

List of Abbreviations	xv
List of Symbols	xvii
List of Figures	xxii
List of Tables	xxiii
1 Introduction	1
1.1 Motivation and Objectives	5
1.2 Main Contributions	8
1.3 Thesis Outline	9
2 Literature Review	11
2.1 Path Planning	11
2.2 Trajectory Optimization	17
2.3 On-line Trajectory Tracking	21
2.4 Scientific Gaps	22
3 Delta Parallel Robot	25
3.1 Delta Parallel Robot Structure	26
3.2 Kinematics of Delta Parallel Robot	27
3.2.1 Inverse Kinematics	27
3.2.2 Forward Kinematics	31
3.3 Jacobian Matrix	34
4 Path Planning	37
4.1 Path Planning using Probabilistic Roadmap (PRM)	37
4.1.1 Learning Phase	37
4.1.2 Query Phase	38
4.2 Path Planning using Genetic Algorithm	39
4.2.1 Population Initialization	40
4.2.2 Cost Function	41
4.2.3 Selection Method	41
4.2.4 Crossover	41
4.2.4.1 Elitism	42

4.2.5	Mutation	42
4.2.6	Pseudo-Code for Genetic Algorithm	42
4.3	Numerical Examples	43
4.3.1	Example 1	43
4.3.1.1	Solution using GA	43
4.3.1.2	Solution using PRM	44
4.3.2	Example 2	45
4.3.2.1	Solution using GA	46
4.3.2.2	Solution using PRM	46
4.4	Comparison between GA and PRM	48
5	Trajectory Optimization	51
5.1	Trajectory Optimization using Phase-Plane Method	51
5.1.1	Transformation of Joint Space to Path Parameter	52
5.1.2	Problem Formulation	54
5.1.3	Phase-Plane Method	55
5.1.3.1	Case-1 (Single Switching Point).....	55
5.1.3.2	Case-2 (Multiple Switching Points)	56
5.2	Trajectory Optimization using Dynamic Programming	57
5.2.1	Dynamic Programming using Path Parameter	57
5.2.2	Dynamic Programming using Joint Coordinates	61
5.2.2.1	Flaws in Singh and Leu's Algorithm	65
5.2.2.2	Joint Selection Criterion.....	65
5.3	Trajectory Optimization using Discrete Mechanics and Optimal Control	67
5.3.1	Problem Formulation	68
5.3.2	Discretization	69
5.3.3	Boundary Conditions	72
5.3.4	Practical Implementation	72
5.3.5	Trajectory Optimization of Predefined Geometrical Path using DMOC	73
5.4	Numerical Example	74
5.4.1	Example 1	75
5.4.2	Example 2	77
5.5	Comparison of Different Optimization Techniques	80
6	Simultaneous Path Planning and Trajectory Optimization	83
6.1	Problem Formulation	83
6.2	Solution using Discrete Mechanics and Optimal Control (DMOC)	86
6.2.1	Practical Implementation	86
6.3	Numerical Examples	87
6.3.1	Example 1	88

6.3.2 Example 2	91
6.4 Comparison of Simultaneous Path Planning and Trajectory Optimization with Conventional Methods	94
7 Summary and Outlook	97
7.1 Summary and Outlook	97
7.2 Future Work	99
A Appendix	101
A.1 Dynamical Model and Energy Equations for Delta Parallel Robot	101
A.1.1 Dynamical Model of Delta Parallel Robot	101
A.1.1.1 Simplifying Hypothesis	102
A.1.1.2 Dynamic Parameters	102
A.1.1.3 Dynamical Model based on Virtual Work Principle	103
A.1.2 Energy Equations for Delta Parallel Robot	105
A.2 Algorithms for Path Planning	106
A.2.1 Algorithm for Path Planning using PRM	107
A.2.1.1 Learning Phase	107
A.2.1.2 Query Phase	108
A.2.2 Algorithm for Path Planning using GA	109
A.3 Algorithms for Trajectory Optimization	109
A.3.1 Dynamic Programming using Path Parameter	110
A.3.2 Dynamic Programming using Joint Coordinates	112
Bibliography	115