Computer simulator for training operators of thermal cameras

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ABSTRACT

A PC-based image generator SIMTERM developed for training operators of non-airborne military thermal imaging systems is presented in this paper. SIMTERM allows its users to generate images closely resembling thermal images of many military type targets at different scenarios obtained with the simulated thermal camera. High fidelity of simulation was achieved due to use of measurable parameters of thermal camera as input data. Two modified versions of this computer simulator developed for designers and test teams are presented, too.

Keywords: thermal imaging, computer simulation, infrared

1. INTRODUCTION

Thermal cameras for night time and TV (CCD or CMOS) cameras for daytime can be nowadays considered as standard military equipment in surveillance applications for air force, navy, ground troops or paramilitary organizations like borders guards, or police. Effectiveness of these imaging systems depends significantly on their operators. There are usually no special problems with training military operators for use of TV cameras as these systems generate images similar to images generated by human eyes. However, training of the operators in use of thermal cameras is much more difficult and time consuming because of four basic reasons.

First, because of different spectral range of thermal cameras in comparison to the spectral range of human eyes, the thermal image differs very significantly to the visible image of the same scenario. Second, at least at present, thermal cameras are not stereoscopic systems like human eyes, field glasses or some image intensifier goggles; and is difficult to visually estimate the range to different objects seen in the thermal image. Third, there is no shades in thermal images even when the scenario is illuminated by the Sun, the moon or other artificial sources. This effect creates additional difficulties in determination the distance to the observed object. Fourth, training operators of thermal cameras is costly due to high price of consumable blocks like the cooler; and the high costs of time consuming field training.

Due to the reasons mentioned above, the interpretation of thermal images is often difficult for thermal cameras operators. Novice operators often are not sure whether they see real military targets of interest in the obtained thermal image or only typical natural objects. They have also difficulties with recognition and identification of the detected objects or to determine the distance to these objects.

Due to military demands there have been developed a few hardware/software image generators (computer simulators) during the last two decades [1-12]. These computer image generators create 2-D or 3-D, dynamic or static, IR or visible/IR synthetic images of different targets. There are however two basic limitation for wider use of present commercial image generators in training operators of thermal cameras. First, high price of dynamic 3-D image generators due to high requirements on computer power, use of specialized hardware accelerators, use of hardware image projection systems, and high cost of development of these highly specialized hardware/software systems. This high cost is usually acceptable in training of airmen but not in training of ground foot soldiers. Second, these image generators cannot simulate a precisely defined thermal camera. At present most of commercial IR image generators simulate images generated by an universal thermal camera, others offer qualitative regulation of a few camera parameters used as input data. However, none of them enable simulation of thermal cameras precisely defined on the basis of measurement results of the camera to be simulated.

A PC based image generator SIMTERM that allows its users to generate images closely resembling thermal images of many military type objects at different scenarios obtained with the simulated thermal camera is presented in this paper.

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High reality of simulation was achieved due to use of as input data measurable parameters of the simulated camera, and the parameters describing observation conditions like type of target, type of background, background temperature, target temperature, atmosphere temperature, atmospheric transmittance, distance between the simulated camera and the target. The developed software works on the standard PC, it is based on standard Windows interface, does not use special hardware accelerators and due to this low requirements can be used in training of foot soldiers or other low cost applications.
This computer simulator was developed with aim to use for training of operators of military thermal cameras. However, it can be used for educational purposes in civilian applications, too.

2. BASIC CONCEPT

An ideal software simulator for training operators of thermal cameras should enable generation of dynamic thermal images of any military target at any conditions and also for any parameters or settings of the thermal camera being used for observation. Generally such software should enable simulation of any factor present in diagram shown in Fig. 1. Therefore we can conclude that an ideal software simulator should posses the following features.
First, it should enable generation of thousands realistic 3-dimensional dynamic thermal and visible images of different military targets at different backgrounds.
Second, it should simulate influence of the observation conditions like the distance to the observed object, the background temperature and emissivity, and the transmittance and emittance of the atmosphere on the output image.
Third, it should enable simulation influence of typical parameters or settings of thermal cameras on the output image. Therefore, it should be required from such a computer simulator to enable changes of camera parameters like the temperature resolution, the spatial resolution, field of view, or such settings like contrast, brightness, polarity of the image.

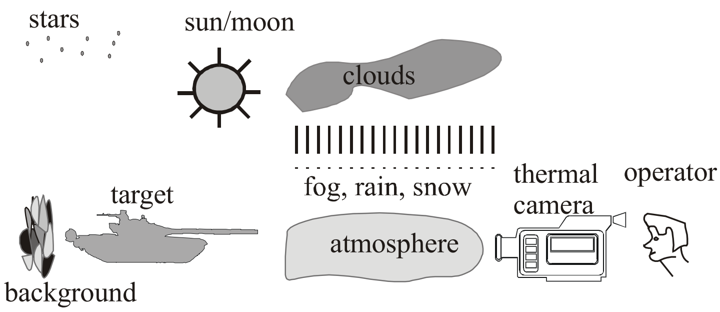


Fig. 1. Diagram of the observation channel

It is very difficult to fulfil all of the above presented requirements due to different reasons.

First, very expensive and time consuming field testing is needed to prepare a large base of realistic 3-dimensional base of interesting targets at different scenarios.

Second, only powerful specialized computers are able to render in the real time dynamic 3-dimensional realistic scalable images. At present typical PCs are able to render only simplified images similar to images used in software games.
Quality of images generated by typical thermal cameras is not high; typically is similar to quality of images from video cameras. However, when we want to simulate realistic thermal images we must generate images of a few times better resolution and simulate realistically noise and blur effects. Practically, this means a requirement for real time generation of photo-realistic 3D images and puts high requirements on required computing power.

Third, sophisticated mathematical models are needed to simulate quantitatively influence of the observation conditions, and parameter and setting of the simulated camera on the generated image.

At present, there are no commercially available computer simulators of thermal imaging systems that could fulfill all the above mentioned requirements [8-12].

Available bases of dynamic 3D thermal images are still too poor to enable training of operators of thermal cameras used in non-airborne applications. None of commercially available image generators does not enable simulation of precisely defined thermal cameras; they simulate a thermal camera in general or enable only qualitative regulation of a few camera parameters.

The concept of the presented in this paper SIMTERM image generator is based on two assumptions.

First, in most applications of thermal cameras by the ground forces, the navy, border guards, and police the thermal images are almost static. Thermal cameras are used for long distance observation and even in case of mobile targets the images can be treated as quasi static. It is usually also acceptable to use in training a series of 2D targets instead of a single 3D target.

Second, effective training of an operator of the thermal camera requires possibility to simulate not a thermal camera in general but exactly thermal camera to be used by the operator.

The consequence of the first assumption is significant decreasing of requirements on computing power to the level of typical PCs. The consequence of the second assumption is decision that the simulation realism must be the most important feature of the Simter simulator. Therefore, the mathematical model of Simterm simulator uses the most important camera parameters (that are measured during typical test process) and camera settings as basic input data.

3. PROGRAM STRUCTURE

Simter image generator is a computer program written in C++ using OpenGL graphic library that can work in the Windows 98/2000/XP operating systems. The program consists of four basic modules: the targets editor module, the observation conditions module, the camera module, and the visualization module.

The targets editor module enables creation and editing of thermal targets. The targets are created as a sum of polygons. Each polygon is characterized by its own temperature, shape, dimensions, and parameters describing its spatial and temporal changes. The polygons can be set in layers of different distance to the thermal camera. In this way, it is possible to create thermal targets of the class that can be classified as between typical 2D targets and true 3D targets.

The observation conditions module enables control of the distance camera-target, and the atmospheric conditions. The module calculates radiant signals emitted by the target and the background that comes to the camera input and creates the input image.

The camera module is the heart of the Simterm image generator. This module enables control of a series of arameters of the simulated thermal camera: field of view, spectral range, minimal resolvable temperature difference MRTD, modulation transfer function MTF, temperature resolution NETD, number of detector pixels, number of dead pixels, non-uniformity, and fixed pattern noise FPN. On the basis of the camera parameters and the data from the previously discussed modules the camera module calculates distortions of the input target image due to camera imperfection.

The visualization module creates final output thermal image for the current camera settings like: mode of field of iew(narrow, wide), brightness, contrast, polarity, digital zoom, optical zoom. The user can use manual mode when he can control manually all these settings or automatic mode when program optimize brightness level and contrast.

4. MENU

When the Simterm is run the user sees on the monitor screen the main window shown in Fig. 2. This figure shows a hermal image of a default target generated by a default thermal camera at default observation conditions. Now, the user has 3 options.

First, he can accept the proposed configuration: the target parameters and the camera parameters. Then he can control camera settings (brightness, contrast, mode of field of view, polarity, electronic zoom, optical zoom) or the observation conditions (distance target-camera, atmosphere conditions) and see how changes of these settings influence the final image. He can also use automatic mode when the brightness and the contrast are optimized automatically depending on the simulated scenario. The can user controls atmospheric conditions by changing action time and visibility conditions or by manual change of atmosphere temperature and atmosphere transmission coefficient.

Second, he can decide to simulate observation of another target, the same target on another background or to modify parameters of the current target. He should then click the button “Load/Edit” and start the target editor module (Fig. 3). Now, he can edit parameters of the current target (temperatures of different polygons, mean temperature of the whole target, dimension and shape of the target or of different polygons), import new targets, set type of background, or come back to the main window and simulate observation of the edited target using the simulated thermal camera.

The user can also choose another target from the targets library. The library consists of over a hundred of thermal targets that are potentially interesting in military and paramilitary applications like: peoples, animals, different buildings civilian and military vehicles, helicopters, aircraft, boats, ships, and different natural features. Most of the targets are static; some of the targets can do simple animations.

In case when the target of interest is not included into the library the user can create its own target and add to the library.

Fig. 2. Main window

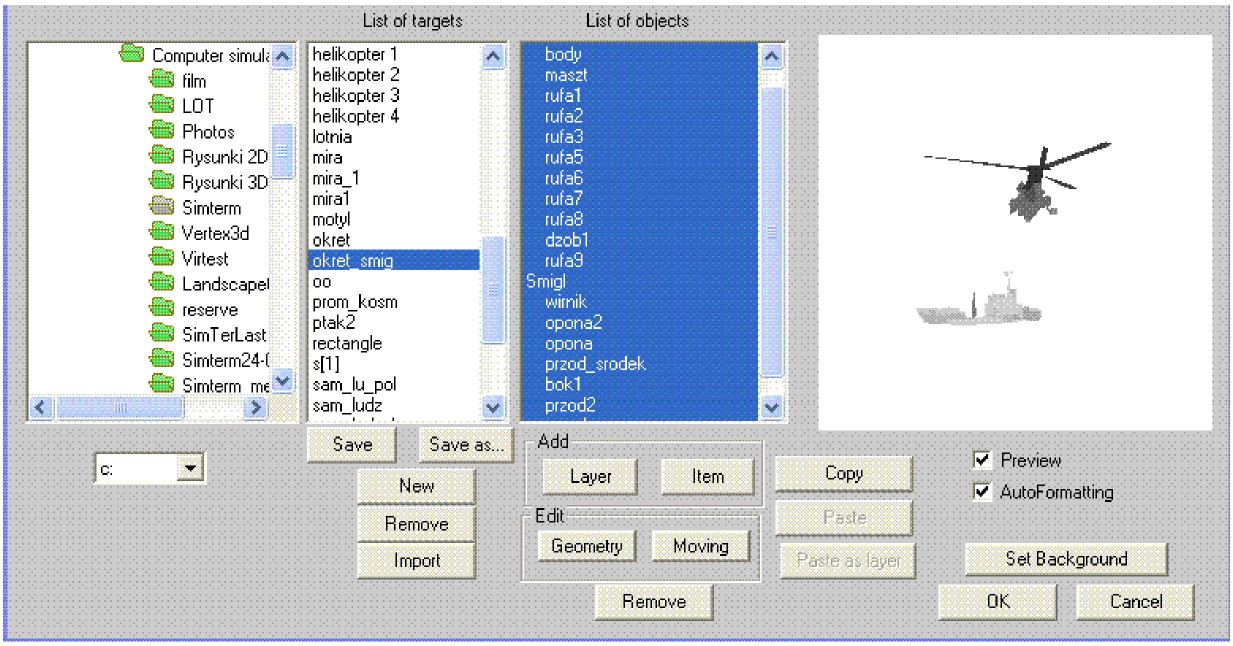


Fig. 3. Target editor window

Third, he can decide to change the simulated thermal camera. He can do it by clicking the button „Characteristics" and using the camera module (Fig. 4). He can then modify the following camera parameters: number of detector pixels, frame rate, field of views, camera vibration level, spectral range, minimal resolvable temperature difference MRTD, modulation transfer function MTF, temperature resolution NETD, number of detector pixels, number of dead pixels, non-uniformity, and fix pattern noise FPN (option: MTF or blur of the optics). The parameters mentioned above precisely define performance of the simulated camera. The user can define a few thermal cameras, create links, and later he can easily switch between images generated by different thermal cameras.

Having all the described options at his disposal the user can generate thermal images that could be generated by different real thermal cameras at different real observation conditions.

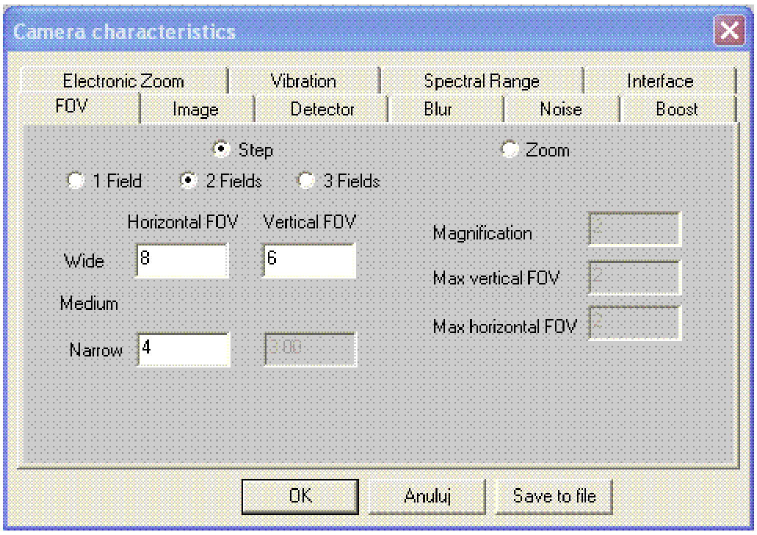


Fig. 4. Characteristics editor window

5. SIMTERM APPLICATIONS

In order to achieve high effectiveness of use of thermal cameras in military and paramilitary applications extensive training is needed. The operators must achieve perfection in control of available camera setting, memorize thermal images of targets of interest in different weather conditions and observation scenarios, and learn about capacities and limitations of the imaging systems they have at their disposal. Practically it means necessity to spend hundreds of hours at field conditions in order to muster these imaging systems. Using Simterm image generator enabling generation of realistic thermal images (Fig. 5, Fig. 6, Fig. 7) a significant part of the necessary training can be done in training rooms instead of field conditions. In this way Simterm creates possibility to speed up and reduce costs of training of operators of thermal imaging systems.

Simterm is currently offered as an independent program or as a part of an computer training system. In the latter case the system consists of a series of multimedia lectures, video films, animated films, and Simterm working in two modes: learning and testing. Using such a computer system the training of operators of thermal cameras can be done almost automatically.

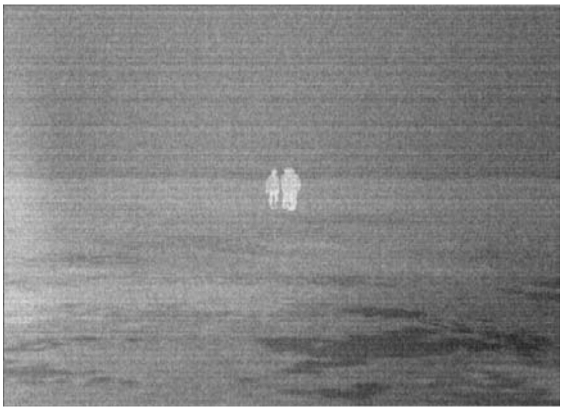
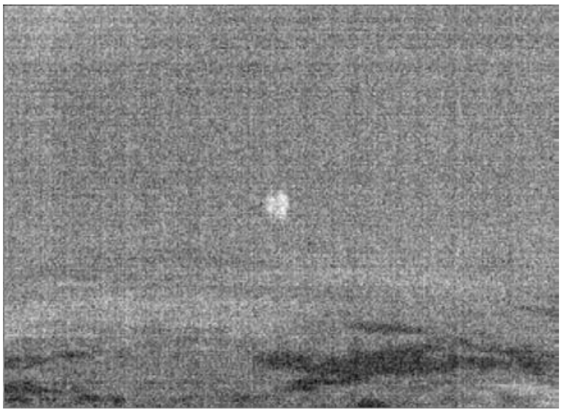
a)  b) 

Fig. 5. Thermal images of a group of people from 400 meters distance generated by a portable non-cooled thermal camera at a) clear atmosphere conditions b) snow conditions

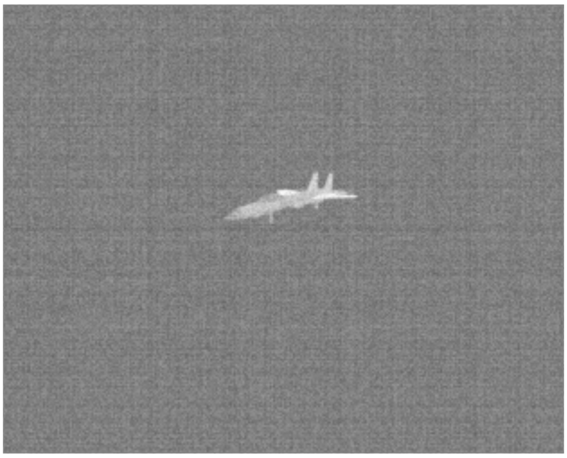
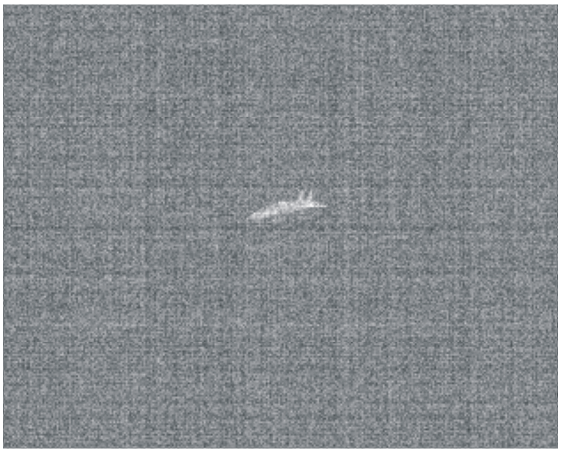
a)  b) 

Fig. 6. Thermal image of an aircraft generated by a cooled III generation thermal camera a) distance 1000 m, medium field of view, fog conditions b) distance 8000 m, narrow field of view, fog conditions

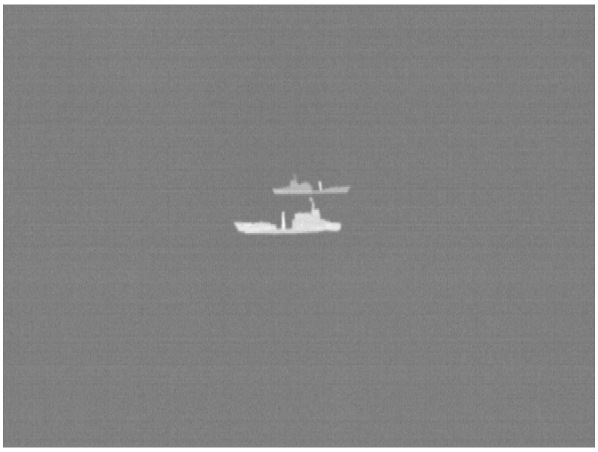
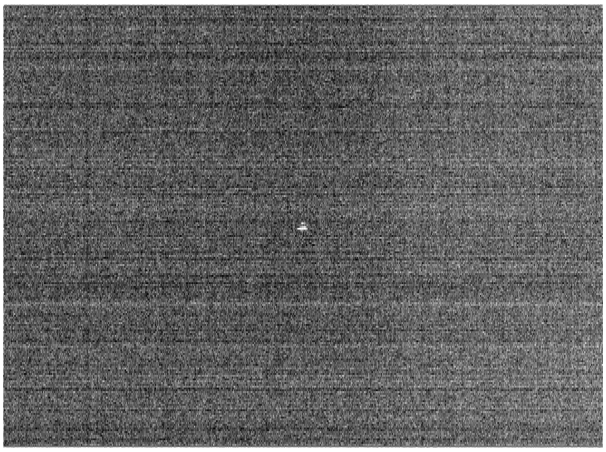
a)  b) 

Fig. 7. Thermal images of two ships generated by a cooled thermal camera at a) 1 km distance b) 10 km distance fog conditions

6. VIRTEST

Virtest is a modified version of Simterm simulator developed to enable training of operators of measuring systems used for measurement of MRTD – the most important characteristic of thermal cameras. MRTD measurement procedure can be fully simulated and repeated many times at any suitable conditions using VIRTEST. By carrying frequent virtual MRTD tests using VIRTEST observers can significantly improve repeatability of their indications.

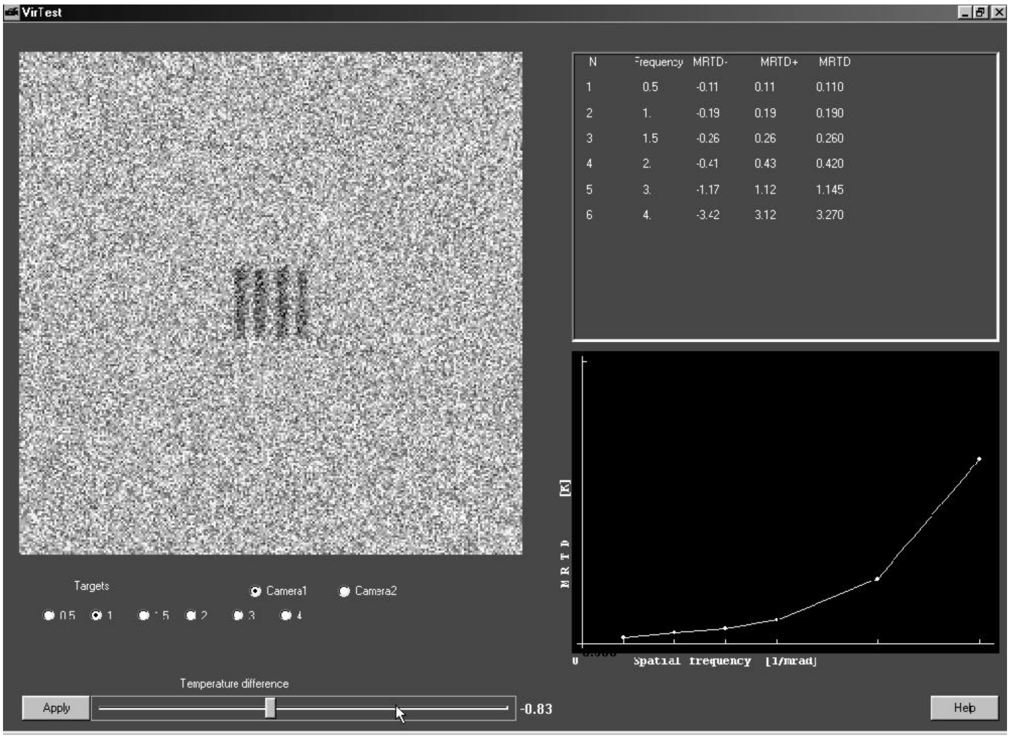


Fig. 8. VIRTEST – the main window

Virtest generates images of the standard 4-bar targets closely resembling images seen by operators of measuring systems used to test thermal cameras during MRTD measurement. The user chooses spatial frequency of the 4-bar target and later he regulates the temperature difference between target temperature and background temperature. Like in case of real measuring systems the user chooses the temperature difference when he recognises the bars. MRTD curve is automatically drawn on the bases of the user decisions.

Virtest can a useful toll for different groups of peoples: from professional working in field of testing thermal cameras seeking to improve accuracy of MRTD measurements to students interested in field of IR technology who want to understand MRTD test methodology. Virtest is a freeware computer program that may be used free of charge by anyone so long as the copyright notice and the comments above remain intact.

7. VIRCAM

Evaluation of different versions of a thermal camera is usually done in two steps [14]. First, calculation of MRTD characteristic of the thermal camera. Second, calculation of detection, recognition, and identification ranges of different targets using the camera of known MRTD characteristic. It is a standard reliable method used for many years all over the world. However, it generates only numbers and sometimes is difficult to compare performance of different cameras even for professionals. In such a situation Vircam simulator can be a valuable tool.

Vircam is another modified version of Simterm simulator developed for designers of thermal cameras to allow quick and easy visualization of capabilities of different version of the thermal camera to be developed. Vircam is based on philosophy that an image is worth thousands of words or numbers. Instead of generating numbers with detection, recognition and identification ranges the program generated realistic images of standard targets that could be generated using different versions of the thermal camera. Now, the decision which version is the best is made by designer on the basis of the quality of the compared images.

There are two most important differences between Vircam and standard Simterm. First, a series of standard targets (4-bar target, circular target, slit target, edge target, silhouette targets) was added to the target library. Second, additional parameters enabling simulation of different modules of the thermal cameras were added like: focal length, diameter and blur of the optics; detector normalized detectivity; bandpass of the electronics etc.

8. CONCLUSIONS

PC based image generator Simterm enables realistic simulation of thermal cameras used by army, navy, border guards and police. It can be used in training of operators of thermal cameras, when static of quasi static images are acceptable. Simterm is also a useful tool for designers of new thermal cameras as it allows visualization of capabilities of different version of the thermal camera to be developed.

In order to extend range of use of computer simulations in training of operators of electro-optical imaging systems the authors are working on a new image generator that could generate dynamic 3D thermal/visible images. The new image generator could be used in training of operators of standard airborne imaging systems: a thermal camera for night-time operation and a TV camera for day-time operations.

REFERENCES

1. J. Ruffner, K. Woodward, *Computer-based and web-based applications for night vision goggle training*, Proc. SPIE Vol. 4361, p. 148-158, Helmet- and Head-Mounted Displays VI, 2001.
2. B. Tingzhu, N. Li, *Digital simulation for low-light-level night vision imaging system*, Proc. SPIE Vol. 4222, p. 100-104, Process Control and Inspection for Industry, 2000.
3. J. Ruffner, K. Woodward, *Development of a night vision device driving training aid*, Proc. SPIE Vol. 3691, p. 184-194, Enhanced and Synthetic Vision 1999, 1999.
4. M. Lorenzo, E. Jacobs, *Optimized mapping of radiometric quantities into OpenGL*, Proc. SPIE Vol. 3694, p. 173-182, Modeling, Simulation, and Visualization for Real and Virtual Environments, 1999.
5. M. Lorenzo, B. Deaso, *DIS IR simulation models for fidelity, signature texture, and atmosphere sensor effects*, Proc. SPIE Vol. 2495, p. 42-50, Distributed Interactive Simulation Systems Applications, 1999..
6. CAE Invertron's "Intrest - *Target Recognition system trainer*" Manual ", 1995.
7. D. Garbo, E. Olson, D. Crow, C. Coker, *Real-Time Three Dimensional Infrared Scene Generation Utilizing Commercially Available Hardware*, Proc. SPIE Vol. 2741, 1996.
8. http://thermoanalytics.com/
9. http://www.cae.ca/
10. http://www.multigen-paradigm.com
11. http://www.es.com
12. http://www.quantum3d.com
13. STANAG 4347, *Definition of nominal static range performance for thermal imaging systems*, 1995.
14. *Night Vision Thermal Imaging Systems Performance Model,* Users Manual and Reference Guide, US Army Night Vision and Electronic Sensors Directorate, 2001