

Contents

1	Introduction	1
1.1	Why Robotic Grasping?	2
1.2	Goals and Objectives	2
1.2.1	Main Goal	2
1.2.2	Specific Objectives	3
1.3	Hypotheses	3
1.4	Contributions	4
1.5	Thesis Outline	4
2	Background	6
2.1	Basic Concepts	6
2.1.1	Robotic Systems and The Grasping Problem	6
2.1.2	Machine Learning	7
2.1.3	Support Vector Machine	9
2.1.4	K-Means	10
2.1.5	DBSCAN	12
2.1.6	Bag of Visual Words Model	13
2.1.7	K-Fold Cross-Validation	15
2.1.8	ROC Curves	16
2.1.9	RGB-D Images and Point-clouds	18
2.2	Software	18
2.2.1	ROS: The Robot Operating System	18
2.2.2	Gazebo	19
2.3	The PR2 Robot	21
2.4	Summary	22
3	Grasp Synthesis	23
3.1	Analytic Methods	24
3.1.1	General Approach	24
3.2	Data-Driven Methods	26
3.2.1	General Approach	26
3.2.2	Classification of Methods	27
3.3	Analytic vs. Data-Driven Methods	30
3.4	Summary	30
4	3D Descriptors	31

4.1	Descriptors for 3D Sensory Data	31
4.1.1	Signature-Based Descriptors	32
4.1.2	Histogram-Based Descriptors	32
4.1.3	Mixed Descriptors	35
4.2	Applicability to Robotic Grasping	37
4.3	Summary	37
5	Directed Curvature Histograms	39
5.1	Premise and Design	39
5.1.1	Design	40
5.2	Computation	42
5.2.1	Computation Parameters	45
5.2.2	Computational Complexity	46
5.3	Coordinate System Selection	47
5.3.1	Coordinate System for Robotic Grasping	48
5.4	Examples	48
5.5	Summary	49
6	Proposed Grasp Synthesis Method	52
6.1	Premise and Design	52
6.1.1	Design	53
6.1.2	DCH Parameters	53
6.2	Stages of the Proposed Method	55
6.2.1	Stage 1: Feature Space Reduction	55
6.2.2	Stage 2: Grasp Candidates Generation	56
6.2.3	Stage 3: Learning	59
6.2.4	Stage 4: Knowledge Exploitation	61
6.3	Summary	62
7	Experimental Setup and Evaluation	63
7.1	Experimental Data Generation	63
7.1.1	Setup	63
7.1.2	Data Generation Procedure	64
7.2	Learning Process and Assessment	67
7.2.1	Learning	67
7.2.2	Assessment	68
7.3	Synthetic and Real-life Sensory Data	69
7.4	Summary	70
8	Experiments and Results	72
8.1	Predictive Performance	72
8.1.1	Classification Performance Using DCH	72
8.1.2	Classification Performance Using Other Descriptors	73
8.1.3	Grasping Performance Using DCH	75
8.2	DCH Sensitivity Analysis	77
8.2.1	Sensitivity to the Number of Bands	78
8.2.2	Sensitivity to the Width of the Bands	79

8.2.3	Sensitivity to the Size of the Bins	81
8.3	Summary	82
9	Conclusions	83
9.1	Conclusions	83
9.2	Future Work	86
	Acronyms	88
	Glossary	89
	Bibliography	90
A	Clustering Algorithms	95
A.1	K-Means Pseudo Code Implementation	95
A.2	DBSCAN Pseudo Code Implementation	96

List of Tables

7.1 Summary of the generated data. 67
7.2 Details of the generated data. 67

List of Figures

1.1	Diagram depicting the outline of this thesis.	5
2.1	Information flow comparison.	8
2.2	Planes defined by SVM.	8
2.3	SVM kernel trick.	8
2.4	Clustering example using K-Means.	11
2.5	Point types defined by DBSCAN.	11
2.6	Comparison of clustering results.	11
2.7	Comparison between BoW and BoVW models.	14
2.8	ROC curve example	17
2.9	Comparison of a color image and a depth image	17
2.10	Examples of ROS runtime architectures.	20
2.11	A simulation performed with Gazebo.	20
2.12	The PR2 robot overview.	20
3.1	Comparison of the different types of effectors.	25
3.2	Force diagram of a wrench applied on a contact point.	25
3.3	General workflow of a data-driven grasp synthesis method.	27
4.1	Spin Images computation.	34
4.2	3D Shape Context support.	34
4.3	Signatures of Histograms of Orientations support.	36
4.4	PFH computation.	36
4.5	Point influence diagram for FPFH.	36
5.1	Coordinate system of the effector.	41
5.2	Alignment of a grasp according to the axis of lower curvature.	41
5.3	A set of bands on the surface of an object.	41
5.4	Vectors defining the direction of each band of DCH.	43
5.5	Example of visible surfaces in a point-cloud.	44
5.6	Computation of DCH on different point-clouds surfaces.	50
5.7	Computation of DCH using different angles.	51
6.1	Design of the proposed grasp synthesis method.	54
6.2	Example of the point-clouds present in the RGB-D Object Dataset.	54
6.3	Segmentation of a cloud captured by the robot.	57
6.4	Results of the DBSCAN algorithm.	58

6.5	Generation of grasp candidates.	58
6.6	Example of grasp candidates.	60
7.1	Example setup used to perform all the experiments.	65
7.2	Objects used for experimental data generation.	65
7.3	Sets of angles used for the experimental data generation.	66
7.4	Computed normals on raw and filtered point-clouds.	71
8.1	Classification performance using DCH.	73
8.2	Classification performance using SHOT.	74
8.3	Classification performance using Spin Images.	74
8.4	Classification performance using FPFH.	74
8.5	Additional experimental objects.	76
8.6	Grasping performance using DCH.	76
8.7	Grasping performance using DCH, by number of orientations.	76
8.8	Sensitivity analysis for the number of bands of DCH.	79
8.9	Sensitivity analysis for the width of each band of DCH.	80
8.10	Sensitivity analysis for the size of the bins of DCH.	81