

# Contents

<b>1</b>	<b>Introduction and Motivation</b>	<b>13</b>
1.1	General Framework and Motivation . . . . .	13
1.2	Structure of this Thesis . . . . .	15
1.3	Original Contributions of this Thesis . . . . .	16
<b>2</b>	<b>Principles of SAR Image Formation</b>	<b>17</b>
2.1	Radar Imaging . . . . .	19
2.2	The SAR Concept . . . . .	21
2.2.1	Resolution in Range . . . . .	22
2.2.2	Resolution in Azimuth . . . . .	25
2.3	Special SAR Image Properties . . . . .	27
2.3.1	Imaging Geometry . . . . .	27
2.3.2	Speckle . . . . .	29
2.3.3	Image Quality . . . . .	30
2.3.4	Image Calibration . . . . .	32
2.4	Lessons Learned . . . . .	32
<b>3</b>	<b>Polarimetry</b>	<b>33</b>
3.1	Propagation of Electro-Magnetic Fields . . . . .	33
3.2	Polarisation . . . . .	34
3.3	The Jones Vector . . . . .	35
3.4	The Stokes Vector . . . . .	36
3.5	Partially Polarised Waves . . . . .	37
3.6	The Scattering Matrix . . . . .	38
3.6.1	Scattering Matrices for Elementary Targets . . . . .	39
3.6.2	Vectorisation of the Scattering Matrix . . . . .	42
3.7	Polarimetric Radar Data . . . . .	43
3.8	Description of the Test Images . . . . .	44
3.9	Lessons Learned . . . . .	49
<b>4</b>	<b>Statistics of SAR Images</b>	<b>51</b>
4.1	Statistics of the Speckle in SAR Images . . . . .	51
4.1.1	The Origin of Speckle . . . . .	52
4.1.2	The Real and Imaginary Part of the SLC . . . . .	52
4.1.3	The Amplitude Image . . . . .	54
4.1.4	The Intensity Image . . . . .	54

4.1.5	The Log-Intensity Image . . . . .	55
4.1.6	Remarks . . . . .	56
4.2	Second Order Statistics . . . . .	56
4.2.1	Spatial Correlation . . . . .	56
4.2.2	Relation between Real and Imaginary Components . . . . .	63
4.2.3	Interchannel Correlation . . . . .	63
4.2.4	Relationship between the Spatial and the Interchannel Correlation . . . . .	64
4.3	Lessons Learned . . . . .	67
<b>5</b>	<b>Edge Detection in High-Resolution SAR Images</b>	<b>69</b>
5.1	Evaluation Method for Edge Detectors . . . . .	75
5.2	Pre-Processor for Edge Detection . . . . .	77
5.3	Uni-Variate Edge Detectors . . . . .	78
5.3.1	Edge Detection based on a Difference in Means . . . . .	79
5.3.2	Edge Detection based on a Difference in Medians . . . . .	93
5.4	Multi-Variate Edge Detectors . . . . .	98
5.4.1	Edge detection based on a Difference in Variance . . . . .	98
5.4.2	Edge Detection based on a Difference in Means . . . . .	109
5.5	Fusing the Results for Different Orientations . . . . .	114
5.6	Post-Processing: Improvement of Edge Localisation . . . . .	117
5.6.1	Bartlett Filter . . . . .	117
5.6.2	Binary Skeleton . . . . .	118
5.6.3	Morphological Filter . . . . .	118
5.6.4	Vectorisation of the results . . . . .	121
5.6.5	Conclusions about Edge Localisation . . . . .	121
5.7	Development of a Fusion Strategy for Edge Detectors . . . . .	122
5.7.1	Combining the Results for the Uni-Variate Edge Detectors . . . . .	123
5.7.2	Fusion Strategy for Multi-Variate Edge Detectors . . . . .	129
5.8	Detection of Communication Lines . . . . .	141
<b>6</b>	<b>Segmentation and Classification</b>	<b>145</b>
6.1	Image Segmentation using Merging Methods . . . . .	145
6.1.1	MUM based on Student-T Test . . . . .	147
6.1.2	MUM based on Hotellings $T^2$ Test . . . . .	149
6.1.3	MUM based on Mahalanobis Distance . . . . .	149
6.2	Image Classification using Decomposition Algorithms . . . . .	152
6.2.1	Van Zyl's Decomposition . . . . .	152
6.2.2	Freeman's Decomposition . . . . .	155
6.2.3	Cloude's Decomposition . . . . .	160
6.3	Lessons Learned . . . . .	165
<b>7</b>	<b>Detection of Built-Up Areas in SAR Images</b>	<b>167</b>
7.1	Radiometric and Polarimetric Characteristics of Built-Up Areas in SAR Images . . . . .	168
7.2	Description of the Features . . . . .	169
7.2.1	Distance Measure . . . . .	170

7.2.2	Skewness Measure . . . . .	171
7.2.3	Variance Measure . . . . .	172
7.2.4	Interchannel Correlation . . . . .	172
7.2.5	Overview of Feature Images . . . . .	173
7.3	Feature Fusion using Logistic Regression . . . . .	175
7.4	Results of the Pixel-Wise Detector of Built-Up Areas . . . . .	177
7.5	Vectorisation of the Detected Built-Up Areas . . . . .	179
<b>8</b>	<b>Image Registration</b>	<b>181</b>
8.1	Evaluation Method for the Registration . . . . .	182
8.2	Development of a Strategy for Registering SAR Images . . . . .	183
8.2.1	The Feature Space . . . . .	187
8.2.2	The Search Space . . . . .	187
8.2.3	The Search Strategy . . . . .	187
8.3	Pre-Processing based on A Priori Information . . . . .	189
8.4	Registration of SAR Images with a Map . . . . .	189
8.4.1	Registration by Feature Consensus . . . . .	189
8.4.2	Refinement of Registration using Contours of Forests . . . . .	200
8.4.3	Refinement of Registration using Communication Lines . . . . .	203
8.5	Registration of SAR Images . . . . .	212
<b>9</b>	<b>Conclusions and Perspectives</b>	<b>217</b>
9.1	Conclusions . . . . .	217
9.1.1	Low-Level Image Interpretation . . . . .	217
9.1.2	High-Level Image Interpretation . . . . .	218
9.1.3	Image Registration . . . . .	219
9.2	Possible Improvements and Future Work . . . . .	219
<b>A</b>	<b>Simulation of SAR images</b>	<b>231</b>
A.1	Simulation of Spatially Correlated Speckle . . . . .	231
A.2	Introducing Interchannel Correlation . . . . .	232
<b>B</b>	<b>Pulse Compression</b>	<b>233</b>
B.1	The Matched Filter . . . . .	233
B.2	Matched Filter for the Chirp . . . . .	235
<b>C</b>	<b>Correction Factors for the Edge Detectors</b>	<b>237</b>
C.1	Variance of the Mean . . . . .	237
C.2	Covariance of the Mean . . . . .	240
C.3	Correction Factors for the Contour Detectors . . . . .	241
<b>D</b>	<b>The Fuzzy Classification Method</b>	<b>243</b>

