TRAINING WITH THERMAL DEVICES – A MAJOR ISSUE IN INCREASING SUCCESS OF ALL APPLICATIONS

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Abstract: *Training is a key factor in increasing success of all military and non military applications. This paper presents the main directions to be reached in a military application, target recognition, but the structured frame can also be applied to other non military applications involving with thermal devices. Training sessions, in both laboratory and real tactical field conditions, is a must considering the multiple threats occurring in a real tactical field. The work described in this paper used real targets as well as simulated targets.*

1. INTRODUCTION

Thermal cameras 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 percept different objects seen in the thermal image.

Third, there are no shades in thermal images even when the scenario is illuminated by the Sun, the moon or other artificial sources.

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 it became a constant need to develop hardware/software image generators and to perfectly match training guidelines suitable for air force, navy, ground troops or paramilitary organizations.

All these conclude to a probability definition for a target in the optoelectronic field of view to be resolved. This aspect will be discussed bellow, from the theoretically point of view.

Generally, a training program should enable simulation of any factor presented in diagram shown in Fig. 1.

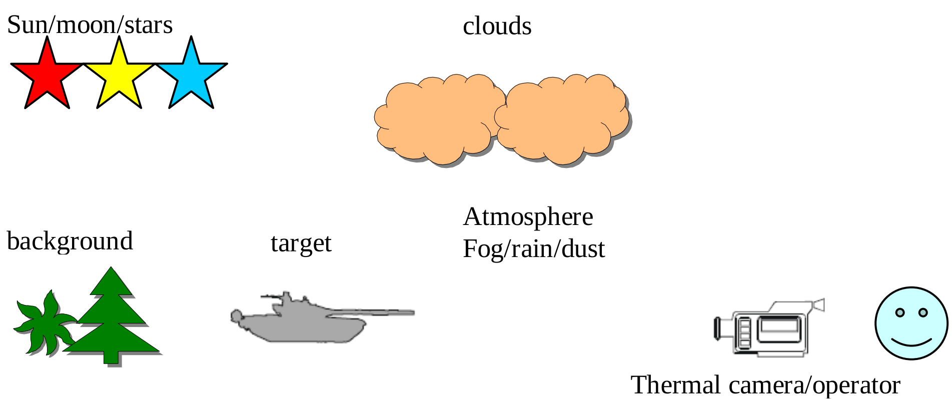

Fig.1 Influencing factors diagram

Talking about training as a key factor in target recognition enhancement, means to describe an entire process, with its hardware/software parts, trainers, subjects, instruction periods with respect to thermal cameras, well defined laboratory conditions and guidelines to be followed by the subjects being trained.

Therefore the software 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 of the influence of typical parameters or settings of thermal cameras on the output image (the temperature resolution, the spatial resolution, field of view, or such settings like contrast, brightness, polarity of the image).

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.

In order to start a training program, having a **training strategy** is a must. The generic training strategy recommended for vehicle recognition and identification skills must have the following core elements:

- ❖ Pretesting to determine where training should start.
- ❖ Teaching critical concepts and information that underlie the skill to be acquired.
- ❖ Training that starts at the soldier's skill level (basic or advanced) as determined by pretests, includes performance feedback and progresses from general to specific and from easy to difficult.
- ❖ Checking on skill progression with embedded or spot tests.
- ❖ Continuing with training as indicated by skill status.
- ❖ Conducting assessments of performance that include testing for transfer of skill.
- ❖ Providing spaced review of vehicles learned previously in conjunction with training on new vehicles.

The success of vehicle recognition and identification training depends greatly on the images available for the training. By success, we mean that soldiers acquire skills transferable to new imagery in the database itself and ideally to field settings with real vehicles as well. Training success does not mean that soldiers simply memorize the images presented during training. To accomplish this goal, a large database must be established, which can be a very costly part of the development process.

At a minimum, the following factors should be considered when wondering what type of IR imagery should be used:

- ❖ General considerations
  - High fidelity images with respect to the sensor(s) under consideration;
  - Imagery with few, if any, incidental cues;
  - Vehicles consonant with the soldiers' mission;
- ❖ Vehicle-specific considerations
  - Images of each vehicle from different viewing angles;

- Images of each vehicle at different ranges (from a close-up distance to distances where target detection should occur);
- Images scaled by actual vehicle size at different ranges;
- Stationary and moving views;
- Day and night time views;
- Black-hot and white-hot views;
- Non tactical views;
- Tactical views (through smoke or dust, live-fire, turret facing forward);
- Imagery taken at different times of the year, in different climates, or both;
- Imagery showing thermal signature changes as a function of vehicle operating time;
- Imagery for test purposes;
- Color photos of each vehicle for comparison with the thermal images.

An image database with these factors provides soldiers with a wide variety of examples. Soldiers need many examples in order to learn “the vehicle” and not “the image” or “the picture”. In addition, they are more likely to transfer their skill to field conditions if they have seen vehicles in a variety of conditions during training.

2. KEY FACTORS IN TRAINING PROCESS

The above shown factors to consider when both obtaining and using imagery for training thermal signatures can be also presented as follows:

2.1 regarding to target and background: vehicle aspect, incidental cues, different types of background (tree line, desert, open field, etc.), congestion coefficient, target area, area to be analyzed.

2.2 regarding to atmosphere: night and day, sunny and overcast, range to target, climatic conditions (dust, smoke, rain, fog, transmittance, emittance, etc.).

2.3 regarding to sensors: sensor type, image fidelity, sensor polarity.

2.4 regarding to operators: observing time, image scanning techniques, knowledge of thermal technology, knowing thermal features of vehicle classes.

2.5 regarding to instructor: presentation of specific vehicles and their cues, training exercise formats and strategies, target positioning in scene, target solving probability calculus, the equation for optimum distance from the observer to the display and the time needed for a single scanning process.

2.1 *Vehicle aspect*

Aspect is important as it strongly influences the ease with which a vehicle can be identified. It is well known that vehicle identification is easiest with flank views, more difficult with oblique aspects and hardest with front and rear views. Appreciation for aspect angle has an interdependent effect on vehicle identification. For instance, if subjects can determine that they are looking at the left front oblique of a vehicle, this has important implications for ascertaining the identity of that vehicle. Knowing the aspect angle also allows subjects to evaluate the level of risk present in a combat situation and to prioritize their attention.

Incidental cues

Incidental cues in the training imagery present a great threat to ensuring that soldiers can identify vehicles in an operational environment. An obvious attempt is often made to conceal any incidental markings or cues as insignias, an atypical vehicle configuration, the presence of a soldier and distinctive backgrounds in the scene. Subjects are likely to focus on these incidental cues rather than the characteristics of the vehicle itself.

Congestion coefficient, target area, area to be analyzed

Congestion coefficient represents the attribute of the whole image presented to the subjects. Ranged from 1 to 10, this factor will be lowered when subjects will have only few targets in the scene and increased when multiple targets will be shown. All of them affect the probability to resolve the target.

2.2 *Night and day*

For thermal signature training, it is critical to have imagery taken during the night and the day. Thermal sensors are often the primary target acquisition system regardless of time of day, and day and night signatures differ dramatically due to solar loading during the day. For instance, parts of the hull or turret may be cool at night and very difficult to detect, whereas during the day these components are quite visible because they have been heated from exposure to the sun. During the day, tracks and wheels often appear less hot relative to the rest of the vehicle.

If the vehicle has been operating, the engine and exhaust will still be hot, but their signatures will not be as distinct when the hull and turret are also hot.

Range to target

The thermal signature changes with range. More detail is visible at closer ranges. Fewer gradations in vehicle temperature are visible at longer ranges although the hottest spots still stand out. In combat, soldiers and leaders should engage targets at the farthest range possible, maximizing their weapon's stand-off capability. The literature suggests that soldiers can identify vehicles at tactical distances, particularly with flank and oblique views. But the most efficient training is on close-up images first, particularly with soldiers who have low initial skills. Advanced skill training should involve vehicles at greater and greater distances. Therefore, the image database must contain images of vehicles at different ranges. We think that 4 ranges will be OK, but 5 or 6 would work as well. More ranges would probably yield unnecessarily redundant information with each increment in range; fewer ranges would probably provide a change too great in the thermal signature with each increment.

2.3 *Image fidelity*

Image fidelity depends on resolution, contrast and luminance. A compromise must be found between these characteristics in order to achieve an image with a good fidelity.

Sensor polarity

Most thermal sensors have reverse polarity, where the hotter spots can be displayed as black (black-hot) or as white (white-hot). Switching from one polarity to the other helps the soldiers to discern critical features. By using both polarities, soldiers frequently are able to discern different pieces of information, which, collectively, help them identify the vehicle.

2.4 *Observing time*

Observing time is also an important characteristic that has to be correctly evaluated. The minimum observing time is calculated as the time necessary to scan the whole image. The value obtained can be an acceptable value for the observing time. Experiments revealed that a value for the observing time greater than 20s is useless and a plot will be presented bellow as example of how the probability of resolving the depends with observing time.

Image scanning techniques

The human eye searches a display by aiming the fovea at different locations in an image, rapidly moving from one fixation point to another. Each fixation lasts about a third of a second on the average. The large jumps are called *saccades;* a saccade plus a fixation is termed *a glimpse*. The saccades last only a few milliseconds and can reach speeds of 1000 deg/s. During the saccadic motion, vision is greatly reduced.

The speed and length of the saccade are dependent on the task, being faster for situations where, for example, the allowed time to perform the search is limited to a short interval, and being physically shorter when the density of information in the image is higher. For more complicated scenes, the fovea will tend to interrogate areas of high information content. The choice of the areas to interrogate will be governed in part by the observer's expectations and by the information desired from the image. Obviously the characteristic motion of the eye will play a central role in the ability of an observer to perform visual search; therefore, models of visual search must explicitly or implicitly account for some aspects of typical eye motion.

There are numerous factors which influence an observer's ability to acquire a target. Only some of the major considerations are discussed here.

For competition search, as would be expected, the more the target differs from the nontargets in contrast, shape, or size, the faster the target will be found. This assumes that other factors such as the number of targets and the target density are kept constant. Any other factors that would act to increase the target discriminability would also lead to decreased mean search times.

Also, as might be expected, increasing the number of false targets, their homogeneity, or the size of the search field will generally result in increased mean search times. Any change to the displayed image that would require an observer either to examine more objects, or to examine the objects in greater detail, will lengthen the search process.

Some authors found that an observer, while first training on a set of targets (in their case, letters of the alphabet), will scan more slowly while searching through a list for one of many targets. Others point out that after learning the target set thoroughly an observer can scan through a list looking for one of many targets in a target set just as fast as when scanning for a single target. There are aso authors who state that even though the scan rate for multiple targets may be the same after learning, the error rates increase. Practice also can improve the performance of tasks such as threshold detection that do not involve learning the shapes or characteristic features of targets.

If the observer has been pre-briefed so that he or she knows probable positions or states of the target, mean search times will be shorter. On the other hand, if a target does not appear very much like the mental image of the target that has been learned by the observer, the search process will be more difficult. If the target is camouflaged or partially occluded, the target discriminability from background decreases and the search process becomes correspondingly more difficult.

Knowledge of thermal technology

The better subjects understand the nature of FLIR and the parameters that affect what is seen through a thermal sight, the more adept they become at interpreting thermal signatures. This knowledge will also facilitate transfer from night to day images, to new tactical images, to interpreting objects in the terrain, and to detecting targets.

Knowing thermal features of vehicle classes

It is obvious that vehicles within a certain class or certain type have similarities (tanks are tracked, have a main gun and a turret and typically the engine is in the rear). In addition, there are some distinctions among classes or types. Basic instruction on vehicle types or classes should precede training on naming individual vehicles, as knowledge of these features helps narrow a soldier's choices considerably.

2.5 *Presentation of specific vehicles and their cues*

When soldiers are first exposed to a set of vehicles, they need to be presented with images that help them internalize the "thermal representations" of those vehicles. There are many ways to accomplish that goal. Critical to this instruction are the following visual displays for each vehicle:

- Comparison of thermal and visible (color) images
- Displays that allow a 360 degrees view
- Displays showing changes in thermal signature with distance
- Videos of the vehicle moving at tactical speeds

Side by side visible and thermal displays help soldiers relate daylight to thermal images. These displays provide connection between the "known" and the "unknown". Another technique can be to mix the images: a visible image of the vehicle is shown, which turns then into a series of white-hot and black-hot thermal images, and then back to the original visible image.

The program (software) should point out the specific thermal features as the images are displayed. Conduct this instruction with near images. Cues common to most vehicles (engine, tread friction and exhaust heat) and cues associated with vehicle classes (large, prominent turrets on tanks) should be pointed out for each vehicle. And finally, the features that give each vehicle its unique thermal signature must be stressed. This signature is impacted by the vehicle's shape, its hot spots, the arrangement of these hot spots and the other temperature differences on the vehicle that are typically less distinct, yet integral to its signature.

Training exercise formats and strategies

To most operators, the vehicle identification task is intrinsically motivating. And if the training exercises are highly interactive, are progressively challenging, provide timely feedback and stress the perceptual nature of the task, operators will learn while also enjoying the training experience. Many exercise formats are possible, but in all cases it is important to keep the following in mind:

- The skills to be trained
  More than one skill can be of concern: determining the vehicle's class, identifying the vehicle by name, determining vehicle angle or aspect, responding quickly as well as accurately, etc.;
- Integration of initial instruction with interactive practice
  Instruction on each vehicle's characteristics should be well integrated with the vehicle sets and part-task training schedule;
- Advanced skill training
  Develop additional exercises to improve soldier skills with more challenging imagery (but not that imagery included in the initial instruction and practice sessions);
- Performance feedback
  Feedback that provides diagnostic information is invaluable. Good feedback will prevent learning plateaus, help soldiers transfer and retain skill and make the learning process meaningful.

Target positioning in scene

A central positioning of the target should be avoided and the range variances should be done without centering the target in the image. The operators are often tempted to spend more attention on the centre of the image and doing so they lose quite lot of information from the edges of the image.

Target solving probability calculus

The probability for a target in the optoelectronic visual spectrum to be discovered is given by the equation:

$$P_{\det} = P_1 \cdot P_2 \cdot \eta$$

where P1 is the probability that the observer, looking an area in the tactical field with a potential target, regards with fovea for a certain time in the target direction, P_2 is the probability that the image shown on the screen, seen with fovea and with no noise, have enough contrast and size to be detected.

The probability P_1 is difficult to be estimated because it is influenced by solid angle of the visual spectrum with the centre in the eye focal plane of the observer, by confused element number in the tactical field and by the presence of any information regarding the target position in the tactical field.

The equation for P_1 is:

$$P_1 = 1 - e^{-\left(\frac{700}{G}\right)\left(\frac{a_t}{A_s}\right)t}$$

where, a_t is target area, A_s is area that will be analyzed and is the visual field area in the object plan, t is the observation time, G is the congestion coefficient having a value from 1 to 10 for majority targets of interest.

The variation of the detection probability with observing time is calculated and plotted in MathCad:

$G_1 := 1 \quad G_2 := 5 \quad G_3 := 7 \quad G_4 := 10$

$a := 4\ m^2$

$A := 2000\ m^2$

$t := 0, 0.1 .. 50s$

$$P_1(t) := 1 - \exp\left[-\left(\frac{700}{G_1}\right)\left(\frac{a}{A}\right)t\right]$$

$$P_2(t) := 1 - \exp\left[-\left(\frac{700}{G_2}\right)\left(\frac{a}{A}\right)t\right]$$

$$P_3(t) := 1 - \exp\left[-\left(\frac{700}{G_3}\right)\left(\frac{a}{A}\right)t\right]$$

$$P_4(t) := 1 - \exp\left[-\left(\frac{700}{G_4}\right)\left(\frac{a}{A}\right)t\right]$$

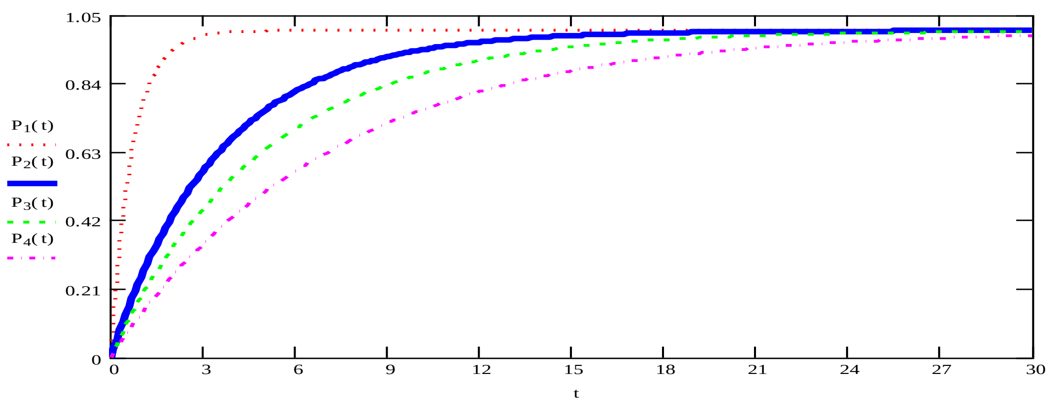

Fig. 2 Detection probability vs observation time and no range variation but with different congestion coefficient

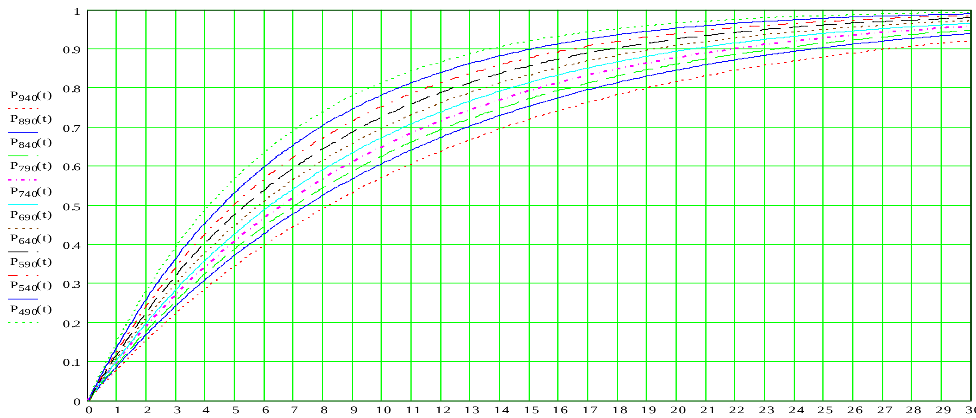

Fig. 3 Detection probability vs observation time
and range variation but with constant congestion coefficient

The equation for optimum distance from the observer to the display and the time needed for a single scanning process

The equation for optimum distance from the observer to the display is:

$$l_{opt} = \frac{L}{2tg\frac{\alpha}{2}}$$

where

- $\alpha = \frac{N}{n_{opt}}$, $n_{opt} = \frac{60}{separation\ angle}$;
- N the number of pixels on L dimension;
- n_{opt} the optimum pixels number in a degree;
- l_{opt} the optimum distance to the display.

The time needed for a single scanning process:

$$t = \frac{horizontal\ view\ angle}{5^0} x \frac{vertical\ view\ angle}{5^0} x0.3$$

where 5 degrees represents the instantaneous field of view of the eye and 0.3 represents the eye integration time.

Table 1 – The separation angle values for human eye

Luminance (cd/m^2)	Separation angle (minutes)	Luminance (cd/m^2)	Separation angle (minutes)
0.000032	50	0.032	3
0.00016	30	0.16	2
0.00032	17	0.32	1.5
0.0016	11	1.6	1.2
0.0032	9	3.2	0.9
0.016	4	32	0.8

Conclusions:

This paper highlights some of the dilemmas that must be attended to when creating a combat vehicle recognition training package, and has given direction to individuals interested in creating a package that offers benefits over and above that which can be taught in traditional ways. Such a program (software) must provide immediate and individually feedback, employ appropriate exercise formats, adapt to individual differences in skill and rate of learning and provide practical, realistic training that truly prepares soldiers to identify vehicles in battle situations. It is also important to strike an even balance between speed and accuracy. Although emphasizing speed in training ensures soldiers learn to react quickly in combat, if accuracy is not equivalently emphasized, many of those rapid reactions can result in misjudgments and fatal errors.

To become proficient in thermal combat vehicle identification is to learn a way to think about vehicles and their respective heat signatures. The instruction and training must balance the use of images and words to facilitate soldiers' understanding of the vehicle's thermal signature. Because thermal imagery is dynamic and battle situations contain factors that cannot be totally anticipated in any training package, the soldier must leave training with a comprehensive and systematic way in which to think about vehicle's heat signatures.

The extent to which these goals can be achieved is not limited by the multi-media training medium. Rather it depends on our knowledge of how individuals best learn the thermal signatures of vehicles and our ability to apply these lessons learned to the instructional software. **Therein lays the art of training.**

4. BIBLIOGRAPHY:

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