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Implementation of Target Trackability Metric based on Gray-Level Co-occurrence Matrix (GLCM)

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Report title (In translation)

Implementation of Target Trackability Metric based on Gray-Level Co-occurrence Matrix (GLCM)

Abstract (not more than 200 words)

A target trackability metric (TM) based on the gray-level co-occurrence matrix (GLCM) has been implemented as a Windows® program. The model can be used for calculating a target's trackability in an image sequence as a function of frame index. An alternative use for the model can be to calculate the trackability of a target in an image assuming that the target could be moved to different positions in the image.

If GLCM TM is used with care it is a powerful tool for evaluation of a target's trackability. The trackability metric for a target can be used as a measure for how well a target's signature has been adapted to its surroundings. It can also be used to evaluate an obscurant countermeasure.

An example of how GLCM TM can be used has been presented. In this example the effect of multispectral waterfog as a countermeasure for an armored vehicle was evaluated. The results were also compared to results from a correlation tracker. Multispectral waterfog was shown to be very effective against a target tracker. However, in order to show that, additional tools had to be used in order to interpret the GLCM TM results correctly.

Keywords

OPTSIM, laser, laser jammer, model, electro-optics

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En värderingsalgoritm baserad på grånivåstrukturmatriser som beskriver möjligheten att följa ett mål har implementerats som ett Windows® program. Modellen kan användas för att beräkna möjligheten att följa ett mål i en bildsekvens som funktion av bildindex. Ett alternativt sätt att använda modellen är att beräkna möjligheten att följa målet beroende på dess position i bilden.
När modellen används med eftertanke är den ett effektivt verktyg för att utvärdera ett måls följbarhet. Följbarheten kan användas som ett mått på hur väl signaturanpassningsåtgärder har lyckats. Det är också möjligt att använda modellen för att utvärdera effekten av motmedel med döljande karaktär.
Ett exempel på hur modellen kan användas har presenterats. I detta exempel har multispektral vattendimma använts för att skyla ett stridsfordon och dess effekt har utvärderats med hjälp av modellen. Resultaten har jämförts med resultat från en korrelationsmålföljare. Modellen visar att den multispektrala vattendimma har god effekt mot en IR-målföljare. Dock fick beräkningen kompletteras med andra typer av beräkningar för att kunna tolka resultaten på ett riktigt sätt.</td></tr>
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1 Introduction

A method to assess the effect of a target's use of countermeasure or camouflage is to try to track the target in recorded image sequences where some kind of countermeasure or camouflage is used. The drawback of this method is that different trackers have different ability to track targets and also that some trackers have parameter settings that can affect the outcome of the evaluation or that the exact lock-on position affects the ability to track the target. The effect of different lock-on positions does, for instance, affect the end result in correlation trackers where a reference image is created depending on the lock-on position of the tracker. In the FOI model, SeekCorr [1], this effect can be studied by the use of a feature in the model which allows parallel simulations using a systematic selection of lock-on positions in a selected area of the image. However, the effect of the parameter setting is more difficult to anticipate and a failure in target tracking does therefore not necessarily mean that it is impossible to track the target and, hence, different model operators can obtain different results. To get a more objective assessment, an independent metric that reflects the possibility to track the target is therefore required. Metrics based on simple target signature statistics (temperature differential, simple background clutter statistics, signal-to-noise ratio) can not consistently predict the ability to track a target [2]. An attempt to develop an alternative metric has therefore been carried out at the US Army Aviation and Missile Research [3] and was presented at a workshop *Introduction to Workshop on Performance Models for Trackers and ATRs* as part of a SPIE Conference in 1998. The proposed model considers the difference between the image structure of the target and of its neighboring surroundings.

When the trackability metric, described above, was tested against different sequences it was discovered that it could not describe the ability to track the target when a predominant feature, such as a hot spot, was present. A modification of how the trackability metric was designed was therefore made where predominant features of the target can be considered [4].

The modified trackability metric based on Gray-Level Co-occurrence Matrix (GLCM) has been implemented in the SeekCorr model at FOI. The implementation and its use are described in the succeeding chapters of this report.

2 Target Trackability Metric based on Gray-Level Co-occurrence Matrix (GLCM)

The ability to track a target is not only dependent on the difference in intensity between the target and the background but also on the amount of clutter in the background and how similar the clutter in the background is to the target. A newly developed trackability metric that addresses both contrast and structure is based on GLCM [3,4]. The GLCM, and its use in the target trackability metric (TM), is described in this chapter.

GLCM is a two-dimensional histogram with information about the probability for the intensities of two pixels at a fixed displacement. That is, if the intensity of the first pixel is I_A then the probability distribution of the second pixel is GLCM (I_A, I_B) where I_B is the intensity of the second pixel. I_A and I_B are also the column and row indexes of the GLCM. Calculating GLCMs, first for pixels on the target and then for pixels in the immediate background, allows a comparison of the target's and background's structure and intensities. If the GLCMs of the target and background are similar the trackability of the target is low.

$$GLCM(I_A, I_B) \approx \Pr\{I(m,n) = I_A, I(m + r\cos\theta, n + r\sin\theta) = I_B\}$$

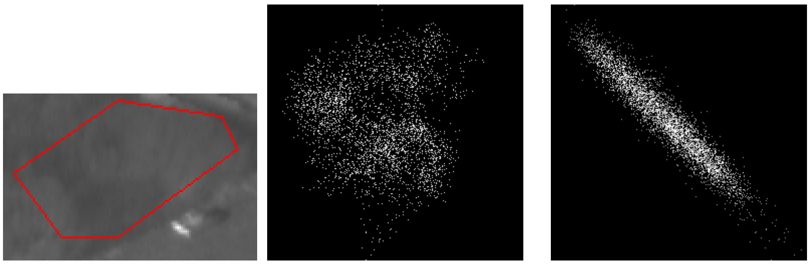
where

Pr {} = the probability that the pixel at (m, n) has intensity I_A and the pixel at (m + r cos(θ), n + r sin(θ)) has intensity I_B

r = the displacement between the pixels

θ = the orientation angel between the pixels

The displacement in the above equation will highly influence the resulting GLCM. If the displacement is too large it is not probable that the intensities of the two pixels are correlated and the GLCM will be uniform (figure 1(b)). On the other hand if the displacement is very small then the random noise in the image will be the main contributor to the distribution in the GLCM. Therefore, provided that the noise is small compared to the intensity distribution in the image the non-negligible elements in the GLCM will be close to the diagonal (figure 1(c)). Consequently, with a displacement that is too small or large then contrast and dynamic range in the target and background will be evaluated but not structure.



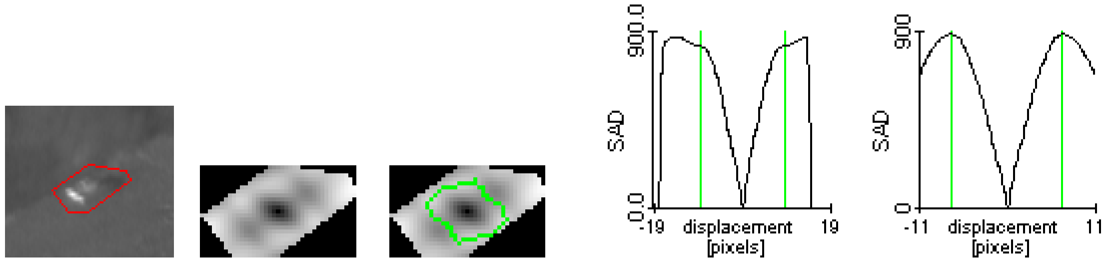
(a) (b) (c)

Figure 1 *(a) Image where the area for GLCM calculation is enclosed (red), (b) GLCM with large displacement (20 pixels), (c) GLCM with small displacement (1 pixel).*

It is apparent that the displacement used when the GLCM is calculated can not be chosen at random. In the proposed model [3], a length characteristic of the structure in the target is selected based on the summed absolute difference (SAD) correlation:

$$SAD(m,n) = \begin{cases} \dfrac{\sum_{i=r_0}^{r_1} \sum_{j=c_0}^{c_1} \left| I(i,j) - I(i-m, j-n) \right|}{(r_1 - r_0 + 1)(c_1 - c_0 + 1)} & \text{if } (i,j) \text{ and } (i\text{-}m, j\text{-}n) \text{ is on the target} \\ 0 & \text{otherwise} \end{cases}$$

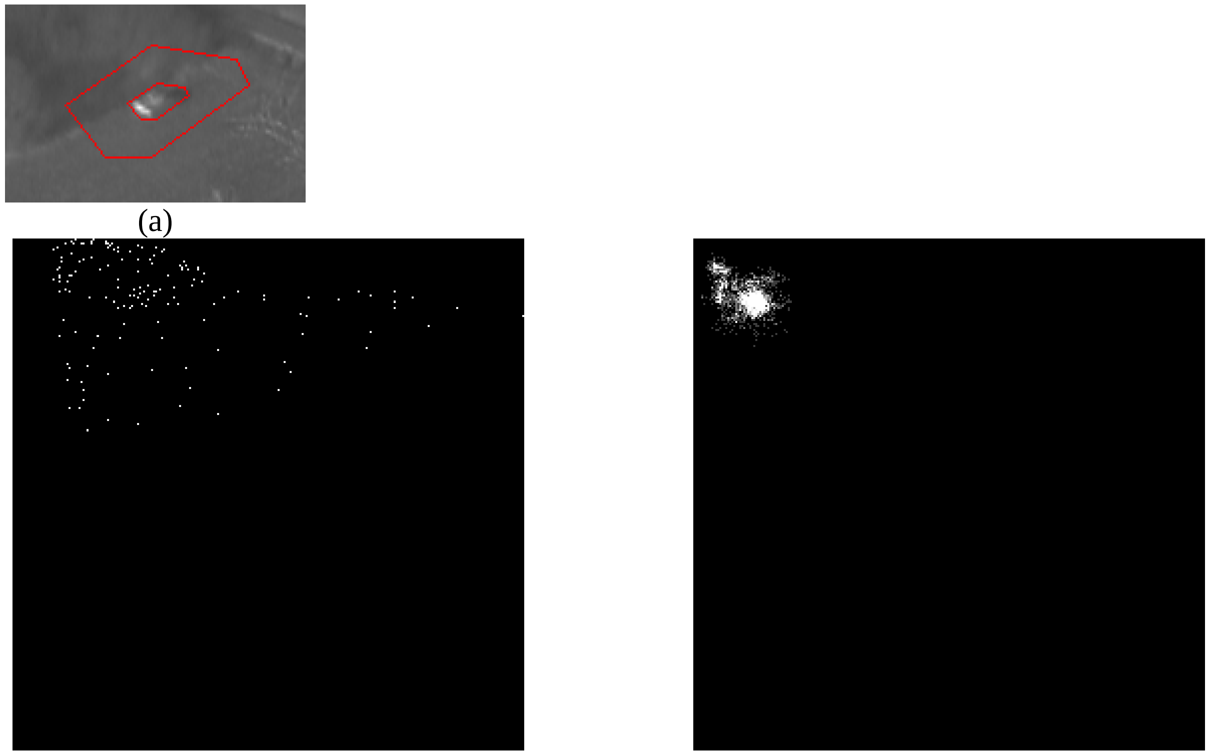
The displacement for a given direction is calculated from the SAD as the position of the first peak (or plateau). If the target does not contain any structure with a characteristic length then the maximum length will be selected which is the distance from the center to the edge of the target. In any case, the displacement will depend on the direction as the example in figure 2 shows.



(a) (b) (c) (d) (e)

Figure 2 *(a) Image with target area enclosed with a red line. (b) SAD surface, (c) SAD surface showing the target's structure length for different directions (in green). (d) Horizontal cross-section of SAD surface showing the position of the target's structure length. (e) Same as in (d) but with a vertical cross-section.*

When the structure length of the target as a function of orientation has been found the GLCMs of the target and background can be calculated as described above. Below is an example showing the GLCMs of a target and background.



(a)

(b) (c)

Figure 3 *(a) Image with target area and background area enclosed with red lines. The target region is the inner region and the background area is the outer region. The background and target areas have no pixels in common. (b) GLCM of the target region. (c) GLCM of the background region.*

The GLCMs of the target and background can be used to evaluate the trackability of the target in its local background using the TM described in reference 3:

$$TM(r_\theta,\theta) = 1 - \frac{\sum_{a,b=\min}^{\max}\left[P_{a,b}^{(tgt)}(r_\theta,\theta)\cdot P_{a,b}^{(bkg)}(r_\theta,\theta)\right]}{\sqrt{\sum_{a,b=\min}^{\max}\left[P_{a,b}^{(tgt)}(r_\theta,\theta)\right]^2\cdot\sum_{a,b=\min}^{\max}\left[P_{a,b}^{(bkg)}(r_\theta,\theta)\right]^2}} \qquad \textit{Equation 1}$$

In order not to compromise the accuracy of the trackability metric the size of the GLCM should be equal to L x L, where L is the number of gray levels within the image. However, some of the synthetic images that sometimes are used for test purposes have intensity values of type float. Furthermore, sequences that are used for evaluation of the trackability are often digitally recorded from an IR-camera with 12-bit resolution (4096 intensity levels) and some modern cameras might have an even higher resolution. If all these intensity levels are used when the GLCM is created it takes an unreasonable amount of time when the GLCM TM is calculated. Therefore, the equation above has been modified slightly compared to what was found in reference 3. The column and row indexes of the GLCMs ($P_{a,b}$) does not necessarily correspond to intensities from zero to the maximum intensity in step of one. Instead, the indexes correspond to intensities from the minimum to the maximum intensity in the image in steps of ΔI, where ΔI is chosen to limit the GLCMs to a maximum size.

Even with a limitation in size, the GLCMs often show sparseness, which means that equation 1 almost always results in a trackability measure close to one even if the GLCMs of the background and target are very similar. The solution is to blur the GLCMs in a controlled manner. If the intensity of pixels corresponding to a certain position on the target is studied as a function of time (frame in the sequence) then this intensity will change slightly from frame to frame. This intensity fluctuation is due to noise and also due to an uncertainty in the target’s position and aspect (how good can the target be aligned between different frames). For instance, a target that, due to rotation, is viewed at different aspects might show a larger intensity uncertainty than a target that is standing still. Intensity fluctuations can also occur naturally due to reflections, moving clouds, etc. In any case, this change in intensity is a measure of the uncertainty of the intensity and can be used to blur the GLCMs.

When the uncertainty distribution is calculated, the target enclosure is aligned from one frame to the next (size changes of the target enclosure is compensated for but not changes of the form e.g. due to rotation). The number of pixels with an absolute intensity difference, |ΔI|, from aligned pixels inside the target enclosures is plotted as a function of |ΔI|. To improve the measured uncertainty distribution of the intensity, more than two frames can be used. The final uncertainty distribution is obtained from the following expression:

$$P_N(|\Delta I|) = \frac{\sum_{Frame=N}^{N+M} \sum_{n}^{\substack{\text{all pixels} \\ \text{on the target}}} \left(\left| \mathrm{I}_{\mathrm{Frame}}(n) - \mathrm{I}_{\mathrm{Frame+1}}(n) \right| = |\Delta I| \right)}{\sum_{Frame=N}^{N+M} \sum_{n}^{\substack{\text{all pixels} \\ \text{on the target}}} 1}$$

where

$P_N(|\Delta I|)$ = probability that the intensity difference is |ΔI|
$I_N(n)$ = intensity at (aligned) pixel n in frame N
N = current frame
M = number of frames used (given by the user)

Since P_N is a measure of the uncertainty of the intensity it is also a measure of the uncertainty of the position in the GLCMs. Thus P_N can be used to blur the GLCM:

$$\overline{GLCM}_N(I_A, I_B) = \sum_{i=-|\Delta I|_{\max}}^{|\Delta I|_{\max}} \sum_{j=-|\Delta I|_{\max}}^{|\Delta I|_{\max}} GLCM_N(I_A + i, I_B + j) \cdot P_N(|i|) \cdot P_N(|j|)$$

The steps used when the $\overline{GLCM}$ is obtained is illustrated in figure 4.

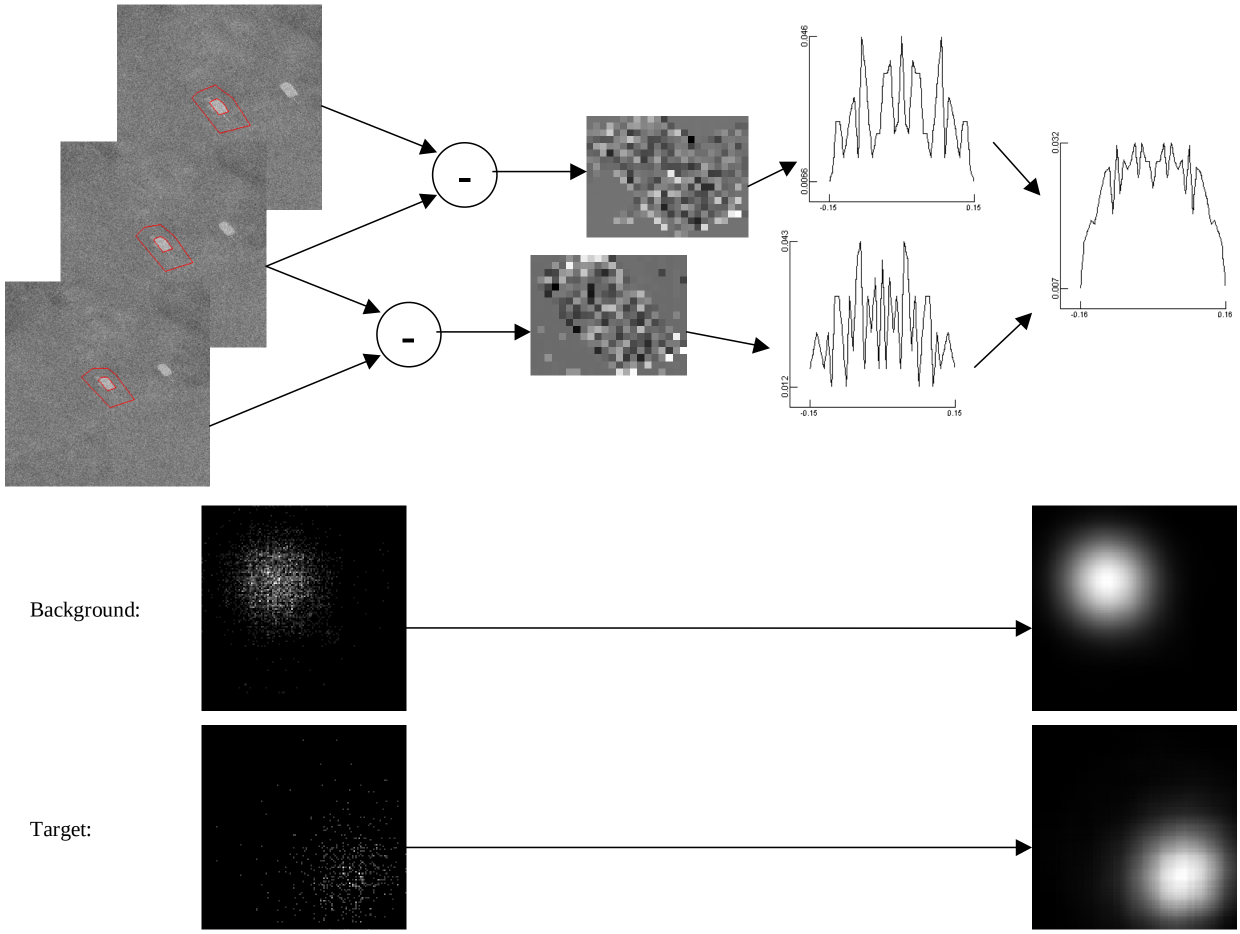


Figure 4 *The uncertainty in target pixel intensities is used to blur the GLCMs of the target and background (both GLCMs are blurred by the same uncertainty histogram). Only pixels on the target are used to determine the shape of the uncertainty histogram.*

When the number of pixels on the target is low then the uncertainty histogram can contain gaps and the blurred GLCMs can therefore still be sparse. To get around this problem the implemented model described here allows a fit of the uncertainty diagram to a Gaussian function that can be used instead of the measured data.

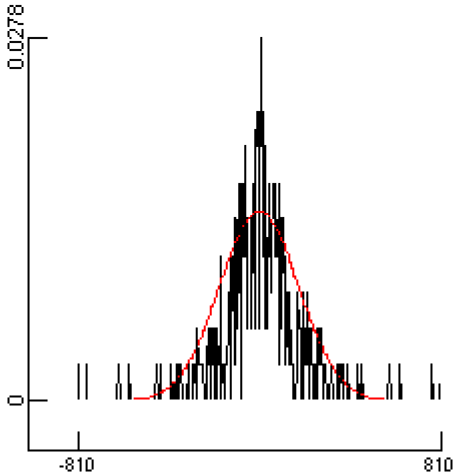


Figure 5 *A measured uncertainty histogram (black curve) can be fitted to a Gaussian function (red curve).*

The complete flow chart when the trackability metric is calculated is displayed in figure 6 below.

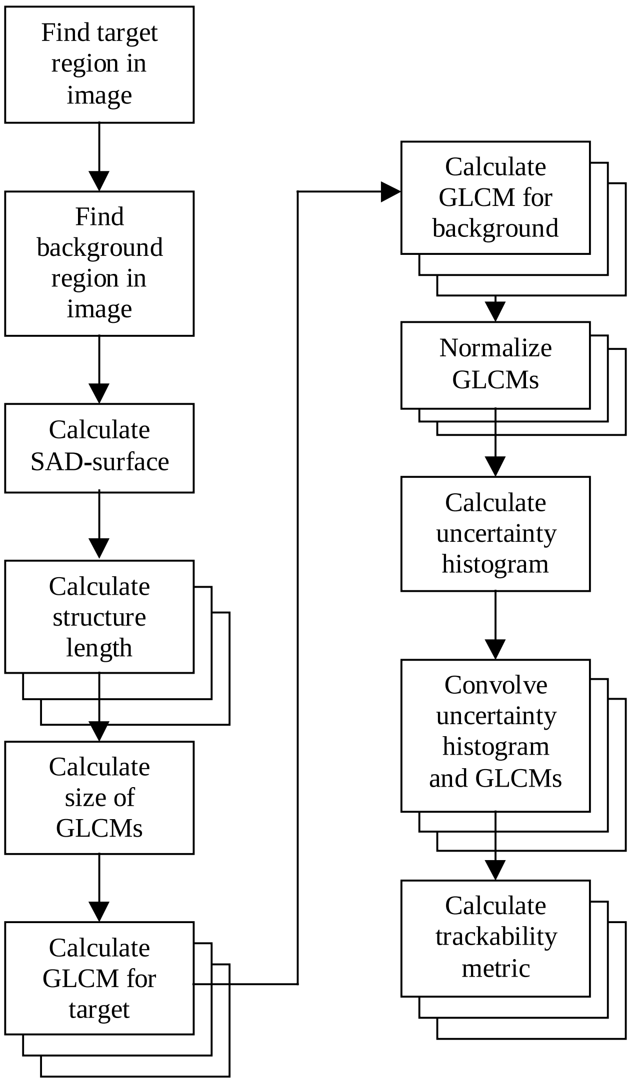


Figure 6 *Flow-chart when the GLCM trackability metric is calculated. A box in the foreground of other boxes indicates that more than one direction can be used.*

3 Modified GLCM Trackability Metric for targets with predominant features

A trackability metric should predict a tracker's ability to track a target. The metric described in the previous chapter works fairly well provided that no predominant feature is present. However, some trackers have the ability to lock on a target's predominant feature, such as a hot spot. If the hot spot only occupies a fraction of the target's total area then this feature will only marginally contribute to the GLCM of the target and will thus only have a marginal effect on the trackability metric. This will of course not reflect the tracker's ability to track the target. The original design of the GLCM based trackability metric was therefore modified in order to account for higher trackability when predominant features are present on the target [4].

To account for predominant features on a target a GLCM based metric can still be used but now the predominant feature is treated as a target. In order to account for the whole target and its predominant feature the final trackability metric is the root mean square of the original and the "hot spot" metric. However, the predominant feature must fulfill certain criteria in order to be used. First, the intensity of the feature must deviate from the median intensity for all pixels on the target (I_{median}) with more than $\Delta I_{max}/2$ where $\Delta I = |I - I_{median}|$. Secondly, the intensity for the most predominant feature (MPF = largest peak or lowest valley) must have an intensity deviation, ΔI_{mpf}, that is at least twice that of the average of the next 5 predominant features. If these two conditions are fulfilled the region of the MPF can automatically be extracted as the area around the MPF-peak with an intensity deviation of more than $\Delta I_{mpf}/2$.

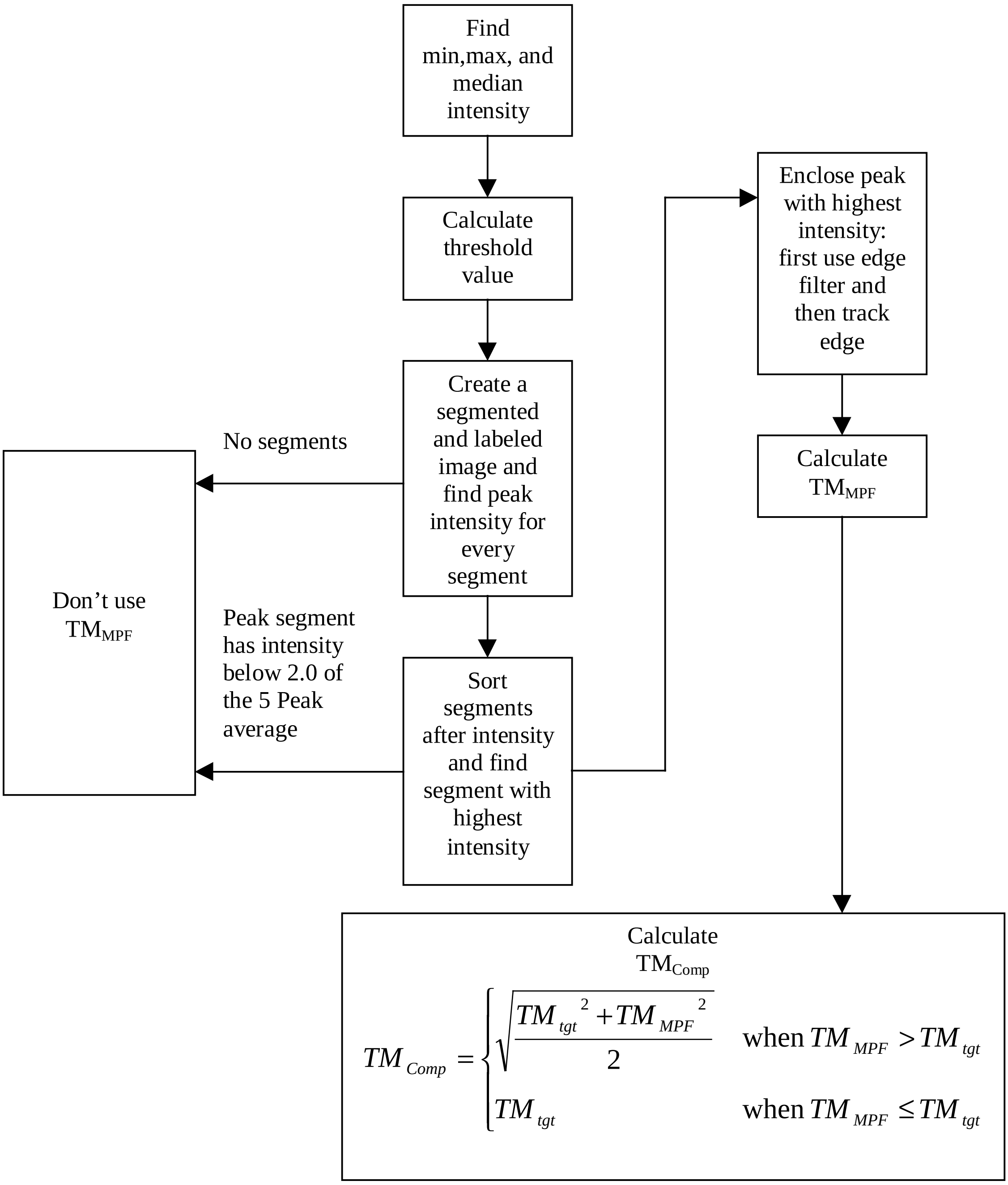


Figure 7 *Flow chart when the GLCM TM is calculated for targets with a predominant feature (e.g. a hot spot)*

4 Extended functionality for assessment of backgrounds

The original design of the GLCM trackability metric aimed at evaluating the ability to track the target at its present position in a sequence. The use of the model can easily be extended in order to calculate the ability to track the target at an arbitrary position in an image. This ability could for instance be used for mission planing. In a background image the background region can be moved over the image (keeping the target region fixed) and a GLCM trackability calculation can be made for every pixel in the image in order to find the optimal path for the vehicle in the background.

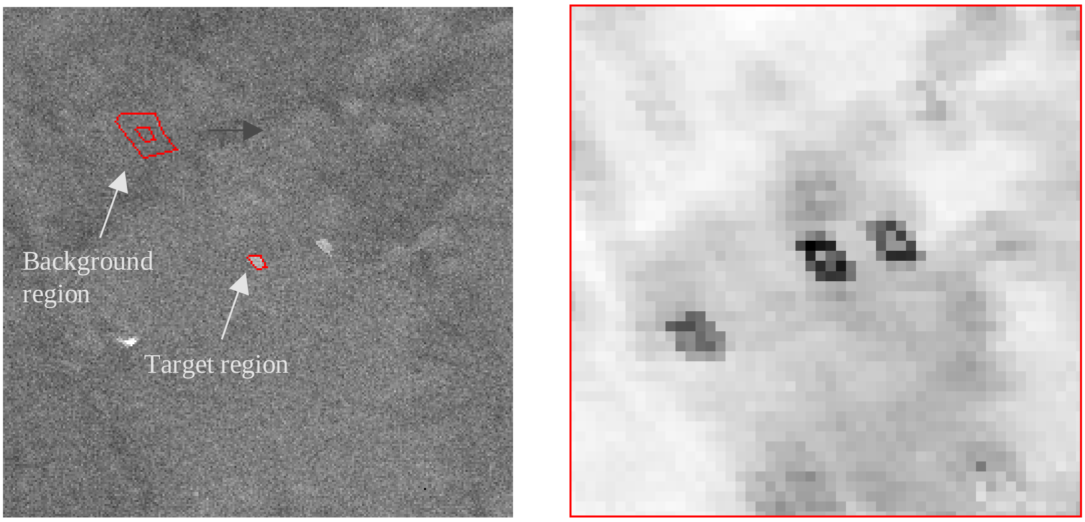


Figure 8 *Image to the left and the result of a GLCM TM calculation for the whole image to the right. In this type of calculation the target region is kept at a fixed position while the background region moves across the image.*

A further extension to the model is to let the size and shape of target and the background areas be identical to the target area. In this way the GLCM can be used as a target detector.

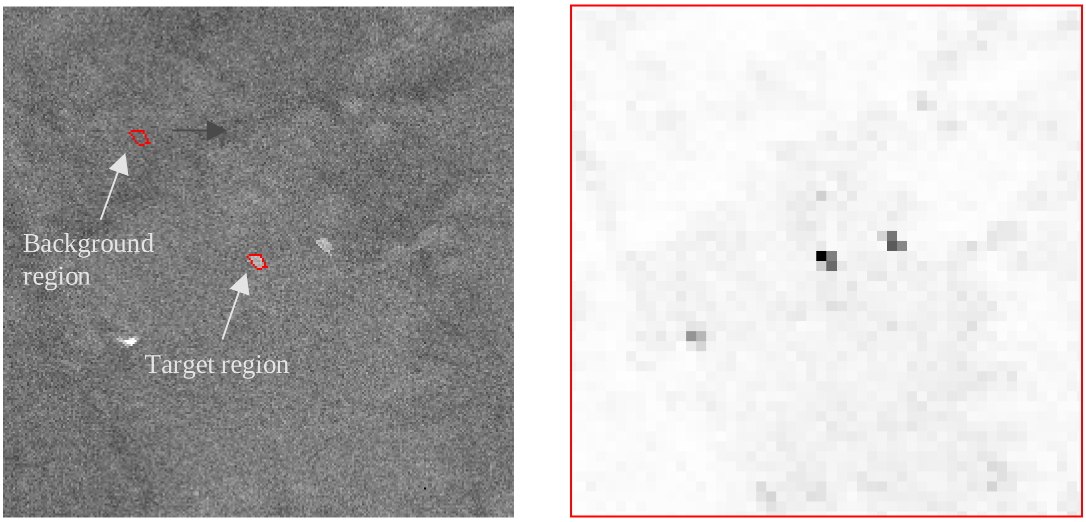


Figure 9 *When the background region is set to be identical in shape and size to the target region then the GLCM technique can be used to identify target like objects in the image.*

One problem that can occur, when the number of gray levels is limited during the GLCM calculation and when the gray level span is set automatically, is that when the background region is above an area containing very cold or hot pixels this will compress the GLCMs. This might lead to an apparent greater overlap of the target and background GLCMs and thus a lower trackability value. Therefore, in the implementation of the model there is a possibility to set the GLCM intensity span to a fix interval.

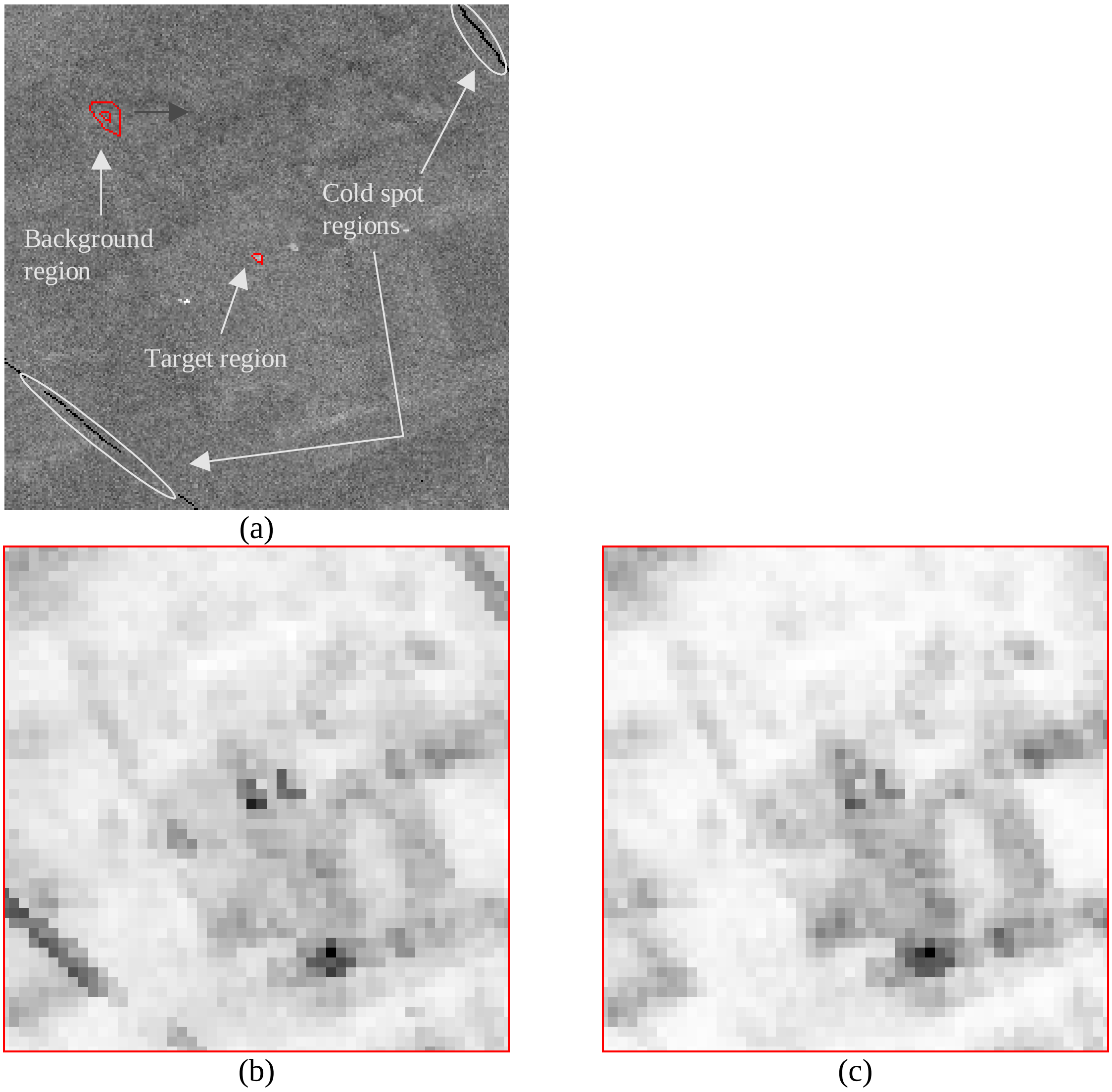


Figure 10 *(a) Image used for GLCM TM calculation, (b) Result of a GLCM TM calculation over the image. In this case the model has automatically selected intensity limits for the GLCM at every pixel. (c) Same as in (b) but in this case the same intensity limits for the GLCMs has been used for every pixel.*

5 Implementation

5.1 Graphical User Interface

The GLCM TM model has been implemented as a Windows® (95, NT, 2000) program using Visual C++ [5]. Figure 11 shows the graphical user interface of the program.

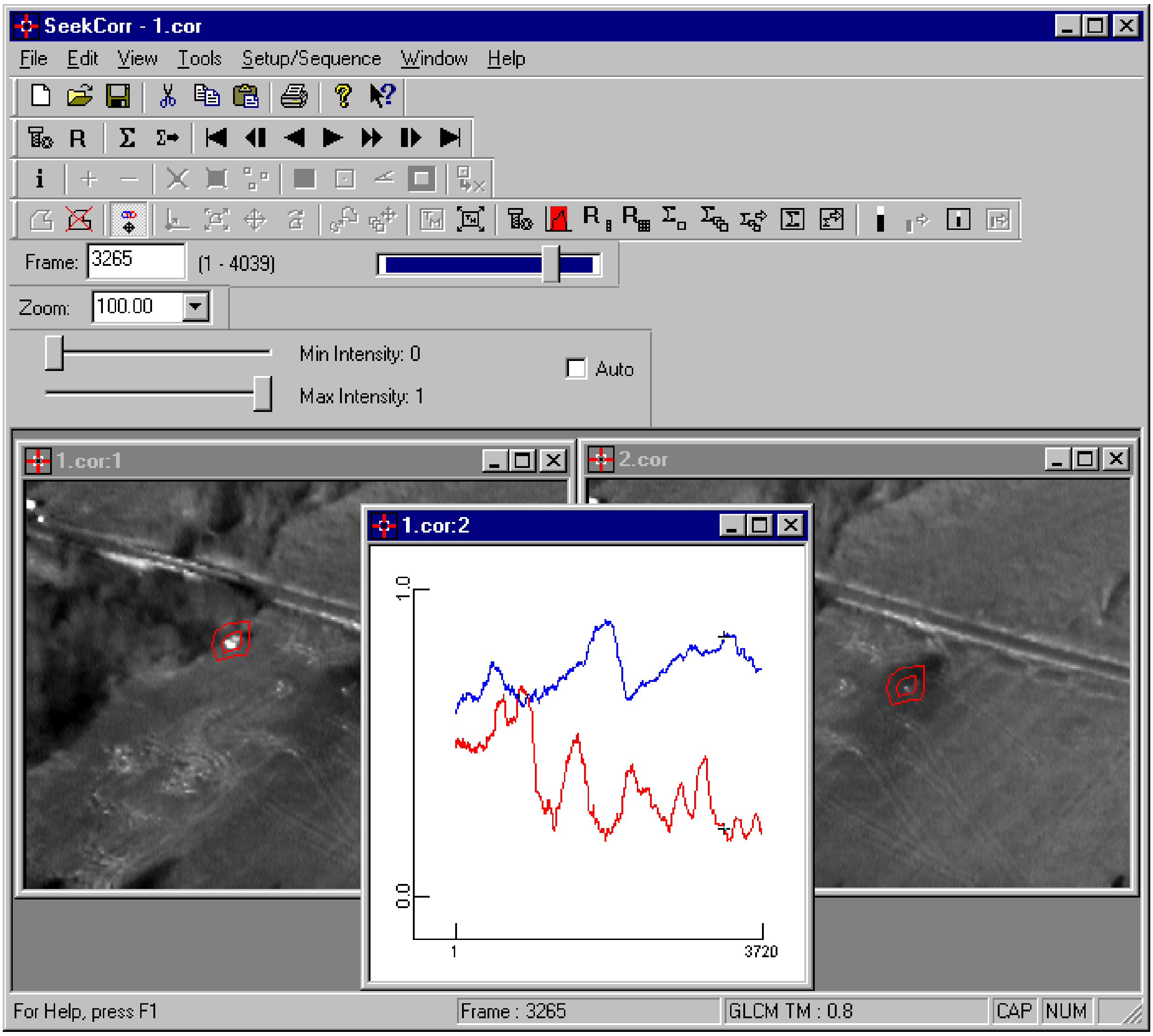


***Figure 11** Graphical user interface of the program for GLCM TM calculations.*

5.2 Model Features

When the GLCM trackability metric is calculated for an image sequence the target region has to be marked in all frames of the sequence. This can be a very tedious task to do manually, especially since a sequence can contain thousands of frames. It is therefore important to have as much as possible of this work automated. In a non-stabilized sequence the target will not be in the same position from frame to frame. The model should therefore contain a tracker that can track the target's position. However, the model can't rely solely on the tracker to find the target's position since it should be possible to do calculations using sequences where the target's trackability is low. A solution is to let the tracker of the model remember the target's position from frame to frame and allow the saved position of the target to be manually editable. A correlation tracker model with these properties had already been developed [1]. It was therefore natural to implement the calculation of the GLCM target trackability metric in the existing correlation tracker model.

When a recorded sequence has a sensor-target distance that changes, then the size of the target region must also be allowed to change. In the implemented GLCM TM model, this size change can be made using one of several methods. One method is to manually edit the individual endpoints of the lines that define the target region. This change of size and/or form of the target region will only affect the target region in the frame where the region is edited*. Another method for changing the size of the target region in a frame is to issue a region size change command. In this case the size of the region will change but not its shape. The third method is to tell the program that the size of the region should increase (or decrease) by a certain rate from frame to frame when the target is tracked. The final method is to select two frames in the sequence (could for instance be the first and last frame) and manually edit the size of the region in these to frames. When the sizes of the regions in these two frames have been chosen, then the program can manually calculate the rate of size change for all frames in between these two frames and then automatically adjust the size.

The region can not only change in position, size and shape but there is also a tool that enables the region to be rotated in any frame. Even though the GLCM calculations are made with pixel size resolution some of the operations used for modifying the shape and size of the target region do not work very well with this resolution. For instance the size change can be rather big in a sequence containing several hundreds of frames, but this does not mean that the size change rate per frame is very big. The positions of the endpoints of the lines that define the target region are therefore saved with a much higher precision.

In the model implementation, there are some features that have not been mentioned yet. These features do not change the results of a simulation but they contribute to the smoothness of the model's day-to-day use. First, all calculations in the model are done in separate threads, which for instance means that windows used in the interface can be moved and their sizes changed. The type of information shown in a window can be changed during a calculation. It is also possible to stop an ongoing calculation (could for instance be a calculation of the trackability metric as a function of frame or as a function of position in the image). The results up to that point can be saved and the calculation can be continued at a later time.

When the trackability metric is calculated as a function of position in the image then this calculation can be made in an arbitrary selected area in the image and with an arbitrary resolution. Later a calculation in another area can be added to the calculation with a different resolution. If there is an overlap between areas calculated at different times then the area calculated at a later time will be the saved result.

* If the frame where the region is edited is the last frame where the region has been saved and the number of save frames are extended by continuing to track the target then the edited region will be used in frames that follows.

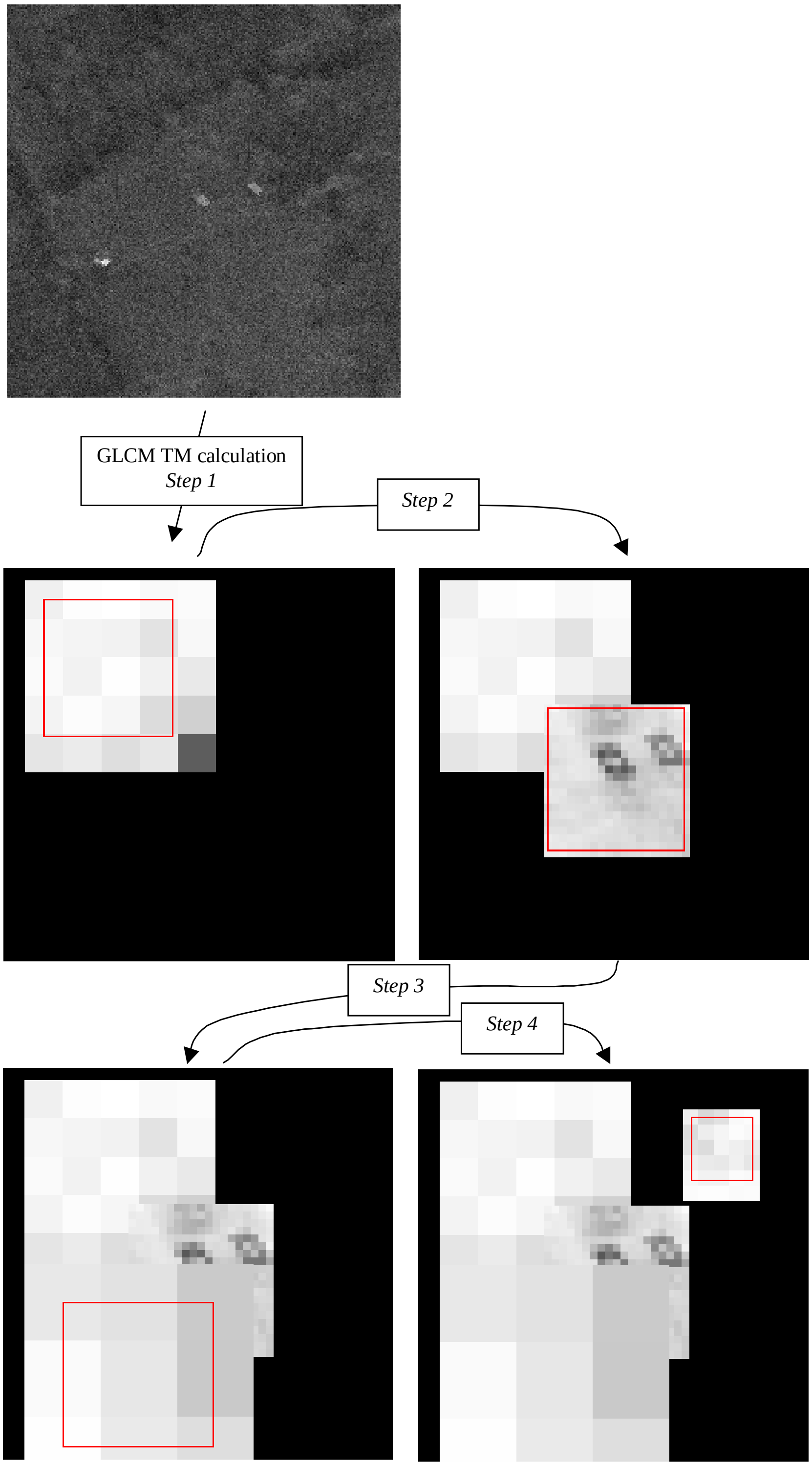
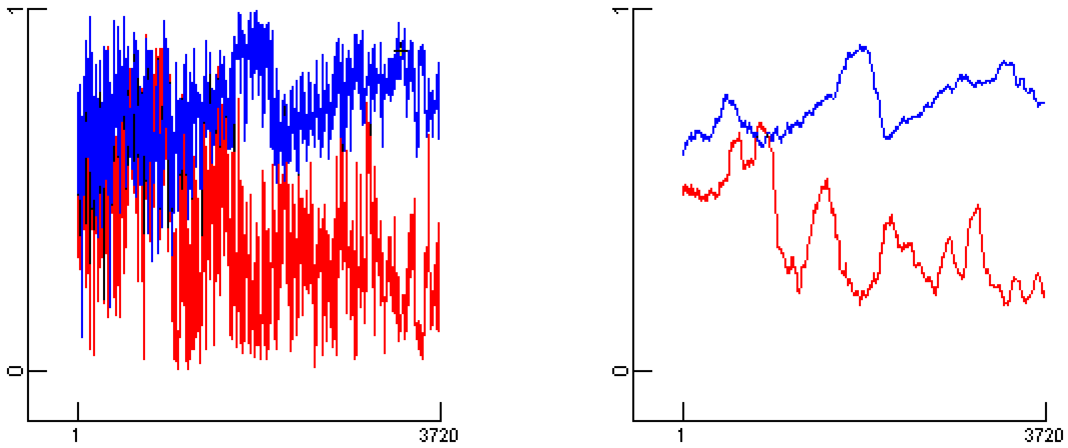


Figure 12 *A GLCM TM calculation as a function of position in a selected area of an image can be made in several steps with different resolution. The original image is shown at the top. Step 1 shows the result of a GLCM TM calculation using a 25x25 pixel resolution. In step 2 the result of a calculation using a 5x5 pixel resolution has been added to the previous result. The result of a calculation using a 50x50 pixel resolution has been added in step 3 and finally in step 4 the result of a calculation using a 10x10 pixel resolution has been added. The different calculations in step 1-4 have been made on different parts of the image and the sizes of the area in the different calcultions were different.*

6 Results

The results that are discussed in this chapter are examples from a digitally recorded IR-sequence recorded from a helicopter approaching two armored vehicles.* One of the vehicles is equipped with a system that can generate multispectral waterfog (MWF) [6, 7]. The MWF is used to conceal the vehicle and the calculated results are used to evaluate the effect against IR-trackers. In the sequence the MWF is not turned on until after about 900 frames (one fourth of the sequence). When the target is concealed by MWF it is very difficult to see the extent of the target in the image. Therefore in the GLCM calculations the same shape and size of the target area used for the unconcealed target has been used for the concealed target. However, the position of the target area has been adjusted to what has been believed to be the position of the concealed target. Below are results from a GLCM trackability metric calculation for both targets. Instead of displaying the average GLCM TM results from different displacement orientations the maximum value has been plotted since this better seems to correspond to results from tracker simulations. This observation is not based on an objective measure but since the maximum trackability when a countermeasure is evaluated represents a worst case scenario for a countermeasure it will not lead to wrong conclusions if the results show that the countermeasure is effective.



(a) (b)

Figure 13 *GLCM TM calculations from an unconcealed armored vehicle (blue curve) and from a by MWF concealed vehicle (red curve). The results in (a) are raw data from GLCM TM calculations while the same results have been low pass filtered in (b), using a rectangular filter (with a width of 51 data points; one data point has been calculated for every 3rd frame). The GLCM TM calculations have been made without the "hot spot" extension. The maximum number of gray levels used is 256 and the minimum and maximum intensity in the GLCM have automatically been calculated for each frame in the sequence. The uncertainty histograms used to blur the GLCMs have been calculated for each frame and have not been truncated. The results from the measured intensity uncertainty have not been used directly, instead the results from fitting these measured histogram to a Gaussian functions have been used.*

The results above show that the GLCM trackability metric from the unconcealed target increases from a value around 0.6 to a value closer to one when the sensor-target distance decreases. The second target (concealed by MWF after about 900 frames) shows a slightly lower contrast in the beginning and therefore has a slightly lower GLCM TM in the first few frames. Contrary to the results from the unconcealed target there is no general increase in the trackability, instead the trend is opposite. This difference can be ascribed to the use of MWF.

Prior to using the GLCM method, the effect of MWF was evaluated using different tracker models, e.g. an autonomous terminally guided projectile [8] and a correlation tracker. The model of the correlation tracker can use parallel simulations with different target lock-on positions, i.e. an

* The experiment and registrations were conducted in collaboration between *FOI* and *Swedish National NBC-School*.

area around the target is selected and every pixel in that area then represents a tracker. The results from all trackers in each frame of the simulation can be saved and thereafter evaluated. Using a manually corrected reference tracker, which is always centered on the target, it is possible to plot (as a function of the frame in the sequence) the number of trackers within a certain radius from the target. Alternatively, the average distance from the target to the different trackers can be plotted. To evaluate the correlation tracker's ability to track the target, different parameter settings for the trackers are tested. The results, from using a correlation tracker on the sequence described above, showed that with the parameter settings used in the simulations it was impossible to track the target when MWF was used to conceal the target. However, the results do not show whether other parameter settings or other types of trackers can track the target.

Below, results from the correlation tracker model are compared with the GLCM TM results. The results show that the correlation trackers do not track the target when the MWF system has been turned on. This can also be seen in the GLCM TM result that shows a large drop at approximately the same time as the correlation trackers lose track of the target.

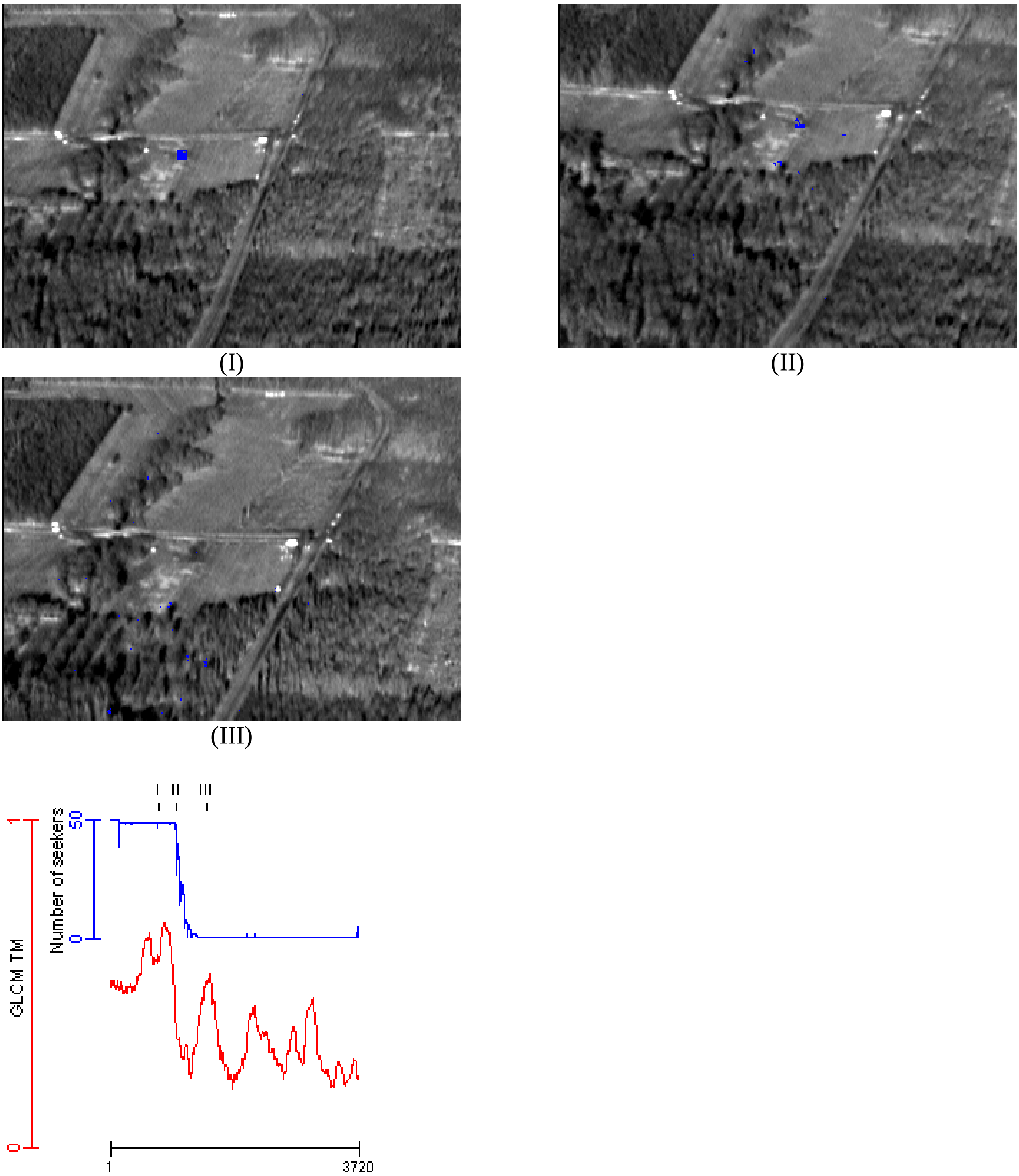


Figure 14 *GLCM TM calculation for a sequence where MWF is used to conceal one of two armored vehicles. The red curve show the maximum GLCM TM result for the concealed vehicle and the blue curve is the result from tracking the concealed vehicle using a correlation tracker (number of seekers within 10 pixels from the target). The blue pixels in the images from the sequence show the positions of the 49 different correlation trackers.*

After the MWF system has been initiated the GLCM TM shows that the trackability on average is much lower than if MWF had not been used. However, the GLCM TM does have peaks appearing after the MWF has been initiated. A quick visual inspection of the IR-sequence does not seem consistent with the GLCM TM result from the vehicle using MWF and a more detailed study of the sequence is therefore required to explain the result. If the target-background contrast, C (equation 2), is plotted in the same figure as the GLCM result for the target using MWF then by a comparison the GLCM TM results can be explained. The MWF reverses the contrast from a bright object on a darker background to a dark object on a not quite as dark background.

$$C = \frac{\langle I_{target} \rangle - \langle I_{background} \rangle}{I_{\max} - I_{\min}} \qquad \textit{Equation 2}$$

where

$\langle I_{target} \rangle$	=	the average intensity in the target region
$\langle I_{background} \rangle$	=	the average intensity in the background region
I_{max}	=	the maximum intensity in target and background region (in one frame or in all frames of the sequence) or some arbitrary value set by the user
I_{min}	=	the minimum intensity in target and background region (in one frame or in all frames of the sequence) or some arbitrary value set by the user

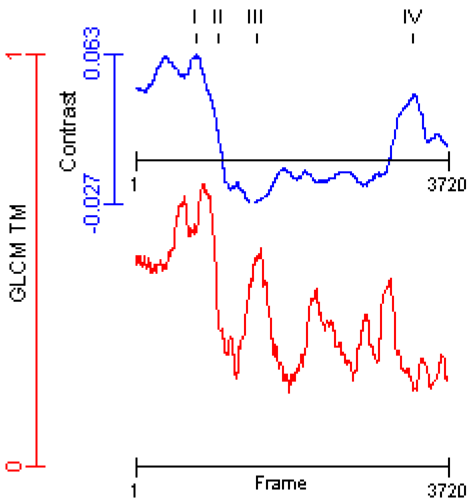
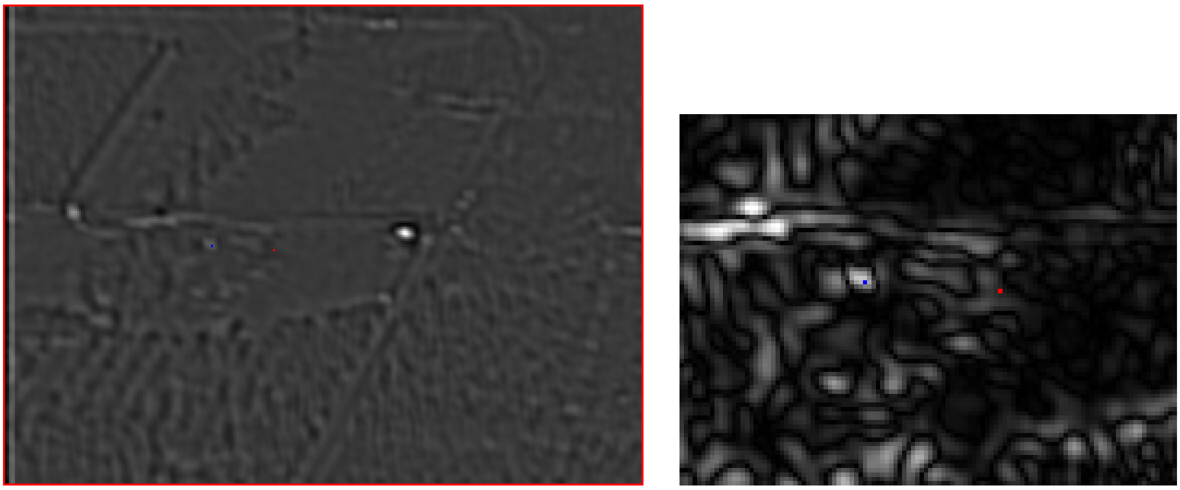


Figure 15 *GLCM TM results (red curve) and contrast (equation 2) at the position of the by MWF concealed target (blue curve) as a function of frame index in the sequence.*

The MWF in this sequence decreases and reverses the contrast from the target. This means that the tracker will be perturbed. It is probablysafe to assume that the tracker will lose track of target when the GLCM TM value decreases after the MWF system has been initiated. The question is if it is possible for an intelligent tracker to relocate the target during the peaks of the GLCM TM curve.

To find the target, whose signature has changed completely by the MWF, a tracker probably has to look for an area with contrast. It is therefore important to investigate the surroundings of the target to see if the absolute value of the contrast at the position of the target is large enough for a tracker to locate the target.

A calculation has been made of the contrast for the image in figure 14(III) (corresponding to the first and also largest GLCM TM peak after the MWF system has started). The result of the contrast image calculation is displayed in figure 16). In this calculation the target and background area have been moved over the whole image and a contrast value, according to equation 2, has been calculated at every pixel. The result shows that a tracker would not relocate the target position based on contrast.



(a) (b)

Figure 16 *Result from a contrast calculation for every pixel in an image. (a) Shows the result for the whole image. In this case a bright pixel correspond to a positive contrast and a dark pixel to a negative contrast. (b) Shows an enlarged area around the unconcealed target (indicated with a blue pixel) and the by MWF concealed target (indicated with a red pixel). In this case a bright pixel corresponds to a contrast with an absolute value above zero and a dark pixel corresponds to a contrast close to zero.*

The contrast curve in figure 15 shows that the contrast is positive at the end of the sequence. If the image is inspected where the contrast curve has a peak (indicated by IV in figure 15), part of the target can be seen through the MWF (figure 17). However, the GLCM TM value is very low at this point. The main reasons for the low GLCM TM is that the measured uncertainty histograms tend to be very wide for these frames. This is due to the behavior of the MWF, which is not static and the part of the target that can be seen will not be the same at all times. Furthermore, since the target is at large concealed by MWF it is very difficult to pinpoint the exact position of the target, which might introduce an artificial widening of the uncertainty histogram. The non static behavior of the MWF will of course also make it more difficult for a tracker to track the target but it is nonetheless valuable to study how much this effect influences the GLCM TM. An uncertainty histogram was therefore calculated from every third frame during which no MWF was present (frame 1-900) and a Gaussian function was fitted to this data (figure 18). Then a new GLCM TM calculation was made using this Gaussian function instead of the measured histogram to blur the GLCMs (the same Gaussian function was used for every frame in the GLCM TM calculation). The result from this calculation can be found in figure 19.

Figure 17 *IR-image of a target partly concealed by MWF.*

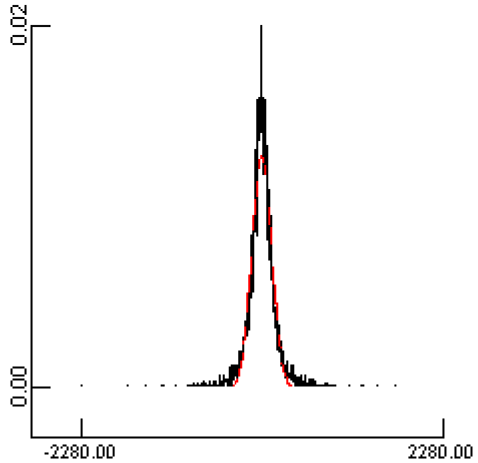


Figure 18 *Measured uncertainty histogram using all frames up until the MWF has been turned on (black curve) and a fit to a Gaussian function (red curve). Only points with values above 0.2 * I_{max} and |x| < 0.3 x_{max} was used for the fit.*

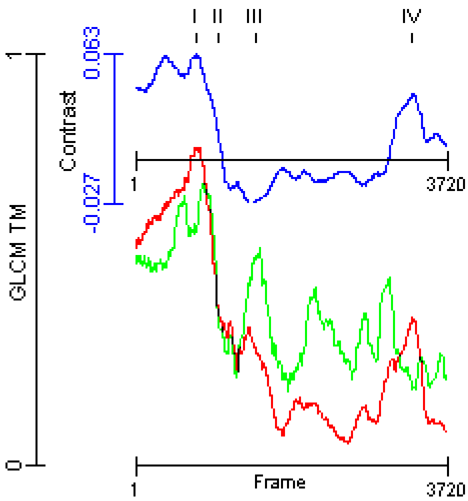


Figure 19 *GLCM TM calculation made with a pre-calculated uncertainty histogram (see figure 18) (red curve). This result is compared to the results obtained by using a new uncertainty histogram for every calculated frame (green curve) and to a contrast calculation (blue curve).*

The results in figure 19 show that by using a fixed pre-calculated uncertainty histogram there is a GLCM TM peak at the same place where the contrast curve has a peak (indicated by IV in the figure). This GLCM TM peak was not present for the calculation where a new uncertainty histogram was created for every calculated GLCM TM value. This difference can be explained by the stochastic behavior of the MWF as explained above. Another difference that can be noticed is that the GLCM TM value is much lower for frames where the MWF is covering the whole target. If the uncertainty histogram used in the green curve of figure 19 is inspected for the frame corresponding to the GLCM TM peak at III it shows a much narrower distribution than the uncertainty histogram in figure 18 used when the red curve of figure 19 was calculated. A narrower distribution in the uncertainty histogram will magnify differences in the GLCMs for the target and background and hence result in a larger GLCM TM value. If a target tracker is adjusted to track a non-concealed target then the red curve in figure 19 is more reliable than the green curve. If the tracker on the other hand tries to anticipate MWF then the green curve should be used. Both results show a much lower GLCM TM value than a non-concealed target (figure 13). The GLCM TM in the green curve show a high enough value in the peaks that indicate that an intelligent tracker might be able to track the target. However, since the valleys in the green curve are very low a tracker will not be able to track the target at these points. Furthermore, since the contrast at the location of the target is low compared to its surrounding a tracker would not be able to relocate the target. Therefore, the conclusion is that MWF is a very effective countermeasure against IR-trackers.

7 Summary and conclusions

A trackability metric based on the gray-level co-occurrence matrix has been implemented as a Windows® program. The model can be used for calculating a target's trackability in a sequence as a function of frame index. An alternative use for the model can be to calculate the trackability of a target in an image assuming that the target could be moved to different positions in the image.

If GLCM TM is used with care it is a powerful tool for evaluation of a target's trackability. The trackability metric for a target can be used as a measure for how well a target's signature has been adapted to its surroundings. It can also be used to evaluate an obscurant countermeasure.

An example of how the GLCM TM can be used has been presented. In this example the effect of MWF as a countermeasure for an armored vehicle was evaluated. The results were also compared to results from a correlation tracker. Multispectral waterfog was in the example shown to be very effective against target trackers. However, in order to show that additional tools had to be used in order to interpret the GLCM TM results correctly.

8 References

[1] L. Tyden and L. Berglund, "Laborationshandledning: korrelationsmålföljare" (instructionmanual for laboratory work with a correlation tracker model, in Swedish), *FOA report* FOA-D--97-00334-3.6,316--SE (1997)

[2] G.C. Holst, "Workshop Summary", in *Proceedings of SPIE*, vol. 3377, pp 255-256 (1998)

[3] B.A. Brackney, M.K. Helton, and R.K. Hammon, "Development of the Gray-Level Co-occurrence Matrix Target Trackability Metric for Infrared Missile Systems" in *Proceedings of SPIE*, vol. 3377, pp 240-254 (1998)

[4] R.L. Hall, R.K. Hammon, B.A. Brackney, and B.J. Schmid, "Design Modification to the Gray-Level Co-occurrence Matrix (GLCM) Based Trackability Metric and the Resulting Performance", in *Proceedings of SPIE*, vol. 4030, pp 172-183 (2000)

[5] http://msdn.microsoft.com/visualc

[6] G. Olsson, Å. Blomberg, G. Dygéus, S.O. Lönneborg, and Ö. Olsson, "Electronic Warfare – an essential component in the future battlefield!", in *Proceedings of the 3rd International EW Conference and Exposition*, Zürich (2000).

[7] G. Olsson, "Multispectral Waterfog as an Obscurant Countermeasure", in *Proceedings of the IXth European AFV Attack and Survivability*, Shrivenham (2000).

[8] U. Andersson, A. Tonnvik, "Detection and Target Tracking in the Infrared Wavelength Region", *FOA report* FOA-R--00-01639-616--SE