Experimental setup for non-subjective method of thermal sensor performance testing with the Triangle Orientation Discrimination (TOD) method using Infratest

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ABSTRACT

The Triangle Orientation Discrimination (TOD) method represents a reliable and non-subjective alternative to the traditional MRTD (Minimum Resolvable Temperature Difference) and MRC (Minimum Resolvable Contrast) metrics for the evaluation of infrared and visible electro-optical (EO) imaging systems[31].[2] However, despite its conceptual advantages, the TOD is complex to implement experimentally: in contrast to the MRTD, which is relatively straightforward to perform, the TOD requires rigorous control of several practical constraints such as stimulus presentation time, balanced occurrence of the four triangle orientations, observer training, and the need to avoid any orientation cues. The purpose of this paper is to address this gap by presenting the experimental methodology of TOD test performed by HGH Infrared Systems on thermal imagers, enabling accurate and repeatable TOD results.
The tested infrared camera is a $FLIR\ Tau2$ with $100mm$ focal length lens. The experimental setup is made up of an off-axis parabola based collimator, a differential blackbody and dedicated test patterns. The blackbody and motorized wheel are controlled by Infratest software,[7] developed by HGH, that also runs the TOD test. We demonstrate that the method successfully respects all TOD constraints while remaining experimentally feasible. The experimental data resulting indicate an increasing trend: as the spatial frequency increases, smaller details become more difficult to distinguish, and a higher thermal contrast ΔT is needed. A curve is fitted to the measurement data to illustrate the nonlinear relationship between ΔT and the reciprocal angular subtense S_R. By successfully addressing the practical constraints that have long restricted experimental TOD testing for infrared cameras, this work offers a validated and reproducible methodology for performing practical TOD measurements, facilitating wider adoption of this metric in EO system assessment.

Keywords: triangle orientation discrimination, TOD, electro-optical system evaluation, infrared systems

1. INTRODUCTION

The Triangle Orientation Discrimination (TOD) is a method used to characterize the performance of electro-optical imaging systems. It was originally introduced by P. Bijl and his team in the late 1990s at TNO (Netherlands Organization for Applied Scientific Research) as a characterization method for optical systems that became later an objective alternative to the classical Minimum Resolvable Temperature Difference (MRTD) metric.[1,2] In contrast to MRTD, which relies on subjective characterization, the TOD method is based on a forced-choice discrimination task, significantly reducing observer subjectivity and improving measurement repeatability.

The TOD methodology has since been developed and used within the electro-optical community and is now recognized as a robust performance metric for imaging systems. In particular, it has been promoted through the European Computer Model for Optronics Systems (ECOMOS),[4]to harmonize test procedures and performance evaluation methodologies. In parallel, NATO standardization efforts have historically relied on MRTD as a reference metric (e.g., STANAG 4347 for thermal imaging systems[6]). However, due to the known limitations of MRTD, particularly its dependence on observer subjectivity and ambiguity between detection and discrimination tasks, recent updates indicate that MRTD-based NATO procedures are being withdrawn, reflecting their decreasing relevance for advanced processed imaging systems. Meanwhile, the TOD method has progressively gained interest as an alternative approach[1].[2] More recent studies and contributions within the electro-optical community have demonstrated that TOD provides a more representative metric of operational performance than MRTD.[3,5]

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Although the underlying concept of the TOD is relatively simple, the practical implementation of the TOD test, including stimulus generation, observer interaction, and data processing, requires a rigorous experimental setup to ensure reliable and reproducible results.

This paper presents the implementation of the TOD test within Infratest software developed by HGH Infrared Systems, the algorithm used to determine the discrimination threshold of 75%. The proposed method details the processing of the experimental data, including the handling of positive and negative contrast values and the fitting strategy used to estimate the threshold. The objective is to provide a clear and reproducible methodology for TOD data analysis in an industrial context.

2. METHODOLOGY

2.1 Principle of the TOD test in Infratest

The TOD test is based on the observation of an equilateral triangle displayed on a uniform background. The triangle has four possible orientations: one of its apexes is directed up, down, left, or right. The observer, who does not configure the setup, must identify the orientation of triangles of different sizes and contrasts.[1] This four-alternative forced-choice paradigm (4AFC) ensures that a random guess corresponds to a success probability of 25%,[8,9] which corresponds to a triangle below discrimination threshold. The 4AFC paradigm also presents additional advantages over the MRTD beyond the forced-choice protocol. Unlike the MRTD, which uses a periodic bar pattern, the TOD relies on a spatial target whose shape is representative of real objects and degrades under imaging system limitations, more consistent with operational conditions. Periodic patterns such as the MRTD 4-bar target can introduce aliasing artifacts that are not representative of actual target appearance. Furthermore, a pseudo-random phase shift is applied between targets of the same size, which is particularly relevant for under-sampled imagers: near the resolution limit, the perceived shape of the displayed triangle — and therefore the observer's response — depends on the position of the target relative to the detector pixels. Historically this shift is set to about 0.5*S[1](S being the triangle size).

In Infratest this concept has been successfully integrated. In case of a lack of response after a certain delay, Infratest chooses a random response on the behalf of the participant. Therefore the probability for this answer to be right is 25%
Although the TOD method is primarily used in thermal imaging as an alternative to MRTD, its principle is not limited to infrared systems and can be extended to the visible domain. In this context, the thermal contrast, $\Delta T = T_{\text{target}} - T_{\text{background}}$ corresponds to a visible contrast defined luminance difference $\Delta C = L_{\text{target}} - L_{\text{background}}/L_{background}$, enabling a similar discrimination based performance assessment.

Similarly to MRTD, a thermal contrast ΔT is applied between the target and the background for different triangle sizes. However, unlike MRTD, only one answer is correct while the other three are incorrect. Therefore, a success rate of 25% corresponds to random guessing, which means that the triangle is not sufficiently visible to allow reliable discrimination. A success rate of 75% is conventionally defined as the discrimination threshold, corresponding to the minimum thermal contrast ΔT for which the orientation of a triangle of a given spatial frequency can be clearly identified.[1] This method requires the observer to discriminate orientation rather than simply assess the presence of a target; consequently, the TOD metric integrates both optical system performance and human visual perception into a single measurement framework and gives an objective characterization of the tested imager.
In our implementation, we used a collimator for projection of the TOD target far in front of the thermal camera. The collimator is an off axis parabola collimator from HGH as shown in figure 1. Another simple setup would be to place the thermal camera directly in front of a differential blackbody with a TOD target fixed on it.

Figure 1. IRCOL collimator used for the TOD implementation

The collimator is equipped with a motorized target wheel driven by a controller through Infratest software installed on the dedicated laptop for the test. The tested thermal camera is mounted with its lens on the optical table in front of the collimator's exit pupil. The camera sees the target image at infinity generated by the collimator and is also connected to Infratest on the test laptop. The image acquisition of the tested camera in displayed on Infratest, on which we can see the target pattern. Before tackling the TOD test, we made sure that the camera lens is well adjusted. To do so we used a knife-edge target mounted on the target wheel, we then launched the LSF/MTF test on Infratest and adjusted the camera lens focus to have the best MTF and LSF as shown in figure 2 .

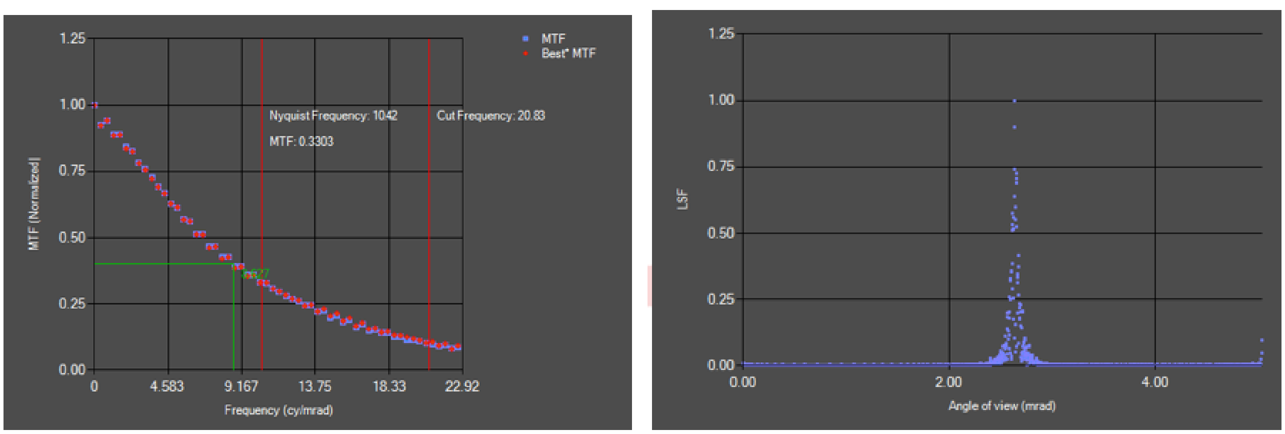


Figure 2. MTF and LSF tests on the camera before TOD test

After adjusting the focus of the camera lens, the TOD test can start.
In Infratest, an important step is built to perform the calibration for any unit under test (here the FLIR Tau2 camera), since the optical properties may vary from one camera to another. The purpose of this calibration is to allow Infratest to accurately locate the triangle patterns in the image so that the software can correctly crop the relevant triangle regions of interest. For each selected spatial dimension S_R, the operator first sets a differential temperature, usually set at $\Delta T = 2K$, to be increased if necessary until the triangle pattern positions become visible. The camera under test must be properly configured (MTF/LSF test done before) before launching this step. The image is then displayed in Infratest image panel, where the operator selects the appropriate region of interest corresponding to the chosen dimension starting from the top-left and then bottom-right triangle. Such calibration is particularly important in an automated TOD procedure, since the reliability of the measurement depends not only on the optical setup, but also on the robustness of the video acquisition and display chain.

2.2 Calculations

As the TOD test is based on the observation of different sized triangles, we need to calculate their size and distribution before their fabrication. The size of the triangle is defined by its base:

$$B = \frac{2}{\sqrt[4]{3}} \times \frac{f_{col}}{S_R} \tag{1}$$

where B is the base of the triangle in mm, S_R the Reciprocal Angular Subtense in $mrad^{-1}$ and f_{col} the focal length of the IRCOL in mm.

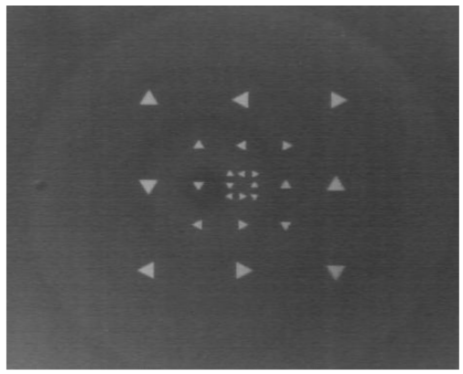


Figure 3. Physical TOD target pattern observed by the thermal camera through the IRCOL during setup and alignment (not to be mistaken with the displayed ROI triangles presentations).

Figure 3 illustrates the physical target arrangement seen by the camera, but it should not be interpreted as the image presented to the observer during each response task. Indeed,during the TOD test, the participant interacts only with the presentations showed by the software. Each presentation is a single triangle in its ROI displayed at a random orientation and location in the screen.
We can compare the triangle pattern of the TOD to the 4-bar pattern used in MRTD measurements. In MRTD test targets, one spatial period is defined by a pair of lines (one "hot" and one "cold"), corresponding to one cycle. In the TOD case, the base of the triangle can be interpreted as an equivalent spatial period, enabling a direct correspondence between the spatial frequency expressed in cycles per milliradian (cy/mrad) used in MRTD and the reciprocal angular subtense S_R used in TOD (in mrad^{-1}). This comparison highlights the similarity between MRTD and TOD definitions of spatial frequency, despite their different target geometries and discrimination tasks.

For each value of S_R (in this experiment we calculated three sizes of triangles), the ΔT values are chosen by the test operator who is not a participant, in order to have the best Weibull distribution covering the 25-100% range of success rate. For each S_R we determined the minimum contrast ΔT giving at least 75% correct answers (TOD threshold). The TOD curve, which is a graph of contrast ΔT at 75% success in (mK) versus S_R, is then plotted as shown in figure 6. In psychophysical experiments, the relationship between stimulus level and probability of correct response is commonly described by a psychometric function.[1] In the TOD test, this function is usually modeled using a Weibull function, which shows the progressive transition from random guessing to reliable discrimination performance.[1] The psychometric function can be written as:

$$P(x) = (1 - \delta) - (1 - \gamma - \delta)\, 2^{-(x/\alpha)^{\beta}} \tag{2}$$

where x is the stimulus level (ΔT in our case), α is the threshold stimulus value, β controls the slope of the function, γ is the random guessing rate (25%), and δ accounts for wrong-typing error historically[1] set at 0.02.

Although the psychometric function is typically modeled using a Weibull function, a second-order polynomial can provide a reasonable local approximation in the transition region, where the probability of success varies smoothly with the stimulus level. In our approximation we used this approach to fit the success rate vs ΔT curves.

3. EXPERIMENTAL IMPLEMENTATION

The objective of the measurement is to determine the minimum contrast ΔT for which the observer correctly identifies the triangle orientation in at least 75% of the trials. This value defines the TOD threshold for the considered spatial frequency S_R. In practice, the reliability of this estimate depends on the number of presentations performed at each contrast level: a higher number of trials improves the statistical reliability of the measured success rate, which follows a binomial distribution in forced-choice experiments.[8,9] Therefore, it is recommended to use a sufficient number of presentations per ΔT, typically on the order of 16 trials and a phase shift of 0.5 to ensure a robust estimation of the threshold. While no strict requirement exists, such values are commonly adopted in practice to provide sufficient statistical reliability in forced-choice experiments.[1,9]

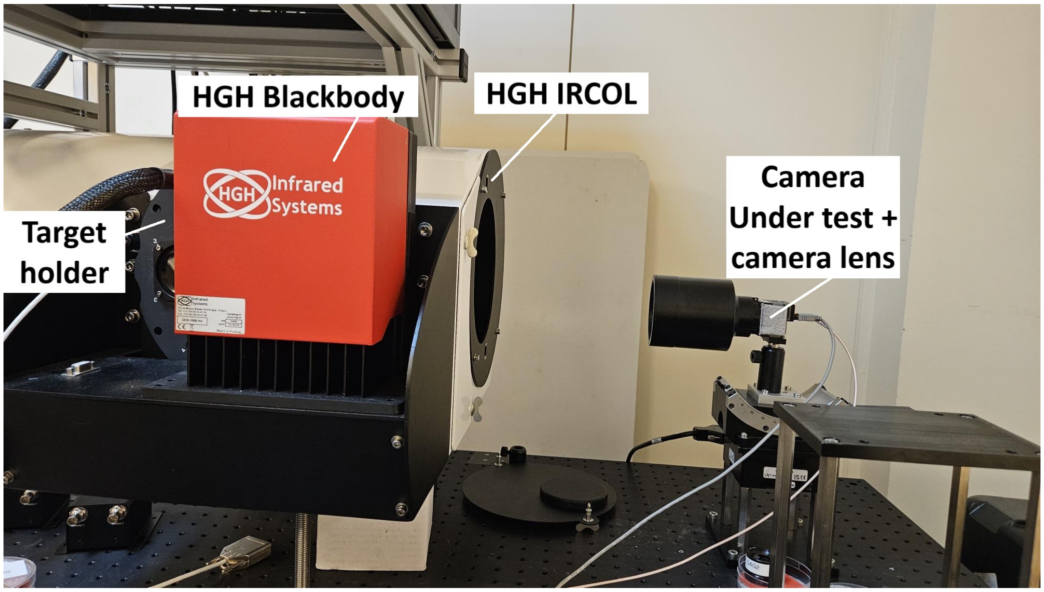
Of course the more presentations the longer the test : each trial lasts $2 seconds$ which means $32 seconds$ per ΔT (for 16 presentations). If we choose 7 ΔT values for each triangle size it would mean $224 seconds$ per triangle size. In our Experiment we defined 3 triangle sizes, which means an effective duration of the experiment of $672 seconds$ (11 minutes). Considering the heating and cooling time of the blackbody we can assume an average duration of 15 minutes, which is extremely short compared to an MRTD test with an equivalent number of frequencies, that can last as long as the participant chooses to contemplate the patterns to decide whether he discriminates them or not. This is one of the major advantages of the TOD implementation in Infratest: the procedure is highly efficient in terms of test duration, and it has been optimized such that each step of the test contributes to both the robustness of the measurement and the overall efficiency of the procedure.

In addition, another factor for relevant statistical data is the levels of ΔT: the sampling should be concentrated in the transition region of the psychometric function, where variations in ΔT result in success probabilities ranging from 25% to 75%, ensuring that the most informative part of the curve is properly sampled. In contrast, fewer measurements are required in the saturation regions (near 25% and 100%), where the probability of success remains nearly constant with ΔT. This strategy maximizes the information content for threshold estimation and is consistent with standard practices in psychophysical experiments and psychometric function fitting.[9,10]

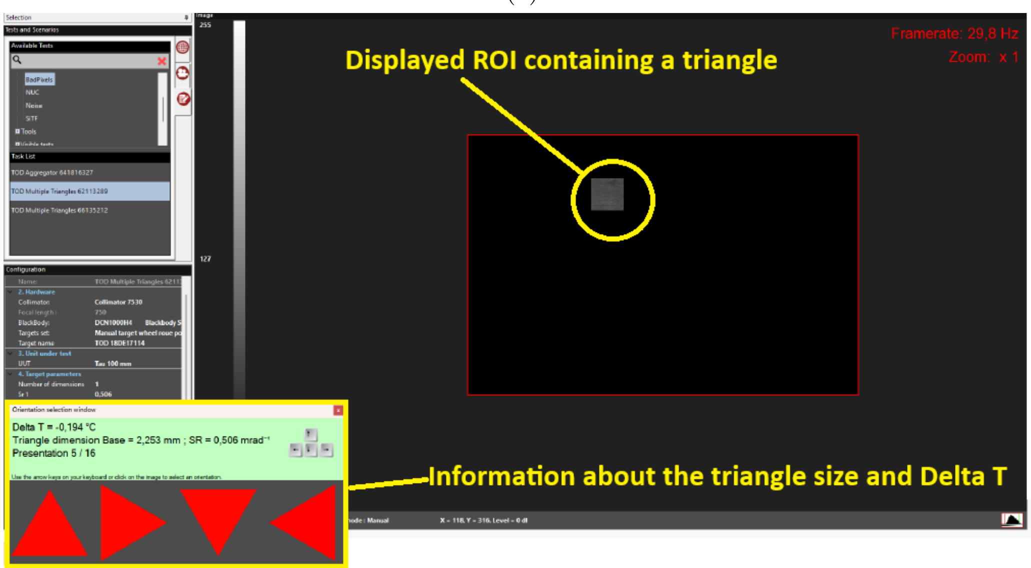
There is a major advantage of the proposed implementation in Infratest which is that no mechanical change of bench arrangement is needed between two successive stimulus presentations. Once the optical alignment and initial preparation are completed, the full TOD sequence is performed through Infratest, by driving the target presentation and the associated test parameters without interrupting the measurement chain. This is a significant practical difference compared with more conventional procedures, in which repeated setup adjustments, manual target changes, or operator intervention may considerably increase the overall test duration. In the present implementation, this continuous and software driven procedure is one of the key reasons why the measurement can be completed in a relatively short time while preserving repeatability.

3.1 Experimental setup

The setup consists of a $150 mm$ diameter, $750 mm$ focal length off-axis parabola based collimator and a differential blackbody DCN1000H4, both from HGH Infrared Systems, test patterns manufactured for the experiment and Infratest Software[7] as shown in figure 4. The target holder is a calibrated motorized wheel that supports a TOD target among other targets (such as the knife edge target for the calculation of the MTF LSF to fine-tune the camera lens focal length before the test as explained in the methodology section). The TOD target is composed of a set of triangles distributed in the four directions as in figure 3. The smallest triangles are located near the center of the target which corresponds to the optical axis where the aberrations are minimal, whereas the largest triangles are the farthest from the center of the target.



(a)



(b)

Figure 4. (a): Picture of the optical bench including the camera under test the collimator and the target holder and (b): Screenshot of the TOD test interface on Infratest

In the Figure 4 (a) we show the experimental setup with the IRCOL, DCN1000H4 and the tested FLIR Tau2 camera and its 100mm focal length lens, and in (b) the screenshot of the TOD interface on Infratest with the displayed in-real time video of regions of interest (ROI) containing a triangle at one of the four directions, the information about the current applied ΔT, the triangle dimensions in mm and $mrad^{-1}$, the presentation progress, and a reminder of the keyboard keys to use by the participant to give an answer about the displayed triangle orientation, in order to minimize the typing error occurrences.

3.2 Test procedure

In a TOD experiment, triangles of several spatial frequencies are displayed to the observer. For each spatial frequency, several levels of thermal contrast ΔT are applied between the triangle and the background using a differential blackbody source (eg. a DCN1000H4[11]). The observer must determine the orientation of the triangle

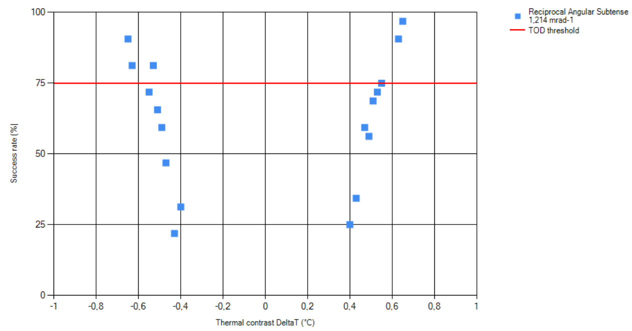
for each presentation.
The TOD test in Infratest has been built so that the correct answer is not known by the observer or by an external operator during the test sequence, but only by the software itself. For each presentation, the software controls which triangle orientation is displayed and stores the corresponding expected response. This point is essential to the non-subjectiveness of the procedure, since it removes any risk of bias in the process. In addition, prior to the TOD sequence, the video signal from the camera under test is calibrated within the software environment so that the displayed region of interest is correctly interpreted and the stimulus presentation remains consistent throughout the measurement. This software-driven control of both stimulus presentation and response validation is one of the main practical advantages of the proposed implementation.
In order to avoid any positional cue in the presentation of the triangles, the software does not present the full target pattern to the observer during the discrimination task. Instead, for each trial, only one triangle is displayed at once in its region of interest, and its orientation and order of presentation is selected according to a randomized sequence controlled by the software. Furthermore, the displayed ROI is not intended to be representative of the real triangle position on the physical target itself, it is indeed displayed at a random location in the screen. This dissociation between the physical arrangement of triangles on the target and the visual information presented to the observer is essential, as it prevents the observer from guessing the correct answer from spatial memory or from the fixed geometry of the test pattern.

For a reliable and repeatable TOD test it is recommended to have two phases in the test : the preparation of the bench including the choice of the thermal contrasts for each size of triangle, and the sequence of the TOD test that only requires the participant interactions with Infratest. Indeed the software handles all the steps from the calibration to the end of the TOD test. A calibration step must be performed for each unit under test, since the optical properties may vary from one camera to another. The purpose of this calibration is to allow Infratest to accurately locate the triangle patterns in the image so that the software can correctly crop the relevant triangle regions during the TOD procedure. For each selected spatial dimension (SR), the operator first sets a differential temperature, typically starting from a default value of 2 K, and increases it if necessary until the triangle pattern positions become visible, without requiring the triangle orientation to be discriminable at this stage. The camera under test must be properly configured and positioned before launching this step. The image is then displayed in the Infratest image panel, where the operator selects the appropriate region of interest corresponding to the chosen dimension and applies a threshold to reference triangles, typically the top-left and bottom-right ones, in order to complete the calibration for that dimension.

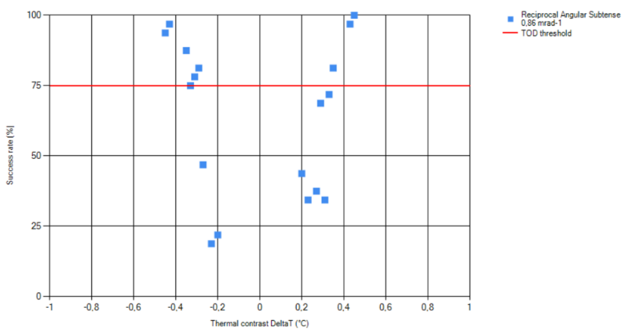
4. EXPERIMENTAL RESULTS

4.1 Data analyis

The resulting success probability vs ΔT data for the three spatial frequencies S_R : 1.2, 0.86 and $0.5 mrad^{-1}$ are plotted in figure 5. We observed in this experiment that the lower the S_R, the less symmetrical the psychometric curve becomes between positive and negative contrasts. This effect can be explained by the combined influence of intrinsic camera noise, background luminance conditions, and the increasing apparent size of the target at lower spatial frequencies. For the largest triangles, corresponding to lower S_R values, negative contrasts tend to be more easily discriminated than positive ones. In practice, when the background is relatively bright and the sensor noise is not perfectly balanced, dark targets on a brighter background may generate a more visible perceptual response than bright targets on the same background. As a result, the discrimination performance is no longer strictly equivalent for $+\Delta T$ and $-\Delta T$, leading to an asymmetry in the success-rate curves.



(a)



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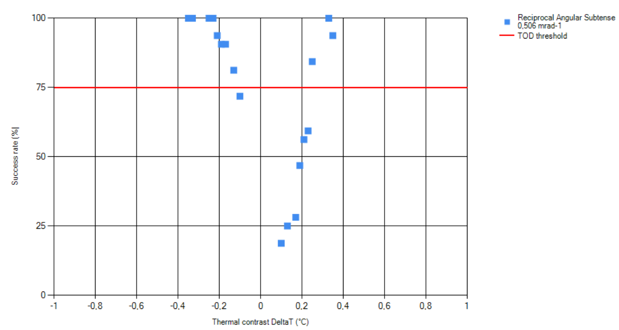

(c)

Figure 5. Success probability data for (a) $S_R = 1.2mrad^{-1}$ (b) $S_R = 0.86mrad^{-1}$ and (c) $S_R = 0.5mrad^{-1}$

Figure 6 shows the plot of the TOD curve which is the ΔT at 75% success rate versus the spatial frequency S_R . The three success probability plots, locally fitted with a second degree polynomial, permitted to determine the 75% threshold values for each S_R for positive and negative , these values are then averaged to calculate to plot the TOD curve in figure 6.

$$\Delta T\ 75\% = \frac{|\text{Positive } \Delta T\ 75\%| + |\text{Negative } \Delta T\ 75\%|}{2} \tag{3}$$

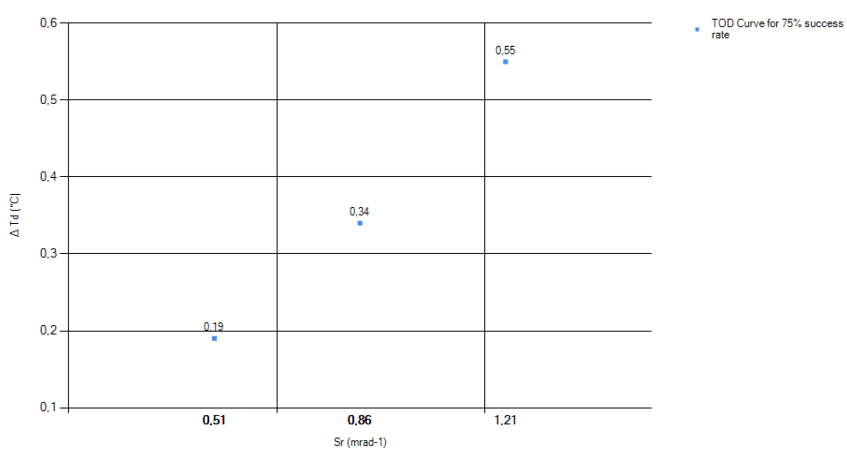

Figure 6. TOD curve of the experiment

Figure 6 shows the TOD curve obtained for the FLIR Tau2 infrared camera. It represents the thermal contrast ΔT required to reach a discrimination performance of 75% as a function of the spatial frequency S_R. As expected, the curve shows that the required thermal contrast increases with spatial frequency, meaning that finer details become progressively more difficult to discriminate and therefore require a stronger contrast to remain visible to the observer.

This behavior is consistent with the general performance of electro-optical imaging systems and is directly comparable to the classical MRTD curves. In both cases, the curve provides a synthetic representation of the sensor's discrimination capability as a function of target size or spatial detail. Although the TOD and MRTD methods rely on different target geometries and different observer tasks, they both characterize the ability of the camera to resolve increasingly small details under limited contrast conditions. The TOD curve can therefore be interpreted as a robust indicator of the effective visual performance of the tested infrared imager, integrating the combined effects of optics, detector, electronic processing, and human perception into a single measurable result.

4.2 Application in the defense and security domain

The TOD provides an objective and reproducible characterization of the effective resolution of a thermal or visible sensor. This metric is particularly important in military operations where camera performance is assessed in terms of detection, recognition and identification ranges. Whether for the defense and security field or the civil, the TOD framework allows a more reliable simulation of the resolution of real world objects.

4.2.1 DRI Ranges and the Discriminant Element Criterion

A DRI range (Detection, Recognition, Identification) is defined as the distance at which the discrimination of a specific object from other potential objects becomes possible. For example a tank or a human in a certain area starts to be discriminated with a thermal camera at a certain distance.

4.2.2 Resolution Criteria and Equivalent Triangle Geometry

The minimum discriminant element is historically defined by Johnson resolution criterion, which is the ratio between the average target dimension and the triangle dimension (spatial resolution).

For instance, if we wanted to discriminate a man (average target dimension of 1.7 m) with a resolution criterion of $N = 3.8$, with S as the square root of the triangle surface "$s_{triangle}$" is:

$$S = \sqrt{s_{triangle}} = \frac{dim_{\text{Target}}}{N_{50}} = \frac{1.7}{3.8} = 0.447\,\text{m} \tag{4}$$

In parallel, the geometrical square root of the surface of the equilateral triangle is:

$$S = \sqrt{s_{triangle}} = \frac{b.\sqrt{\sqrt{3}}}{2} \tag{5}$$

That permits to calculate the basis of the triangle as a function of the dimension of the target dim_{target}

$$b = \frac{2}{\sqrt{\sqrt{3}}} \frac{dim_{\text{Target}}}{N_{50}} = 68cm \tag{6}$$

If this human was at 1000m from the camera then the angular size of the triangle basis would be $\theta = \arctan(0.68/(2* 1000)) = 0.34mrad$ which corresponds to an S_R of $4.46mrad^{-1}$

5. CONCLUSION

The Triangle Orientation Discrimination (TOD) method is a robust, perceptually grounded metric for electro-optical (EO) imaging system evaluation. Its ability to integrate optical, sensor, and processing characteristics into a single performance measure makes it particularly relevant for modern imaging system design. The results presented in this work confirm the strong correlation between TOD performance and key system parameters, supporting its continued adoption as a standard evaluation tool in electro-optical engineering.

The TOD test has been successfully implemented within the Infratest software, enabling efficient and repeatable measurements while maintaining a good level of accuracy. In the proposed configuration, the total test duration is kept below 20 minutes by using a limited but sufficient number of stimulus presentations, typically 16 trials per ΔT level and 7 ΔT values per spatial frequency S_R. This configuration provides a good compromise between statistical reliability and test duration.

However, the validity of the TOD test relies on several experimental constraints. The observer must have adequate visual acuity and be sufficiently trained to ensure consistent responses and efficient interaction with the test interface. In addition, the task must be presented without any visual or auditory cues that could bias the identification of the triangle orientation. Furthermore, these results also highlight a limitation of the current analysis method. At lower spatial frequencies, the psychometric curves become increasingly asymmetrical between positive and negative contrasts, suggesting that the sensor response depends on contrast polarity. As a consequence, 75% threshold estimation from a simple averaging of success rates for $+\Delta T$ and $-\Delta T$ may introduce a bias. Future work will therefore investigate on the influence of background conditions and sensor noise on TOD performance and handle this issue. Another perspective of improvement regarding the current data processing approach would be introducing a Weibull psychometric fit and a quantitative goodness-of-fit criterion, such as the (χ^2). These developments would provide a more rigorous framework for threshold estimation and for validating the consistency between the fitted model and the experimental data.

6. ACKNOWLEDGMENTS

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