

Contents

1	Introduction and Motivation	1
1.1	Earth Observation from Geostationary Orbit	1
1.1.1	Example: Event Tracking	2
1.1.2	Geometrical Image Distortions	3
1.1.3	Geometrical Image Correction	4
1.2	Aim of the Thesis	4
1.2.1	Today's Satellite Image Registration Methods	4
1.2.2	Limitations of Today's Methods	6
1.2.3	Concept Overview	6
1.2.4	Organisation of the Thesis	8
2	Image Acquisition	11
2.1	Introduction to Image Acquisition	11
2.2	GEO Satellite Model	13
2.2.1	Earth Model	14
2.2.2	Orbit Model	14
2.2.3	Attitude Model	14
2.2.4	Payload Assembly	15
2.3	Scanning Instrument Model	15
2.3.1	Spherical Projection Function	16
2.3.2	Scanner Motion	17
2.3.3	Handling of Scan Imagery	19
2.3.4	Parameters of the considered Scanning Payload	21
3	Optical Flow Computation	23
3.1	Introduction to Optical Flow	23
3.1.1	Definitions and Assumptions	23
3.1.2	Camera and Object Motion	24
3.2	Estimation of the Optical Flow	25
3.2.1	Cross-Correlation	26
3.2.2	Phase-Correlation	27
3.2.3	Example: Optical Flow Computation	28
3.3	Modifications to improve the Accuracy and Reliability	32
3.3.1	Detection of Subpixel Image Shifts	32
3.3.2	Wrong Vector Detection	33
3.3.3	Hierarchical Optical Flow Computation	34

3.3.4	Correction Function	35
3.3.5	Median Outlier Detection	35
3.4	Reliability Value of the 2d-Correlation	36
4	Optical Flow based Image Navigation from Scanning Images	39
4.1	Camera's Egomotion	39
4.2	Derivation of the Optical Flow Egomotion Equation	40
4.2.1	Rotational Motion	41
4.2.2	Translational Motion	41
4.2.3	Combined Motion	42
4.3	Egomotion Estimation	42
4.3.1	Estimation of the Camera Motion	42
4.3.2	Propagation of the expected Accuracy	44
4.3.3	Optimal Quaternion Method	46
4.3.4	Adaption to Scanning Imagery	46
4.3.5	Outlier Detection based on redundant Optical Flow Vectors	48
4.4	Cloud Detection	49
4.4.1	Multispectral Cloud Detection	49
4.4.2	MSG Cloud Mask	51
4.5	Image Navigation Concepts	52
4.5.1	Direct Optical Flow Navigation	52
4.5.2	Virtual Optical Flow Navigation	54
5	The Navigation Filter	59
5.1	Filter Concept	59
5.2	Sequential State Estimation	60
5.3	Derivation of the Multiplicative Extended Kalman Filter	61
5.3.1	The Error State Model	61
5.3.2	Discrete-Time Attitude Estimation	64
5.3.3	Filter Update by Image Shift Vectors	66
5.3.4	Filter Update by full 3d Attitude Measurements	67
5.4	AOCS Sensor Models	68
5.4.1	Gyroscope Sensor Model	68
5.4.2	Star Tracker Model	69
5.5	Image Navigation Sensor Model	70
5.5.1	Image Navigation Model	70
5.5.2	Camera Misalignment	71
5.6	Integration of the MEKF	73
5.6.1	The Implementation of the Estimation Process	74
5.6.2	Observability	77
6	Geometrical Image Correction and Registration	79

6.1	Image Registration	79
6.2	Image Rectification	82
7	Performance Analysis	85
7.1	Analysis of the Optical Flow Algorithm	86
7.1.1	OF Analysis – Overview	86
7.1.2	OF Analysis – Preparation	88
7.1.3	OF Analysis – Implementation and Results	90
7.1.4	Summary of the OF Analysis	94
7.2	Analysis of the Motion Estimation Algorithm	95
7.2.1	Analysis Motion Estimation – Overview	96
7.2.2	Analysis Motion Estimation – Preparation	97
7.2.3	Analysis Motion Estimation – Implementation and Results	97
7.2.4	Summary of the Analysis Motion Estimation	102
7.3	Analysis of the Navigation Filter	103
7.3.1	Analysis Navigation Filter – Overview	103
7.3.2	Analysis Navigation Filter – Preparation	104
7.3.3	Analysis Navigation Filter – Implementation and Results	105
7.3.4	Summary of the Analysis Navigation Filter	110
8	Conclusion	113
8.1	Achieved Results	113
8.2	Possible follow-on Activities	115
A	Algorithms and Tables	117
A.1	Quaternion Algebra	117
A.2	Runge Kutta Algorithm	118
A.3	MEKF	119
A.4	Spectral Channels	120
B	Results of the Performance Analysis	121
B.1	Results of the Analysis of the Optical Flow Algorithm	121
B.2	Results of the Analysis of the Navigation Filter	123
	List of Figures	125
	List of Tables	129
	Bibliography	131