CART III: Improved camouflage assessment using moving target indication

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ABSTRACT

In order to facilitate systematic, computer aided improvements of camouflage and concealment assessment methods, the software system CART (<u>C</u>amouflage <u>A</u>ssessment in <u>Real-Time</u>) was built up for the camouflage assessment of objects in image sequences (see contributions to SPIE 2007 and SPIE 2008 [1], [2]). It works with visual-optical, infrared and SAR image sequences. The system comprises a semi-automatic annotation functionality for marking target objects (ground truth generation) including a propagation of those markings over the image sequence for static as well as moving scene objects, where the recording camera may be static or moving. The marked image regions are evaluated by applying user-defined feature extractors, which can easily be defined and integrated into the system via a generic software interface.

This article presents further systematic enhancements made in the recent year and addresses particularly the task of the detection of moving vehicles by latest image exploitation methods for objective camouflage assessment in these cases. As a main topic, the loop was closed between the two natural opposites of reconnaissance and camouflage, which was realized by incorporating ATD (Automatic Target Detection) algorithms into the computer aided camouflage assessment. Since object (and sensor) movement is an important feature for many applications, different image-based MTI (Moving Target Indication) algorithms were included in the CART system, which rely on changes in the image plane from an image to the successive one (after camera movements are automatically compensated). Additionally, the MTI outputs over time are combined in a certain way which we call "snail track" algorithm. The results show that their output provides a valuable measurement for the conspicuity of moving objects and therefore is an ideal component in the camouflage assessment. It is shown that image-based MTI improvements lead to improvements in the camouflage assessment process.

Keywords: Image exploitation, ATD, camouflage assessment, ground truth generation, MTI, multi sensor, regions of interest (ROIs), semi-automatic annotation, visual / infrared / SAR image data, multispectral camouflage, signal-to-noise ratio (SNR) in vision tasks.

1. MOTIVATION

Mobility and indirect protection by means of multispectral camouflage are to be combined in actual deployments of armed forces. Mobile camouflage systems are one solution to achieve a good compromise between mobility and indirect protection.

However, the question how to evaluate camouflage effectiveness of a mobile system is not yet answered. Especially the camouflage against thermal sensors is not only done by signature reduction, because current reconnaissance systems or seeker heads in missiles have highly developed algorithms to find and track autonomously military targets. In order to develop modern mobile camouflage systems it will be necessary to use moving target identification (MTI) and tracking algorithms to visualize the camouflage effectiveness of mobile equipment. Form, thermal patterns and the reduction of original signatures can have quite an influence to the minimal necessary thermal signal-to-noise ratio needed to find and track targets.

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Figure 1. Snail track example. The image was generated synthetically for illustration purposes.



Figure 2. Left: Virtual measurement port overlayed to an infrared image data sequence. Right: Measurement value plot over time while three vehicles are passing through (upper plot line). The plot parts correlated with a vehicle visibility inside the port are marked with boxes. The lower plot line was calculated for the entire image and serves as a measurement reference.

The use of pure tracking algorithms cannot explain why it fails due to the effectiveness of camouflage. So it is necessary to look behind the curtain of MTI methods by analyzing and visualizing the "view" of a MTI system. One method to visualize the effectiveness against MTI and target tracking is to add frame by frame image flux signatures. The image produced by this method will be called "snail track" in this paper.

Figure 1 illustrates a snail track of a circling vehicle. The black area shall be seen as a noise threshold level. All white pixels are image flux signatures about the noise level. A good camouflage should have the effect that a moving target cannot be extracted out of the background clutter.

Figure 2 shows another possibility to visualize camouflage efficiency of moving targets. Due to the technique of automatic annotation [1], [2] it is possible to set virtual measurement ports on a motion scenario. In this case three targets with different stages of camouflage drive through a virtual port where a virtual thermal sensor plots some image feature signals. It has to be mentioned here that the underlying measurement function does not rely on movement information but only on image contrast features. The camouflage assessment advantage for the state of movement derives from the evaluation over time.

In order to optimize the evaluation of camouflage effectiveness of moving targets WTD 52 GF 310 gave a R&T contract to Fraunhofer IITB.

2. SNAIL TRACK CONSTRUCTION AND IMPLICATIONS

The basic idea to realize the snail track procedure is to accumulate the informations of an appropriate moving target indication (MTI) algorithm over time in a feature image (or, to be more accurately, in a feature image

mosaic, see section 4 for details). Low movement indications are represented by dark pixels and high indications by bright ones, respectively.

Provided that the MTI algorithm exhibits a sufficient signal-to-noise ratio (SNR), the resulting image data will show white traces where object movements are taking place and which can clearly be distinguished from background information, image noise and clutter (represented with dark colors as far as possible).

The main challenge is to achive a suitable SNR. Otherwise the snail track method will produce useless whiteoverloaded images due to a rapid accumulation of noise over time. Furthermore, the better the SNR of the MTI algorithm the better is the benefit for moving target detection and camouflage assessment.

Therefore, a main topic of the snail track algorithm is the construction of a high-performance MTI algorithm which is described in detail in the following section 3.

3. MULTI TARGET INDICATION (MTI) ALGORITHM

In the following, the successive development and improvement of the MTI with its resulting increasing performance is subdivided into three levels: (1) the basic algorithm, (2) an image history extension and (3) a further extension basing upon image structure consideration.

3.1 Basic algorithm (Level 1)

A well-known basic idea for an MTI algorithm is to use an image-to-image subtraction after doing an imageto-image registration. The registration first compensates for camera movements while the subtraction extracts differences occuring from one image to the other one as produced by moving objects in the scene, for example.

In this paper, the image-to-image registration is done by robustly estimating the projective transformation matrix $T_{ji} \in \mathbb{R}^{3\times3}$ (see [3], [4], [5], [6] for details) which warps an image *i* onto an image *j*, i.e. transforms the coordinates (x_i, y_i) of image *i* onto the coordinates (x_j, y_j) of image *j* by calculating

$$\begin{pmatrix} x'_{j} \\ y'_{j} \\ z'_{j} \end{pmatrix} := T_{ji} \cdot \begin{pmatrix} x_{i} \\ y_{i} \\ 1 \end{pmatrix}$$
(1)

and

$$x_j = x'_j / z'_j , \qquad (2)$$

$$y_j = y'_j / z'_j . (3)$$

After warping one image onto the other one, the grayvalues or camera colors at each pixel position can be subtracted leading to the resulting MTI feature image representing a map of changes between the two images.

Figure 3 depicts an example. The underlying image sequence shows a flying crow before trees and some houses recorded with a moving camera capturing the crow. The shown MTI feature image was calculated for the image frames 155 and 158. Since the sequence was recorded with 25 Hz, this image frame difference corresponds to a time difference of 120 milliseconds.

This difference was chosen here to show a typical effect: The feature image contains not only the object response for the crow in the current image frame 158 (as desired) but also the response for the crow's position in image frame 155 which is disadvantageous in many applications.

Furthermore, one can see a lot of clutter in the whole MTI result image of figure 3 due to differences calculated in the background for multiple different reasons.



Figure 3. Left: Image 158 of an image sequence showing a flying crow. Right: MTI feature image. The MTI response region for the crow is marked with a circle.

3.2 History extension (Level 2)

In the second MTI development level this doubling effect of moving objects is eliminated and the over-all clutter is reduced by incorporating a larger image sequence history. That means, that the image registration and difference calculation is not only done for an image frame with respect to a previous one. Instead, the calculation of registration and subtraction is done for the current image frame with respect to all images in a defined history, i.e. for n images in the past. The resulting MTI response is calculated by determining the Minima (emerging dark object part before bright background) and Maxima (emerging bright object part before dark background) over all n MTI feature images. This calculation corresponds to a logical AND operation and extracts in this way all differences stemming truly and certainly only from the current image frame excluding some unwished effects to a large extent. We use image frame windows of size 10 (current image plus history), i.e. n = 9 as image history length in the examples shown in this paper.

Figure 4 shows the resulting MTI response using history consideration for the same situation as figure 3. As one can see, object doubling is eliminated and the background clutter is significantly reduced without considerably degrading the crow signal.

As one can see in figure 4, in presence of fast camera movement the image region with white pixels is smaller than in figure 3. That's because of the AND operation for images with different viewing regions (assuming that outside an image is no content leading to a zero difference in subtraction with other images). This effect seems not to be a problem for the snail track procedure as our practical experiences have shown.

3.3 Structural extension (Level 3)

As a third MTI development level, the results can further be enhanced by incorporating image structure information in order to improve the SNR and to further lower the clutter effects in the MTI response image.

The underlying idea is as follows. When doing registration and image substraction, the pixels of a past image fall onto their target positions in the current image frame according to the registration's position transformation. Before thinking of the grayvalue or color subtraction step there, the transformed pixels at first may hit different structural situations in the current image like homogenous regions or different kinds of image edges. Examinations have shown that there are multiple reasons to produce differences from one image frame to the next one which are not desired to be noticed by the MTI algorithm (a fact which makes methodical improvements quite difficult in general). But on the one hand, most clutter generating effects occur right in the places of image edges or because the edge itself can explain a pixel difference for some reasons (as, for example, rounding effects or the camera's pixel aliasing). On the other hand, a moving object generates only accidentally with a quite low occurrence possibility the same edge informations as in the background. A change detection would be quite uncertain in



Figure 4. MTI feature image example with history consideration.



Figure 5. MTI feature image example with history and structural extension. Left: Using four neighbors in the algorithm (see text). Right: Using eight neighbors.

such situations, anyway. In contrast to image edges, pixel changes at homogeneous regions are quite sure to stem from object movements.

Therefore, the image subtraction step is extended as follows. After doing the registration transformation for an image pixel of a past image, the hit target pixel of the current image is analyzed together with its four direct neighbors. The minimal and maximal grayvalue (or the spanned color space when using color images) is calculated for the resulting five pixels. The image difference is calculated then as the difference of the registrated pixel content and the determined grayvalue interval (or the determined local color space, respectively), i.e. with respect to the local image edge information.

Figure 5 shows in the left image part the result when combining the described structural extension with the history extension for the situation depicted in figures 3 and 4. When comparing figure 5 with figure 4 it can clearly be seen that the SNR is significantly improved by using the structural extension.

As a further enhancement, the structural extension can also be used with eight neighbors instead of four, i.e. by regarding the four direct neighbors as well as the four diagonal neighbors. But, as the right part of figure 5 shows, the achieved further improvement is marginal in a lot of cases. Therefore, the examples shown in this paper use the variant with four neighbors.

Finally, it should be mentioned that the structural extension suppresses object movements below two pixels from one image frame to the following one. This is obvious by algorithmic construction. It should not be signifikant if the object movements have a dynamic up to many pixels in the image plane. If the object movement happens in the magnitude of below two pixels (due to a great camera distance, for example), it is useful to evaluate not every single image frame of an image sequence but only every k-th image frame (k = 2, 3, 4, ...) leading to object movements equal or greater than the two pixel theshold. If this is not possible or not desired, the structural extension has to be left out along with its advantages and the MTI variant with history extension only (level 2) can be used.

4. SNAIL TRACK ALGORITHM

The snail track algorithm accumulates the MTI response images in an integral image. Additionally, in order to improve the snail track benefit, the accumulator images are stitched together to a mosaic image which presents a large or sufficient wide overview if the camera moves far over time or if the camera moves fast.

The calculation of the mosaic image bases on the image-to-image registration described in subsection 3.1. The calculated transformation T_{ji} is used to stich two consecutive image frames *i* and *j* together so that they are acurately fitting. It has to be mentioned that the calculation of T_{ji} is always done with the camera image data material. Stitching can then be done for the camera data and/or the MTI images since their T_{ji} is the same.

There are two implemented modes. The first one stitches the MTI images together over time. Alternatively, the camera images are stitched together and the MTI outputs are overlayed in the respective image positions using T_{ji} . Both modes will be depicted in the following.

5. SNAIL TRACK RESULTS

In a first experiment, a synthetic image sequence is generated by using a real background image and a real object with militarily relevant features. The object starts somewhere in the middle of the image and is moved via software over the image in a straight horizontal line to the left through the image until it is moved out of the image plane. Finally, the result is combined with additive noise. Figure 6 shows in the upper part the first image of the sequence as well as an image during the sequence before its end. Despite high noise influence, the object movement produces a strong signature with very low clutter around, see lower part of figure 6. This means first considerable indications for a high performance also in real image data.

A very important feature of the approach in our discourse of camouflage assessment is, of course, the robustness and usability in cases with camouflaged objects - a circumstance which naturally hinders computer vision algorithms significantly.

A lot of animals are masters of camouflage. Figure 3 in section 3 showed a flying crow. In this specially selected image the crow can be found and seen relatively easy. But in most parts of the sequence it is quite difficult even for humans to find the crow in a single image without playing the sequence. But when playing, the movement information allows an observer to track the crow. So, the crow shows an optimal camouflage and can mainly only be detected by its movement. Therefore, this image sequence is ideal for testing and for using the snail track procedure.

Figure 7 shows the snail track results for the crow image sequence using the MTI algorithm at level 1 (top image in the figure), the MTI algorithm with history extension (level 2; second image of the figure), the MTI algorithm with history and structural extension (level 3; third image) and the MTI algorithm with history and structural extension (level 3; third image) and the MTI algorithm with history and structural extension (level 3; third image) and the figure). The results show the significant improvements for the resulting snail track which could be reached by developing the MTI from one level to the next one. The benefits are directly and intuitively clear when looking at the images.

Figures 8 and 9 demostrate the performance of the snail track algorithm in two realistic infrared scenarios. It has to be mentioed here that the used IR camera exhibits significant noise artefacts in the delivered image data material. But despite the low contrast of the truck in figure 8 and the small sizes of the recorded vehicles in figure 9 the snail track is clearly visible and distinguishable from the clutter influences.



Figure 6. Top left: First image of a synthetically generated image sequence. Top right: Image before the end of the sequence. Bottom: Snail track result. The software to generate the image sequence was written by Thomas Honke.

The presented snail track procedure works on an Intel Pentium D 3.20 GHz for images of size 720×576 pixel at a frame rate of about 1.4 Hz (MTI level 1), 0.40 Hz (MTI level 2) and 0.36 Hz (MTI level 3), respectively.

6. CAMOUFLAGE ASSESSMENT BENEFITS

The presented snail track procedure has a direct benefit for camouflage assessment as described in the introduction section 1. It provides a direct, visible and objectively measurable access to camouflage success by generating a signature with a brightness proportional to the changes which occur with respect to the background evoked by the movement. That means the better a moving object is camouflaged, the lower the snail track intensity.

In the example shown in figure 10 the snail tracks of an uncamouflaged military vehicle (shown in the top left part of the figure) as well as the same vehicle with modern camouflage (depicted top right in the figure) are calculated and drawn into the same signature image (bottom part of figure 10). As one can see, the snail track of the uncamouflaged object is much brighter and more dense than the snail track calculated for the vehicle with camouflage. The averaged grayvalue of the uncamouflaged object's snail track is 229 and the one for the camouflaged object is 124. The latter value or, alternatively, the difference between these values can be interpreted as a direct, objective quantification of the camouflage success. The task is to minimize the calculated value for the camouflaged object or to maximize the value difference between the camouflaged and uncamouflaged state in order to optimize the camouflage method.

By combining the snail track's MTI component with the semi-automatic annotation and evaluation functions of the CART system (cf. [1] and [2]), the following movement conspicuity evaluation contributes as well directly



Figure 7. Snail tracks for the crow sequence using MTI at level 1 (top), level 2 (second image) and level 3 (third image). Bottom: Camera image mosaic overlayed with the MTI level 3 results. The image sequence consists of 371 images which were all processed and stitched together.



Figure 8. Top row: Two images of an infrared image sequence in an overflight scenario where a truck drives on a road and under a bridge. Bottom: Snail track result (MTI level 3) overlayed to the image data.

to the camouflage assessment. After the regions of interest (ROIs) for camouflaged and non camouflaged objects as well as for background structures are generated (as it was done in the example image sequence depicted in the first row of figure 11), the MTI movement information can be evaluated by applying dedicated image features inside the MTI image areas marked by the ROIs (cf. bottom left image of figure 11) leading to measurements for the objects and background structures over time. The plot graphic on the bottom right part of figure 11 shows an example evaluation. All upper plot lines belong to marked vehicles and the lower plot lines to background ROIs. By comparison and suitable mathematical conjunction of the measurement values for vehicles and background, camouflage success can be quantified. The width of the gap between the vehicle plots and the background plots mirrors, on the one hand, the reached signal-to-noise ratio worked out in section 3 and, on the other hand, is directly correlated with the conspicuity of the vehicles in the given environment. The camouflage optimization goal is to minimize the distance between the vehicle plots and the background plots or even to mix them up.

The evaluation measurements can be combined with the image plane based features used so far (see the example at the end of section 1 which is depicted in figure 2) in order to further maximize the camouflage assessment benefit.

7. SUMMARY AND OUTLOOK

The snail track idea was born as a valuable tool for camouflage assessment concerning moving objects. Thereupon, a high-performance MTI algorithm was systematically developed providing the kernel algorithm for its realization



Figure 9. Two images of an infrared image sequence in an overflight scenario (upper two images) and snail track results done with MTI level 3 (bottom).

in order to fulfill the requirements in the field of camouflage assessment. The significant benefit in this field could be demonstrated by numerous examples.

By using an MTI algorithm as a form of an ATD (Automatic Target Detection) technique the loop was closed between the two natural opposites of reconnaissance and camouflage. In this way, the conspicuity of moving objects could quantitatively be evaluated contributing directly to an objective camouflage assessment in a systematic camouflage improvement process. As a considerable advantage, improvements in the ATD/MTI component lead directly to benefits in the camouflage assessment.

In the near future, further utilizations of the presented algorithms in the field of camouflage assessment in workaday practice will be performed.

Future work should deal with filter components in order to reduce high camera noise influences especially when using infrared sensors. This should further improve the snail track and MTI results in these cases.

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Figure 10. Military vehicle without camouflage (top left) and with modern camouflage (top right) placed in a background scene. The bottom part shows the snail track result for both moving objects drawn into the same image. The software to generate the image sequence was written by Thomas Honke.

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Figure 11. Upper image row: Two images of an infrared image sequence in an overflight scenario with generated regions of interest (ROIs) for vehicles and background structures. Bottom left: Evaluation of the MTI information inside the ROIs. Bottom right: Resulting evaluation plots for the image sequence.