

Real-time image processing and fusion for a new high-speed dual-band infrared camera

Markus Müller^{*a}, Oliver Schreer^b, Mónica López Sáenz^b

^aFraunhofer Institut Informations- und Datenverarbeitung, Fraunhoferstr. 1, D-76131 Karlsruhe, Germany

^bIRCAM GmbH, Nürnberger Str. 71, D-91058 Erlangen, Germany

ABSTRACT

A dual-band infrared camera system based on a dual-band quantum well infrared photodetector (QWIP) has been developed for acquiring images from both the mid-wavelength (MWIR) and long-wavelength (LWIR) infrared spectral band. The system delivers exactly pixel-registered simultaneously acquired images. It has the advantage that appropriate signal and image processing permit to exploit differences in the characteristics of those bands. Thus, the camera reveals more information than a single-band camera. It helps distinguishing between targets and decoys and has the ability to defeat many IR countermeasures such as smoke, camouflage and flares. Furthermore, the system permits to identify materials (e.g. glass, asphalt, slate, etc.), to distinguish sun reflections from hot objects and to visualize hot exhaust gases.

Furthermore, dedicated software for processing and exploitation in real-time extends the application domain of the camera system. One component corrects the images and allows for overlays with complementary colors such that differences become apparent. Another software component aims at a robust estimation of transformation parameters of consecutive images in the image stream for image registration purposes. This feature stabilizes the images also under rugged conditions and it allows for the automatic stitching of the image stream to construct large mosaic images. Mosaic images facilitate the inspection of large objects and scenarios and create a better overview for human observers. In addition, image based MTI (moving target indication) also for the case of a moving camera is under development. This component aims at surveillance applications and could also be used for camouflage assessment of moving targets.

Keywords: Dual-band infrared, QWIP, image processing and exploitation, registration, MTI

1. INTRODUCTION

Infrared scenes often contain spectral information which cannot be resolved using normal single-band infrared cameras. Only multispectral infrared imaging cameras give access to the comprehensive information contained within infrared scenes. Today's state-of-the-art multispectral imagers use special optical and mechanical components like, e.g., filter wheels, beamsplitters and lenses in order to spectrally separate and focus the radiation onto one or more monospectral IR focal plane arrays (FPAs) or even separate cameras [1]. These systems, due to their technical complexity, are difficult to manufacture (and thus expensive) and difficult to handle. Moreover, the images generated by these systems have an inherent temporal and spatial registration problem. These problems and limitations can be overcome by real multispectral focal plane arrays (FPA) which have been under development during the last few years.

The first approach to build multispectral imagers are FPAs operating at two different spectral ranges, either in two separate atmospheric windows ("dual-band") or within one atmospheric window ("dual-color"). Several bispectral demonstrators operating both in the 8-12 μm long-wavelength infrared regime (LW) and the 3-5 μm mid-wavelength infrared spectral range (MW) have been realized using either HgCdTe (MCT) technology, GaAs-based quantum-well infrared photodetectors (QWIPs) or superlattice detectors [2, 3, 4, 5, 6].

* markus.mueller@iitb.fraunhofer.de; phone 49 721 6091 250; fax 49 721 6091 233; iitb.fraunhofer.de

Dual-band detectors simply offer the advantage that the pros of both infrared bands can be combined in one imager. For example, MWIR imagers exhibit smaller blur spots for longer ranges and better performance in hot humid areas, whereas LWIR imagers deliver better performance in case of stray light or when the object under investigation is close to hot sources. A dual-band imager can be used in a wider range of ambient conditions. Moreover, dual-band detection permits the spectral discrimination of unique object features and thus a better distinction between targets and background clutter or automatic target recognition due to specific emissivity features or to find camouflaged targets.

Dual-color detectors are considered to be useful for improved missile approach warning (MAW) sensors to decrease reaction time and false alarm rates. High frame rate detection modules are crucial for this application.

2. CAMERA SYSTEM HARDWARE DESCRIPTION

A dual-band IR camera system based on a dual-band QWIP FPA was developed. The dual-band QWIP FPA has been developed in a cooperation between Fraunhofer IAF and AIM GmbH. QWIP detectors, due to their narrow band absorption characteristic are well suited for multispectral IR-FPAs. The QWIP FPAs are manufactured on large GaAs substrates with a high yield and exhibit a good homogeneity and pixel operability. The major drawback of QWIPs is their poor quantum efficiency which limits the integration time for good thermal resolution to approximately 5 - 10 ms.

The dual-band QWIP FPA has a format of 384x288 pixels and a 40 μm pitch. The pixels are made in a sandwich-like structure. The FPA is integrated in a Dewar with an F/2 cold shield and is cooled with a 1.5 Watts Stirling cooler. The fast readout circuit permits a high maximum fullframe rate of 310 Hz. The NETD for both bands is around 30-40 mK.



Figure 1: Dual-band IR camera system, consisting of dual-band camera, $f=50$ mm lens and computer.

The camera (Fig. 1) has a compact all metal enclosure with an effective convection cooling/ventilation system. The camera electronics performs pixel re-ordering and pre-processing and outputs the image data via standard Camera Link (base configuration) interface or Gigabit Ethernet (GigE) interface. The camera also has an MIO (measurement input & output) interface for synchronization with external devices and for triggering purposes.

Several lenses with different focal lengths ($f=50$ mm, $f=100$ mm, $f=86/390$ mm dual field of view) were tested with the camera. The lenses have a broadband AR coating and exhibit identical foci for both spectral ranges.

The camera is operated from a standard personal computer running Windows XP operating system. The PC is equipped with a Camera Link frame grabber card which the camera is connected to.

The system's software performs all basic functions, like camera control, image acquisition, image display and non-uniformity correction and also offers radiometric functionality. Moreover, it permits image processing functions like image addition, subtraction, multiplication and division. It separates the two images of the dual-band camera and displays them in real-time either as separate images with individual contrast and offset or as an overlay image.

3. IMAGE PROCESSING

There are different approaches for processing and visualizing the images of the dual-band camera. The approach depends on the application and also on the available monitor to display the images. At first, however, it is usually necessary to calibrate the camera such that it delivers a radiometric output. This requires a non-uniformity correction and a calibration which compensates for the different characteristics of the IR intensity within both bands. The resulting images can then be processed further.

It is sensible to display the images as real "color images". Usually, color images are made up of three complementary colors which can generate any color when used in different parts or add up to grey values when used in equal parts. For TV and computer monitors, the colors red, green and blue (RGB colors) are used. The overlay of a red, a green and a blue image results in a color image. When only two spectral images are available they should be assigned to appropriate color pairs (e.g. red/cyan or orange/light blue) such that the overlay again results in grey when their intensities are identical.

When one of the two images exhibits higher intensity than the other image, this will result in a colored part of the overlay image. At identical intensity the overlay image appears grey, white or black. The big advantage of this method over the method of just subtracting the two images is that both the absolute intensities and the differences of the two images can be perceived simultaneously. The overlay image appears like a normal IR image, but with slight color tones.

The system's software not only offers image fusion but also mosaicking as well as MTI (image-based Moving Target Indication) and tracking capability. All the automatic image processing methods operate in real-time, i.e. the system is e.g. capable of very fast registering subsequent overlapping images and stitching them together for creation of large format images (image carpets, panoramas or mosaics). This makes the system a powerful tool for observing and analyzing extended scenes and quickly detecting spectral IR signatures with less false alarms.

Images were taken with the dual-band IR camera system under different environmental conditions and of different scenes:

- a) Panorama of the city of Freiburg, Germany. The images were taken from a hill in the city center in the daytime.
- b) Same as a), but at night.
- c) Panorama of the countryside village Langensendelbach, at night.
- d) Images of an office building, taken on a cloudy day.
- e) Images of a landing airplane, taken against direct sunlight

The images were processed both interactively, by stitching a number of images together using a standard commercial panorama software, and automatically by using advanced real-time algorithms for mosaicking and tracking of moving targets. The results are shown in the following two chapters.

4. INTERACTIVE IMAGE PROCESSING FOR CARPETING

Images were taken of the city of Freiburg, Germany on a cold day in January, both in the night and in the daytime (Fig. 2). Approximately 100 single images were taken and stitched together to large panorama images. The MWIR and the LWIR images were overlayed with complementary colors as described above. The city panorama shows numerous buildings, streets, cars, trees and other vegetation, mountains and clouds near the horizon and the sky. The panorama of Langensendelbach (Fig. 3) was created stitching only 10 images together.

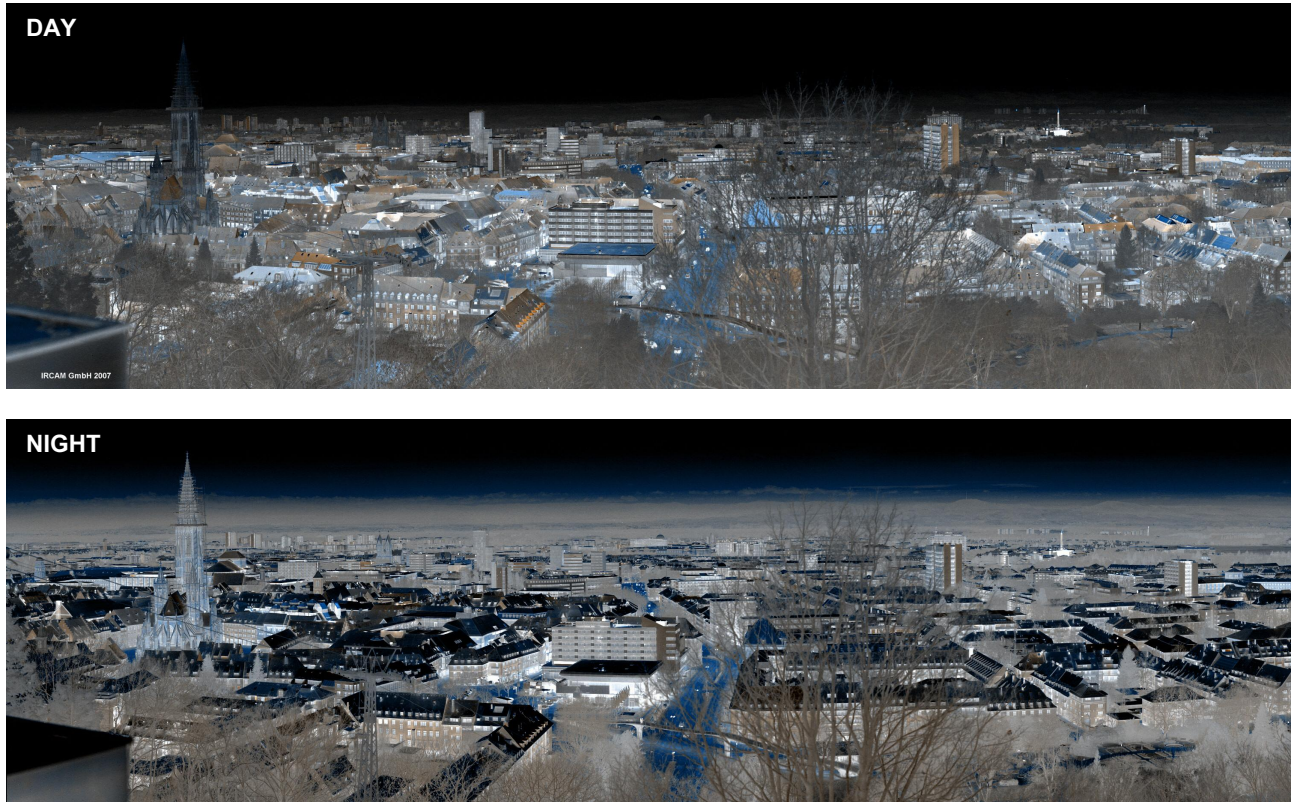


Figure 2: Dual-band IR images (3000 x 900 pixels) of the city of Freiburg, Germany at daytime (top) and nighttime (bottom). MWIR image and LWIR image are overlayed with complementary colors (not apparent in the grey color print). The panorama images are stitched from approx. 100 single images.

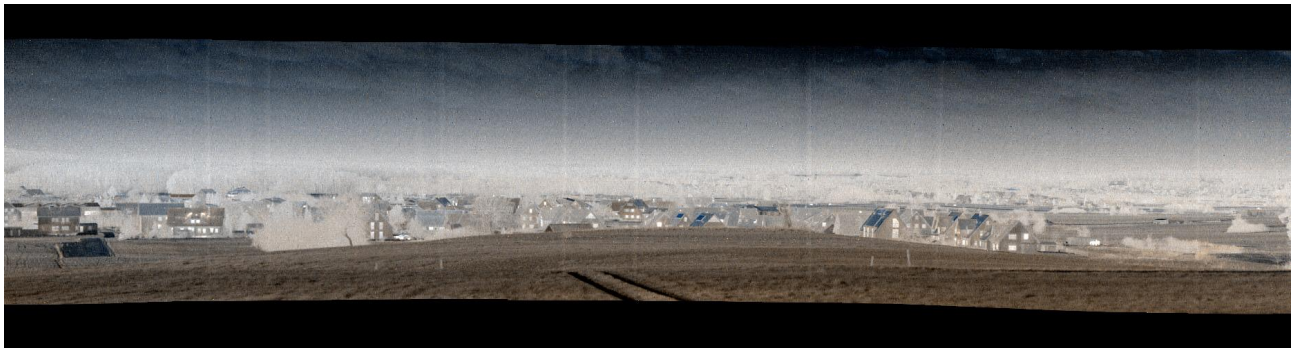


Figure 3: Dual-band IR panorama image (overlay) of the village Langensendelbach, at nighttime. The panorama image is stitched from 10 single images.

4. AUTOMATIC IMAGE PROCESSING

Multisensor approaches allow for better inferences than could be achieved by employing only a single sensor (or band). Hence multiple sensors or bands increase reliability and the exploitation of the complementary data allows for perception of physical characteristics that are not detectable by a single sensor. Therefore these approaches improve observability. Data association is one important and often cumbersome task for utilizing multisensor data. The data association is unnecessary in the case of the dual-band sensor since the data is already registered.

The following sections present first results of applying automatic image processing and exploitation algorithms to dual-band IR data. The first algorithm generates image carpets from the dual-band IR sequences by estimating the transformation from image to image in the sequences. We consider collineations (planar projective transformations, homography) which can be computed from point or line correspondences for estimating the geometric transformation between the consecutive frames of a sequence. The automatic approach for stitching images together is based solely on the image content, no geometric nor radiometric calibration required (exception: fish-eye optics or other optics with large distortions). The method follows the following processing steps (details: [9], [10]; for further applications of the methods see [8]):

1. Calculation of pass points (approximately 40-60 per image) in consecutive frames each.
2. Robust match of the point fields.
3. Estimation of the parameters of the transformation matrix.
4. Application of the transformation and adding the new image content due to pan/tilt movements of the sensor.

The results of this approach can be seen as an estimation of the sensor movements relative to the static background. The prominent features of the approach are:

1. Real-time capability on moderate COTS hardware without any special hardware involved.
2. Neither parameterization (e.g. pan/tilt parameters of the sensor) nor calibration required.
3. High precision (sub pixel accuracy).

In the following examples we took sequences consisting of hundreds of image frames. The approaches were tested on:

1. Grey value combinations of the MWIR and the LWIR bands.
2. The MWIR band alone and
3. the LWIR band alone.

The first results show (large) city panoramas of Freiburg (Fig. 4) and Langensendelbach (Fig. 5). The results show that the sequence was taken while standing on a hill with a smooth pan. The high sub pixel accuracy together with the projective mapping in the registration process avoids cutting edges in the example carpets and in most other cases.

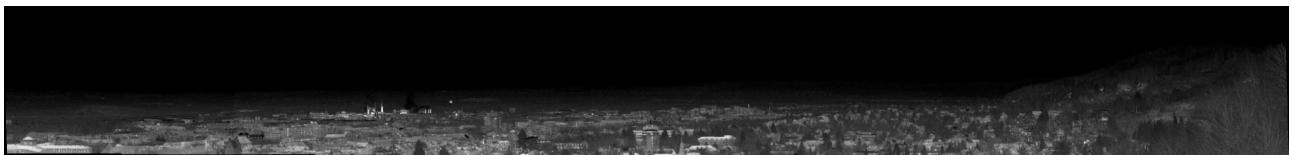


Figure 4: Image mosaic of Freiburg (grey value combination of MWIR and LWIR).

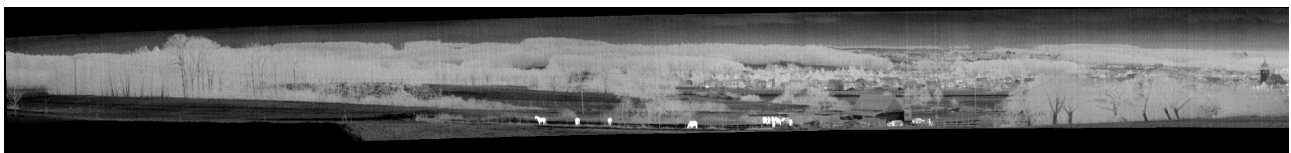


Figure 5: Image mosaic of Langensendelbach (grey value combination of MWIR and LWIR).

Image carpets may bend (or distort) mainly due to error propagation in the registration process, inconvenient geometry of the captured scenario, and/or pan/tilt of the camera. The two latter effects took place in the following example (Fig. 6): geometry of the scenario and camera pan/tilt.

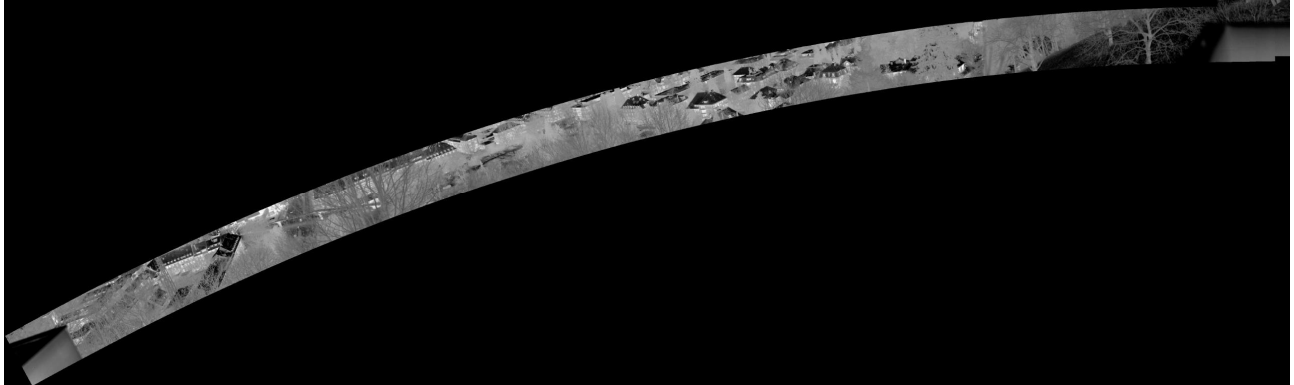


Figure 6: Camera pan causes a bending image mosaic (Freiburg, MWIR).

Another situation may arise when the automatic stitching process overlaps with areas that have already been stitched together. This results in distortions because the registration process takes only the last two frames of the sequence into account and hence the error propagation effects get noticeable. These distortions could be avoided when also overlaps with already stitched areas contribute to the calculation of the transformation parameters. This could result in a time consuming recalculation of all previous transformations for all frames making real-time processing impossible. Other distortions may happen when the sensor captures 3D objects from a short distance. These distortions result from parallax effects. The next result example (Fig. 7) incorporates both effects: distortions due to overlaps with the stitching history and parallax phenomena.

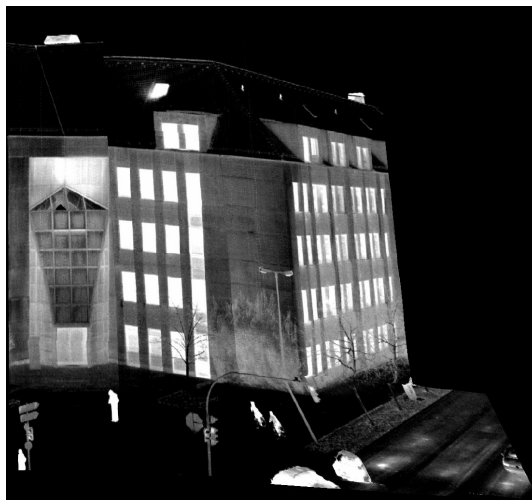


Figure 7: Close-up mosaic of a large building (LWIR). Distortions stem from parallax effects and overlaps with the stitching history.

The next examples show the result of an image based MTI (Moving Target Indication). The image sequences captured a flying aircraft with a moving camera (Fig. 8). The approach suppresses the background and therefore objects that are moving relative to the static background pop out (Fig. 9).



Figure 8: Image-based MTI (MWIR left and LWIR right). Target and camera were moving.

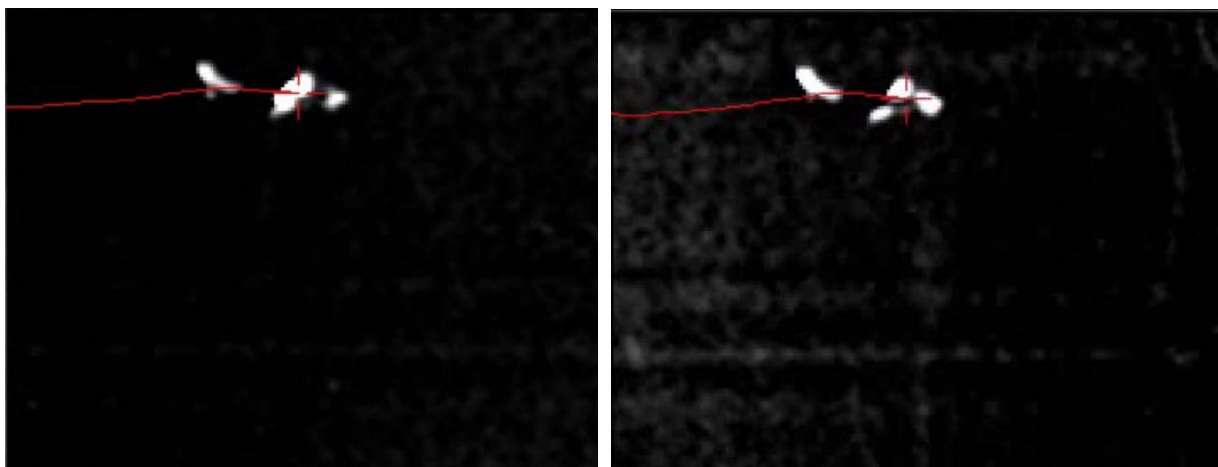


Figure 9: Result of the background suppression (MWIR left and LWIR right) while target and camera were moving.

Fig. 10 shows the result when the sequence with the aircraft is automatically stitched together.

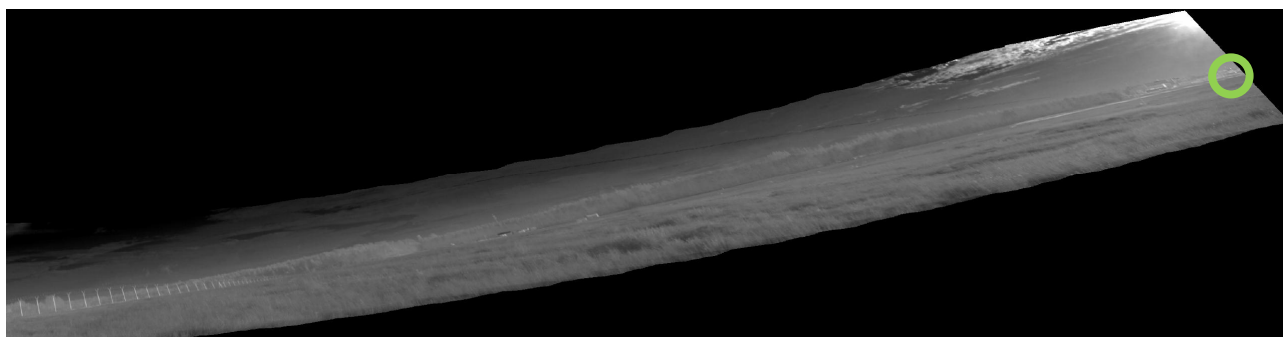


Figure 10: Mosaic of an aircraft landing (MWIR band). The aircraft signature (denoted by the green circle; interactively drawn) is very small compared to the large mosaic. Note the perspective effects while the FOV went from left (close fence) to the right (runway far away) and while the growing horizon impacts the carpeting process.

The presented MTI approach relies on a good image-to-image registration quality for suppressing the background. The next approach aims at object tracking and it does not require image registration since it depends solely on pixel intensity statistics.



Figure 11: Application of a tracking approach (MWIR left and LWIR right). Target and camera were moving.

5. CONCLUSIONS

A dual-band IR camera system was developed, based upon dual-band QWIP FPA detector. The system permits to process and display the images in different ways, including overlay with complementary colors. The camera system was tested under different conditions and with different scenes. It appears that due to the spectral characteristics of the materials within a scene, using a color display for the images, the contrast of IR images can be improved, i.e. the perceptibility of details becomes significantly better. Apart from that, the system simply permits to switch between the two spectral ranges and to display the image which under the present conditions delivers the subjectively better image. The experiments employing automatic image processing and exploitation algorithms show that especially tracking and moving object detection approaches profit from the dual-band sensor system. Also the automatic carpeting process may profit in cases where one single band delivers not enough features for the matching process. In this case the combination of the features of both channels may enable the continuation of the automatic carpeting process. Further work will take more the dual-band characteristics into account for proving quantitatively the gain of processing dual-band images.

6. ACKNOWLEDGEMENTS

The images shown in this paper were made using the dual-band IR camera of the Forschungsinstitut für Optronik und Mustererkennung (FGAN-FOM, Ettlingen).

REFERENCES

1. O. Schreer, M. López Sáenz, Ch. Peppermüller, Th. Hierl, K. Bachmann, J. Fries, Proc SPIE Vol. 5074, p 637 (2003)
2. W. Cabanski, K. Eberhardt, W. Rode, J. Wendler, J. Ziegler, J. Fleissner, F. Fuchs, R. Rehm, J. Schmitz, H. Schneider, M. Walther, Proc SPIE Vol. 5406, p 184 (2004)

3. W. Cabanski, M. Münzberg, W. Rode, J. Wendler, J. Ziegler, J. Fleissner, F. Fuchs, R. Rehm, J. Schmitz, H. Schneider, M. Walther, Proc SPIE Vol. 5783, p 340 (2005)
4. M. Münzberg, R. Breiter, W. Cabanski, H. Lutz, J. Wendler, J. Ziegler, R. Rehm, M. Walther, Proc SPIE Vol. 6206, (2006)
5. R. Rehm, M. Walther, J. Fleißner, J. Schmitz, J. Ziegler, W. Cabanski, R. Breiter, Proc SPIE Vol. 6206 (2006)
6. A. Manissadjian, D. Gohier, E. Costard, A. Nedelcu, Proc SPIE Vol. 6206 (2006)
7. IRCAM homepage: <http://www.ircam.de>
8. M. Müller, N. Heinze, D. Clement, ATR-Based Camouflage Effectiveness Evaluation of MUSTAFA Targets, Proc SPIE, Targets and Backgrounds XI: Characterization and Representation, 2005
9. W. Krüger, Robust and efficient map-to-image registration with line segments, Machine Vision Applications 13, 2001
10. M. Müller, W. Krüger, G. Saur, Robust Image Registration for Fusion, to be published in Information Fusion, Elsevier, 2007