New night vision sensors for digitized battlefield

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ABSTRACT

Presently two types of night vision sensors are in use for aerospace and battle field applications- one based on image intensifier(II) technology and the other based on thermal imaging (TI) technology. The image intensifier sensors have certain limitations and also they can not be used to capture the image digitally. Thermal imaging sensors over come the limitations of image intensifiers to some extent, but the cost of the systems is very high. This paper covers the new night vision sensors that are coming up to address the challenges posed by digitized environment in the aerospace and battle field. With the advent of new digital age night vision sensors, it is expected that low cost night vision with many promising features will be available to the users in the army, air force and navy. It is likely that the battlefield scenario will undergo tremendous changes with regard to the night vision capability. Designers and manufacturers of night vision devices should gear up to face these challenges and come out with new devices based on these sensors to meet the user needs.

Keywords: Night vision, image intensifier, thermal imaging, digitized battle field

1. INTRODUCTION

Night Vision sensors came to the forefront about 40 years ago with active devices requiring infrared illumination. During the last 30 years image intensifier based night vision sensors gained central importance for contemporary operations. They enjoyed popularity among the armies throughout the world because of affordability, performance and reliability. How ever, image intensifier based night vision sensors do not meet the requirements of modern armies as their output is not usually digitized and can not be used for communications. The inherent drawbacks are - image data can not be distributed; fusion of image data with other sensors not possible; no computing power available at image end; image treatment, analysis, screening of images for certain objects or hints not possible; situational awareness at commander level lacks timeliness; Storage and retrieval of image data for future needs is not possible.

Over a period of time various generations of thermal sensors have emerged in 3-5 and 8-12 micrometer wavelength bands. These thermal sensors overcome, most of the drawbacks of image intensifier based sensors. But they are still not as affordable as image intensifier based sensors. At present their application is limited to critical missions, where the deployment price is not a determining factor. They have their own disadvantages as well – they are rather bulky, require cryogenic coolers, x-y scanners and consume much higher power. Even the latest uncooled thermal sensors are yet to prove their merit in terms of mass deployment. Of course, the cooled and uncooled thermal sensors are highly suitable for digitised battle field applications.

Experiments in digital night vision started over 15 years ago when commercial-of-the-shelf (COTS) products, such as Helmet Mounted Displays (HMD) and compact Charge-Coupled Devices (CCD), became available. The evolution and growth of digitized night vision sensors on the battlefield is likely to increase dramatically overtime. Increased situational awareness using digital night vision sensors that enhance C4SIR functions within the battle-space are paramount for commanders to remain in synch with war fighters engaged in hostilities. Information from digitized sensors will play a vital role in future aerospace and warrior systems. To be effective, the type of sensor information (video, still imagery, or contextual) provided to the war fighter must be balanced against mission needs, information timeliness and network constraints. Further, actionable intelligence will require digitization at the soldier level. New soldier worn, unattended and dual band surveillance sensors are now being designed that will enable networked operations without sacrificing sensor performance.

2. PROMISES OF NEW NIGHT VISION SENSORS

There are numerous advantages of the new and emerging digital night vision components and sensors. Dismounted troops advantage-Possibility to add images from external sources (maps, directions, etc.); Image fusion: mixing signals from different sensors (thermal, low-level CCD, etc.); significantly reduced forward projection; better ergonomics. C4ISR advantage - Possibility to view the battlefield "through soldier's eyes"; digital image can be easily spread over network; "Digital battlefield" approach. Target recognition applications-possibility to create passive systems for orientation and aiming (e.g a missile's course can be controlled through visual channel without laser designation).

2.1 Digital Signal Processing

The biggest advantage lies in image enhancement by digital image processing. It is possible to reduce noise to significantly low levels by averaging image data, also correct for motion while averaging data and at the same time exchange temporal resolution for better Signal-to-Noise ratio. Contrast enhancement becomes simple especially after noise reduction, more dynamic range may be present then easily visualised. Contrast Enhancement can also help visualise simultaneously all details. Resolution can be enhanced by Super Resolution techniques. Artefacts, such as non-uniformity in Thermal Infrared, can be suppressed by processing. Electronic stabilisation can be introduced which reduces jitter in images. By implementing signal processing and filtration it is possible to reveal hidden targets, achieve larger recognition / detection distances and at the same time realise better identification of the observed objects.

2.2 Network Centric Warfare

In current scenarios warriors do not operate alone but are part of the bigger picture. Current and future communication equipment allow transmission of very much data including (streaming) image data. Allowing sharing of information is a driving factor not to have analogue-only Night Vision capability

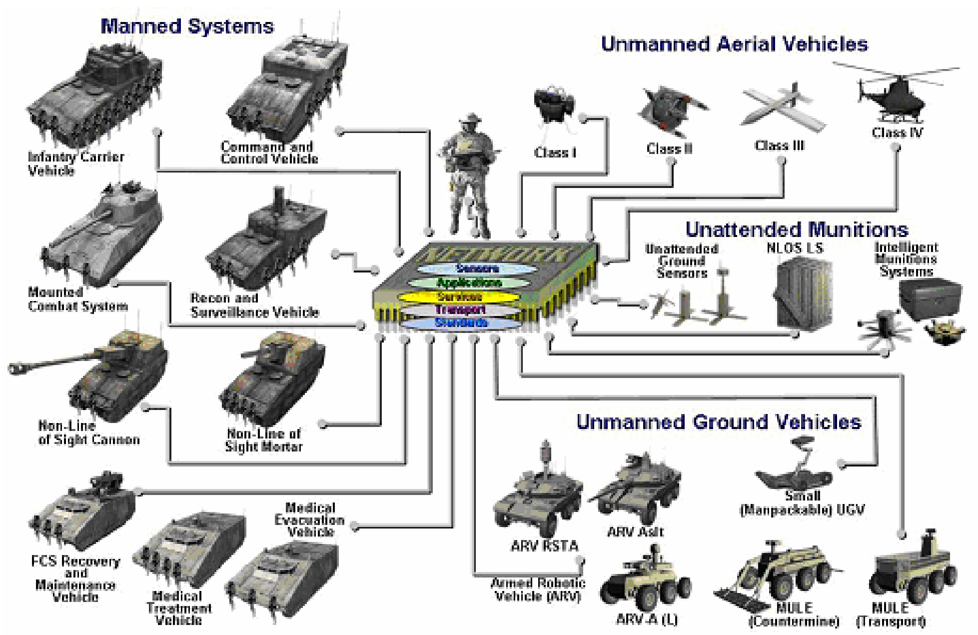

Fig. 1. Typical network centric battlefield scenario

To distribute image data by digital communication channels, the output of a image sensor must be numeric. The digital communication itself is not totally ready for the new night vision sensors. Nowadays the bandwidth of comparatively low cost transmission channels is sufficient for video data and where links are at their limits, compression helps. Most platforms are equipped with monitors, but it is still difficult to get monitors accessible to all soldiers. Good helmet display is heavy and expensive, and other concepts of using image information during action are not yet convincing. So, while much looks feasible, some specific technical solutions to some communication technologies are still to be developed.

While some demands on the links remain unsolved, the status of imaging sensor data links definitely is impressive. Aerospace sensors especially UAV operations with imaging sensors can be and some times are controlled and exploited in real time around the globe. Image treatment and image analysis for data use is available and is already in military use.

Further, the definition of sensor is undergoing changes. It is hard to think of it as being the sensor chip itself, but rather "sensor" got to be the name for a device that senses image data and presents it for direct use or transmits it to some other location for exploitation. Like in the present day digital camera, the combination of a sensing array and some computing power, a typical future sensor will always have local intelligence.

2.3 Future Infantry solidier programs

The primary objective of new night vision sensors is to enhance safety and communication for individual soldier in mission-critical field situations. In many countries modern infantry soldier programs are at the forefront of military work in this direction. These include Future Force Warrior (FFW) program of United States, India's Future Infantry Soldier, Slovenia's 21^{st} Century Warrior, Australia's Land 125, Portugal's Soldado do Futuro, France's FELIN, the Swedish Markus program, Germany's Infantryman of Future, the UK's Future Infantry Soldier Technology project and Israel's Advanced Infantry System program. In each case the focus is on bringing advanced communication, imaging and logistical tools to the soldier in the field-a concept known as 'soldier as system'. How to integrate and utilize the information from the image sensors with the onboard computer, eyewear, weapon systems, network access and other communications is of course a big challenge.

While the goal is to use cutting-edge technologies to give soldiers in the field every advantage possible-referred to as situational awareness-other critical factors must also be taken into consideration, such as how much weight can realistically be carried and the need to keep hands on weapons at all times. Another important aspect of soldier as a system approach is integration of image sensors with the weapon, display, communications and networks as a unified environment. This differs from the conventional practice of just adding each gadget onto the individual soldier.

3. DIGITAL NIGHT VISION TECHNOLOGIES

3.1 Low Light Level CCD

The technological drive for CCD sensors used in military imaging applications has been towards the detection of ever-smaller signals at increasing pixel rates. In order to form images at low photon flux, all of the noise components within the CCD must be minimized and the signal maximized, i.e. essentially by achieving high quantum efficiency. This technology is capable of having high quantum efficiency at high fill factors. CCD technology also allows high resolution at reasonable costs. But the CCD technology is hampered by temporal noise which limits this technology for extreme low light levels . The two main sources of temporal noise in a CCD are amplifier noise and shot noise associated with the thermally generated "dark signal". Amplifier noise can be reduced by minimizing the output node capacitance. State-of-the-art amplifiers have the capacitance as small as 10 fF and achieve noise with a floor value of less than 2 electrons at very low read-out rates, rising to tens of electrons at MHz rates. The dark signal can be reduced by use of inverted mode operation (IMO), also called multi-phase pinned (MPP), and/or by cooling.

As noted above, the ability to perform useful imaging at low photon flux levels requires both the reduction of all noise components and a high probability that a photon will be converted to a signal electron, i.e. high quantum efficiency. In this context, it should be noted that in an image intensifier with a channel plate, the photo-cathode quantum efficiency must be multiplied by the open area ratio of the channel plate to give a "useful quantum efficiency". The open area ratio of a typical LLLCCD is 100%. Taking this into account, Fig 2 shows typical quantum efficiencies for image intensifiers and CCDs. It can be seen that a current front-illuminated CCD compares well with an intensifier and that back-illumination, as may be available with LLLCCD technology in the near future, can give significant improvements. The back-illuminated devices can have anti-reflection coatings optimized for the red or blue regions of the spectrum, as indicated.

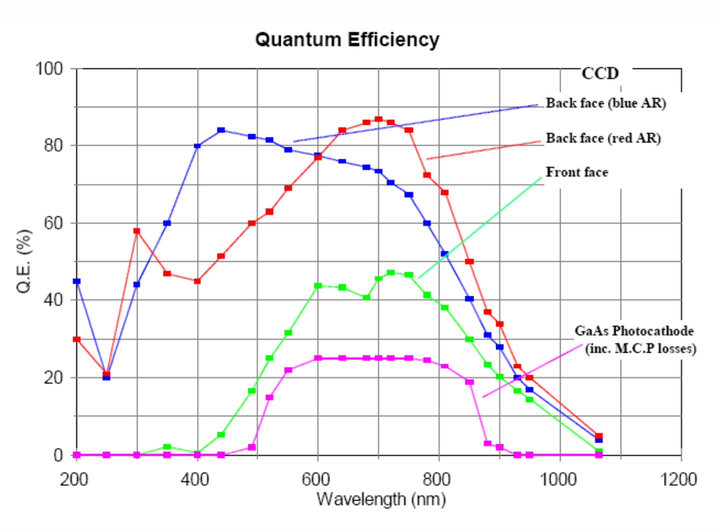

Fig. 2. Comparison of Quantum Efficiencies of Low Light Level CCD sensors

3.2 ICCD Sensors

An **intensified charge-coupled device** (ICCD) is a CCD that is fiber-optically connected to a micro-channel plate (MCP) to increase the sensitivity. In ICCD cameras, a photo-cathode in front of the MCP converts photons to electrons which are multiplied by the MCP. After the MCP a phosphor screen converts the electrons back to photons which are fiber-optically guided to the CCD. In short, ICCD is nothing but a ttraditional Image Intensifier tube glued to a CCD. Besides the gain in sensitivity the possibility of gating the MCP also offers the possibility to gate ICCD cameras very fast. Therefore ICCD cameras are also used for range-gated imaging. A digital delay and pulse generator is often used to control the delay (range) and the duration (gate) of the ICCD's gating signal.

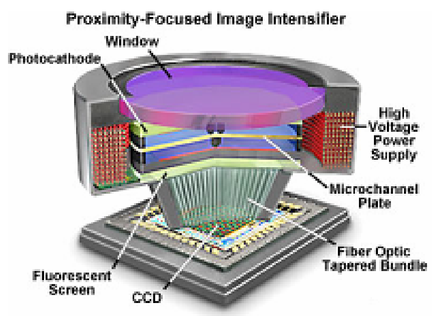

Fig.3 Construction of intensified charge-coupled device

3.3 Electron Multiplying CCD

An **electron-multiplying CCD** (EMCCD) is a charge-coupled device in which a gain register is placed between the shift register and the output amplifier. The gain register is split up into a large number of stages. In each stage the electrons are multiplied by impact ionization in a similar way to an avalanche diode. The gain probability at every stage of the register is small ($P < 2\%$) but as the number of elements is large (N > 500), the overall gain can be very high ($g = (1 + P)^N$), with single input electrons giving many thousands of output electrons. Reading a signal from a CCD gives a noise background, typically a few electrons. In an EMCCD this noise is superimposed on many thousands of electrons rather than a single electron; the devices thus have negligible readout noise.

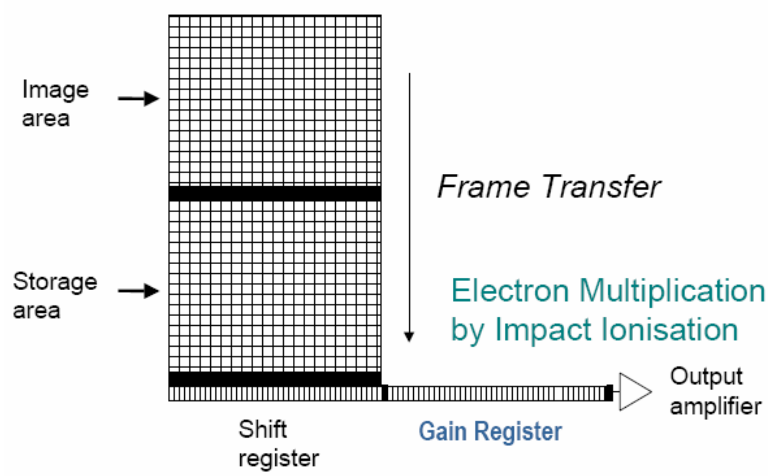

Fig 4. EMCCD Gain register

EMCCD cameras overcome a fundamental physical constraint to deliver high sensitivity with high speed. Traditional CCD cameras offered high sensitivity, with readout noises in single figure <10e- but at the expense of slow readout. Hence they were often referred to as ‘slow scan’ cameras. The fundamental constraint came from the CCD charge amplifier. To have high speed operation the bandwidth of the charge amplifier needs to be as wide as possible but it is a fundamental principle that the noise scales with the bandwidth of the amplifier hence higher speed amplifiers have higher noise. Slow scan CCD’s have relatively low bandwidth and hence can only be read out at modest speeds typically less than 1MHz. EMCCD cameras avoid this constraint by amplifying the charge signal before the charge amplifier and hence maintain unprecedented sensitivity at high speeds. By amplifying the signal the readout noise is effectively by-passed and readout noise no longer is a limit on sensitivity.

The probability of charge multiplication varies with temperature – the lower the temperature the higher the probability and hence gains of the EMCCD. There fore most EMCCDs requires TE cooling driving toward higher power. How ever because of the lower costs and the better resolution EMCCDs are capable of replacing ICCDs in many applications.

3.4 Image Intensifier coupled CMOS

This is an integrated solution in which, Image intensifier and CMOS sensor are packed in one housing through a fiberoptic cone as shown in Fig(6).

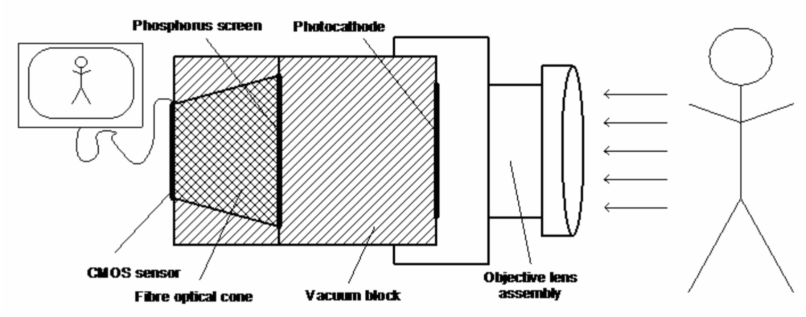

Fig 5. Pictorial view of Image Intensifier coupled CMOS

This sensor solution can provide optimal parameters-to-cost value for some applications in low light imaging area. How ever, this being a non-solid state solution and hence excess noise factor cannot be ruled out.

Maximum theoretical digital resolution can be counted as

*Rd = Ra*2*18 (mm)*

With Ra = 64 line pairs/mm

Rd = 2304 lines

3.5 CCDD/CMOS Hybid FPA

This is a fully Solid state, silicon-to-silicon hybrid assembly consisting of CCD imaging core and CMOS ROIC. Charge from the CCD image core is directly transferred to a CMOS ROIC in a massively parallel architecture. It uses low bandwidth, low noise, high gain amplifiers on ROIC. CCD and CMOS are individually optimized for low light imaging The spectral response of the sensor is shifted further to the near IR, matching with the night sky.

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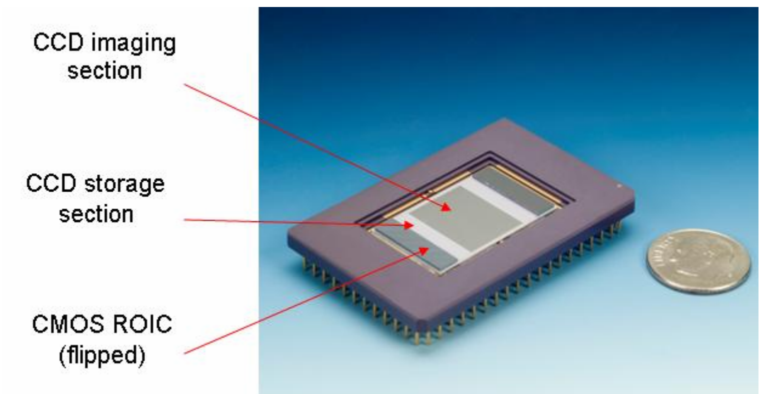

Fig 6. CCD/CMOS Sensor from Fairchild Imaging, USA

Because of System-on-chip (SOC) integration, power consumption is extremely low. The sensor is very much light in weight because of solid-state non-vacuum package. As the architecture is massively parallel, it leads to lower electronic bandwidth. Also the architecture provides direct digital video out and is fully compatible with advanced image processing algorithms. This all silicon solution for low light imaging needs to be developed further to enable take up mass manufacture

4. DIGITAL NIGHT VISION CHALLENGES

4.1 Spatial and display resolutions

Spatial resolution is the foremost challenge. Current Night Vision tubes have about 8 million channels in its MCP. Uncooled TIR is up to 640x480 = 300 000 pixels. The new digital night vision sensors do not reach those 8 Mpixels. Analogue NV tube still winning in the spatial resolution domain! The digital night vision sensors require high resoloution miniature displays in the end product. Most limiting factor is the display resolution. VGA format at 300 000 pixels and XGA at 1.3 Mpixels are far below the expected sensor spatial resolution.

4.2 Power consumption

Digital Night Vision requires power for - Digitising the image, processing the image and for image display. In addition to Night Vision sensor, power is needed for sensor cooling and for ensor microscan in some cases depending on actual sensor used. For now, Digital Night Vision requires an order of magnitude more powerThis is limiting in man-carried operations!

4.3 Weight

Digital Night Vision weight is not only the sensor weight but includes processor weight, display weight and battery weight. This becomes another limiting factor in man carried operations.

5. CONCLUSION

Digital Night Vision is promising in fields of image enhancement, sensor fusion and network capabilities. New night vision imaging sensors are ready for use in digital communications, but they have considerable room for improvement to fully exploit their value in communication networks. Digital networks without them would be blind. The next revolution will come with automatic registration, warning, verification etc Competing Digital Night Vision exist with no clear winner. Spatial resolution, display resolution, power consumption and weight currently limit Digital Night Vision applicability. The cost of digital night vision is approaching the cost of analog night vision.

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