




Centrum voor Wiskunde en Informatica

View metadata, citation and similar papers at core.ac.uk

brought to you by  **CORE**

provided by CWI's Institutional Repository

REPORT *RAPPORT*

PNA

Probability, Networks and Algorithms



Probability, Networks and Algorithms

A matlab toolbox for image fusion (MATIFUS)

P.M. de Zeeuw, G. Piella, H.J.A.M. Heijmans

REPORT PNA-E0424 DECEMBER 2004

CWI is the National Research Institute for Mathematics and Computer Science. It is sponsored by the Netherlands Organization for Scientific Research (NWO).

CWI is a founding member of ERCIM, the European Research Consortium for Informatics and Mathematics.

CWI's research has a theme-oriented structure and is grouped into four clusters. Listed below are the names of the clusters and in parentheses their acronyms.

Probability, Networks and Algorithms (PNA)

Software Engineering (SEN)

Modelling, Analysis and Simulation (MAS)

Information Systems (INS)

Copyright © 2004, Stichting Centrum voor Wiskunde en Informatica

P.O. Box 94079, 1090 GB Amsterdam (NL)

Kruislaan 413, 1098 SJ Amsterdam (NL)

Telephone +31 20 592 9333

Telefax +31 20 592 4199

ISSN 1386-3711

A matlab toolbox for image fusion (MATIFUS)

ABSTRACT

The MATIFUS toolbox is presented. It is a collection of functions and furnished with a graphical user interface that supports a range of image fusion operations. Almost all of the toolbox functions are written in the MATLAB language. Implementations of multiresolution schemes are used that are either publicly available or can be purchased as licensed software. MATIFUS can be downloaded from a website and is available under the conditions of an agreement with the Dutch Technology Foundation STW.

2000 Mathematics Subject Classification: 62H35; 65T60; 65Y15; 94A08

1998 ACM Computing Classification System: G.1.0; G.4

Keywords and Phrases: Discrete wavelets; gradient pyramids; image fusion; Laplacian pyramids; lifting scheme; MATLAB toolbox; quincunx; region-based image fusion; second generation wavelets; mathematical software; steerable pyramids

Note: The work was carried out under project PNA4.2 "Image Representation and Analysis". This research was supported by Stichting Technische Wetenschappen (STW), projectnumber CWI.4616.

A Matlab Toolbox for Image Fusion (MATIFUS)

P.M. de Zeeuw

CWI

P.O. Box 94079, 1090 GB Amsterdam, The Netherlands

`Paul.de.Zeeuw@cwi.nl`

G. Piella

Département Traitement du Signal et des Images

École Nationale Supérieure des Télécommunications

37-39 rue Dareau, 75634 Paris Cedex 13, France

`piella@ieee.org`

H.J.A.M. Heijmans

CWI

P.O. Box 94079, 1090 GB Amsterdam, The Netherlands

`Henk.Heijmans@cwi.nl`

ABSTRACT

The MATIFUS toolbox is presented. It is a collection of functions and furnished with a graphical user interface that supports a range of image fusion operations. Almost all of the toolbox functions are written in the MATLAB[®] language. Implementations of multiresolution schemes are used that are either publicly available or can be purchased as licensed software. MATIFUS can be downloaded from a website and is available under the conditions of an agreement with the Dutch Technology Foundation STW.

2000 Mathematics Subject Classification: 62H35, 65T60, 65Y15, 94A08

1998 ACM Computing Classification System: G.1.0, G.4

Keywords and Phrases: Discrete wavelets, gradient pyramids, image fusion, Laplacian pyramids, lifting scheme, MATLAB[®] toolbox, quincunx, region-based image fusion, second generation wavelets, mathematical software, steerable pyramids.

Note: The work was carried out under project PNA4.2 "Image Representation and Analysis". This research was supported by Stichting Technische Wetenschappen (STW), projectnumber CWI.4616.

1. INTRODUCTION

Image fusion methods aim to combine images in such a way that all the salient information is put together into (usually) one image suitable for human perception or further processing. An important example is that one and the same scene is recorded by cameras operating for different bands of light (e.g. infrared and visible light). Many applications exist in the areas of defense, surveillance, medical imaging, remote sensing etc.

Multiresolution decomposition has become an important means within the development of image fusion methods. Wavelet methods for instance are eligible because of the spatial localization and hierarchy in scaling.

MATIFUS is a MATLAB[®] toolbox for image fusion, based on various multiresolution decompositions and fusion schemes. It accompanies the thesis of Piella [10] and has been developed concurrently. In the said thesis an axiomatic framework for multiresolution image fusion is formulated. Firstly, a general pixel-based MR fusion scheme is described with a combination algorithm involving different

activity and match measures. An early (and far more basic) example of such schemes has been formulated by Li et al. [6]. Secondly, a region-based MR fusion scheme is introduced which involves a segmentation procedure. The particular segmentation performed is *multisource*, that is a single segmentation is obtained from all the input images. Moreover, a new quality measure for the result of image fusion is introduced, see also Piella et al. [11]. This measure has not been implemented (yet) in MATIFUS. The region-based MR fusion scheme has been incorporated within the toolbox, but only for the case of Laplacian pyramids. For the pixel-based MR fusion scheme an important range of MR schemes is present, together with options for activity and match measures and combination parameters. It is assumed throughout that images have already been registered. Accurate image registration is a problem on its own for which algorithms exist but are also still in development.

The strength of MATIFUS is its versatility. The toolbox enables the user to experiment with various important multiresolution schemes (and filters) and to steer the fusion algorithm with respect to its ingredients. The graphical user interface (GUI) relieves the user from the need of programming in doing so. For the advanced user there is the possibility to extend the toolbox with a multiresolution scheme of his (her) own making. In view of the above, MATIFUS may prove useful in the design process of new image fusion methods.

The MATLAB[®] Image Processing Toolbox is a prerequisite for the functioning of MATIFUS. This toolbox is essential for reading images from graphics files (which exist in many different formats) but is also needed for image manipulation if called for in the GUI by the user. If for the multiresolution decomposition one opts for a wavelet scheme as implemented in the MATLAB[®] Wavelet Toolbox, the latter is also a prerequisite.

In the coming sections we give a description of the outer appearance of the outer appearance (Section 3) and some of the knots and bolts that can be found under the hood (Section 2).

MATIFUS is the result of teamwork carried out by the authors of this report, and with the help of two students from the Indian Institute of Technology, see the acknowledgments. The contents of MATIFUS are readily available and be downloaded from the web (see Section 4). For-profit legal entities are allowed to test it but need to pay a non recurring fee to the Dutch *Technology Foundation STW* after a certain duration of use. For all the details we refer to the website from where MATIFUS is downloaded.

2. UNDER THE HOOD

The four pillars on which MATIFUS rests, are: multiresolution (MR) analysis, a unifying MR interface, fusion schemes, and the graphical user interface. The latter is described in Section 3. For the fusion schemes we refer to Chapters 6 and 7 of Piella's thesis [10], where they are described and discussed in great detail. Below, in Section 2.1, we briefly review the MR schemes and how they are used by MATIFUS. The unifying MR interface is described in Section 2.2.

2.1 Multiresolution analysis

We list the multiresolution schemes employed in MATIFUS, the acronyms '**wt**' etc. are the ones used in the computer code. All schemes have been written in MATLAB[®].

'wt' Wavelet Toolbox.

Method: E.g. Mallat [7].

Implementation: The MathWorks Inc. [8].

Conditions: licensed software, Copyright ©1996, The MathWorks Inc.

'wl' Wavelab.

Method: ditto.

Implementation: Donoho, Duncan, Huo & Levi-Tsabari [3].

Constraints: the dimensions of the images need to be dyadic.

Conditions: free software, copyrighted.

'sp' Steerable Pyramid.

Method: Simoncelli and Freeman [13].

Implementation: Simoncelli [12].

Conditions: free software, Copyright ©1995, University of Pennsylvania.

'ql' Quincunx Lifting Scheme (LISQ).

Method: Sweldens [14], Kovacevic and Sweldens [5], Uytterhoeven and Bultheel [15], Heijmans and Goutsias [4].

Implementation: P.M. de Zeeuw [16, 17].

Conditions: free (GPL) software, Copyright ©1998–2003, Stichting CWI, Amsterdam.

'lp' Laplacian Pyramid.

Method: Burt and Adelson [1].

Implementation: Simoncelli [12].

Conditions: free software, Copyright ©1995, University of Pennsylvania.

'gp' Gradient Pyramid.

Method: Burt and Kolczynski [2].

Implementation: P.M. de Zeeuw.

Conditions: free (GPL) software, Copyright ©2002–2003, Stichting CWI, Amsterdam.

The Matlab Wavelet toolbox (**'wt'**) contains a wealth of two-dimensional wavelet tools for the decomposition and reconstruction of signals. The wavelets used are tensor products of one-dimensional wavelets.

Wavelab (**'wl'**) is similar to the Matlab Wavelet toolbox but is available for free. The dimensions of the images need to be dyadic.

The Steerable Pyramid (**'sp'**) provides a linear multi-scale, multi-orientation image decomposition. In the toolbox we allow for a maximum of six orientations, implying the same number of bands. The transform is of overcomplete type.

The toolbox LISQ (**'ql'**) has been built on the lifting scheme and uses quincunx downsampling of rectangular two-dimensional grids. The lifting scheme has been invented by Sweldens [14]. In [5, 15] the lifting scheme is used with quincunx downsampling to develop non-separable wavelets on a rectangular grid. The prediction filters include linear filters (Neville orders of increasing order) as well as a few nonlinear filters which preserve local maxima and / or minima (Heijmans and Goutsias [4]).

The Laplacian Pyramid (**'lp'**) is the classic hard-to-beat approach in the analysis and synthesis of images. It leads to an overcomplete representation.

The Gradient Pyramid (**'gp'**) constructs Gaussian pyramids by convolution and downsampling and then applies gradient filters in the horizontal, vertical and two diagonal directions.

Table 1 lists a few properties of the MR schemes and how they have been implemented. The last row in the table refers to the property of perfect reconstruction. This property means that applying the backtransform after the MR transform of an image results into the original. Two of the MR schemes in the table lack this property. In practice, the violation of the property proves to be to such a little extent that it does not present any substantial distortion. For a detailed review of the above schemes see Piella [9, 10].

	'wt'	'wl'	'sp'	'ql'	'lp'	'gp'
# filters	> 30	26	4	5	2	1
# bands	3	3	[1,2,4,6]	1	1	4
perfect rec.	yes	yes	no	yes	yes	no

Table 1: Implementation as is of MR schemes

2.2 Unifying MR interface

The multiresolution decompositions that we use in the toolbox are all written in MATLAB® but differ both by mathematics and by implemented datastructure. What the various schemes have in common is that they involve filters for the decomposition and the reconstruction, down- and upsampling towards and from scales and storage of approximation coefficients and detail coefficients collected in so-called bands. For example, in the Wavelet Toolbox and Wavelab we count three bands of detail coefficients: horizontal, vertical and diagonal, see also Table 1. The said similarity is exploited in an interface, consisting of MATLAB® routines, that pass data from the decompositions to the fusion part of the toolbox and vice versa from the fusion part to the reconstruction part in the MR schemes. Here we list the headings of the more important routines in the unifying interface. Input parameter **dectype** corresponds to the acronyms **'wt'** ... **'gp'** in Section 2.1, the other names of parameters are self-evident.

```
function [C,S] = makeDec2(F, levels, dectype, filtername)
```

Yields the decomposition C with bookkeeping array S of image F for a desired number of scales levels and for the MR scheme of type dectype with specified filter filtername.

```
function F = makeRec2(C, S, dectype, filtername)
```

Reconstructs image F by the decomposition C with specified filter filtername using bookkeeping array S. This is the counterpart of makeDec2.

```
function coeffs = getdetcoef2(C, S, level, dectype, band)
```

Retrieves detail (band) coefficients coeffs from the decomposition C using bookkeeping array S for a specified level of the MR scheme of type dectype and specified band.

```
function C = putdetcoef2(C, S, coeffs, level, dectype, band)
```

Stores detail (band) coefficients coeffs into the decomposition C using bookkeeping array S for a specified level of the MR scheme of type dectype and specified band. This is the counterpart of getdetcoef2.

```
function coeffs = getappcoef2(C, S, dectype)
```

Retrieves approximation coefficients coeffs of the MR scheme of type dectype from the decomposition C and using bookkeeping array S.

```
function C = putappcoef2(C, S, coeffs, dectype)
```

Stores approximation coefficients coeffs into the decomposition C of the MR scheme of type dectype and using bookkeeping array S. This is the counterpart of getappcoef2.

```
function maxlev = genmaxlev(dectype, sizeX, filtername)
```

Determines the maximum number of levels maxlev that is possible for given size sizeX of an image and the MR scheme of type dectype with specified filter filtername.


```
function bands = listofbands(dectype, filtername, level)
```

Lists the names of all the bands of the MR scheme of type `dectype` with filter `filtername` for a specified `level`.

etc.

By the above interface the fusion part is written in a manner independent from the particular choice for the MR schemes. Another important advantage is that the toolbox can easily be extended with other MR schemes provided one takes the trouble of extending the unifying interface routines above.

3. OUTER APPEARANCE – MANUAL

3.1 Preliminaries

Below, it is assumed that one works in a Linux environment. If not, one has to look for alternative instructions at the website from where MATIFUS has been downloaded. Firstly, after downloading the software, it needs to be unzipped at a directory of your choice. Secondly, one needs to set the pathname in the m-file `ourpath.m`. It should point to the directory where `matifus.m` resides. Start the MATLAB® desktop and type `matifus`.

After typing `matifus` two panels should pop up. One panel is the so-called control panel, see Figure 1, which is used to change the parameters from the default settings in the fusion method. The other panel is the so-called visualization panel, see Figure 3, with pictures of the loaded input images, the fused image and intermediate results.

The implementation is as is. Not all features work for all combinations of parameters as set in the panels. However, such occurrences always lead to clear warning signs. Some of the limitations are explicitly written down in this report. One should check the log-book for recent changes (including additions) and errata.

As for documentation we refer to this report and Piella's thesis [10], both are distributed along with the toolbox. There is a `QuickStart.html` present, in order to run through a simple example. Right-click the mouse button on the Control Panel for this and other help.

3.2 Control panel

Figure 1 shows the control panel with a default choice of parameters. By pressing the buttons like "Activity Measure" and "Combination" one can set optional parameters. Figure 2 shows the control panel, with an such optional choice of parameters. Below we describe the pop-up menus and buttons in detail.

MR analysis Here we can choose the specific type of MR decomposition (see Section 2.1) as well as the number of levels. The selections are made through a series of pop-up menus: **Type**, **Filter Family**, **Filter** and **Level**, which we briefly describe.

- **Type** pop-up menu with options: Wavelet toolbox (default), Laplacian pyramid, Steerable pyramid, Gradient pyramid, Wavelab and Quincunx lifting scheme.
- **Filter Family** and **Filter** pop-up menus depend on the selected **Type**. When Wavelet toolbox is selected the filter families are: Coiflets, Daubechies, symlets and biorthogonal wavelets. The specific filters can be chosen with increasing order, e.g. for Daubechies from 1 to 10 vanishing moments respectively. For biorthogonal wavelets the naming convention in the Wavelet Toolbox is used. When Laplacian pyramid is selected there is only one family with filters `binom3` and `binom5` (filters `Others` are not active yet). When Steerable pyramid is selected there is also only one family with filters corresponding to the number of orientation bands (the first level has one more band). When Gradient pyramid is selected only the default filter for this type can be used. When Wavelab is selected the filter families are: Coiflets, Daubechies, symlets and Battle (spline orthogonal wavelet). The specific filters can be chosen with increasing order. When



Figure 1: The control panel of MATIFUS, default parameters.

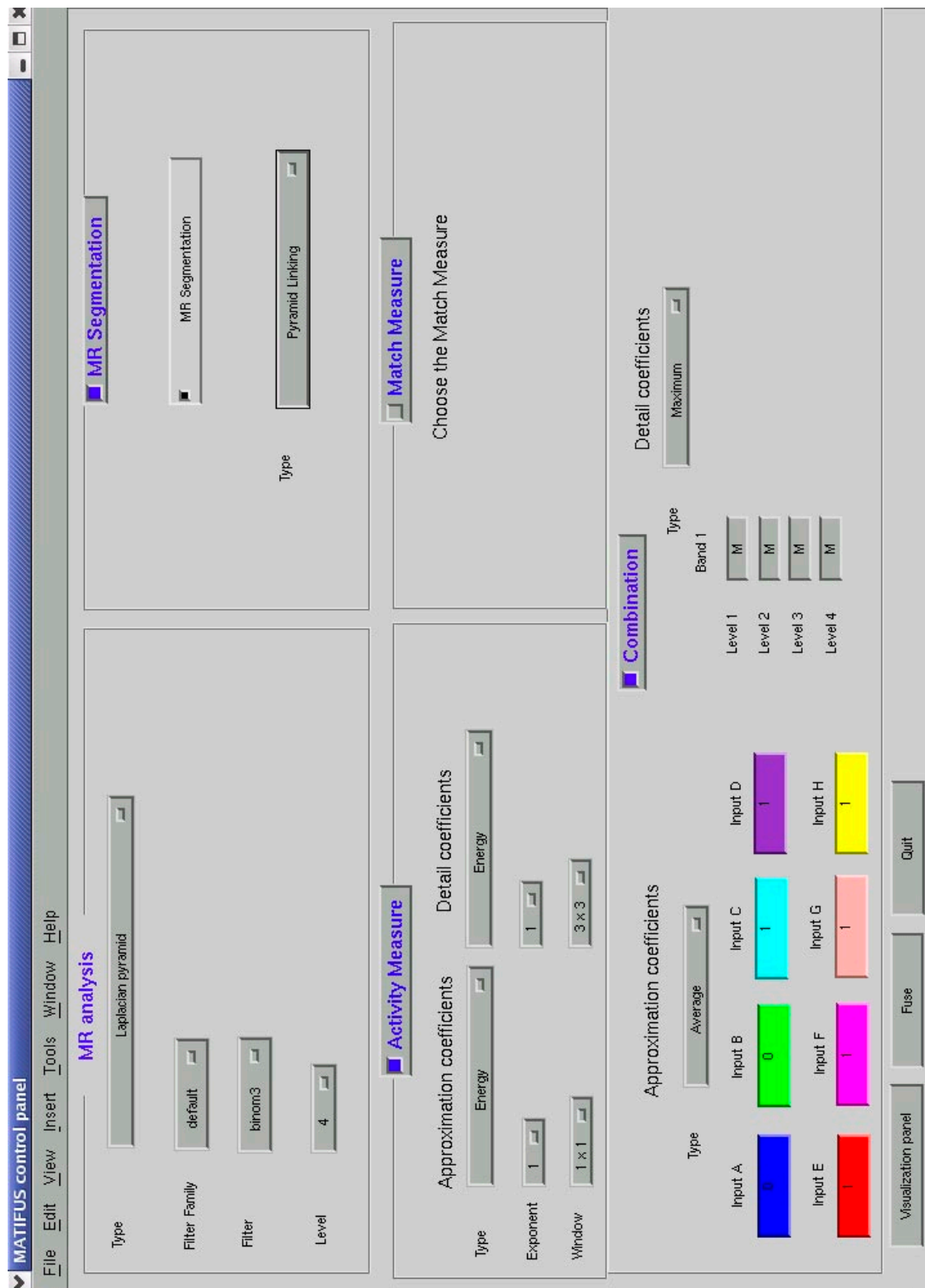


Figure 2: The control panel of MATIFUS, optional parameters.

Quincunx lifting scheme is selected there are the linear Neville filters with increasing order: `Neville2`, `Neville4`, `Neville6`, `Neville8`. Moreover, three nonlinear filters are available: `maxmin`, `maxmax` and `minmin`.

- **Level** pop-up menu with options from 1 to 5 (default) levels.

Activity measure Here we can choose the activity measure we want to use, see [10, § 6.2.4]. The choice is made through the settings of the **Type**, **Exponent** and **Window** for the approximation and detail coefficients separately.

- **Type** pop-up menu with options: **Energy** (default), **Median** and **Variance**.
- **Exponent** pop-up menu with options from 1 (default) to 4.
- **Window** pop-up menu with options 1×1 (default), 3×3 and 5×5 .

If **Window** is 1×1 then the **Type** is ignored.

Combination Here we can determine how the approximation and detail coefficients are going to be combined to form the composite approximation and detail coefficients, see [10, § 6.2.6–§ 6.2.7]. The approximation and detail coefficients are not treated the same. Firstly, we describe the options for the approximation coefficients.

- **Type** pop-up menu with options **Average** and **Maximum**.
- **Input A**, **Input B**, ..., **Input H** edit-boxes where the weight 1 is put by default.

Example 1 Assume the active loaded inputs are A, B and C, and that **Average** has been chosen as **Type**. If one changes the default value 1 of **Input C** to 0, the composite approximation coefficients are going to be computed from the average from inputs A and B because input C has been given weight 0. If one had chosen **Maximum** as **Type** then the composite approximation coefficients would have been computed by choosing the approximation coefficients from A or B whose activity measure is maximum. Note that choosing **Average** as **Type** implies omitting the activity measure of the approximation coefficients.

Now we describe the options for the detail coefficients.

- **Type** pop-up menu with options: **Maximum**, **Average** and **Max-Level**.
- Edit-boxes which form a matrix whose rows correspond to the different levels in the MR decomposition and whose columns correspond to the different bands. With steerable pyramids the number of bands also depends on the **Filter**. By default the matrix is filled depending on the above **Type**: M for **Maximum**, A for **Average** and ML for **Max-Level**.

Example 2 Suppose the user has opted for 5 levels and selects **Gradient Pyramids** as **Type**, and **Maximum** under **Detail coefficients**. This results in the display of Table 2 in the control panel. Here M stands for **Maximum**. Due to the choice of **Gradient Pyramids**, 4 bands are displayed. The user can overwrite each entry M and put other available options like A for **Average**, ML for **Max-Level**, a weight (i.e. a number), or a lower-case letter a...h specifying the input image from which the band has to be selected. See Table 3 for an example. It shows that for the first level the maximum selection rule is used for the bands 1, 2 and 3 while the coefficients of band 4 are taken from input B (specified as b). On level 2, the maximum selection rule is used. For level 5, the average rule is used for bands 1 and 2 (this implies omitting the activity measure of detail coefficients) and the maximum selection rule is used for bands 3 and 4. On level 4 the maximum-per-level (**Max-Level**) selection rule is used (by definition, the option ML only makes sense when it is on all bands throughout a level). On level 3 weights are specified, in this particular example it says that the third band is ignored for evaluation of (any) selection rule.

Level	Band 1	Band 2	Band 3	Band 4
1	M	M	M	M
2	M	M	M	M
3	M	M	M	M
4	M	M	M	M
5	M	M	M	M

Table 2: Default combination of detail coefficients

Level	Band 1	Band 2	Band 3	Band 4
1	M	M	M	b
2	M	M	M	M
3	1	1	0	1
4	ML	ML	ML	ML
5	A	A	M	M

Table 3: Combination of detail coefficients, manually reset

Example 3 Suppose the user has selected in the *MR analysis*: **Type** → **Wavelet toolbox**, in the *Combination of the Detail coefficients*: **Type** → **Max-Level**. and has opted for 3 levels. This results in the display at the control panel of the upper half of Table 4. After manual resetting as indicated

Level	Band 1	Band 2	Band 3
1	ML	ML	ML
2	ML	ML	ML
3	ML	ML	ML

Initial state

Level	Band 1	Band 2	Band 3
1	ML	ML	ML
2	M	M	M
3	1	1	0

After manual reset

Table 4: Panel display **Max-Level** type combination of detail coefficients

the maximum-level selection rule is unchanged at level 1, at level 3 the maximum-level selection rule is also still used but now with weights 1, 1, 0 for bands 1, 2, 3 respectively. That is, band 3 (diagonal details in this example) is disregarded. At level 2 the maximum selection rule is used for all bands.

MR segmentation By choosing a MR segmentation method, the region-based approach described is used instead of the typical pixel-based approach. There is a pop-up menu **Type** with options: **None** (default) and **Pyramid linking**. Obviously, if **None** is selected, no segmentation is done and the fusion algorithm is pixel-based. The presently implemented **Pyramid linking** only works for the

Laplacian pyramid and for the Haar wavelet of the Wavelet toolbox. Further, the **Pyramid linking** has its parameters fixed regardless of the input images, this implies that a poor segmentation can be obtained. This is a topic for future improvement.

Match measure Hereby we can choose an optional **Match measure** which measures the similarity between the transform coefficients of *two* source images. So far a correlation measure based on one by Burt and Kolczynski [2] has been implemented. It does not depend merely on the setting of the **Window** (the neighborhood over which the coefficients are averaged) but also on the settings of the **Exponent** (the power to which the coefficients are raised). See also Piella's thesis [10, § 6.2.5].

At the bottom we find the following three buttons.

- **Visualization panel** button. This is the only right way to switch to the visualization panel (for loading source images etc.).
- **Fuse** button. Evokes the fusion algorithm with the parameters set in the control panel and the images loaded through the visualization panel.
- **Quit** button. This the way to quit MATIFUS.

3.3 Visualization panel

Figure 3 shows the visualization panel. In it one observes eleven image boxes. The top two rows of four image boxes each are for the maximum of eight input images (sources) that can be loaded in the GUI. Here, as an example we have loaded three images of a ship. They are surveillance images from *TNO Human Factors* and kindly provided by Dr. A. (Lex) Toet. They are stored in the directory *images* of MATIFUS and have been made available through imagefusion.org.

The bottom left image box is for the result of fusion, the bottom middle image box shows the segmentation (the case of region-based fusion) and the bottom right image box is for just one of the decisionmaps. The colours of the borders around the input images correspond to the colours used in the decision map.

Pressing the "Show all" button (beneath the bottom right image box) yields a picture of all relevant decisionmaps, see Figure 4. It corresponds to MR analysis by steerable pyramids on four levels and four bands (set at the control panel). The ordering is as is customary with the implementation of the steerable pyramids (see Section 2.2).

The visualization panel contains a menu bar and buttons at the input and output images for (pre)processing and specific visualization tasks.

Menu Apart from the standard entries (**File**, **Edit**, ...) there are the following menu items.

- **Tools** including the following entries:
 - **Zoom in**. A moveable magnifying glass appears that points to a position in an image where zooming in is activated by clicking.
 - **Zoom out**. This the counterpart of the above option.
- **Preprocess** with the following entries:
 - **Blur**. A menu appears in which the image to be processed is selected. The image is blurred through multidimensional filtering using convolution.
 - **Contrast**. A menu appears in which the image to be processed is selected. The contrast is enhanced.
- **Visualize** with the following entries:

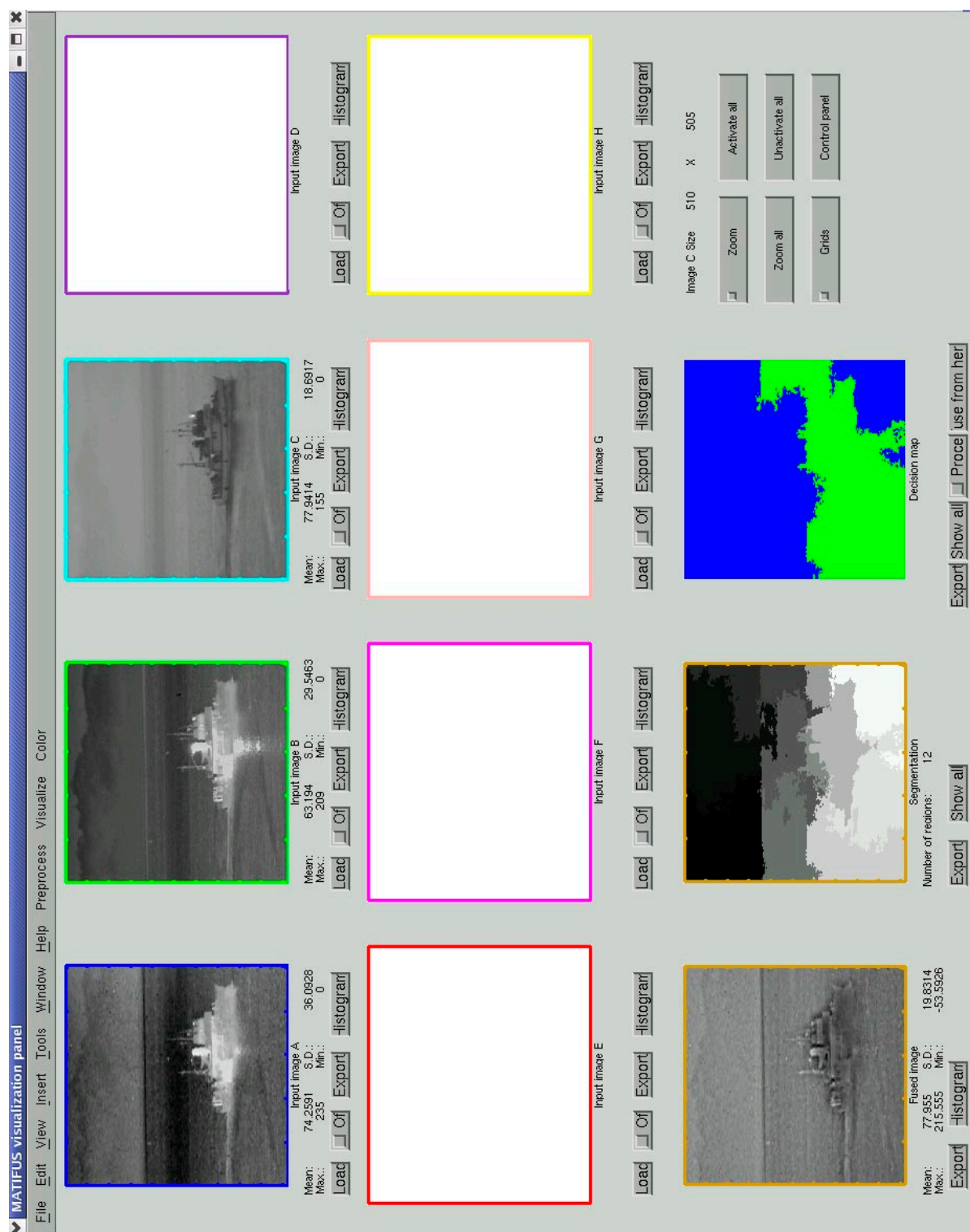


Figure 3: The visualization panel of MATIFUS.

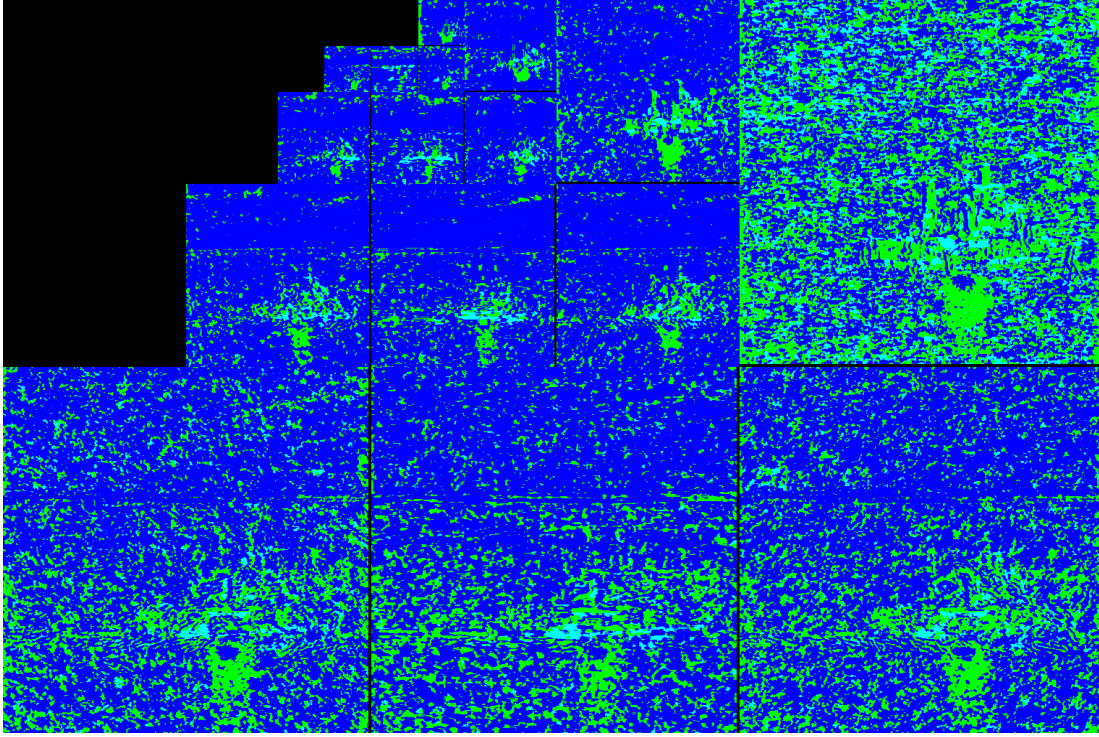


Figure 4: Result of "Show all" decisionmaps.

- **Decomposition.** If selected, the MR decompositions of all active inputs in the source figures are displayed. Each MR decomposition is displayed in a new separate window. The ordering is as is customary with the implementation of the chosen MR scheme (set at the control panel).
- **Activity.** If selected, the MR activity measures of all active images in the source figures are displayed. Each MR activity measure is displayed in a new separate window. The ordering is as is customary with the implementation of the chosen MR scheme (set at the control panel).
- **Initial Image.** If selected, large versions of all loaded images are displayed in new separate windows.

• **Color** with the following entries:

- **Convert to RGB.** When chosen, a window pops up containing the matrix below. The

Image	A	B	C	D	E	F	G	H	Fused
R	1	0	0	0	0	0	0	0	0
G	0	1	0	0	0	0	0	0	0
B	0	0	1	0	0	0	0	0	0

entries signify weights to construct the RGB-image. E.g., if the weights in the R-row are 1, 2, 1, 0, 0, etc., then $R(x) = A(x) + 2B(x) + C(x)/4$. Linear normalization is applied such that the minimum and maximum value of $R(x)$ are scaled to 0, 1 respectively. In

the window a button is present to produce a RGB image (based on the input images with corresponding weights) and an **All Zeros** button to put all weights to zero.

- **Convert RGB to gray.** When chosen, a window pops up containing a matrix like the following. The positions of the X's show where the RGB components should go. Note that

Image	A	B	C	D	E	F	G	H
R	X	0	0	0	0	0	0	0
G	0	X	0	0	0	0	0	0
B	0	0	X	0	0	0	0	0

in one column only one button can be nonzero. In the window a load button is present to get a specified RGB image and an **All Zeros** button to put all entries to zero. The source images that receive input are automatically activated.

The (maximum of eight) source figures display the input images (original or processed) which are going to be fused (if active). Each source figure has the following associated buttons:

- **Load** button. A new input image is automatically displayed in the corresponding source figure. The image dimensions and several statistics (minimum, maximum, average, standard deviation, ...) are also displayed just below the figure.
- **Off** check-button. Hereby the corresponding input image becomes unactive. This means that this image will not participate in the fusion process. An unactive image is displayed in a low-contrast mode.
- **Histogram** button. Hereby a new window pops up displaying the histogram of the image contained in the source figure.
- **Export** button. Hereby a copy of the image contained in the source figure emerges in a separate window. In this way, we have save and export facilities.

Through pressing the **Fuse** button at the control panel the fused image (bottom left) is generated. The image is normalized to the range $[0, 255]$ by a linear transformation. Moreover, for visualization purposes, a histogram stretching is performed. A few statistics (with respect to the non-normalized version) are also displayed. A **Histogram** button and **Export** button are present with similar function as for the source images.

At the right-hand side of the fused image one observes the segmentation figure (but only if one had opted for MR segmentation at the control panel). Just the first level of the MR segmentation is depicted. The number of regions is displayed underneath. By pressing the **Show all** button a new window shows up displaying the MR segmentation for all levels.

The third bottom row figure displays a ‘representative’ decision map for the first level of the chosen decomposition. The colours of the borders around the input images correspond to the colours used in the decision map. At each position, the color of the input image which contributes most to the fused image is the one that is displayed. By pressing the **Show all** button a new window shows up displaying the decision maps for all levels and all bands. The ordering in which the bands at the various levels are shown in such a figure is as is customary with the implementation of the chosen MR scheme (see Section 2.2).

At the bottom right end corner of the we find the following six buttons.

- **Activate all** button. If pressed, all source images are made active.

- **Unactivate all** button. If pressed, all source images are made unactive.
- **Zoom** button. This is a shortcut to the **Zoom in** under the **Tools** menu.
- **Zoom all** button. If pressed, the same zooming is applied to all source windows as the one applied with **Zoom** to the fused image.
- **Grids** button. A grid is put on the source images and the fused image.
- **Control panel** button. This is the only right way to switch to the control panel.

4. CONCLUDING REMARKS

MATIFUS is a MATLAB[®] toolbox for image fusion, based on various multiresolution decompositions and fusion schemes. It accompanies the thesis of Piella [10]. We have given a description of the GUI of MATIFUS with its major panels, buttons and functions and explained some of its inner workings. The software is amenable to be supplied with more functionality (MR schemes, processing steps).

The software described in this document is furnished under a license agreement. The bottom line reads that the copyrighted software is free for researchers and students of not-for-profit legal entities. However, for-profit legal entities have to pay a non recurring fee to the Dutch *Technology Foundation STW* (www.stw.nl) after a certain duration of use. The program is distributed as is, in the hope that it will be useful, but without any warranty; without even the implied warranty of fitness for a particular purpose. For all the legal details we refer to the website from where MATIFUS can be downloaded, see:

<http://www.cwi.nl/ftp/pauldz/Codes/MATIFUS/>

or via the link from:

<http://homepages.cwi.nl/~pauldz/>

Further, any result obtained by this code or part of it, and published in any publication whatsoever, electronically or otherwise, has to make reference to Piella's thesis [10] and the report you are now reading.

ACKNOWLEDGMENTS

Nitin Gupta and Anand Kumar, at the time students from the Indian Institute of Technology, are gratefully acknowledged for the vital contributions they have made to the graphical userinterface at the occasion of summer internships at CWI.

REFERENCES

1. P.J. BURT AND E.H. ADELSON, The Laplacian pyramid as a compact image code, *IEEE Transactions on Communications*, 31 (4), pp. 532–540 (1983).
2. P.J. BURT AND R.J. KOLCZYNSKI, Enhanced Image Capture through Fusion, Proceedings Fourth International Conference on Computer Vision, Berlin, pp. 173–182, IEEE (1993).
3. D.L. DONOHO, M. DUNCAN, X. HUO, AND O. LEVI-TSABARI, Wavelab 802 for Matlab, computational algorithms related to wavelet analysis.
www-stat.stanford.edu/~wavelab
4. H.J.A.M. HEIJMANS AND J. GOUTSIAS, Multiresolution signal decomposition schemes. Part 2: Morphological wavelets, CWI Report PNA-R9905, Centrum voor Wiskunde en Informatica, Amsterdam (1999).
www.cwi.nl/ftp/CWIreports/PNA/PNA-R9905.pdf
5. J. KOVACEVIC AND W. SWELDENS, Wavelet families of increasing order in arbitrary dimensions, *IEEE Trans. Imag. Proc.*, 9(3), 480–496 (2000).
6. H. LI AND B.S. MANJUNATH AND S.K. MITRA, Multisensor image fusion using the wavelet transform, *Graphical Models and Image Processing* 57 (3): 235–245 (1995).

7. S. MALLAT, A theory for multiresolution signal decomposition: the wavelet representation, in: *IEEE Pattern Anal. and Machine Intelligence*, vol. 11, no. 7, pp. 674–693 (1989).
8. M. MISITI, Y. MISITI, G. OPPENHEIM, J.-M. POGGI, *Wavelet Toolbox User's Guide (For Use with Matlab)* The MathWorks Inc. (1996).
www.mathworks.com
9. G. PIELLA, A general framework for multiresolution image fusion: from pixels to regions, *Information Fusion* **9** 259–280 (2003).
Based on: CWI Report PNA-R0211, Centrum voor Wiskunde en Informatica, Amsterdam (2002).
www.cwi.nl/ftp/CWIreports/PNA/PNA-R0211.pdf
10. G. PIELLA, *Adaptive Wavelets and their Applications to Image Fusion and Compression*, Ph.D. Thesis, CWI & University of Amsterdam (2003).
11. G. PIELLA AND H.J.A.M. HEIJMANS, *A new quality metric for image fusion*, in: Proceedings of the IEEE International Conference on Image Processing, Vol. 3, 173–176, Barcelona (2003).
12. E.P. SIMONCELLI, Matlab tools for multi-scale image processing including steerable pyramids, www.cis.upenn.edu/~eero/steerpyr.html
13. E.P. SIMONCELLI AND W.T. FREEMAN, The steerable pyramid: a flexible architecture for multi-scale derivative computation, *Proceedings of the IEEE International Conference on Image Processing*, pp. 444–447, IEEE Signal Processing Society (1995).
14. W. SWELDENS, The lifting scheme: A construction of second generation wavelets, *SIAM J. Math. Anal.*, 29(2), 511–546 (1997).
15. G. UYTTERHOEVEN AND A. BULTHEEL, The red-black wavelet transform, *Proceedings of IEEE Benelux Signal Processing Symposium*, 191–194 (1998).
16. P.M. DE ZEEUW, A Toolbox for the Lifting Scheme on Quincunx Grids (LISQ), CWI Report PNA-R0224, Centrum voor Wiskunde en Informatica, Amsterdam (2002).
www.cwi.nl/ftp/CWIreports/PNA/PNA-R0224.pdf
17. P.M. DE ZEEUW, LISQ – A Matlab Toolbox for the Lifting Scheme on 2D Quincunx Grids,
<http://ftp.cwi.nl/pauldz/Codes/LISQ/> or via
<http://homepages.cwi.nl/~pauldz/>