Color blackbody for testing multi-sensor/fused imaging systems

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ABSTRACT

A broadband reference source of optical radiation emitting at the same time longwave thermal radiation in the MWIR-LWIR band and shortwave light in spectral band from middle UV to the middle SWIR is presented in this paper. Since this reference radiation source works at the same time like a typical low temperature blackbody in the MWIR-LWIR range and as a source of white light in the UV- SWIR range it has been called a color blackbody. This reference radiation source cab be a perfect solution for systems for testing multi-sensors imaging systems or fused imagers.

Keywords: fused blackbody, color blackbody, multi-sensors imaging systems, fused imagers.

1. INTRODUCTION

Modern imaging surveillance systems used in defense and paramilitary applications, search and rescue operations, environmental protection, etc. are available as single-sensor, multi-sensor or fused systems.

The first group basically consists of thermal imagers, VIS-NIR cameras, SWIR imagers or UV cameras used as independent units[1]. The second group includes surveillance systems built by combining several imagers into a single unit[2], it is typically thermal imager with a VIS-NIR camera. Such systems are often enhanced by addition of a laser range finder. Although the multi-sensor systems can generate several video images simultaneously, usually only one of them is fully active and displays output image to a user. Fused systems are built by combining at least two imagers, typically VIS-NIR camera and thermal imager, into a unit that generates a single fused image[3].

Independent surveillance systems are commonly used since 1980s. Multi-sensor surveillance systems have become more available for less than a decade. Fused surveillance systems are still a market novelty. In such a situation two most important groups of imaging systems, thermal imagers and VIS-NIR cameras, have been traditionally tested with separate test stations. Tests of thermal imagers sensitive in the MWIR-LWIR use reflective image projectors that employ low temperature area blackbodies as reference radiation sources. Tests of VIS-NIR cameras are done using refractive/reflective image projectors that employ reference light sources calibrated in visible and near infrared range.

Introduction of the multi sensor surveillance systems followed by the emergence of fused surveillance systems has created a demand for a single system capable of testing imaging systems working at least two different spectral bands. In particular for testing both VIS-NIR cameras and MWIR/LWIR thermal imagers. A broadband calibrated radiation source that is capable of emitting light at least in the VIS-NIR band and the MWIR-LWIR band is crucial to fulfill this need.

In this paper a new type of broadband radiation source named color blackbody is presented. It significantly exceeds performance of other broadband radiation sources known in the literature due to a set of excellent performance parameters.

2. BROADBAND RADIATION SOURCES

Systems for testing electro-optical imaging systems have been traditionally built as image projectors that project static images of reference targets. They are built from four main blocks: a collimator, a rotary wheel, a set of targets and a

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radiation source. The collimator is usually broadband off axis reflective optical system. It can project images in both far infrared and visible range. Furthermore, due to the rotary wheel switching targets is quick and easy. However, what makes the real challenge is a construction of broadband radiation source capable of working as a reference radiation source at least in both MWIR/LWIR band and VIS-NIR band.

Nowadays, there are three different designs of broadband radiation sources for testing multi-sensor/fused imagers:

1. Two mechanically exchangeable radiation sources (longwave area blackbody and a shortwave light source) located on a single mechanical system that exchange their position.
2. Two radiation sources (longwave area blackbody and a shortwave light source) optically combined with a beam combiner,
3. Two typical radiation sources (longwave area blackbody and a shortwave light source) fused into a single radiation source.

The first broadband radiation source type is built by placing an area blackbody and a light source on a linear slider as in Fig. 1[4]. Linear slider transports either the blackbody for testing a thermal imager or light source for testing a VIS-NIR camera. This is a classical solution is systems for testing multi-sensor imaging systems. The disadvantage is necessity to swich from one mode to another, big mass and dimensions, and limited reliability due to necessary to use movable mechanical parts.

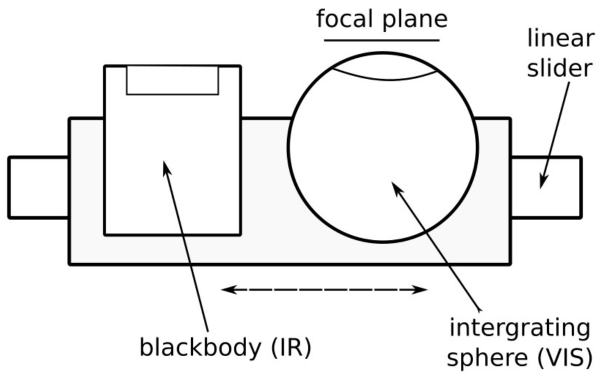


Fig. 1 Concept of two exchangeable radiation sources on a linear slider.

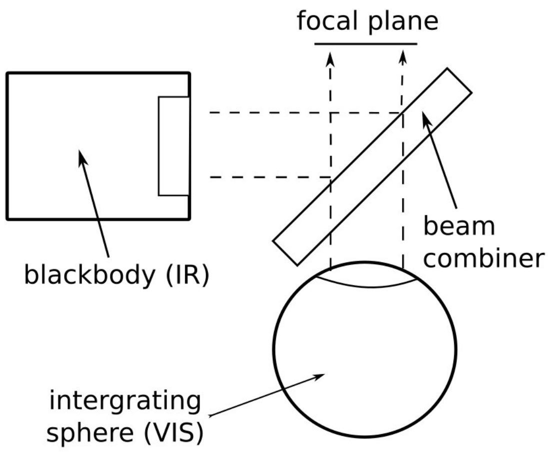


Fig. 2 Concept of two separate radiation sources optically combined using a beam combiner.

The second type of broadband radiation source combines an area longwave blackbody with a shortwave light source using beam combiner as in Fig. 2[5,6]. This solution is more elegant and efficient because mechanical source exchange is unnecessary.

Significant advantage of such a broadband radiation source is the ability to simultaneously project an image of a test target in both LWIR/MWIR and VIS-NIR spectral band. However, this solution is also characterized by a set of disadvantages:

1. Beam combiners attenuates radiation emitted by the blackbody and emits its own thermal radiation. These effects influence the test results of thermal imagers and must be compensated for.
2. Beam combiner may also change spectral characteristic of emitted light in the VIS-NIR due to its selective transmittance. It is a significant drawback when fixed color temperature of a light source is required.
3. The source is bulky as it consists of three blocks: a blackbody, a light source and a beam combiner.

The most elegant and efficient design of a broadband radiation source is when radiation sources are fused into a single source by a non optical method[7, 8, 9]. This method is based on a concept of a low temperature area blackbody coated with a special coating of high reflectivity in the visible band and high emissivity in the MWIR/LWIR spectral band (Fig.3). This blackbody emitter/reflector is illuminated by an integration sphere integrated with a visible light source. Therefore, the blackbody emitter emits a longwave thermal radiation in the MWIR/LWIR range and reflects a shortwave visible radiation. This allows designing a compact, efficient broadband radiation sources needed in multi-sensor or fused imaging systems testers.

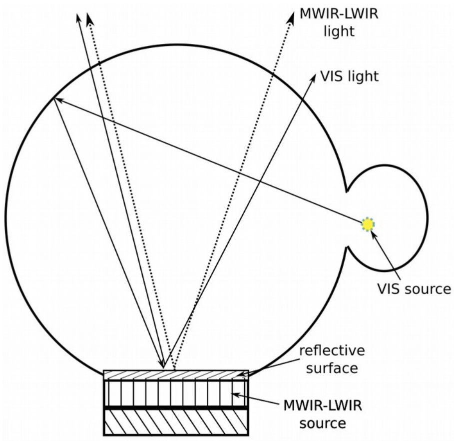


Fig. 3 Concept of fused light source[8].

3. DRAWBACKS OF TYPICAL FUSED BLACKBODIES

Authors of both Ref. 7 and Ref. 8 claim to have achieved so called "white blackbody" because of high reflectance of the fused source in visible range (white color) and high emissivity (black color) in the MWIR/LWIR range. However, these claims are exaggerated because there are several important drawbacks of these fused light sources.

Firstly, reflectance of emitter coating in two fused blackbodies presented in Ref. 7 is non uniform, decreases rapidly with wavelength and reflectivity even in the middle of visible band and in general is too low to consider the emitter as perfect reflector (Fig. 4). The case in Ref. 8 is more evident. Here, although reflectivity of the coating is uniform in the visible and near infrared band, it is at low level of about 0.3 (Fig. 5). Therefore, both developed fused sources should not be called as "white blackbodies", but no more than "grey blackbodies".

Secondly, the emissivity in the MWIR band of the developed fused light sources is at modest level between 0.8 and 0.9 when emissivity at level over 0.95 is expected from blackbodies in systems for testing thermal imagers[10].

Thirdly, both Ref.7 and Ref. 8 propose an emitter of high reflectance in visible band but omit the problem of the reflectance in NIR, SWIR and UV bands. An emitter of high reflectivity in the visible band is sufficient when testing a color CCD cameras, but many modern multi-sensor systems also use monochrome CCD cameras sensitive in both visible and NIR bands or use a non cooled SWIR cameras sensitive up to about 1700nm in the SWIR band. An ability to test UV cameras is desirable too. Therefore the emitter of near perfect fused blackbody should have ultra high, uniform reflectance from the UV to at least middle of the SWIR band (up to about 1700nm).

Fourthly, Ref. 8 proposes to built a diffusive light source using a concept of a small integrating source emitting light into a bigger integrating source (Fig. 3). This method works well and is often employed in high performance Lambertian sources. However, big size of such integrating spheres is a disadvantage of this solution when compact light source is needed. Moreover, light efficiency (ratio of output source luminance to power of light bulb) of this solution is low.

Therefore, the conclusion can be drawn that typical fused blackbodies known from the literature or commercially available are far from ideal. The significance of these drawbacks is supported by market situation. Nowadays test systems based on a mechanically exchangeable blackbody/integrating sphere are offered as typical solution by manufacturers of equipment for testing multi sensor imaging systems[11-14] but situation can change soon.

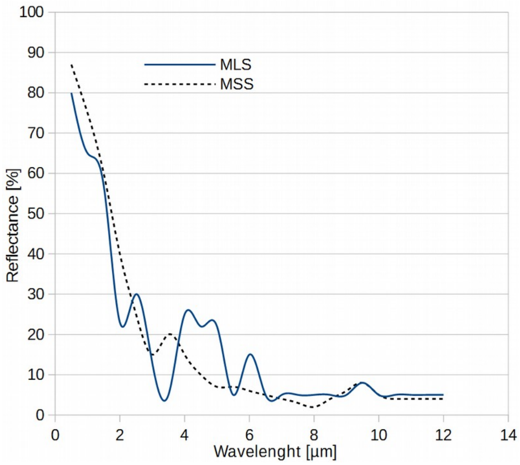


Fig. 4 Reflectance of emitter coating in two fused blackbodies presented in Ref. 7.

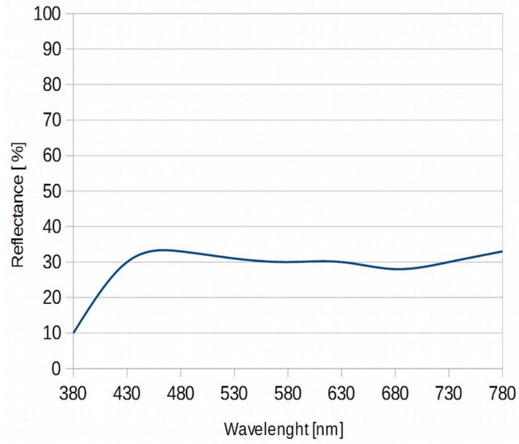


Fig. 5 Reflectance of emitter coating used in Ref. 8.

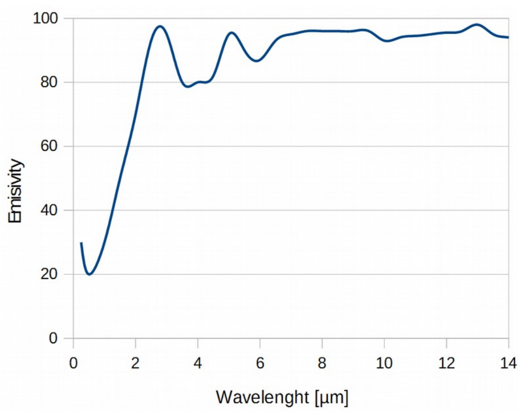


Fig. 6 Emissivity of blackbody emitter in Ref 8.

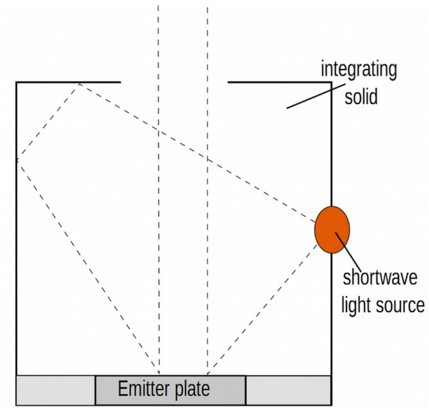


Fig. 7 Graphical concept of the new fused light source.

4. CONCEPT OF AN IMPROVED FUSED BLACKBODY

A new concept of a significantly improved fused blackbody is presented in this paper. The general idea behind the new fused blackbody is similar to the designs presented earlier but without the disadvantages.

As shown in Fig. 7 the new fused blackbody is a broadband reference source of optical radiation built from three main blocks: a blackbody emitter, a shortwave light source and an integrating solid.

The emitter module at the same time emits a longwave thermal radiation in the MWIR-LWIR region like a near perfect blackbody and reflects light emitted by a shortwave light source of spectrum located in a spectral region from the UV band to the middle of the SWIR band. In detail, the emitter is a plate of regulated temperature coated with ultra high reflectance (over 0.95) coating in an extremely wide spectral region from about 300 nm to about 1800nm and of high emissivity (over 0.95) in the MWIR-LWIR spectral bands as shown in Fig. 8 and Fig. 9. This coating is made mainly of a mixture of water based barium sulfide, crown glass micropowder and zinc oxide micropowder under high pressure process.

The shortwave light source emits light of regulated intensity in a wide angle including the direction of the blackbody emitter. The design enables to use halogen/tungsten bulbs, LEDs, xenon bulbs, or laser diodes of different spectrum (broadband, bandpass, monochromatic) in range from about 300 nm to about 1800nm.

The integrating solid is built as an empty cylinder or cuboid that has the same coating as the blackbody emitter. There are three holes in the integrating solid. Two inputs: to attach the emitter module and shortwave source and output to project radiation emitted or reflected by the blackbody emitter.

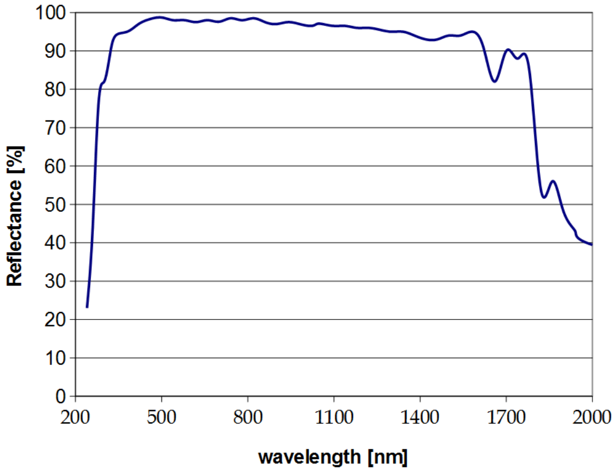


Fig. 8 Reflectivity of emitter of proposed light source in the UV-SWIR spectral region.

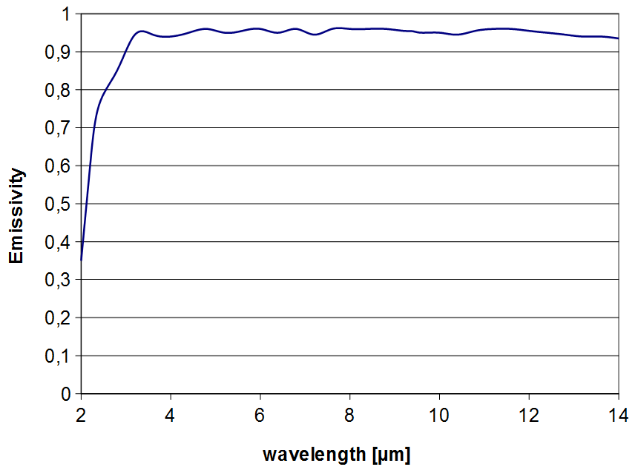


Fig. 9 Emissivity of proposed light source in the MWIR-LWIR spectral region.

The presented description shows four main differences between the new and typical fused blackbodies:

1. Much wider reflective spectral band of the new blackbody emitter. From the UV to the middle of the SWIR in comparison to only the visible band in Ref. 8
2. Higher reflectance of the new blackbody emitter the in the wide spectral band UV-SWIR. Over 0,95 compared to 0.3 in Ref. 8
3. Higher emissivity in the MWIR region (about 0.95 in comparison to about 0.8 at 4 µm in Ref. 8)
4. Use of an integrating solid instead of an integrating sphere,
5. The improved fused blackbody acts like a near perfect white body in the UV-SWIR range and as a near perfect blackbody in MWIR-LWIR range when other fused sources known from literature barely can be called gray sources.

The consequences of these differences are very significant:

1. Wider reflective spectral band of the emitter means that light sources operating at the UV, VIS, NIR and SWIR can be used as shortwave sources when in case of typical fused blackbodies only VIS sources could be used. This means that the new fused blackbody can be used as an ultra broadband radiation source in systems for testing thermal imagers, VIS, VIS-NIR, SWIR and UV cameras when typical fused blackbodies – only in systems for thermal imagers and VIS cameras.
2. Higher reflectance of the emitter means that the new fused blackbody can simulate much brighter illumination condition than a typical fused blackbody. It also provides better temperature stability since the emitter absorbs only negligible amount of incoming shortwave light that does not change temperature of the emitter noticeably.
3. Due to higher emissivity in the MWIR region the new fused blackbody can be treated as a near perfect blackbody in both MWIR and LWIR bands as it fulfills the classical requirement of emissivity of blackbody to be used in systems for testing thermal imagers[9].

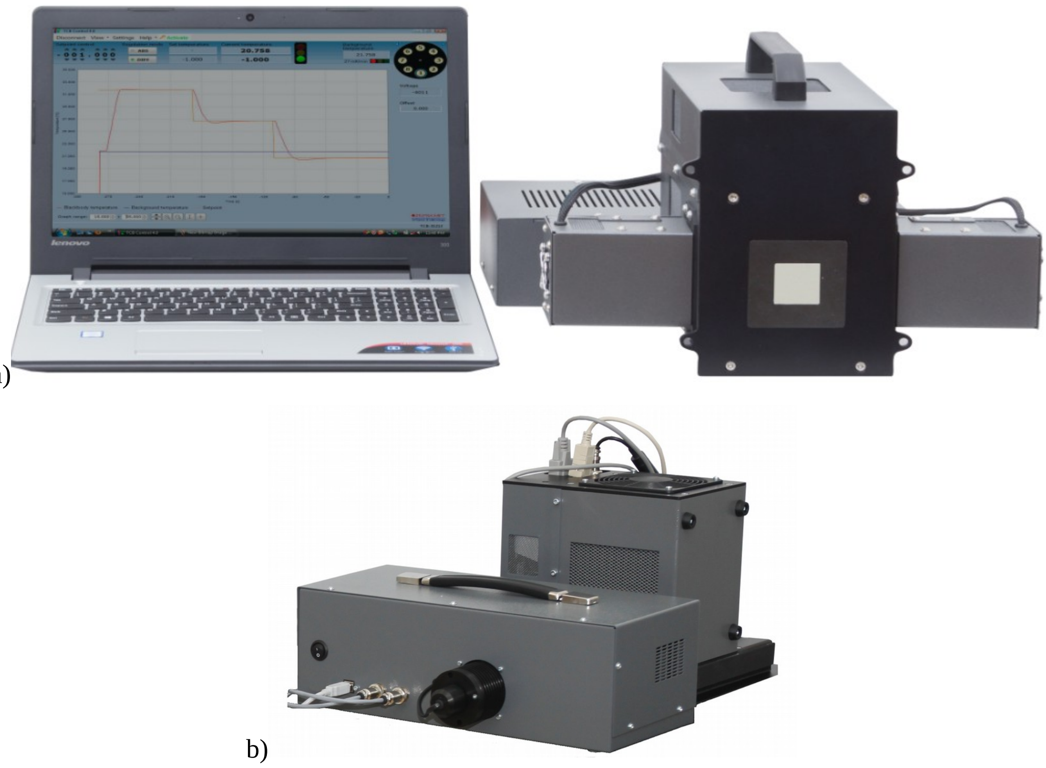
4. Choice of integrating solids (cylinders or cuboids) over an integrating sphere allows for both easier machining required mechanical blocks and applying coating.

The improved fused blackbody behaves like a color (white/black) blackbody and the term color blackbody will be further applied in the article.

5. DEVELOPMENT OF COLOR BLACKBODIES

A new color blackbody (code DCB blackbody) based on the concept described in previous section has been designed by Inframet company by significant modification of its typical TCB-2D area differential blackbody. Parameters of typical TCB-2D blackbody with 50x50mm emitter are shown in Ref. 15. Two main versions of DCB blackbody have been designed: DCB-2D-SEM and DCB-2D-HAL (Fig. 10). Both of them are built from four main blocks: blackbody head of regulated temperature, shortwave light source, integrating cylinder that connects two first blocks, and control electronics.

The blackbody head in both versions is similar to a typical TCB-2D blackbody presented in Ref. 15. The main difference is that emitter is coated with a special coating described in the previous section and insertion of the integration cylinder. The integrating cylinder is an empty cylinder coated with the same coating as the blackbody emiter and has three holes: first for the blackbody emitter, second for the shortwave light source and third for the radiation output.



a)

b)

Fig. 10 Photos of two DCB-2D color blackbodies: a) DCB-2D-SEM (with multi-band LED light source) LED controlled from a laptop b) DCB-2D-HAL (with halogen light source) in vertical position to be used on a collimator.

The main differences between these two versions of DCB blackbody is the shortwave light source:

1. DCB-2D-SEM blackbody – shortwave light source is built using multi LEDs emitter that emits light of approximate 5000K temperature greybody spectrum in 400-1100nm band (Fig. 11)
2. DCB-2D-HAL blackbody – shortwave light source is equipped with opto-mechanically controlled halogen bulb that emits light of approximate 2856K temperature greybody spectrum in approximate 400-2000nm band (Fig. 12).

DCB-2D-SEM is recommended for testing color VIS cameras or monochromatic VIS-NIR cameras used to surveillance of targets illuminated by Sun light (color temperature approximately about 5000K).

DCB-2D-HAL version is recommended when broadband (VIS-SWIR) light source of 2856K color temperature spectrum is needed: testing broadband VIS-SWIR cameras, testing SWIR cameras, testing night vision devices.

Total specifications of the developed DCB-2D color blackbody in two different versions (DCB-2D-SEM, DCB-2D-HAL) are shown in Table 1.

Table 1 Parameters of DCB-2D color blackbodies.

Parameter	Value
Blackbody mode	
Active aperture	35x35 mm
Emitter size	50x50 mm
Absolute temperature range	0ºC to 100ºC at 25ºC ambient temperature
Differential temperature range	-25ºC to + 75ºC
Effective emissivity	0.95±0.02
Temperature uniformity (temperature spatial uncertainty)	<0.015ºC or 0,6% of ΔT
Set point and resolution	1 mK
Regulation stability	±3 mK at ΔT=10ºC
Total temperature uncertainty	Abs(T-25ºC)+12[mK]
Heating/cooling rate	0.8ºC/sec / 0.3ºC/sec
Settling time	<30sec
Light source mode	
Active aperture	35x35 mm
Spectral band	About 400 nm to 2000 nm –HAL; 400-1000nm -SEM
Luminance range	at least 0.2 to 2000cd/m2 – day option at least 0.00001 to 2000cd/m2 – day/night option
Spectrum of shortwave light source	Depends on type of light emitter
Other parameters	
Computer control	USB 2.0
Power supply	115-230VAC 50/60Hz
Operating temperature	+5ºC ÷ 45C (non condensing)
Storage temperature	-10ºC ÷ +60ºC
Dimensions	DCB-2D-SEM: 379 x 276x 207 mm, DCB-2D-HAL 503x235x425
Mass	DCB-2D-SEM 9 kg; DCB-2D-HAL 11 kg

If we compare parameters of newly developed DCB-2D color blackbody working in blackbody mode are very similar to parameters of typical TCB blackbody shown in Ref. 9 with one exception: temperature uniformity. The latter parameter is significantly worse in case of DCB-2D blackbody but still is at level acceptable when testing majority of thermal imagers.

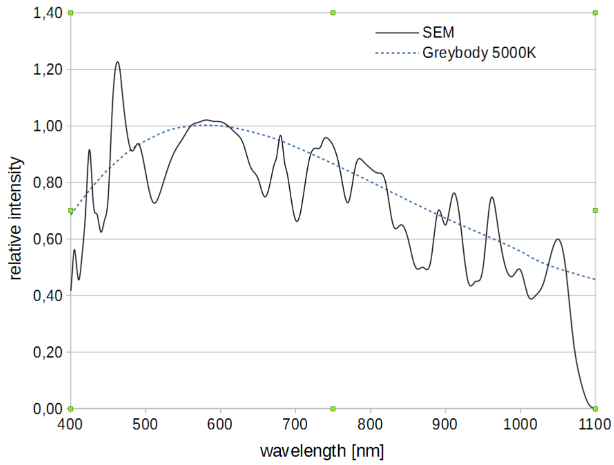


Fig 11. Relative spectrum of SEM light source.

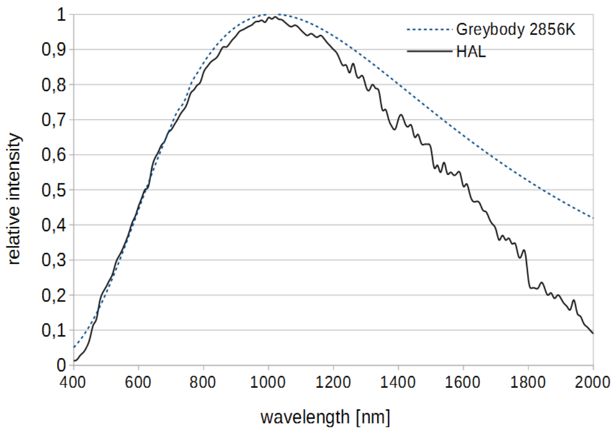


Fig. 12 Relative spectrum of HAL light source.

6. TEST VALIDATION

Main applications of the DCB color blackbodies are multi-sensor/fused imagers testing systems. Therefore it has been decided to validate performance of the color blackbodies DCB-2D presented in previous section by testing a multi-sensor imaging system using test systems built using on two radiations sources:

1. Set of two exchangeable radiation sources: TCB-2D blackbody and DAL light source. The latter light source can work in two modes: halogen mode (like DCB-2D-HAL blackbody) and LED mode (like DCB-2D-SEM blackbody). Data sheet for DAL light source is available at the website[16].
2. The newly developed DCB-2D-HAL/ DCB-2D-SEM color blackbodies described in previous sections.

The tested multi-sensor imaging system is a dual-channel imaging system built from two imagers: 1)KTL thermal imager (based on ULIS IR Pico640 sensor) manufactured by Etronika company with Shalomeo 100F1 objective; 2) KPC650 hi-res color camera manufactured by KT&C company with fixed focal length 50mm optical objective. The following parameters have been measured: 1)Thermal imager: NETD, MRTD, MTF, SiTF, distortion, FOV; 2) VIS camera: NEI, sensitivity, MRC, MTF, SiTF, distortion, FOV.

Results of this experiment shows that classical system built using the TCB-2 blackbody and DAL light source working in halogen mode has generated practically identical measured parameters of tested multi-sensor system as a system built using DCB-2D-HAL color blackbody. The same conclusion is valid when comparing classical test system with TCB-2 blackbody and DAL light source working in LED mode and system built using DCB-2D-SEM color blackbody. The differences have been below repeatability level of about 3% of the test system. The discrepancies can be considered as low and negligible in situation of the measurement uncertainties of thermal imagers/VIS-NIR cameras parameters being at level over 20% are quite common[17].

7. CONCLUSIONS

A new fused blackbody coded DCB blackbody has been developed. Its performance parameters significantly exceeds parameters of other known fused blackbodies. It has been experimentally verified that test systems based on DCB blackbody offers the same accuracy of tests of thermal imagers and VIS-NIR cameras as classical test systems based on set of two exchangeable radiation sources: blackbody and light source.

DCB color blackbody is a perfect solution when a reference broadband radiation source for testing multi sensor/fused imaging systems is required. By eliminating mechanically switching source during measurements, testing procedures are not only completed faster but with increased reliability as well. This blackbody has a potential to become a standard solution for testing multi sensor/fused imaging systems.

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