

**Sensor-Based Surgical Robotics:
Contributions to Robot Assisted
Fracture Reduction**

Von der Carl-Friedrich-Gauß-Fakultät
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Preface

The present thesis originates from my scientific work as employee at the *Institute for Robotics and Process Control* at the *Technical University of Braunschweig*, Germany.

I would like to express my gratitude to Prof. Dr.-Ing. Friedrich M. Wahl, the head of the institute, who has given me the chance to work on this interesting and challenging research project, and whose continuous feedback, encouragement, and technical discussions brought the project and this thesis to the current stage. Moreover, I am indebted to Prof. Dr.-Ing. Heinz Wörn, who agreed to be the second reviewer of my thesis.

I would also like to thank my colleagues and students at the institute who contributed to this work. Especially I would like to thank Dr.-Ing. Simon Winkelbach for his valuable contribution to the successful completion of this research project.

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Abstract

Nowadays, the treatment of choice for femoral shaft fractures is the minimally invasive technique of intramedullary nailing. Apart from its advantages, however, the technique also has a number of known shortcomings like a frequent occurrence of malaligned reductions, which may have a significant impact on the functional biomechanics and the rehabilitation process of the patient. The high X-ray exposure, especially for the operating team, is a second point, why it may be desirable to support this surgical procedure by sophisticated technical tools. An interdisciplinary research project between the Hannover Medical School and the Technical University of Braunschweig is investigating the applicability of robotized surgical procedures in this context.

The present thesis originates from this project and shows the potential of supporting surgeons by means of robotic assistant systems, which can perform the reduction process of broken bone fragments. First, the development of a telemanipulator system is presented, with which the reduction can be performed based on 2D and 3D imaging data. This system is evaluated using exposed bones as well as human specimens. Based on the experiences from the telemanipulator system, a new concept for a (semi-)automated robotized fracture reduction procedure is developed. First, the automated reduction computes a reduction trajectory, which minimizes additional traumatization of the patient's soft tissue and subsequently moves the robot along that trajectory utilizing skill primitives incorporating sensor guarded and sensor guided motions.

Furthermore, this work presents automated image analysis methods, enabling the use of a robot as a precise drill guidance tool. Apart from fracture reduction, the insertion of the intramedullary nail and the distal locking of the nail are further challenging operation tasks, which remarkably benefit from the integration of surgical navigation, computer assisted surgery, and robotics. In this context, a concept to integrate Petri-nets and skill primitives within the well-known "Model-View-Controller"-pattern is presented in order to achieve a reliable workflow, which is not limited to strictly sequential execution tasks.

It can be shown that the methods developed in this thesis can improve the precision of these surgical operations and at the same time reduce the X-ray exposure to the patient and the operating team.

Zusammenfassung

Frakturen des menschlichen Femurs werden heutzutage üblicherweise mit einer minimal-invasiven Methode, der so genannten Marknagelung, fixiert. Bei dieser für den Chirurgen überaus anstrengenden Operationsmethode kommt es häufig zu postoperativen Fehlstellungen, die einen beträchtlichen Einfluss auf die funktionale Biomechanik und den Rehabilitationsprozess des Patienten haben können. Die hohe Strahlenexposition des OP-Personals ist ein weiterer Faktor, der bei den Chirurgen den Wunsch nach technisch ausgereiften Hilfsmitteln weckt und das interdisziplinäre Forschungsprojekt zwischen der Medizinischen Hochschule Hannover und der TU Braunschweig motiviert.

Die vorliegende Arbeit ist im Rahmen dieses Projekts entstanden und zeigt die Möglichkeiten auf, den Chirurgen mithilfe von Robotersystemen bei der Durchführung solcher Operationen zu unterstützen und die Reponierung der Knochenfragmente durchzuführen. Es wird zunächst die Entwicklung eines Telemanipulatorsystems vorgestellt, welches basierend auf 2D und 3D Bildgebung am exponierten Knochen und am menschlichen Präparat evaluiert wird. Anhand der Erfahrungen aus den telemanipulierten Reponierungen werden Konzepte abgeleitet, die eine (semi-)automatische Reponierung durch einen Roboter ermöglichen. Diese automatische Reponierung berechnet einen weichteilverträglichen Bewegungspfad und führt diesen mithilfe von Aktionsprimitiven sensorüberwacht bzw. sensorgeführt aus.

Darüber hinaus werden Bildanalyseverfahren entwickelt, die den Einsatz des Roboters als vollautomatische Bohrerführung ermöglichen. Neben der Frakturreponierung sind das Einbringen und das Verschrauben des Marknagels zwei weitere für den Chirurgen anspruchsvolle Aufgaben, die so auf optimale Weise durch die Kombination von chirurgischer Navigation, Computer assistierter Chirurgie und Robotik unterstützt werden. In diesem Zusammenhang wird ferner ein Konzept entwickelt, bei welchem Petri-Netze und Aktionsprimitive im bekannten "Model-View-Controller"-Muster integriert werden, und so einen verlässlichen und nicht notwendigerweise strikt sequentiellen Operationsablauf ermöglichen.

Insgesamt konnte gezeigt werden, dass durch den Einsatz der entwickelten Methoden eine hohe Präzision der Operationsergebnisse zu erreichen ist und gleichzeitig die Strahlenbelastung für Patient und OP-Personal reduziert werden kann.

Contents

I	Introduction and Survey	1
1	Introduction	3
1.1	Motivation	4
1.1.1	Closed Intramedullary Nailing	5
1.1.2	Known Problems of Closed Intramedullary Nailing	7
1.2	Organization of this work	9
2	Survey on Surgical Robotics	11
2.1	Fracture Reduction Robotics	16
2.2	Concepts for Surgical Robotics	18
2.2.1	Classification of the Presented Work	20
II	The Surgical Robotic System	23
3	Telemanipulated Fracture Reduction	25
3.1	Related work	26
3.2	Development of the Telemanipulator System	26
3.2.1	The first Laboratory Set-up	26
3.2.2	2D Telemanipulator Evaluation using Human Specimens	29
3.2.3	3D Telemanipulated Reduction	32
3.3	Telemanipulator Control Architecture	44
3.4	Conclusion about Telemanipulated Reductions	50
4	Automated Robotized Fracture Reduction	53
4.1	Computation of the Target Poses	56
4.2	Automated Reduction	57
4.2.1	Computation of the Approach Direction	59
4.2.2	Probabilistic Motion Planning	67
4.2.3	Experiments and Results	79
4.3	Conclusion about Automated Reductions	79
5	Robotized Drill Guidance	83

5.1	Related work	84
5.2	Nail Insertion	84
	5.2.1 Insertion Trajectory Computation	85
	5.2.2 Robotized Drill Guidance	93
	5.2.3 Experiments	96
	5.2.4 Results	96
5.3	Distal Locking	97
	5.3.1 Screw Trajectory Computation	98
	5.3.2 Experiments	102
	5.3.3 Results	103
5.4	Reliable Procedure Control	104
	5.4.1 Petri Net Controller	105
	5.4.2 Petri Net Extensions	110
5.5	Future Developments	114
5.6	Conclusion of Automated Robotized Drill Guidance	116
 III Discussion and Outlook		119
6 Discussion		121
6.1	A Look Ahead	123
 IV Appendix		125
A Skill Primitives		127
B Hough Transform		129
B.1	Hough Transform Applications	129
	B.1.1 Hough Transform for Lines	129
	B.1.2 Hough Transform for Circles	131
B.2	Cluster Detection	132
	B.2.1 The Identify and Remove Algorithm	132
C Petri Nets		135
C.1	The Petri Net Formalism	135
C.2	Common Petri Net Extensions	137
D Own Publications		139
 V Index		143
List of Abbreviations		145

Glossary	147
List of Figures	153
Bibliography	157
Index	169