IR-Dual-Band-Camera Demonstrator
Experimental Assessment – Practical Applications

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ABSTRACT
The IR-Dual-Band-Camera demonstrator collects simultaneously infrared data in the 3–5 µm (mid-wave infrared, MWIR) and 8–12 µm (long-wave infrared, LWIR) atmospheric windows. The demonstrator is based on a two-layer QWIP focal plane array with 384 x 288 x 2 detector elements. Images are typically acquired with a frame rate of 100 Hz at 6.8 ms integration time and are stored as 14-bit digital data. Two different IR-Dual-Band-Optics were designed and developed: first an 86 mm and 390 mm focal length, F/2 dual field of view optics based on refractive and reflective components and second a pure refractive 100 mm focal length, F/1.5 optics. We present the performance of this IR-Dual-Band-Camera and demonstrate fusion techniques to the pixel-registered dual-band images which show in laboratory tests and field trials promising results with respect to image improvement.

Keywords: Thermal Imager, dual-band, multispectral, image fusion

1. INTRODUCTION
During the last decades the thermal imagers have developed from “simple” scanning systems to the now state-of-the-art focal plane arrays (FPA). Nowadays different trends of development can be seen, for example decrease in pixel size, new materials (InAs/GaSb superlattices) and especially the multispectral imagers.

A multispectral imager is able to acquire information in different channels of the electromagnetic spectrum at the same time, while a broadband or standard system only works in one channel of the electromagnetic spectrum. One type of multispectral imager are the so called Dual-Band-Cameras which typically acquire images simultaneous in the 8–12 µm (LWIR) and 3–5 µm (MWIR) spectral range1. Advantages foreseen for these cameras are manifold. They go from simply using the pros and cons of both bands at the right time to automatic target recognition due to specific emissivity features.

In Germany AIM-Infrarot-Module GmbH2 in co-operation with the Fraunhofer IAF3 (Institute for Applied Solid State Physics) developed a Dual-Band-Detector based on QWIP technology [1, 2]. This detector-cooler-assembly was made available to FGAN-FOM for system integration which was conducted in co-operation with IRCam GmbH4. The necessary special IR-Dual-Band-Optics was developed in co-operation of FGAN-FOM and Opto-System-Technik5. All components together resulted in the IR-Dual-Band-Camera demonstrator which was then experimentally assessed in the thermal imager laboratory of FGAN-FOM. Additionally this demonstrator was used to test dual-band image fusion techniques in the laboratory as well as in field trials.

2. THE IR-DUAL-BAND-CAMERA DEMONSTRATOR
The IR-Dual-Band-Camera demonstrator is based on a cooled QWIP FPA detector with 384 x 288 detector elements of 40 µm pitch. It is operating simultaneously in the spectral range of 4.3 µm to 5.3 µm (in the following MWIR) and 7.7 µm to 8.7 µm (in the following LWIR) whereby the pixels for the two spectral ranges are stacked one upon the other.

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1 Often designated as “3rd Generation” thermal imagers.
2 www.aim-ir.de
3 www.iaf.fraunhofer.de
4 www.ircam.de / the system is now commercially available as Geminis 110k ML by IRCam GmbH.
5 www.optosystems.de
So the acquisition occurs simultaneously spatial as well as temporal. This is the ideal acquisition for a multispectral system from the signal processing point of view.

The specially developed optics consists of a mirror / lens combination for a dual field of view. Its construction was laid out to assure a stable focus for both bands also under changing thermal conditions. Focal lengths are 86 mm for the Wide Field of View (WFOV) and 390 mm for the Narrow Field of View (NFOV). The resulting fields of view are $10.2^\circ \times 7.7^\circ$ and $2.3^\circ \times 1.7^\circ$ respectively, F-number is two for both fields of view. During the test of the demonstrator some measurements were also made with broadband optics that resulted in the manufacturing of a pure refractive optics. More on this topic is reported in chapter 4.

Image acquisition is carried out with 14-bit depth and up to 300 Hz frame rate. The integration time depends on the frame rate. Typically a frame rate of 100 Hz is used which corresponds to an integration time of 6.8 ms. The acquisition soft- and hardware allows the loss-free image acquisition up to the maximum frame rate. It shows both bands simultaneously and additionally allows the superimposition of the two bands in real time false color presentation.

### 3. EXPERIMENTAL ASSESSMENT

Up to date no special rules for the experimental assessment of multispectral imagers exist. Based on experience with such systems it is recommended to use the figures of merit for broadband thermal imagers\(^6\) and to conduct three additional measurements with regard to the spectral crosstalk, the temporal synchronization and the spatial pixel alignment [3]. Presented in the following are results for Spectral Response, System Transfer Function (SiTF), temporal and spatial Noise (Noise Equivalent Temperature Difference, NETD, and Inhomogeneity Equivalent Temperature Difference, IETD), and Modulation Transfer Function (MTF)\(^7\). For all measurements an integration time of 6.8 ms corresponding to 100 Hz frame rate was used.

#### 3.1 Spectral Response and Spectral Crosstalk

The spectral response of the demonstrator was measured using equipment developed by FGAN-FOM and based on a glow bar as radiation source, an integrating sphere to achieve a homogeneous radiation and narrow filters for the spectral selection. It results in the normalized spectral response as presented in Fig. 1.

![Normalized Spectral Response](image)

Fig. 1: Normalized spectral response for the two bands of the Dual-Band-Camera demonstrator\(^8\).

Based on the measurement the central wavelengths were found to be 4.8 $\mu$m and 8.2 $\mu$m respectively. The full width at half maximum is approximately 1 $\mu$m for both bands, so the overall spectral behavior corresponds to the typical QWIP one. From the measurement it is obvious that the LWIR band has some response in the MWIR, whereas it is not vice versa. The contribution of the spectral crosstalk to the response in the LWIR band is approximately 7%. A reason for

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\(^6\) Unfortunately the STANAGs were not following the development of the thermal imagers and thus are outdated. For an overview on the problems of measuring modern FPAs and the state-of-the-art measurement procedures see for example [4] or the corresponding chapters in [5].

\(^7\) Normally the Minimum Temperature Difference Perceived (MTDP) is also measured, but this was not conducted yet.

\(^8\) The spectral range between 5.6 $\mu$m and 7.4 $\mu$m was not covered in the measurement. Meanwhile the equipment is updated and covers this range too.
this crosstalk has not determined yet and up to date it is also unknown how such a crosstalk influences possible applications [3].

3.2 System Transfer Function (SiTF) and Noise

The SiTF describes the system response in form of output signal (here: digital levels, DL) as function of input signal (here: temperature). The responsivity is the slope of the SiTF at a given scene temperature. It is calculated by deviation of the SiTF at this temperature.

For measuring of the SiTF a black-body was placed in front of and covering the optics. Using the digital output, image sequences were recorded in the temperature range from 5 °C to 75 °C with a step of 5 K and an additional measurement at 26.85 °C (300 K). These image sequences were averaged and then the average signal in dependence of scene temperature was calculated. From this data the responsivity is calculated for a scene temperature of 300 K.

The temporal noise is determined for 300 K scene temperature using the data acquired during the SiTF measurement. It is calculated separately for each pixel in the time domain and then averaged over all pixels excluding bad ones. The ratio calculation between temporal noise and responsivity results in the Noise Equivalent Temperature Difference (NETD).

The Fixed Pattern Noise (FPN) is calculated in dependence of scene temperature, again using the data acquired during the SiTF measurement. First the image sequences were averaged in order to remove the temporal noise. Then the standard deviation of the signal was calculated using a high pass filter. As the FPN depends on the scene temperature it was averaged in the temperature range from 10 °C to 45 °C for comparison.

The performance data is summarized in Table 1 and Fig. 2 for both fields of view and both spectral ranges.

<table>
<thead>
<tr>
<th></th>
<th>WFOV</th>
<th>NFOV</th>
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<tbody>
<tr>
<td></td>
<td>MWIR</td>
<td>LWIR</td>
</tr>
<tr>
<td>Response at 300 K</td>
<td>43 DL/K</td>
<td>46 DL/K</td>
</tr>
<tr>
<td>Temporal Noise at 300 K</td>
<td>1.8 DL</td>
<td>1.6 DL</td>
</tr>
<tr>
<td>NETD at 300 K</td>
<td>42 mK</td>
<td>34 mK</td>
</tr>
<tr>
<td>Fixed Pattern Noise (10 °C – 45 °C)</td>
<td>1.5 DL</td>
<td>1.5 DL</td>
</tr>
<tr>
<td>IETD (10 °C – 45 °C)</td>
<td>35 mK</td>
<td>31 mK</td>
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</table>

Fig. 2: SiTF of the Dual-Band-Camera demonstrator for WFOV (left) and NFOV (right) and both spectral ranges measured at 100 Hz frame rate and 6.8 ms integration time (DL: digital levels).
As shown in Fig. 2, the signal level is higher in the LWIR for both fields of view. Also the LWIR-SiTF is more linear than the MWIR-SiTF, a typical feature already known from single band QWIPs and a behavior that should be considered when signal (two-band) processing is applied.

Table 1 shows the response for both fields of view to be slightly higher in the LWIR. The temporal noise depends on the spectral range, it is approximately 13% higher in the MWIR, but is independent of the field of view. Together this results in a NETD that is approximately 20% higher in the MWIR compared to the LWIR. In spite of these differences the bands are very close together in their performance. This is advantageous for signal processing as well as for practical use. For example the selection of the best band is not limited by the camera performance.

FPN and IETD show the typical 2-point-correction behavior. In the average the values are lower than temporal noise and NETD respectively. Because of the eye integration time and the frame rate the IETD and not the NETD is the parameter that affects the observer performance.

### 3.3 Modulation Transfer Function and Spatial Alignment

The Modulation Transfer Function (MTF) is the parameter that describes both, the spatial resolution and image quality of an imaging system in terms of spatial frequency response. The MTF concept is not suited to assess the spatial transfer characteristics of an advanced thermal imager (e.g. Focal Plane Arrays) as a whole. Here a separation in prefilter MTF (all components that act on the signal before sampling, e.g. front optics, detector etc.) and postfilter MTF (all components that act on the signal after sampling, e.g. electronics, video display etc.) is necessary [4]. As the measurements for the Dual-Band-Camera demonstrator were done in the digital signal, the measured MTF corresponds to the prefilter MTF.

Different methods for measurement of the MTF are known. The one applied here is the so-called scanning edge method. For this method an edge is moved in small steps over the detector mosaic and the signal of one detector element is measured in dependence of edge position. The resulting edge function is deviated to get the Line Spread Function (LSF) from which the MTF is derived by Fourier transformation.

Fig. 3 shows LSF and MTF of the IR-Dual-Band-Camera demonstrator measured vertically in NFOV. Presented are both spectral ranges. Additionally pitch and Nyquist-Frequency are given within the graphs.

The LSF is relatively broad and shows spatial crosstalk which normally is typical for QWIP detectors. As measurements with other optics showed much better results (compare chapter 4) it is assumed that the MTF of the Dual-Band-Optics is not as good as designed and that the methods used to improve the detector MTF [1] were successful. Measurements are in progress to verify these assumptions.

LSF and MTF automatically give a statement about the spatial alignment of a multispectral system if the measurement is conducted at the same time in all spectral channels [3]. As this was done here, it can be concluded that a perfect spatial alignment is given and thus superimposition of the bands is possible without disturbing effects. This conclusion is possible because a misalignment would result in differences in LSF and/or MTF of the two bands [3].
3.4 Conclusion of the Experimental Assessment

The experimental assessment showed a behavior that is very similar to the one known for single band QWIPs. It showed narrow spectral bands with a spectral crosstalk from the MWIR into the LWIR but not vice versa. The reason for this crosstalk is still unknown. The performance related to System Transfer Function (SiTF), Response, temporal and spatial Noise and Modulation Transfer Function (MTF) is similar in the MWIR and the LWIR. This is advantageous for image fusion techniques as well as for practical use. For example the selection of the optimum band for a given scene is not limited by the camera performance. The MTF of the optics degrades the performance but the detector MTF seems to be improved compared to the single band QWIPs. Altogether the IR-Dual-Band-Camera demonstrator is comparable to the single band QWIPs and very appropriate for the analyses of dual-band-techniques.

4. REFRACTIVE IR-DUAL-BAND-OPTICS

During the assessment of the IR-Dual-Band-Camera demonstrator measurements were done with standard broadband optics for comparison purposes. Especially interesting were the results achieved with a 100 mm F/1.5 optics. When the MTF was measured (Fig. 4), it was found to give a very good result in both spectral bands. This was somewhat surprising as the optics was only designed for the MWIR. From this point of view the optics would be well suited for the demonstrator. Unfortunately when measuring the performance data it was found that the response in the LWIR is a magnitude of five times smaller than in the MWIR (Fig. 6, Table 2). Although the temporal noise corresponds to the one measured with the IR-Dual-Band-Optics, the NETD increases accordingly. Both aspects would favor the MWIR band in all but very good infrared conditions and would also prevent signal processing methods.

It was assumed that the anti-reflective coating, which is adapted to the MWIR, is the reason for the response differences. Based on this assumption the idea was developed to equip such optics with a coating that is suited for both spectral ranges. This idea was realized within short-time and the results of the following experimental assessment are presented in Fig. 5, Fig. 6 and Table 2.

LSF and MTF (Fig. 5) are practically the same as for the MWIR optics. They are independent of the spectral range and the spatial crosstalk is small. More interesting are the SiTF and the noise behavior as shown in Fig. 6 and Table 2. For the MWIR the SiTF and the performance data are practically unchanged. In the LWIR the SiTF is improved, but still not as good as the MWIR one. For the response the difference is in a magnitude of 2 and for the NETD in a magnitude of 1.75. The temporal noise is the same within the measurement accuracy.

![Fig. 4: LSF (left) and MTF (right) of the Dual-Band-Camera demonstrator measured horizontally when equipped with a 100 mm F/1.5 MWIR optics. Presented are both spectral ranges. Additionally pitch and Nyquist-frequency are given within the graphs.](image)

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9 Because of the cold shield the F-number of the system stays at 2.
Fig. 5: LSF (left) and MTF (right) of the Dual-Band-Camera demonstrator measured horizontally when equipped with the 100 mm F/1.5 Dual-Band-Optics. Presented are both spectral ranges. Additionally pitch and Nyquist-Frequency are given within the graphs.

Fig. 6: SiTF of the Dual-Band-Camera demonstrator when equipped with 100 mm F/1.5 MWIR- and Dual-Band-Optics respectively. The data was measured at 100 Hz frame rate and 6.8 ms integration time for both spectral ranges (DL: digital levels).

Table 2: Performance data of the Dual-Band-Camera demonstrator equipped with 100 mm F/1.5 MWIR- and Dual-Band-Optics respectively. The values were measured at 100 Hz frame rate and 6.8 ms integration time respectively (DL: digital levels).

<table>
<thead>
<tr>
<th></th>
<th>MWIR-Optics</th>
<th>LWIR</th>
<th>Dual-Band-Optics</th>
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<tbody>
<tr>
<td><strong>Response at 300 K</strong></td>
<td>60 DL/K</td>
<td>12 DL/K</td>
<td>58 DL/K</td>
</tr>
<tr>
<td><strong>Temporal Noise at 300 K</strong></td>
<td>1.8 DL</td>
<td>1.6 DL</td>
<td>1.9 DL</td>
</tr>
<tr>
<td><strong>NETD at 300 K</strong></td>
<td>30 mK</td>
<td>135 mK</td>
<td>32 mK</td>
</tr>
<tr>
<td><strong>Fixed Pattern Noise (10 °C – 45 °C)</strong></td>
<td>1.4 DL</td>
<td>1.3 DL</td>
<td>1.6 DL</td>
</tr>
<tr>
<td><strong>IETD (10 °C – 45 °C)</strong></td>
<td>24 mK</td>
<td>116 mK</td>
<td>27 mK</td>
</tr>
</tbody>
</table>

Altogether the new coating has improved the performance in the LWIR approximately in the magnitude of 2.5. Although not perfect, the differences between the MWIR and the LWIR are now within a magnitude that not automatically favors the MWIR spectral range.
The optics was already used under different climatic conditions, ranging from very cold (winter, temperatures below zero degree) to very hot (desert, temperatures above plus forty degree). Under all these conditions no problems with respect to focusing both bands and focus changes caused by temperature changes occurred.

Although there is still room for improvements, this shows that the manufacturing of IR-Dual-Band-Optics is possible with performance and costs similar to broadband ones.

5. DUAL-BAND IMAGE FUSION TECHNIQUES

Dual-Band image fusion techniques were studied at FGAN-FOM for some time already before the IR-Dual-Band-Camera demonstrator was available. They were based on single band MWIR and LWIR QWIP cameras. The problem with a two camera approach is that a lot of effort goes in the problem of pixel registration, a problem that vanishes with a true Dual-Band-System.

An often used approach for multispectral image fusion and one that is also in the software of the demonstrator is color fusion. Here for each band a different color (for example red and blue for two bands) is used, resulting in a false color presentation of the fused information. The problem associated with this approach is the dependence of the resulting image from the scaling (gain and offset) applied to convert the information into 8-bit for presentation. Examples for this technique can be found in the literature [6, 7].

Another approach is the measurement of the absolute temperature based on the ratio principle\(^{10}\) [8-11]. Although this method looks very promising, it is problematic for “low scene temperature” applications because the reflective radiation component is neglected.

The methods we developed have the goal to show up the differences between the two bands in order to get new/additional information on the scene. The idea is very simple as a band dependence of an object parameter (emissivity etc.) should result in different signals in the two bands. In order to extract these differences, the bands have to be adapted somehow because the SiTF are different (compare Fig. 2 and Fig. 6). If the bands are adapted, ratio or subtraction reveals the differences. As there is a complex behavior of emission, reflection, transmission and path radiance in both bands it is in most cases difficult / impossible to extract the exact reason for a signal difference.

5.1 Apparent Temperature

The first approach for the adaptation was to calibrate the two bands in apparent temperatures \((T_{\text{app,LW}}, T_{\text{app,MW}})\) and then calculate the ratio \((R_T)\) or the difference \((D_T)\) of the apparent temperature\(^{11}\):

\[
R_T = \frac{T_{\text{app,LW}}}{T_{\text{app,MW}}} \tag{1}
\]

\[
D_T = T_{\text{app,LW}} - T_{\text{app,MW}} \tag{2}
\]

For the calibration a method was developed that uses two reference images at known temperatures and the once measured SiTF of the two bands [12].

An example for the method is shown in Fig. 7. It shows a cup filled with hot water in front of a panel with printed bar patterns. The cup itself is also printed with some kind of advertisement. The scene was recorded with the IR-Dual-Band-Camera demonstrator and the acquired data was calibrated in apparent temperatures. In Fig. 7 this calibrated data is presented using the same temperature range for both spectral ranges. With the standard linear scaling it is impossible to show the bar pattern as well as the printing on the cup at the same time. So the data is shown with two different temperature ranges. The left image shows the printing on the cup, which is more prominent in the LWIR, whereas there is no contrast in the background. The right image shows the bar pattern, whereas the cup is saturated. Here the reflection of the hot cup on the panel in the background is obvious. After calculating the fused image, the bar pattern as well as the printing on the cup show up within the same image. As shown in Fig. 7 it makes no difference if the ratio or the

\(^{10}\) The method is also known as dual wavelength or two-color temperature measurement.

\(^{11}\) Obviously it is possible to do the calculations vice versa resulting in inverted values. For the difference calculation it is also possible to use the absolute value if only the differences and not their direction are interesting.
difference of the apparent temperatures is calculated. We prefer the difference as the temperature difference gives a magnitude of the difference in the two bands and this may be usable to quantify spectral features.

![Fused Image: Difference and Ratio](image)

Fig. 7: Test image of a cup filled with hot water in front of a panel with bar targets. Presented are the two apparent temperature calibrated original images and the fused image. The fused image shows the difference in the apparent temperature of the two bands (upper image) and the ratio of the apparent temperature (lower image). The original images are displayed using the same temperature range for the two bands but with two different temperature ranges to show different details.

Two more practical images are presented in Fig. 8 and Fig. 9. The first image (Fig. 8) shows a car that was parked in front of the institute. Whereas the two single band images showed nothing special, the fused image reveals writing on the rear window. The image also gives the impression as if the license plate would be readable if the camera had a better spatial resolution.

Fig. 9 presents the two-band images of a truck with running motor. The exhaust of the truck is covered behind a low emissive material. When the image fusion is conducted, the low emissive material shows up as bright spot and is clearly detectable. Additionally some other spectral effects are also visible on the street and the windows.

![Fused Image: RGB](image)

Fig. 8: Car with writing on the rear window recorded with the IR-Dual-Band-Camera demonstrator. Presented are the two apparent temperature calibrated original images and the fused image. The fused image shows the difference in the apparent temperature of the two bands. The original images are displayed using the same temperature range for both bands.
5.2 Adapted Histogram

The disadvantage of the method described before is the need to calibrate the data in apparent temperature. Although this would be possible in real time, it would introduce additional components that would increase system costs and the susceptibility to trouble. So in a second approach it was tried to develop a method without the need to know about the band behavior.

The idea used here is to take the grey level histogram of both bands and to recalculate one band in such a way that afterwards both average values (μ₁ and μ₂) and standard deviations (σ₁ and σ₂) of the histograms are the same. This is schematically shown in Fig. 10. The new signal is then calculated according to

\[ \text{Signal}_{\text{Band 2, adapted}} = (\text{Signal}_{\text{Band 2}} - \mu_2) \cdot \frac{\sigma_1}{\sigma_2} + \mu_1 \]  

(3)

As it can be assumed that the signal is linear to the radiance, the method results in removing the linearity constants and adapting the radiances. Thus it is possible to calculate ratio (R_H) or difference (D_H) of the signal\(^{12}\):

\[ R_H = \frac{\text{Signal}_{LW}}{\text{Signal}_{MW, adapted}} \]  

(4)

\[ D_H = \text{Signal}_{LW} - \text{Signal}_{MW, adapted} \]  

(5)

\(^{12}\) Obviously it is possible to do the calculations vice versa resulting in inverted values. For the difference calculation it is also possible to use the absolute value if only the differences and not their direction are interesting. Additionally it does not matter which spectral range is adapted. The results are more or less the same.
It is possible to do this adaptation because the spectral ranges used here are very similar in their behavior and thus also the signal histograms are comparable. If the MWIR would include the whole 3–5 µm range it would be difficult to do this for daytime applications because of the sun radiation component. For the 4–5 µm and 8–9 µm ranges used here this component is more or less similar.

An example for the practical application of this method is shown in Fig. 11. It uses the same scene as Fig. 8 to give an impression of the method. Again the writing on the rear window becomes obvious when the fused image based on Adapted Histogram signal difference is calculated\(^\text{13}\). So this method gives results very similar to the apparent temperature method but without the need to calibrate the data.

\[\text{Fig. 11: Car with writing on the rear window recorded with the IR-Dual-Band-Camera demonstrator. Presented are the two original images and the fused image based on the Adapted Histogram method with calculation of the signal difference.}
\]
\[\text{The same signal range is used for the two original images.}\]

5.3 Conclusion

The presented two-band image fusion techniques show promising results for the examples presented here. They have to be checked now if they improve observer and/or algorithm performance especially in military applications under different conditions (weather, camouflage, etc.). Additionally the limitations of the methods have to be explored. Work in these directions has already started.

6. SUMMARY AND CONCLUSIONS

The IR-Dual-Band-Camera demonstrator was build by four partners and FGAN-FOM. It collects simultaneously infrared data in the 4–5 µm (MWIR) and 8–9 µm (long-wave infrared, LWIR) bands. The demonstrator is based on a two-layer QWIP focal plane array with 384 x 288 x 2 detector elements and 40 µm pitch. Images are typically acquired with a frame rate of 100 Hz at 6.8 ms integration time and are stored as 14-bit digital data. It is equipped with dual field of view F/2 optics of 86 mm and 390 mm focal length, based on refractive and reflective components.

The experimental assessment showed typical QWIP detectors with narrow bands and a low number of defective pixels. It shows a spectral crosstalk from the MWIR into the LWIR but not vice versa. The performance related to System Transfer Function (SiTF), Response, temporal and spatial Noise and Modulation Transfer Function (MTF) is similar in the MWIR and the LWIR. This is advantageous for image fusion techniques as well as for practical use, for example selecting the best band is thus not limited by the camera performance. Altogether the IR-Dual-Band-Camera demonstrator is comparable to the single band QWIPs and very appropriate for the analyses of dual-band-techniques.

During the assessment the IR-Dual-Band-Camera demonstrator was also tested with standard MWIR broadband optics. This somewhat surprisingly resulted in very good MTFs in both spectral ranges. Unfortunately the response in the LWIR was found to be approximately a magnitude of five times less than in the MWIR. As the reason for this difference was assumed in the anti-reflective coating, a similar optics was ordered, equipped with a coating adapted to the two spectral ranges. In the resulting optics the good MTFs were preserved; the response difference was decreased to a magnitude of two and is thus within a range that not automatically favors one band. The optics was used under different climatic conditions and showed no problems with respect to focusing the two bands simultaneously. Although there is still room

\(^{13}\) Although not presented here in detail, also for this method the fused images based on difference and ratio respectively look the same.
for improvements, this proves that the manufacturing of Dual-Band-Optics is possible with performance and costs similar to single band ones.

In addition to the experimental assessment of the demonstrator, image fusion techniques were presented. These techniques have the goal to show up the differences between the two bands in order to get new/additional information on the scene. In order to do so the bands have to be adapted somehow. For this purpose the “Apparent Temperature” method calibrates the two bands in apparent temperatures and ratio or subtraction reveals the differences. The second “Adapted Histogram” method uses the signal distribution (histogram) of the both bands to calculate coefficients to adapt one band on the other. Thus no knowledge about the behavior of the two bands is necessary. Again ratio or subtraction reveals the differences. Both methods show similar results and are promising for a gain in information. They have to be checked now if they improve observer and/or algorithm performance especially in military applications under different conditions (weather, camouflage, etc.). Work in these directions has already started.

7. ACKNOWLEDGEMENTS

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REFERENCES