

---

Andreas Bihlmaier

# Learning Dynamic Spatial Relations

The Case of a Knowledge-based  
Endoscopic Camera Guidance Robot

 Springer Vieweg

# Contents

<b>Glossary</b>	<b>XIII</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Minimally-Invasive Surgery . . . . .	2
1.1.1 A new kind of surgery . . . . .	2
1.1.2 Ergonomic Challenges . . . . .	4
1.2 Medical Robotics . . . . .	10
1.3 Knowledge-based Cognitive Systems . . . . .	17
1.4 Overview of Thesis . . . . .	19
<b>2 Endoscope Robots and Automated Camera Guidance</b>	<b>23</b>
2.1 A Survey of Motorized Endoscope Holders . . . . .	23
2.1.1 Endex . . . . .	25
2.1.2 AESOP . . . . .	26
2.1.3 Begin and Hurteau et al. . . . .	30
2.1.4 LARS / PLRCM . . . . .	31
2.1.5 HISAR . . . . .	33
2.1.6 Laparobot, EndoSista, EndoAssist . . . . .	35
2.1.7 FIPS Endoarm . . . . .	38
2.1.8 Munoz, ERM . . . . .	40
2.1.9 LER, ViKY . . . . .	42
2.1.10 Naviot . . . . .	46
2.1.11 SOLOASSIST . . . . .	48
2.1.12 LapMan . . . . .	52
2.1.13 SWARM . . . . .	54
2.1.14 COVER . . . . .	55
2.1.15 SMART / P-arm . . . . .	56
2.1.16 Tonatiuh II . . . . .	58

2.1.17	PMASS . . . . .	59
2.1.18	FreeHand . . . . .	60
2.1.19	EVOLAP . . . . .	62
2.1.20	RoboLens . . . . .	64
2.1.21	Tadano et al. . . . .	65
2.1.22	Further systems . . . . .	67
2.1.23	Telemanipulation Systems . . . . .	68
2.1.24	Summary . . . . .	71
2.2	Approaches for Automated Camera Guidance . . . . .	75
2.2.1	Related Problems . . . . .	76
2.2.2	Classification of Approaches . . . . .	80
2.2.3	Survey of Approaches . . . . .	82
<b>3</b>	<b>System Architecture and Conceptual Overview</b>	<b>103</b>
3.1	Conceptual System Architecture . . . . .	103
3.1.1	Perception . . . . .	104
3.1.2	Interpretation . . . . .	106
3.1.3	Knowledge Base . . . . .	108
3.1.4	Action . . . . .	112
3.2	Camera Guidance as a Knowledge-based Cognitive System . . . . .	113
3.2.1	Perception: Surgeon and Instruments . . . . .	115
3.2.2	Interpretation: Optimal Endoscopic View . . . . .	119
3.2.3	Knowledge Base: Camera Quality Classifier . . . . .	120
3.2.4	Action: Smooth and Pivot-constrained Robot Motion . . . . .	124
<b>4</b>	<b>Modular Research Platform for Robot-Assisted Minimally-Invasive Surgery</b>	<b>127</b>
4.1	The Robot Operating System (ROS) . . . . .	127
4.2	A Modular Platform . . . . .	130
4.2.1	On Modularity . . . . .	132
4.2.2	Sensors . . . . .	134
4.2.3	Distributed Processing . . . . .	135
4.2.4	Actuators . . . . .	136

4.2.5	Model Management . . . . .	139
4.3	Simulation Environment . . . . .	140
4.3.1	Robotics Simulators . . . . .	142
4.3.2	Laparoscopic Surgical Simulators . . . . .	146
4.3.3	Robot Unit Testing . . . . .	148
4.4	Distributed Monitoring, Reliability and System Diagnosis . . . . .	152
<b>5</b>	<b>Learning of Surgical Know-How by Models of Spatial Relations</b>	<b>157</b>
5.1	Perception . . . . .	160
5.2	Interpretation . . . . .	160
5.2.1	Tracking of Instrument Tips . . . . .	161
5.2.2	Online Phase Recognition . . . . .	171
5.3	Learning a Camera Guidance Quality Classifier . . . . .	172
5.3.1	Learning Spatial Relations: A Static 1D Example	172
5.3.2	Reduction of Parameter Space . . . . .	176
5.3.3	Deriving Synthetic Learning Examples . . . . .	178
5.3.4	Meta-Parameter Optimization . . . . .	182
5.3.5	Classifier Evaluation: Point in Time and Period of Time . . . . .	183
<b>6</b>	<b>Intraoperative Robot-Based Camera Assistance</b>	<b>185</b>
6.1	Preliminaries . . . . .	187
6.1.1	Calibration and Registration . . . . .	187
6.1.2	Trocar and Robot Placement . . . . .	190
6.1.3	Collision Avoidance . . . . .	192
6.1.4	Basic Robot Performance . . . . .	193
6.1.5	Mapping to Spherical Coordinates . . . . .	197
6.1.6	Modeling and Execution of Surgical Workflow .	197
6.2	Intraoperative Action . . . . .	198
6.2.1	Inverting the Forward Model by Adaptive Sampling . . . . .	199
6.2.2	From Current Pose to Next Good Pose . . . . .	202
6.2.3	Multimodal Human-Robot-Interaction . . . . .	203

6.3	Optional Action Components . . . . .	204
6.3.1	Extended Field of View through Live Stitching	205
6.3.2	Optimization of Redundant Degree of Freedom	207
<b>7</b>	<b>Evaluation Studies</b>	<b>209</b>
7.1	Metrics for Objective Assessment of Surgical Tasks . .	210
7.2	Experimental Setup . . . . .	211
7.2.1	OpenHELP . . . . .	211
7.2.2	Laparoscopic Rectal Resection with Total Mesorectal Resection . . . . .	212
7.3	Experimental Results . . . . .	214
<b>8</b>	<b>Conclusion</b>	<b>219</b>
8.1	Discussion . . . . .	219
8.2	Future Work . . . . .	221