

Contents

1	Introduction	1
1.1	Antecedents	3
1.2	Goal of the Thesis	4
1.2.1	Objectives	5
1.3	Outline of the Thesis	6
2	State of the Art	7
2.1	The SLAM Problem	7
2.2	History	7
2.3	The Use of Sonars for SLAM	10
2.4	Underwater SLAM	12
2.5	Discussion	20
2.6	Aims of This Work	21
3	Design and Development of the Ictineu AUV	23
3.1	Mechanical Aspects	23
3.2	Tethered/Untethered Modes of Operation	24
3.3	Power Module	25
3.4	Computer Module	25
3.5	Actuators	26
3.5.1	Thrusters	26
3.5.2	Marker Dropper	27
3.6	Sensor Suite	27
3.6.1	Miniking Imaging Sonar	27
3.6.2	Doppler Velocity Log	28
3.6.3	Motion Reference Unit	29
3.6.4	Cameras	29
3.6.5	Hydrophone	30
3.6.6	Safety Sensors	30

3.7	The O ² CA ² Software Architecture	30
3.7.1	Robot Interface Module	31
3.7.2	Perception Module	31
3.7.3	Control Module	32
3.8	Summary and Further Work	35
4	Understanding Mechanically Scanned Imaging Sonars ...	37
4.1	Principles of Operation	37
4.2	Interpreting Sonar Images	38
4.3	Measurement Perturbations	42
4.4	Peculiarities of the MSISs	43
4.4.1	Polar Sensor Representing a Cartesian Space	44
4.4.2	Continuous Dataflow	44
4.4.3	Motion Induced Distortions	46
5	Localization with an <i>a priori</i> Map	47
5.1	Data Association and Localization	47
5.2	Voting-Based Localization Method	48
5.2.1	Voting Algorithm	49
5.2.2	Dealing with Continuous Acoustic Images	50
5.2.3	Managing Compass Errors	52
5.2.4	Discretization of the Voting Space	54
5.2.5	Experimental Results	55
5.3	EKF-Based Localization Method	58
5.3.1	Defining the Map	58
5.3.2	State Vector	59
5.3.3	Initializing the Filter	60
5.3.4	System Model	61
5.3.5	Measurement Model	62
5.3.6	Updating the Position Estimate	64
5.3.7	Experimental Results	66
5.4	Hybrid Approach	68
5.4.1	The Filter	68
5.4.2	Adapted Voting Algorithm	69
5.4.3	Experimental Results	71
5.5	Summary and Further Work	74
6	Simultaneous Localization and Mapping	77
6.1	Line Feature Extraction	77
6.1.1	Classical Approaches for Line Feature Extraction	78
6.1.2	Hough-Based Feature Extraction Method for MSIS	79
6.2	Uncertainty Model for Line Features	84
6.2.1	Classical Approach	84

6.2.2	Estimating Feature Uncertainties from Acoustic Images	86
6.2.3	Correlations in the Extracted Features	90
6.2.4	Validation of the Feature Extraction Algorithm	91
6.3	Obtaining Segments	93
6.4	EKF-Based SLAM	95
6.4.1	Map Initialization	95
6.4.2	Prediction	96
6.4.3	Sensor Updates	97
6.4.4	About the Use of a Compass in SLAM	98
6.4.5	Map Building Process	99
6.5	SLAM with Local Maps	101
6.5.1	Local Map Building	102
6.5.2	Local Map Joining	103
6.6	Experimental Results	105
6.6.1	Water Tank	105
6.6.2	Marina Environment	107
7	Conclusion	113
7.1	Summary	113
7.2	Contributions	114
7.3	Future Work	115
7.4	Research Framework	116
7.5	Related Publications	118
A	The Kalman Filter	121
A.1	The Linear Kalman Filter	122
A.1.1	Linear System Models	122
A.1.2	The Discrete Kalman Filter Equations	123
A.2	The Extended Kalman Filter	124
A.2.1	Non-linear System Models	124
A.2.2	The Discrete Extended Kalman Filter Equations	124
B	Correlations in DVL Measurements	127
C	Transformations in 2D	131
C.1	Inversion	131
C.2	Composition	132
C.3	Composition of Point Features	133
C.4	Composition of Line Features	133
	References	135