Colour-the-INSight: combining a direct view rifle sight with fused intensified and thermal imagery

Hogervorst, M.A.[1], Jansen, C.[1], Toet, A.[1], Bijl, P.[1],
Bakker, P.[2], Hiddema, A.C.[3], van Vliet, S.F.[4]

[1]TNO Human Factors, P.O. Box 23, 3769 GZ Soesterberg, the Netherlands,
maarten.hogervorst@tno.nl, +31 888 665840
[2]Thales Nederland B.V., Bestevaer 46, Huizen, The Netherlands
[3]PHOTONIS Netherlands B.V., P.O. Box 60, 9300 AB Roden, the Netherlands
[4]Ministry of Defence , Joint Soldier & Equipment Centre of Expertise, Wuytierslaan 198 Amersfoort, the Netherlands

ABSTRACT

We present the design and evaluation of a new demonstrator rifle sight viewing system containing direct view, red aim point and fusion of an (uncooled, LWIR) thermal sensor with a digital image intensifier. Our goal is to create a system that performs well under a wide variety of (weather) conditions during daytime and nighttime and combines the advantages of the various sensor systems. A real-time colour image with salient hot targets is obtained from the night vision sensors by implementing the Colour-the-Night fusion method (Hogervorst & Toet, 2010) on the on-board processor. The prototype system was evaluated in a series of field trials with military observers performing detection and identification tasks. The tests showed that during daytime the addition of a thermal image to direct vision is advantageous, e.g. for the detection of hot targets. At nighttime, the fusion of thermal and image intensified imagery results in increased situational awareness and improved detection of (hot) targets. For identification of small (handheld) objects, the technology needs to be further refined

Keywords: image fusion, false colour, natural colour mapping, real-time fusion, night vision

1. INTRODUCTION

Present and future military practice puts large demands on the viewing capabilities of the soldier. Armed forces have to operate in a wide range of environments (urban as well as open field) under varying conditions (weather, lighting, day, night). Urban missions are becoming increasingly important and require optimal viewing at short range and fast responsive action. At night special night-vision systems such as image intensifiers and thermal imagers are essential to create sufficient situational awareness. At daytime one has to deal with varying lighting conditions (shadows, dark areas), smoke, mist etc. that hinder good viewing. Sensor technology and especially fusion of different sensors can be used to overcome many of the problems. TNO, Thales and Photonis in collaboration with The Dutch MoD have developed a rifle sight viewing system that combines direct view (including a red aim point) and fusion of an LWIR thermal imager and a digital image intensifier. This prototype system is termed Colour-the-INSight (Integrated Night vision Sight). The goal is to create a rifle sight and aiming system that functions well under a wide range of conditions. It combines the strengths of the individual sensor systems. The thermal sensor is especially well suited for the detection of hot targets. The image intensifier is suited for displaying the surroundings at night. The image of the thermal sensor and the image intensifier are fused using the "Colour-the-Night" fusion method[1]. By fusing the images of the two sensors an image is created that contains the combined information of the two sensors. For instance, the fused image displays hot targets while at the same time showing the surroundings. The image does not only show that a hot target is *present* but also *where* it is located (the context). This is an example of the added value of sensor fusion. When implemented properly, fusion results in an image that may display information surpassing that of the individual sensor images. Also, the fused image conveys the information from the individual sensor images without the need to inspect the individual sensor images sequentially (leading to shorter reaction times).

Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications 2012,
Proc. of SPIE Vol. 8407, 84070O · © 2012 SPIE · CCC code: 0277-786X/12/$18 · doi: 10.1117/12.919128

The “Colour-the-Night” colour fusion method, implemented in the Colour-the-INSight system, is simple and fast, can easily be deployed in real time, can display night-time imagery in natural daytime colours, and provides stable colourization under variations in scene content. The principle of the approach is illustrated in Figure 1. This figure shows

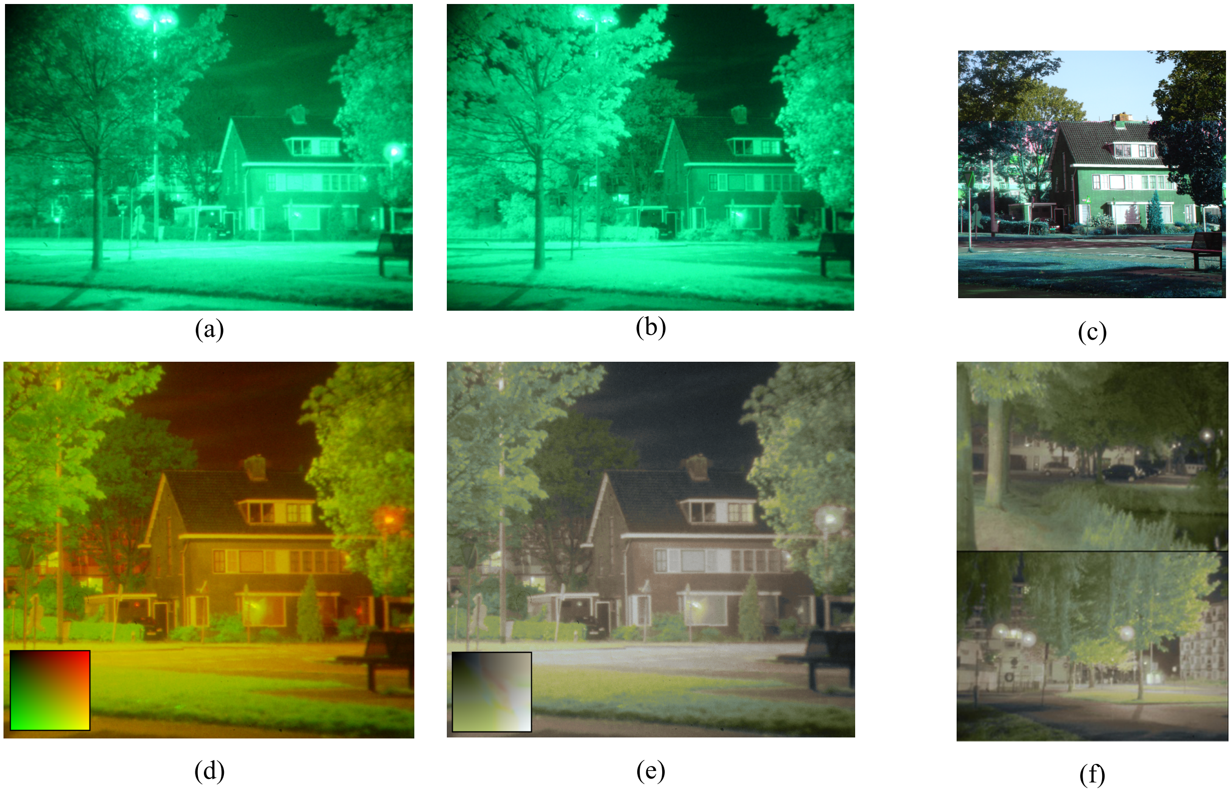


Figure 1. (a) image of image intensifier fitted with low-pass filter (< 700 nm), (b) image of image intensifier fitted with high-pass filter (> 700 nm), (c) daytime reference image, (d) RG false colour representation of (a) and (b), inset showing all possible multiband sensor outputs, (e) result of the application of the “Colour-the-Night” mapping scheme, inset showing the output colour corresponding to each multiband sensor output. The colour mapping is contained in the colour mapping between the insets. (f) result of applying the colour mapping to new multiband sensor images.

a dual-band image intensifier system consisting of an image intensifier fitted with a filter transmitting only wavelengths in the visible range (<700 nm, Figure 1a) and an image intensifier fitted with a filter transmitting only near infrared (>700 nm, Figure 1b). As a first step, the multi-band sensor image can be represented as an RG-image resulting from taking the visible band as R and the NIR band as G (Figure 1d). All possible sensor combinations can be represented in this figure by shades of red-green-yellow (inset in Figure 1d, top-left corresponding to no response in both channels, bottom-right corresponding to maximum response in both channels). Figure 1e is the result of the application of the natural colour mapping to Figure 1c. Note that the image pair of the insets in Figures 1d and 1e fully defines the natural colour mapping in a lookup table representation. In the training phase, the “Colour-the-Night ” method derives the best matching colour transformation from a multiband sensor image (e.g. Figure 1d) and a daytime reference image (Figure 1c). Once the colour mapping has been derived it may be applied to other multi-band nighttime images (Figure 1f). To obtain a fused image with natural (daytime) colours it is only required that the scenes are comparable to the scene used in the training phase. For details see Hogervorst & Toet[1].

Colour imagery has several benefits over monochrome imagery for surveillance, reconnaissance, and security applications. Colour may improve feature contrast, which allows for better scene recognition and object detection. It is important to use a colour mapping whose chromatic characteristics correspond in an intuitive or obvious way to those of a scene viewed under natural photopic illumination. Unnatural colour mappings may disrupt the recognition process, resulting in an observer performance that is even worse compared to that obtained with single band imagery alone[2]. It has been shown that the use of colour fusion leads to improved target detection performance and improved depth perception[3], better situational awareness[4,5] and faster reaction times[6]. Colour fusion allows for better discrimination and recognition of materials, and can break camouflage (see Toet & Hogervorst[7] for an overview).

The "Colour-the-Night" fusion technique has been implemented earlier in a range of demonstrators, including the Gecko and the Viper[8] and the TRICLOBS[9,10]. The Gecko is a dual-band image intensifier system fusing intensified visual and near-infrared images (much like the example shown in Figure 1). The two-band Viper system provides an intuitive target-enhancing colour representation of the fused signals of an image intensifier and a long-wave infrared thermal camera. The tri-band TRICLOBS system combines the benefits of the two previous systems and fuses intensified visual, near-infrared, and long-wave infrared images. The sensors in these fusion systems are optically aligned through the use of mirrors and filters. The advantage of this is that these systems do not display any parallax and the images can be brought in perfect alignment. The disadvantage is that these systems are rather bulky. Moreover, the fusion is performed in realtime on a standard PC, which makes the complete system even more bulky.

The requirements of the newly developed Colour-the-INSight system are rather different from that of the previous demonstrators. Whereas demonstrators such as the Gecko, Viper and TRICLOBS are developed to demonstrate the Colour-the-Night fusion technique, the Colour-the-INSight system was developed as a prototype sensor system that may replace future rifle sight systems. This implies that the system should combine the capabilities of a current rifle sight system (direct view, aiming point) with those of a system fusing a digital image intensifier and a thermal sensor. It should be small and compact, easy to use, respond quickly (without delays), robust, and the processing should be performed on-board. The prototype Colour-the-INSight system was developed to meet these (sometimes conflicting) demands.

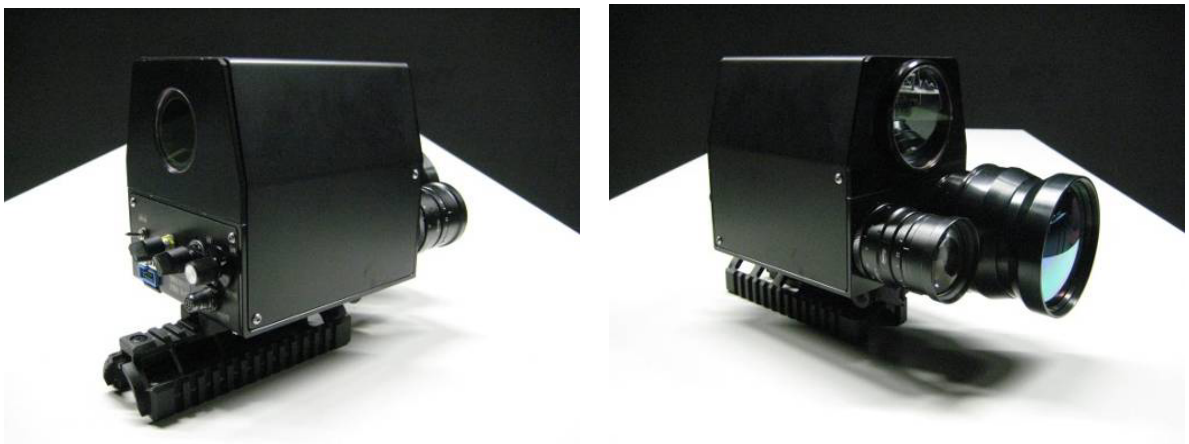
2. COLOUR-THE-INSIGHT RIFLE SIGHT SYSTEM

Figure 2 shows the prototype Colour-the-INSight (CTI) rifle sight system. It consists of various components. Direct viewing is possible through the system (the circular exit window is shown in Figure 2a, the entry window is shown in Figure 3b at the top). A target aim point (the image of a LED cross) is optically placed at infinite distance and added to the direct view using a collimator mirror. A LWIR sensor and the digital image intensifier are mounted side-by-side underneath the direct viewing system (see Figure 2b). The fused image of the two sensors is shown on a display that is combined with the direct view via a mirror.

The system contains an uncooled LWIR sensor (ULIS UL 04 17 1) with a resolution of 640 x 480 pixels. It is fitted with a lens with focal length of 75 mm (the large lens visible in Figure 2b), resulting in a horizontal field of view (HFOV) of 12.2 deg., and a vertical field of view (VFOV) of 9.1 deg. The digital image intensifier is an IBIS-10 with resolution of 1280 x 1024 pixels (fitted with a 75 mm lens, see small lens in Figure 2b), a HFOV of 10.5 deg. and a VFOV of 8.4 deg.

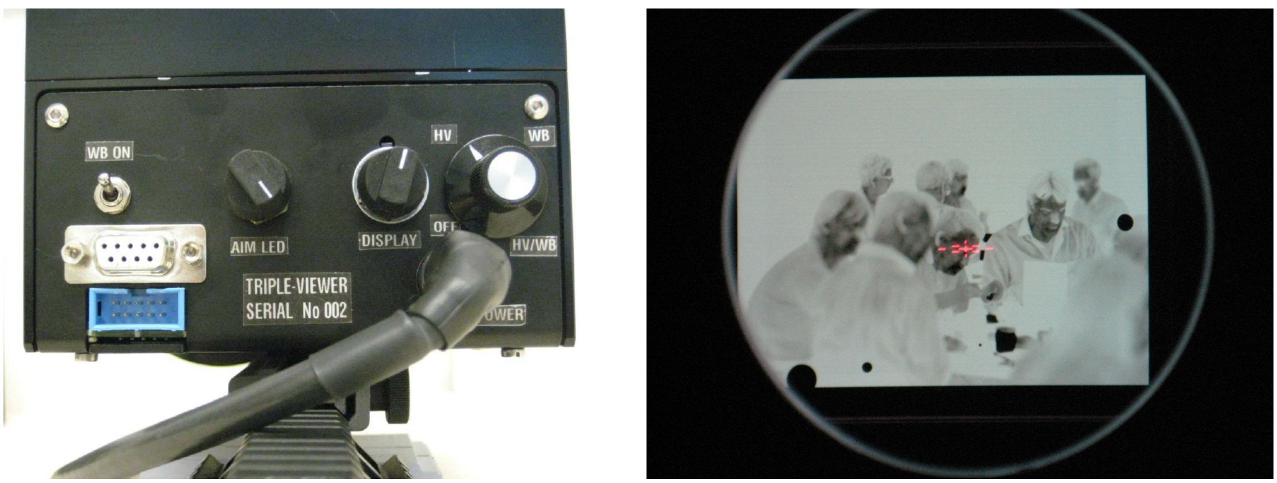
The images of both sensors are displayed onto a microdisplay (1280 x 1024 pixels), which is projected via a mirror and a lens into the viewing system. This results in a display with a HFOV of 12.2 deg and a VFOV of 9.8 deg. The images of the individual sensors are transformed in such a way that the FOVs are brought into correspondence with that of the display and the direct view. This means that the LWIR image is mapped onto a display area of 1280x960 pixels, and the image intensifier image is mapped onto a display area of 1106x885 pixels.

In this configuration the optical paths of the individual subsystems (direct view, image intensifier, thermal sensor) are not perfectly aligned, leading to some parallax. The distance between the thermal sensor and the image intensifier is 62 mm and the direct viewing path is located 70 mm above that of the sensors. This option was chosen because it results in a more compact design and no extra signal is lost due to filters or mirrors (as with the Viper, Gecko and TRICLOBS). The parallax is limited and may have an effect only on the recognition of objects that are small relative to the displacement. This means that for large objects this will have a negligible effect. However, the evaluation (to be discussed later) indicated that this may have interfered with the recognition of smaller objects. Still, this can easily be solved in the near future (see Discussion).



(a) (b)

Figure 2: The Colour-the-INSight system mounted on a picatinny rail (which can be mounted on a rifle).



(a) (b)

Figure 3. a) Back panel of the CTI-system showing the various user options. b) Photograph taken through the entry window showing the display with an image of the LWIR sensor with the aim mark superimposed.

To allow for maximum flexibility several options have been implemented in the system. Figure 3a shows the back panel of the system. Power to the system is fed via a cable from a (standardized) battery pack. By turning a knob the user can switch between various options. The user can choose to display the fused image, only one of the sensors (the LWIR sensor or the image intensifier) or no sensor at all ('off'). The brightness of the display can be adjusted using a separate knob. Also, the light intensity of the LED aim point can be adjusted. These light adjustments are necessary in case the display and LED are used in combination with the direct view: the light output has to match that of the scene which may vary widely from condition to condition. If the light output does not match that of the direct light either the display (or LED) becomes invisible (e.g. on a sunny day) or the direct view is masked (e.g. near sunset). The thermal sensor can be turned on or off via a switch. Figure 4 shows the LED aim point superimposed on the LWIR sensor image.

A RS232 connection can be set up with a computer to change various settings. This can be used to overrule the standard automatic gain control of the thermal sensor and optimize these settings by hand. The user can also choose for the option of using the thermal image in "black=hot" mode instead of the standard "white=hot" mode. The "Colour-the-Night" fusion algorithm is implemented using the colour lookup table method. A suitable colour transformation was derived from recordings made with the TRICLOBS system[9] and was uploaded in the form of a colour lookup table. The system allows one to upload other colour lookup tables that may be derived for a specific environment. A future user may have a set of colour transformations available that are dedicated to the particular environment or task of the upcoming mission, and choose a suitable colour transformation before starting the mission.

3. EVALUATION

A series of field trials were conducted to evaluate the Colour-the-INSight system. These evaluations involved tests with soldiers in the field as well as evaluations involving experts from TNO and expert users from the Ministry of Defense of the Netherlands. The field tests were performed in Bergen-Hohne (Germany) in august 2011. The tests that were performed during the daytime focused on the additional value of an overlay of the thermal image to the direct viewing system. At night additional benefit was expected from the colour fusing the two sensors.

Daytime

Figure 4a shows a daytime scene of a cabin with a person inside. The person is standing in the dark and therefore invisible to the naked eye. Figure 4b shows the same image with the thermal image superimposed into the direct view. The person is now clearly visible. This shows that a thermal sensor has added benefit also during daytime. Moreover, the combination with direct view (by optical fusion) makes apparent what the context is in a single image. The thermal image can therefore be used during daytime for the detection of hot targets or camouflaged persons. In these cases, the person will be difficult to detect by the naked eye, but will show up when combining direct view with a thermal image.

Identification of handheld objects

During night-time we determined identification performance for handheld objects using the CTI system. These tests involved a number of elongated objects (which could be mistaken for a weapon, such as broom, axe, etc) and two types of guns (see Beintema et al.[11] for a comparable test) and a number of soldiers as participants. Performance was determined in a static situation (using different distances) as well in a dynamic situation in which the soldiers carrying the objects were walking back and forth at decreasing distances from the viewer. Performance was compared for the fused image, the thermal image, and the image intensifier image alone. Performance for the fused image was found to be equal or worse than that of the image intensifier image, while performance using the thermal image was found to be best. This somewhat disappointing finding could be contributed to the fact that the sensor images turned out to be not properly aligned. This fact as well as the presence of a parallax in the system turned out to especially harmful for the recognition of objects that are small in relation with the misalignment (see section 2) placed at short distances, such as this case. This can partly be solved by realignment of the optical axes. The effect of the parallax may be further reduced by adding a variable offset to the images, without the need to modify the apparatus (see Discussion).

Detection of persons

Fusion can also help in the detection of targets, since it will display targets that are visible in one of the individual bands (see also Hogervorst & Toet[3]). For instance, when half of the targets is visible in one band and the other half in the other, performance with a single sensor will be 50% while performance can be up to 100% using the fusion system. To determine the extent to which the prototype CTI fusion system resembles such a perfect fusion system we performed a detection experiment in which the participants were required to detect persons under varying conditions. Figure 5 shows images of the scene containing all possible locations of persons used in the experiment: a) inside the cabin in the dark, b) in the cabin behind a window, c) at the driver's seat of a car with open window, and d) in the back of the car. At each of these 4 locations a person could either be present or not, leading to 16 (=2^4) configurations.

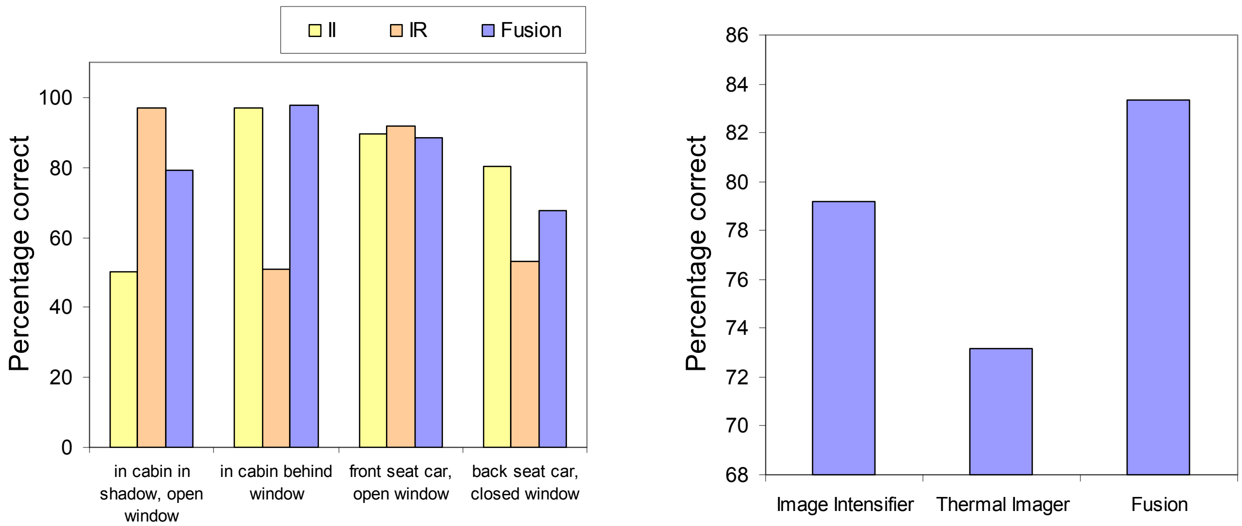
(a) (b)

Figure 4. During daytime combining direct vision with an overlay of the thermal image reveals hot targets (in this case a person in the shadow of a house).

(a) (b) (c)

Figure 5. Images of the scene used in the experiment; in this case persons are present at all 4 locations (behind left open window, behind right closed window, front seat of the car with open window, back seat of the car with closed window). Shown are images from the image intensifier (a), the thermal imager (b) and the fusion system (c).

An experiment was performed involving 9 soldiers as participants. To each of the participants we showed all 16 configurations (of persons in the scene) in random order for two of the image types (LWIR, image intensifier, or Fused image). With each scene the participant was required to report the locations where a person was present. Figure 6a shows the results of this experiment for the individual locations (the average standard error in the mean is 4.5%). In location (a) the thermal imager shows a performance which is close to 100%, while performance with the image intensifier is at chance level (50%). Intermediate performance is found for the fused image. In location (b) performance is at chance level with the thermal imager, and performance is close to 100% with the image intensifier. Performance with the fused image is the same as with the image intensifier. In location (c) high performance is found for all three image types. In location (d) performance with the thermal imager is close to chance, while the image intensifier shows the best performance. Also in this case, performance with the fused image is intermediate. Chance performance with the thermal imager for persons behind glass is as expected. A perfect fusion system would should performance that is similar to that of the best performing single band imager. This is the case for locations (b) and (c). In locations (a) and (d) performance is less than perfect. Figure 6b shows the average performance over all locations (the average standard error in the mean is 4.6%). The CTI-fused imager shows the best overall performance.



(a) (b)

Figure 6. Performance for detecting persons for the single band sensor systems as well as the CTI-colour fusion system for the individual location (a) as well as the overall performance (b), i.e. averaged over locations. Average standard errors in the means are around 4.5% in both cases.

(a) (b) (c)

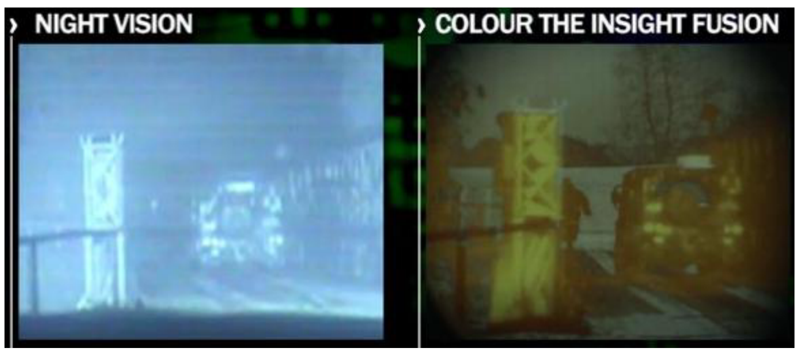
Figure 7. Images of the different sensor systems: a) image intensifier, b) thermal imager as well as the CTI-colour fusion system (c).

Overall impression

During the tests various situations were encountered that showed the additional value of the CTI-fusion system. Figure 7 shows the fusion image of a tank. Figure 7a shows the image of the digital image intensifier. This image clearly shows the camouflage pattern on the tank. Figure 7b shows the LWIR image with the (hot) tank and persons prominently in the scene. In the fused image (Figure 7c) the hot targets (tank and persons) are highlighted and the camouflage pattern is apparent. This is a good example of a fusion image that conveys the information apparent in the individual sensor images.

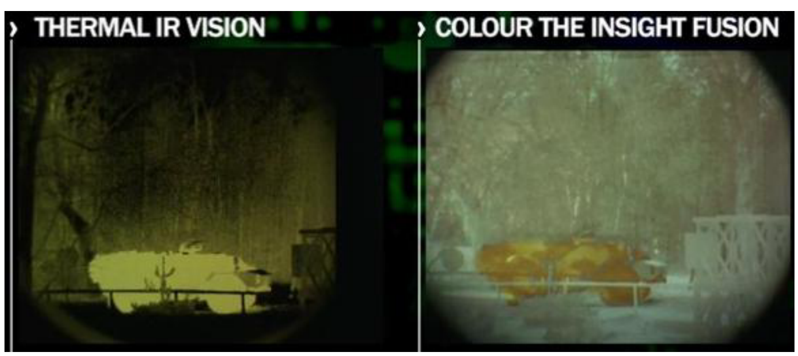
(a) (b)

Figure 8. Images of a scene of a person hiding in the back of a van, with a) the image as seen by the naked eye, and b) the image taken through the CTI-system with a thermal overlay superimposed on the direct view.



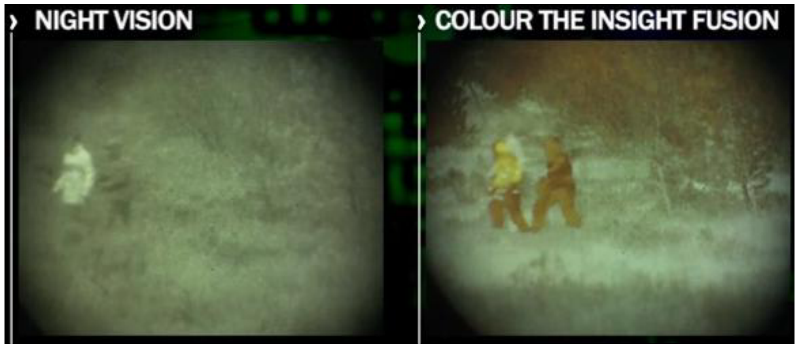
(a) (b)

Figure 9. Images of a nighttime scene containing a car and a person on a bridge during mist. Figure a) shows the image of a standard (white) image intensifier, b) shows the image of the CTI-colour fusion system.



(a) (b)

Figure 10. Images of a nighttime scene containing a military vehicle. Figure a) shows the thermal image, b) shows the image of the CTI-colour fusion system.



(a) (b)

Figure 11. Images of a nighttime scene containing an uncamouflaged person (a civilian) and a camouflaged person (a soldier). Figure a) shows the image intensifier image, b) shows the image of the CTI-colour fusion system.

Figure 8 shows a daytime scene that is comparable to Figure 4, with a person hiding in the back of a van. The person is invisible with the naked eye (Figure 8a) but becomes visible when the thermal overlay is added to the direct view (Figure 8b).

Figure 9 shows a comparison of a standard image intensifier and the CTI-fusion system taken in the mist. The person on the bridge disappears in the mist in the image intensifier image. The CTI-fusion image shows the person as well as the scene in the background (horizon, tree, etc) as well as the frontal parts that are visible in the image intensifier image.

Figure 10 makes a comparison between a thermal imager and the CTI-fusion system. The thermal imager shows the military vehicle but the surroundings not clearly visible. The CTI-fusion system shows the vehicle including the camouflage pattern as well as the surroundings (context), which originate from the image intensifier image.

Figure 11 shows a scene consisting of an uncamouflaged person (a civilian) and a camouflaged person (a soldier). The civilian is clearly visible in the image intensifier image, while the soldier is difficult to detect. The CTI-fusion system clearly shows both persons. This is another example in of image fusion in which the thermal imager is used to break camouflage, while the image intensifier gives information about the context.

4. CONCLUSIONS

In this study we have presented an innovative aiming device for a hand-carried weapon that incorporates sensor fusion based on thermal IR and night vision developed by TNO, Thales and Photonis in collaboration with the Ministry of Defense of the Netherlands. Images from both sensors are fused and coloured in real time, and then presented in the aiming device part of the system. The result is an aiming device that provides good visual information on the scenery during night & day, also in impaired vision situations (e.g., smoke, behind windows, in camouflage). The system displays various features that make it suitable for a wide range of situations. During daytime, the addition of a thermal overlay is beneficial for detecting hot targets (e.g. persons) that are invisible in direct view due to shadows or camouflage. During night-time the combination of an image intensifier with a thermal imager results in a colour fused image in which the information of the individual imagers is combined (e.g. salient hot targets and contextual information from the background, or targets that are visible in the individual sensor bands).

Various options have been implemented to make the system adaptable to the circumstances. The user can choose for the colour fusion system, one of the individual sensors or no sensor at all. The colour scheme can be adjusted by uploading a colour table that is optimized for the theatre or tasks of the upcoming mission. The brightness of the display and the aiming cross can be adjusted to match the lighting conditions.

Initial pilot experiments indicate that the alignment of optical axes of the individual sensors is critical for the identification of small objects (for which the detection distances are small), and that realignment may lead to improved performance. The parallax may further be reduced by implementing an adjustable offset that depends on the distance to the target. This can either be done by hand (using an additional knob on the system), or automatically (using the image content). Note however, that the parallax only affects the fusion for objects that are small (relative to the parallax) and close to the system. When viewing (larger) objects at larger distances, this is less of a problem (see e.g. Figure 7).

The current system is still rather large relative to a standard aiming system or an image intensifier. The availability of increasingly smaller sensor systems makes further miniaturization well feasible in the near future. This will also lead to a further decrease in parallax.

The availability of digital imagery enables the application of digital image enhancement techniques (e.g. super-resolution, local-contrast enhancement, noise reduction), and the combination of the images with synthetic databases[10,12]. Also, the imagery can be shared with others to create better situational awareness.

Initial tests have shown that there is still room for improvement. Many of these improvements can be implemented with relatively little effort in the system and do not represent fundamental problems of the system. Other improvements (i.e. miniaturization) require some more effort but do not (necessarily) lead to a design that is fundamentally different from the current one.

REFERENCES

1. Hogervorst, M.A. & Toet, A. (2010). Fast natural colour mapping for night-time imagery. Information Fusion, 11(2), 69-77.
2. Shi, J., Jin, W., Wang, L. and Chen, H., Objective evaluation of color fusion of visual and IR imagery by measuring image contrast, In: H. Gong, Y. Cai & J.-P. Chatard (Ed.), Infrared Components and Their Applications, pp. 594-601, The International Society for Optical Engineering, Bellingham, MA, 2005.
3. Hogervorst, M.A. and Toet, A., Evaluation of a color fused dual-band NVG-sensor, In: B.V. Dasarathy (Ed.), Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications 2009, pp. 734502-1-734502-7, SPIE - The International Society for Optical Engineering, Bellingham, WA, 2009.
4. Toet, A. and Franken, E.M., Perceptual evaluation of different image fusion schemes, Displays, 24(1) ,pp. 25-37, 2003.
5. Toet,A. (2006). Fusion of images from different electro-optical sensing modalities for surveillance and navigation tasks. In: R.S.Blum & Zheng Liu (Eds.), Multi-sensor image fusion and its application. (pp. 237-264). Boca Raton, Florida, USA: Taylor & Francis CRC Press.
6. Stuart, G.W. & Hughes, P.K. Towards understanding the role of colour information in scene perception using night vision devices, (Report DSTO-RR-0345), DSTO Defence Science and Technology Organisation, Fishermans Bend, Victoria, Australia, (2009).
7. Toet, A., Hogervorst, M.A. (2012) Progress in color night vision. Optical Engineering, 51 (1), 010901 (Feb 06, 2012);
8. Toet, A. and Hogervorst, M.A., Portable real-time colour night vision, In: B.V. Dasarathy (Ed.), Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications 2008, pp. 697402-1-697402-12, The International Society for Optical Engineering, Bellingham, WA, USA, 2008.
9. Toet, A. & Hogervorst, M.A. (2009). TRICLOBS portable triband lowlight colour observation system. In B.V. Dasarathy (Eds.), Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications 2009, SPIE-7345 (pp. 734503-1-734503-11). Bellingham, WA: SPIE - The International Society for Optical Engineering.
10. Toet, A., Hogervorst, M.A., van Son, R. & Dijk, J. (2011). Augmenting full color fused multiband night vision imagery with synthetic imagery for enhanced situational awareness. International Journal of Image and Data Fusion, Online first. DOI: 10.1080/19479832.2011.598135.
11. Beintema, J.A., Bijl, P., Hogervorst, M.A., Dijk, J. (2008) Target Acquisition performance: effects of target aspect angle, dynamic imaging and signal processing. Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XIX, edited by Gerald C. Holst, Proc. of SPIE Vol. 6941.
12. Dijk, D., Schutte, K., Toet, A. & Hogervorst, M.A. (2010). Image enhancement on the INVIS integrated night vision surveillance and observation system. In J.J. Güell & K.L. Bernier (Eds.), Enhanced and Synthetic Vision 2010, SPIE-7689-8 (pp. 1-12). Bellingham, WA: SPIE - The International Society for Optical Engineering.