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THESIS

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Subject

Robotic surgical tool manipulator - Recognition,
control and manipulation of laparoscopic tools

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ΠΙΣΤΟΠΟΙΗΣΗ

Πιστοποιείται ότι η διπλωματική εργασία με θέμα

**Robotic surgical tool manipulator - Recognition, control and manipulation of
laparoscopic tools**

του φοιτητή του Τμήματος Ηλεκτρολόγων Μηχανικών και Τεχνολογίας Υπολογιστών

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παρουσιάστηκε δημόσια και εξετάστηκε στο τμήμα Ηλεκτρολόγων Μηχανικών και Τεχνολογίας
Υπολογιστών στις

___/___/___

Ο Επιβλέπων

Ο Διευθυντής του Τομέα

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Contents

1	Introduction	3
2	Robotic arm Kinematic Analysis	3
2.1	Robotic arm, DH parameters & Forward Kinematics	3
2.2	Inverse Kinematics	3
2.2.1	Decoupling Technique	3
2.2.2	Workspace constraints & Singularity points	4
2.2.3	Solutions for 7DoF numerically	4
2.2.4	Comparison of Inverse Kinematics Techniques	4
3	Grasping	4
3.1	Gripper & Forward Kinematics	4
3.2	Gripper Inverse Kinematics	4
3.3	Force closure	4
3.4	Firm grasping algorithm & Force control	5
4	Laparoscopic tool recognition with Computer Vision	5
4.1	Tool detection	5
4.2	Calculation of grasping points	5
5	Laparoscopic tool manipulation	5
5.1	Pivoting motion with respect to Fulcrum Point	5
6	Path Planning	5
6.0.1	Collision avoidance	5
6.0.2	Pick and place algorithm	5
7	Trajectory Planning	5
7.1	Trajectory planning in cartesian coordinates	5
7.2	Trajectory planning in joint angles space	6
8	Simulation with the ROS framework	6
	Nomenclature	7
	List of Figures	8
	List of programs	8
	Bibliography	8

1 Introduction

2 Robotic arm Kinematic Analysis

2.1 Robotic arm, DH parameters & Forward Kinematics

i	θ_i (rad)	L_{i-1} (m)	d_i (m)	α_{i-1} (rad)
1	θ_1	0	0.36	0
2	θ_2	0	0	$-\pi/2$
3	θ_3	0	0.36	$\pi/2$
4	θ_4	0	0	$\pi/2$
5	θ_5	0	0.4	$-\pi/2$
6	θ_6	0	0	$-\pi/2$
7	θ_7	0	0	$\pi/2$

$${}^{i-1}M_i = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & L_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1}d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & c\alpha_{i-1}d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

2.2 Inverse Kinematics

2.2.1 Decoupling Technique

$$R_{target} = \begin{bmatrix} i_x & j_x & k_x \\ i_y & j_y & k_y \\ i_z & j_z & k_z \end{bmatrix} {}^0\mathbf{p}_5 = {}^0M_4 {}^4\mathbf{p}_5 = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix}$$

$$\theta_6 = \text{atan2}\left(\pm\sqrt{1-k_y^2}, k_y\right)$$

$$\theta_7 = \text{atan2}(-j_y, i_y)$$

$$\theta_5 = \text{atan2}(-k_z, k_x)$$

$$\theta_2 = \text{atan2}\left(\sqrt{p_x^2 + p_y^2}, {}^1p_{5z}\right) \pm \varphi$$

$$\varphi = \text{acos}\left(\frac{d_3^2 + \|{}^1p_5\|^2 - d_5^2}{2d_3\|{}^1p_5\|}\right)$$

$$\theta_4 = \text{atan2}\left(\pm\sqrt{1-c_4^2}, c_4\right) \quad , \quad c_4 = \frac{\|{}^1p_5\|^2 - d_3^2 - d_5^2}{2d_3d_5}$$

$$\theta_1 = \text{atan2}\left(\pm\frac{p_y}{\sqrt{p_x^2 + p_y^2}}, \pm\frac{p_x}{\sqrt{p_x^2 + p_y^2}}\right)$$

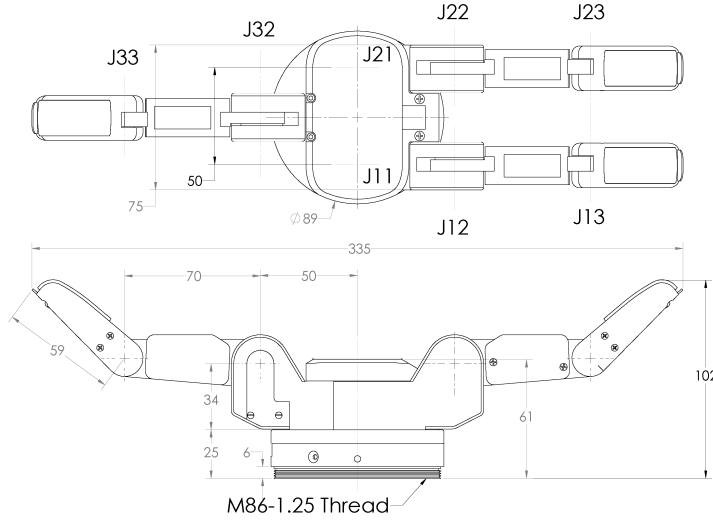
2.2.2 Workspace constraints & Singularity points

2.2.3 Solutions for 7DoF numerically

2.2.4 Comparison of Inverse Kinematics Techniques

3 Grasping

3.1 Gripper & Forward Kinematics



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3.2 Gripper Inverse Kinematics

The following Inverse Kinematics analysis refers to one finger of the Barrett Hand gripper, which has 3 revolute joints. Finger 3 has only 2 revolute joints for which the angle solutions are the same with the solutions of the last 2 joints of the other fingers. Let

$$\mathbf{p} = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix}$$

be the position of the grasp point for one finger. The first angle can easily be calculated as

$$\varphi_1 = \text{atan2}(p_y, p_x)$$

Next, we calculate the third angle based on the law of cosines (see fig.)

$$\cos\left(\pi - \varphi_3 - \frac{2\pi}{9}\right) = \frac{L_2^2 + L_3^2 - p^2}{2L_2L_3}$$

$$\cos\left(\varphi_3 + \frac{2\pi}{9}\right) = \frac{p^2 - L_2^2 - L_3^2}{2L_2L_3}$$

$$\varphi_3 = \text{atan2}\left[\pm\sqrt{1 - \left(\frac{p^2 - L_2^2 - L_3^2}{2L_2L_3}\right)^2}, \frac{p^2 - L_2^2 - L_3^2}{2L_2L_3}\right] - \frac{2\pi}{9}$$

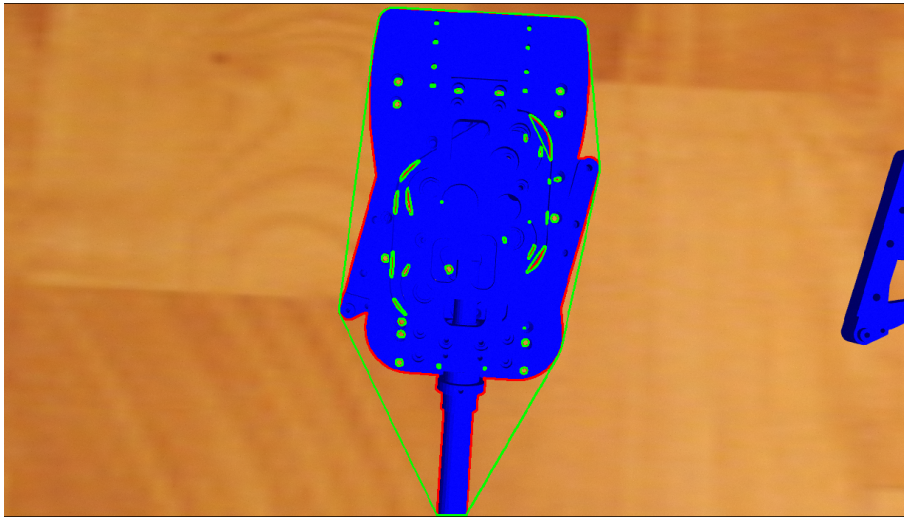
3.3 Force closure

The planar case, the spatial case & convex hull test.

3.4 Firm grasping algorithm & Force control

4 Laparoscopic tool recognition with Computer Vision

4.1 Tool detection



4.2 Calculation of grasping points

5 Laparoscopic tool manipulation

5.1 Pivoting motion with respect to Fulcrum Point

6 Path Planning

6.0.1 Collision avoidance

Find path points (position and orientation) by avoiding collisions

6.0.2 Pick and place algorithm

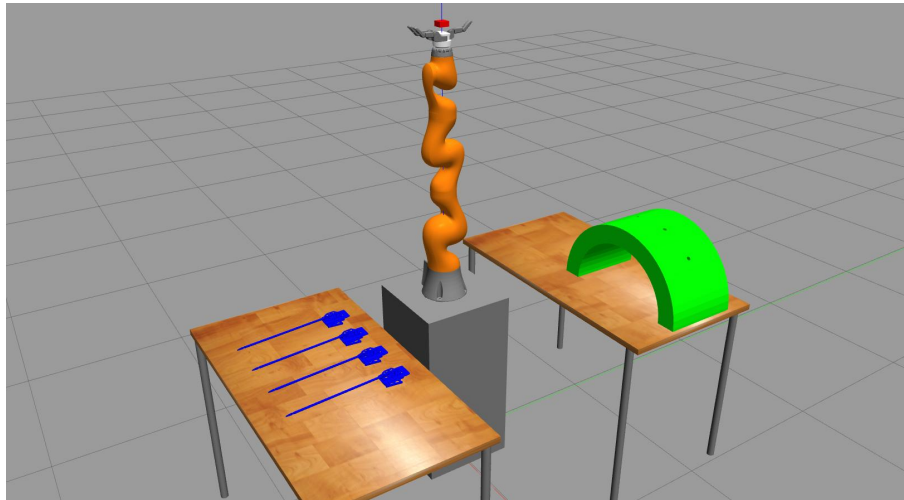
7 Trajectory Planning

7.1 Trajectory planning in cartesian coordinates

Connect the points from path planning with line segments and add more points if needed

7.2 Trajectory planning in joint angles space

8 Simulation with the ROS framework



Nomenclature

${}^{i-1}\mathbf{p}_{iO}$	Position vector from the origin of the coordinate frame $\{i\}$ to the origin of the coordinate frame $\{i-1\}$
${}^{i-1}M_i$	Transformation matrix from coordinate frame $\{i\}$ to coordinate frame $\{i-1\}$
${}^{i-1}R_i$	Rotation matrix from coordinate frame $\{i\}$ to coordinate frame $\{i-1\}$
c_i	Shorthand notation for $\cos\theta_i$
J^\dagger	Geometric Jacobian or the Pseudoinverse of the Jacobian
s_i	Shorthand notation for $\sin\theta_i$

List of Figures

List of programs

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