Design of a single optical bench for complete Performance characterization of night vision device

PRESENTED AT SPIE REMOTE SENSING 2023

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ABSTRACT

Low light night vision systems based on I² tubes have been expanding rapidly over the past few years, due to a combination of the growing advancement of this technology and the increased pressure in the current climate.

The design of a single optical bench able to fully characterize night vision devices is presented into this paper, focused more specifically on spot defects and goggle axes parallelism tests.

These criteria are indeed very important: misalignment between the two binocular images may be one source of visual fatigue and could degrade task performance of the night vision user, and spot defects can act as visual distractions and may be large enough to mask critical information pilots need to conduct normal night vision operations.

Thanks to HGH's IRCOL bench, these two tests are integrated on the same support. Spot defect measurement utilizes machine vision algorithms to determine the size and location of the defects, and the parallelism measurement identifies the angular misalignment between the two channels under test. The spot defect test has also been completely automatized compared to the only visible test previously available

All these results will be compiled and directly integrated into a computer-generated report that can be easily used for quality control or for maintenance applications.

Keywords: night vision system, spot defects, goggle axes parallelism, optical bench

1. INTRODUCTION

Night vision devices are electronic devices that allow the wearer to see better in the dark without using any external light source such as a torch or a lamp. Light amplification technology is not only the most widely used technology today, but also the most popular. Devices using this technology are commonly referred to as Night Vision Devices (NVDs) or Night Vision Goggles (NVGs). This type of device generally integrates a special tube, called an image intensifier tube or I² tube, to capture and amplify light, whether infrared or visible. This tube consisting of a photocathode, an anode in form of a phosphor screen, and other components intensifies an input low luminance image into a brighter image created on the anode (screen) [1].

These NVD systems can be used both in civilian life (animal observation or civil aviation, for example), and of course in the military field, to give significant supremacy in night-time operations. The improvements in night optics in the last decade have been immense. Drastic technological advancements have meant clearer images, improved light amplification, and unbelievable leaps forward for durability and portability. In the current context (terrorism, war in Ukraine), these systems are becoming crucial.

The purpose of this article is to present and document some of the tests that are now included in the HGH's IRCOL bench in order to fully characterize NVDs.

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2. IRCOL TEST BENCH

2.1 Optical setup

The IRCOL benches are test equipment designed for the characterization and the performance validation of a wide array of electro-optical sensors, like visible cameras, NIR, SWIR, MWIR, LWIR imagers and laser rangefinders.

Figure 1: IRCOL Optical Test Bench

The core of the IRCOL system is the IRCOL collimator. The IRCOL collimator features an off-axis mirror-based projector with a wide clear aperture, a diffraction limited output beam and a high transmittance covering a wide spectral range from near UV to far IR.

In order to test and characterize any Electro-Optical system the IRCOL collimator projects to infinity optical stimuli, thanks to the specific targets or patterns located at its focus.

The bench is equipped with various sources such as blackbodies or visible to SWIR sources, depending on the Unit Under Test (UUT) type: thermal cameras, visible cameras, etc.

2.2 Infratest software

The INFRATEST software completes the IRCOL system, for the automated control of the bench and the computation of an exhaustive range of measurements: noise functions, NETD and other signal resolutions, bad pixel location and non-uniformity correction, MTF and spatial resolution data, distortion, MRTD, TOD, MRC and ranges calculation, multiple axes alignment control and laser rangefinder accuracy measurement and many other functions.

3. NVD TESTING CONFIGURATION

3.1 Light source specifications

The optical source is an integrating sphere-based source with a color temperature of 2856K +/- 50K . This value is a prerequisite for testing any NVD. The ISV range of sources of HGH’s portfolio is precisely set in color temperature to the desired level using a calibrated colorimeter.

The ISV source is also equipped with a set of neutral densities enabling to adjust the irradiance of the NVD. Knowing the luminance of the sphere (adjustable between 1 and 3400 cd/m^2), the density used and the collimator geometrical parameters, the software automatically calculates the luminance setpoint of the ISV source as a function of the irradiance setpoint of the NVD. This configuration can simulate night levels down to level 5, i.e., an irradiance <0.7 mlux, essential for NVD tests.

3.2 Eye-camera

Night Vision Devices necessarily have an optical output through one or two eyepieces. Indeed, many of the tests on NVDs are nowadays still carried out thanks to the human eye of a technician, for example to count the number of spots defects. These procedures may lead to errors or subjective results depending on the operator's experience.

One of the major advances of our bench is the use of a camera collecting the image through the eyepiece to replace the human eye in order to analyze and validate all NVD characterization tests.

The main specifications of our Eye-camera are listed into the below table:

Parameter	Specification
Horizontal and Vertical Field of view	49 x 49 degrees
Input aperture	6 mm (similar to output aperture of the eyepiece)
Size of the smallest detectable spot defect for 16 mm diameter tubes	<75 µm[1]

Table 1: Specifications of the Eye-camera

The substitution of the operator by this monochrome camera allows to carry out all the tests usually done through the human eye. In addition to the removal of the subjectivity of the human eye for the tests, this feature allows to streamline and automate these tests integrated into Infratest software.

We integrated the ability to fully characterize NVDs into our existing software Infratest, focusing in more details on Spots Defects and Goggle axes parallelism tests. Thanks to the integration of these functions into the IRCOL optical bench, users are now be able to use the functions previously available in dedicated benches on their main bench, alongside the other applications already available on the IRCOL.

4. GOGGLE AXES PARALLELISM TEST

4.1 Principle

Goggles axes parallelism control is performed by measuring and comparing the positions of a pinhole image through each axis of the goggle. This function uses a high-resolution camera looking through the eyepiece. Figure 2 shows the setup used to carry out this test, consisting of our analysis camera, a translation stage and a collimator associated with a pinhole sight and a light source.

[1] Spot size of category 1 according to [6]

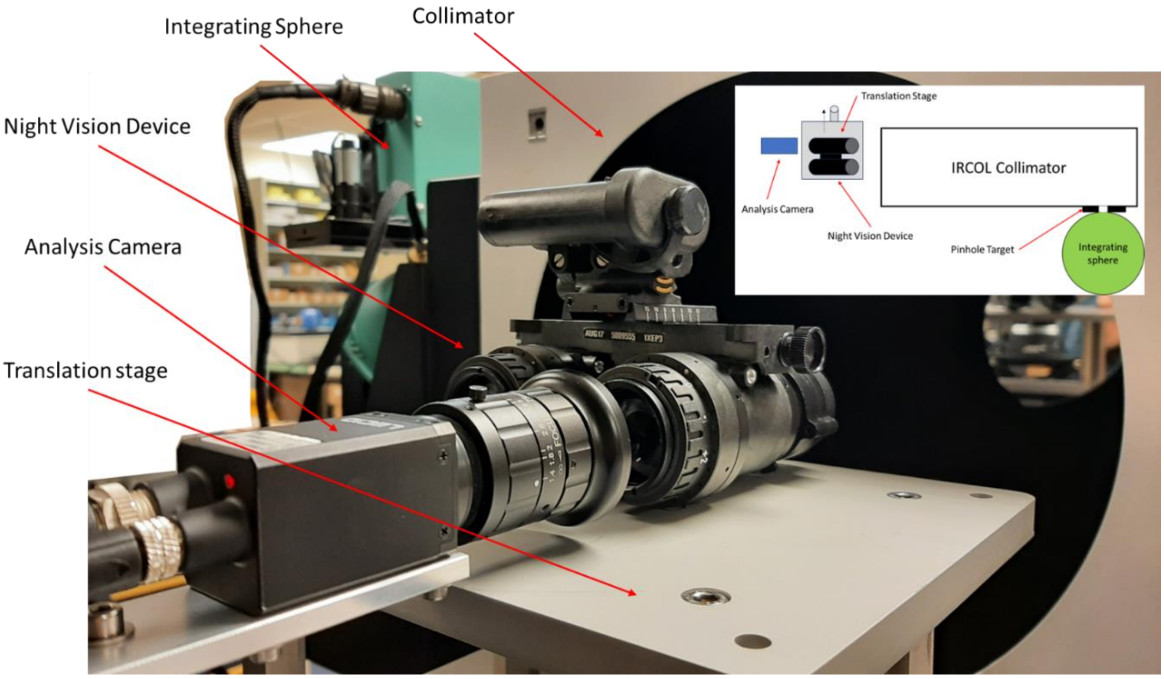


Figure 2: Optical setup (photography and scheme) for Parallelism test.

The first test step is to align the Eye-camera with the pinhole test pattern, the NVD to be tested being removed. Once this is done, we insert and align the first channel of the NVD with the Eye-camera and pinhole. Having maximized the signal, we then move the NVD using the translation stage to align the second channel of the NVD.

The misalignment $\Delta\theta_x$ between the two channels can be expressed as follows:

$$\Delta\theta_x = \text{atan}\left(\frac{(x_2 - x_0)\times p_x \times 10^{-3}}{f'}\right) - \text{atan}\left(\frac{(x_1 - x_0)\times p_x \times 10^{-3}}{f'}\right) \quad (1)$$

Where x_2, x_1 *and* x_0 are the barycentre positions of the pinhole images respectively on channels 2 and 1 of the goggle and on the camera alone. p_x corresponds to the horizontal pixel pitch (in µm) and f' to the focal length (in mm) of the Eye-camera.

4.2 Results

The procedure described above was carried out five times in succession, three times measuring first the right and then the left channel, and twice measuring first the left and then the right channel. Each time, the goggle was removed and then reinstalled. Figure 3 presents a screenshot of Infratest software during the measurement phase.

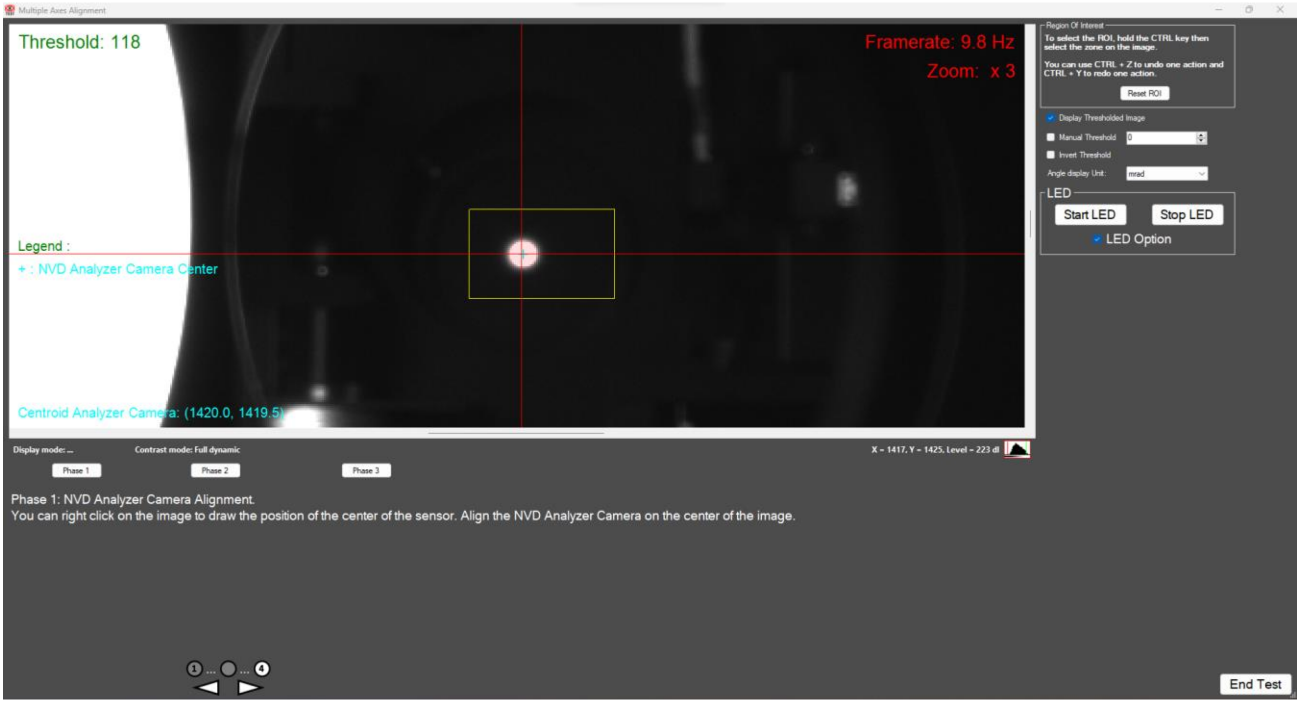


Figure 3: Infratest screenshot of Parallelism test.

The deviation found was 5.9 ± 0.50 mrad. As current market values are of the order of a few mrads [2], and as we were unable to compare the measured value with the supplier's reference data, further tests on the subject are planned, notably on other NVDs with factory-certified values.

5. SPOT DEFECTS MEASUREMENTS

Spots or Spot Defects are little black spots that can appear in an intensifier tube. They can happen for several reasons, but the most common are photocathode or phosphor burns, broken light fibres, bad channels in the microchannel plate and dust on the outside surfaces of the I^2 tube. These dark spots of various sizes are inevitable and can be located on any part of the field of view [3, 4].

5.1 Algorithm and setup definition

In order to provide the best possible quality products, standards have been defined for manufacturers of intensifier tubes to define the maximum number of spots and their size according to the area in which they are located on the image. Spots are always measured according to [6]. Figure 4 shows a graph identifying the three main zones of an 18 mm I^2 tube: Zone 1 correspond to a diameter below 5.6mm, Zone 2 of a diameter between 5.6 and 14.7mm and Zone 3 of a diameter between 14.7 and 17.5mm.

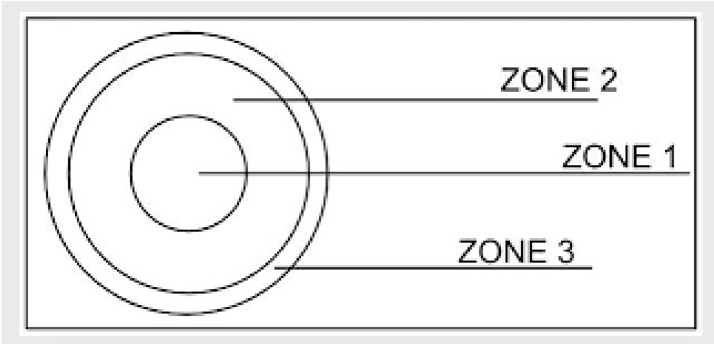


Figure 4: Zone chart

The presence of spot defects is obviously more critical in Zone 1 than in any other zone. The usual method for spot defect test is to locate them through visual inspection on a large target panel showing the above zones and covering the NVD field of view.

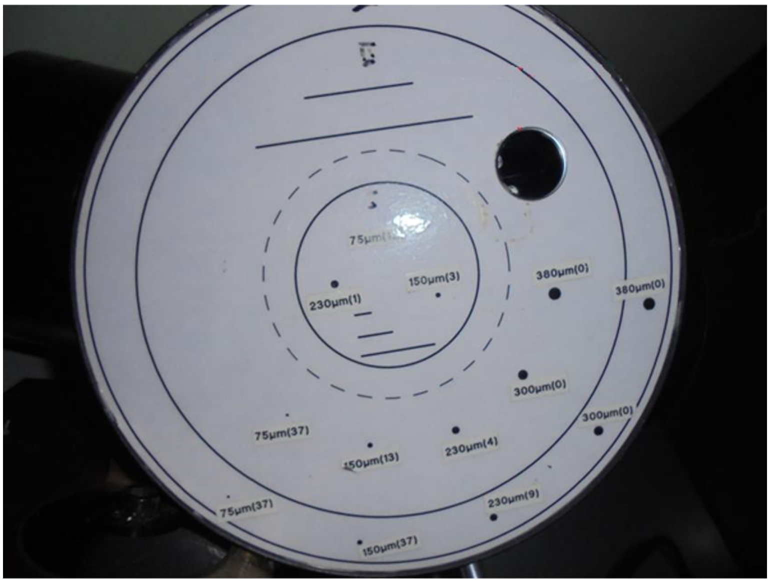


Figure 5: Example of spot defect panel used in visual inspection

The subjectivity of this method is obvious.

Our spot defect detection algorithm is based on the method described by Aghaziyarati et al. in [5] and uses absolute average difference weighted by cumulative directional derivatives.

From a hardware point of view, to integrate the characterization of these dark spots on our optical bench, we removed the integrating sphere source available on IRCOL bench coupled with our Eye-camera and a set of optical densities. A sleeve is also inserted to eliminate any stray light from the measurement. Figure 6 shows the setup for this measurement, integrated with the optical bench.

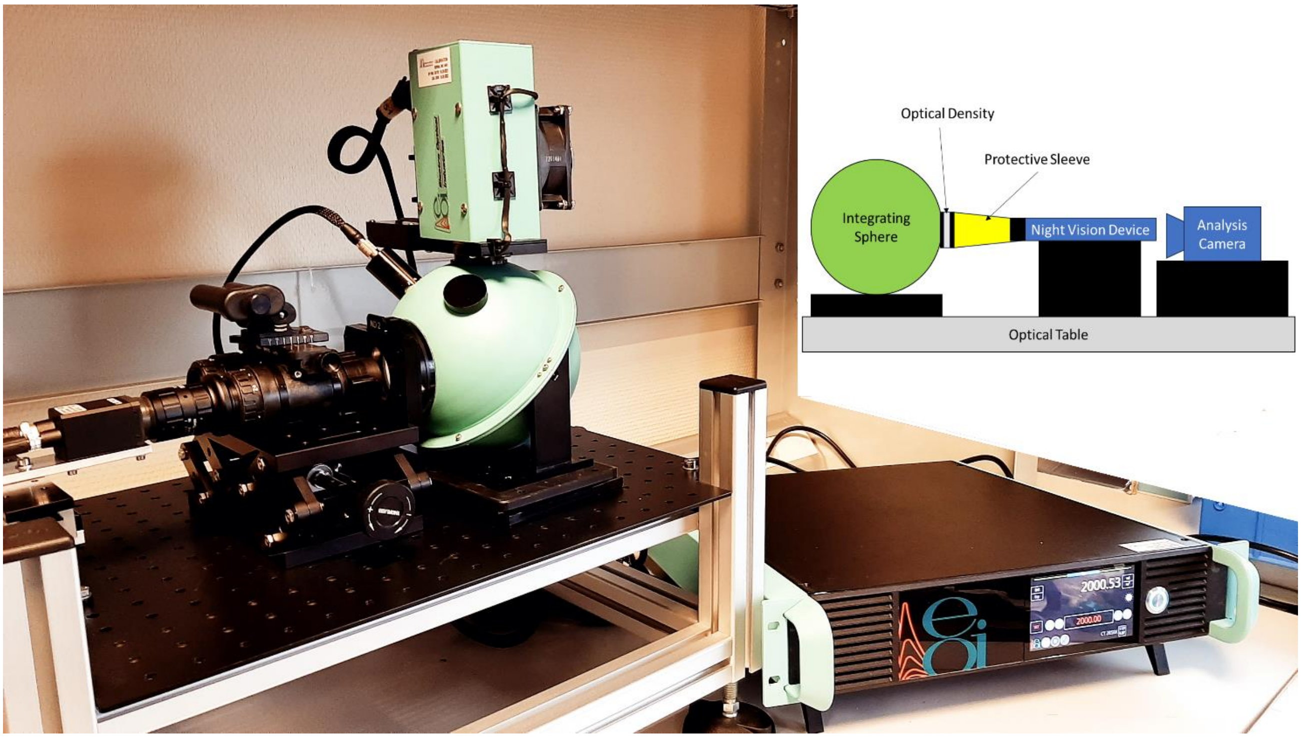


Figure 6: Optical setup and photography for Spot Defect Measurement

5.2 Tests presentation

Three tests were carried out to demonstrate the correct operation of this automated and objective method.

<u>Test no 1: Spot detection</u>. The objective of this test is to compare the number of spots found by our software with those identified by an experienced operator. In this test, the operator performed two counts: the first directly through the eyepiece of the NVD and the second by counting the spot defects saved by the camera image.

<u>Test no 2: Repeatability</u>. The second test is to demonstrate the repeatability of the bad pixel detection measurement by completely dismantling and reassembling five times the NVD on our measurement setup. We performed this test of both NVG Dual Tubes and NVG Mono Tube. As a reminder, Table 2 shows the categories defining spot sizes according to [6].

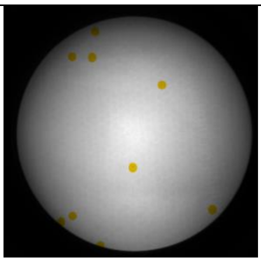
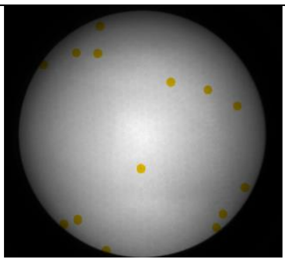
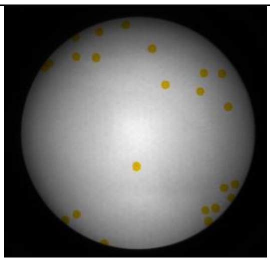
Table 2: Spot size classification

Spot Category	Spot Size (µm)
Category 1	< 75
Category 2	75-150
Category 3	151-230
Category 4	231-300
Category 5	301-380
Category 6	381-500

<u>Test no 3 : correct classification</u>. We compare the classification found by the software with the classification made by the operator and measured directly on the image, thanks to the knowledge of the diameter of the tube.

5.3 Test results

Table 3: Results of Test no 1

Results of Test n°1		
Result found by operator		**Result found by software**
Observer looking directly out of binoculars	Observer looking at the raw image taken by the camera	Software result from the raw image taken by the camera
 9 spots identified	 14 spots identified	 23 spots identified

At least all the spots identified by the operator are identified by the software. There is no missing spot through the software method.

Table 4: Results of Test no 2

Results of Test n°2			
2.1: Result found on NVG Dual Tubes			
		Nb of points detected on left optical path	**Nb of points detected on right optical path**
Zone 1 (Inner Circle)	**Cat. 1**	1.20 ± 0.45	0.13 ± 0.35
	Cat. 2	No spots detected	1.00 ± 0.00
	Cat 3 to 6	No spots detected	No spots detected
Zone 2 (Middle Circle)	**Cat 1**	12.40 ± 5.98	12.88 ± 8.54
	Cat 2	1.00 ± 0.00	No spots detected
	Cat 3	No spots detected	No spots detected
	Cat 4	No spots detected	No spots detected
	Cat 5 to 6	No spots detected	No spots detected
Zone 3 (Outer Circle)	**Cat 1**	12.40 ± 3.65	11.63 ± 6.93
	Cat 2	No spots detected	No spots detected
	Cat 3	1.00 ± 0.00	No spots detected
	Cat 4 to 6	No spots detected	No spots detected

2.2: Result found on NVG Mono Tube			
		Nb of points detected on left optical path	**Nb of points detected on right optical path**
Zone 1 (Inner Circle)	**Cat 1**	61.60 ± 36.61	150.50 ± 16.26
	Cat 2	No spots detected	1.00 ± 0.00
	Cat 3 to 6	No spots detected	No spots detected
Zone 2 (Middle Circle)	**Cat 1**	239.20 ± 90.01	305.00 ± 14.14
	Cat 2	1.80 ± 0.84	2.00 ± 0.00
	Cat 3	No spots detected	No spots detected
	Cat 4	1.00 ± 0.00	1.00 ± 0.00
	Cat 5 to 6	No spots detected	No spots detected
Zone 3 (Outer Circle)	**Cat 1**	121.60 ± 32.12	42.00 ± 1.41
	Cat 2	2.00 ± 0.00	2.00 ± 0.00
	Cat 3	No spots detected	No spots detected
	Cat 4 to 6	No spots detected	No spots detected

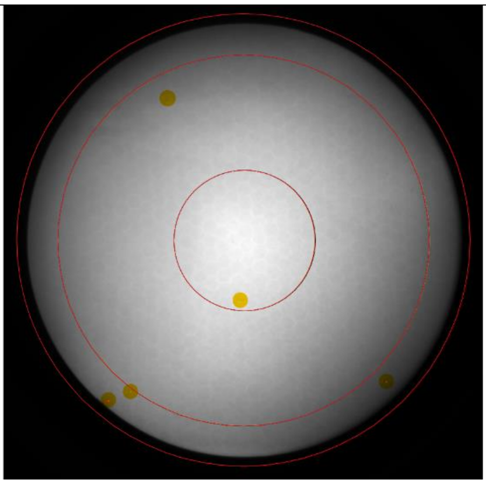
Table 4 shows the results of spot detection as an average of the 5 successive measurements. It shows that the measurements are very repeatable for all spots of category ≥2 as the dispersion values are almost always 0.00.

The repeatability of identification of spots of category 1 is much less repeatable but these spots are disregarded according to [6, 7].

Table 5: Results of Test no 3

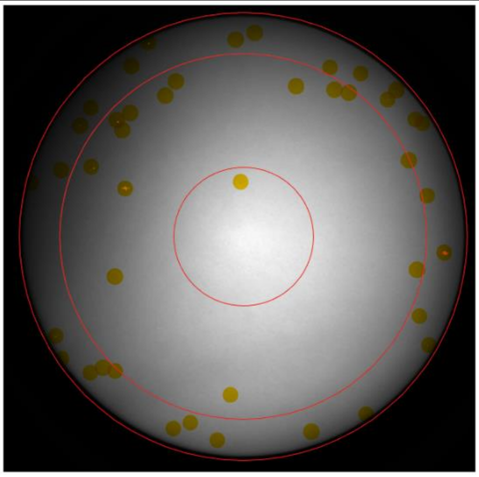
Results for Test n°3

3.1: Result found on the left optical path of NVG Dual Tubes



	Values noted by the observer			Values found by software		
	Cat.1	**Cat.2**	**Cat.3**	**Cat.1**	**Cat.2**	**Cat.3**
Zone 1 (Inner Circle)	0	1	0	0	1	0
Zone 2 (Middle Circle)	1	0	0	1	0	0
Zone 3 (Outer Circle)	2	1	0	2	1	0

3.2: Result found on the right optical path of NVG Dual Tubes



	Values noted by the observer			Values found by software		
	Cat.1	**Cat.2**	**Cat.3**	**Cat.1**	**Cat.2**	**Cat.3**
Zone 1 (Inner Circle)	1	0	0	1	0	0
Zone 2 (Middle Circle)	13	1	0	11	1	0
Zone 3 (Outer Circle)	27	0	1	13	0	1

Similarly, as category 1 spots are those of least importance for NVDs (<75µm), the fact that our operator measures more spots of this size than the software does not influence the overall performance of NVDs.

Finally, a check on spot size (linked to spot diameter) is carried out thanks to knowledge of tube diameter. Indeed, on two spots of categories 3 and 4, we measured diameters of 210µm and 250µm respectively, which correspond perfectly to the categories identified by the software for these spots.

5.4 Implementation of the test in the software

Figure 7 shows the interface for the Spot Defect test, integrated into the Infratest software. Its user-friendly interface includes full explanations of how to perform the test, output values and a complete report directly available. It is important to note that the diameter of the tube as well as its Field of View is a user selectable parameter of the software, which allows this test to be carried out for any NVD.

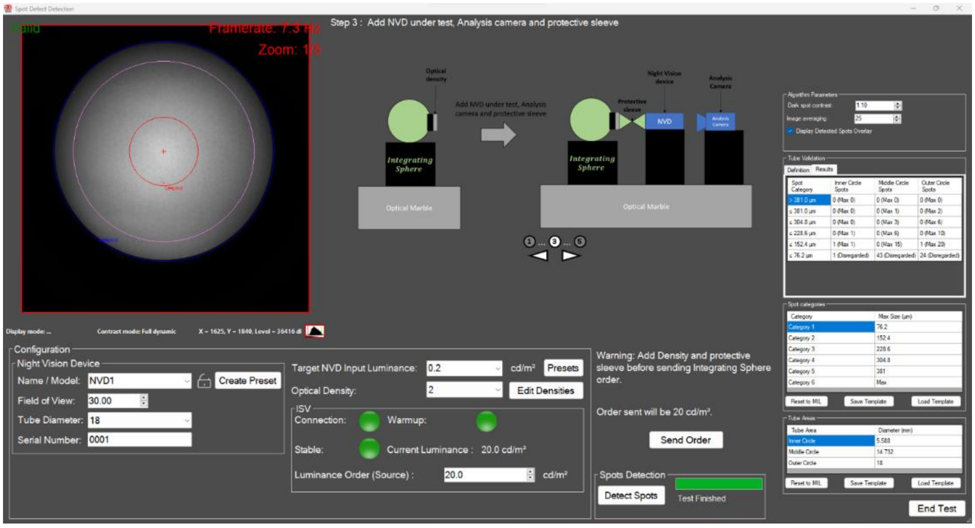


Figure 7: Spot Defects test with Infratest software

6. CONCLUSION

In conclusion, we have demonstrated in this article the integration in our Infratest software of several measurements enabling NVDs to be tested simply and efficiently in detail. In particular, we have detailed the parallelism and spot defect tests. We have also demonstrated the benefits of using an analysis camera instead of the human eye to eliminate any subjectivity in the analysis of the results obtained. Further measurements will enable us to improve and implement new tests in our software, and its combination with our range of source products (ISV) or collimators (IRCOL) will open up even further the possibility of measurements on the NVDs, which have become indispensable today.

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