality. The ongoing convergence of AI with night vision systems promises exciting prospects for enhanced night-time visibility across various domains. Future research will continue to push boundaries, making night vision capabilities smarter, more intuitive, and more effective in diverse operational contexts.

Looking ahead, it is evident that night vision monocular technology will continue to evolve rapidly, driven by advancements in materials science, optics, electronics, and computational techniques. This evolution promises to unlock new possibilities for night vision applications, ultimately improving situational awareness and operational effectiveness across diverse sectors.

In summary, this research underscores the dynamic landscape of night vision monoculars, revealing a trajectory of continuous improvement and innovation. By exploring both foundational elements and future directions, this study contributes valuable insights to the broader field of optical and imaging technologies, offering a roadmap for further advancements in night vision capabilities.

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