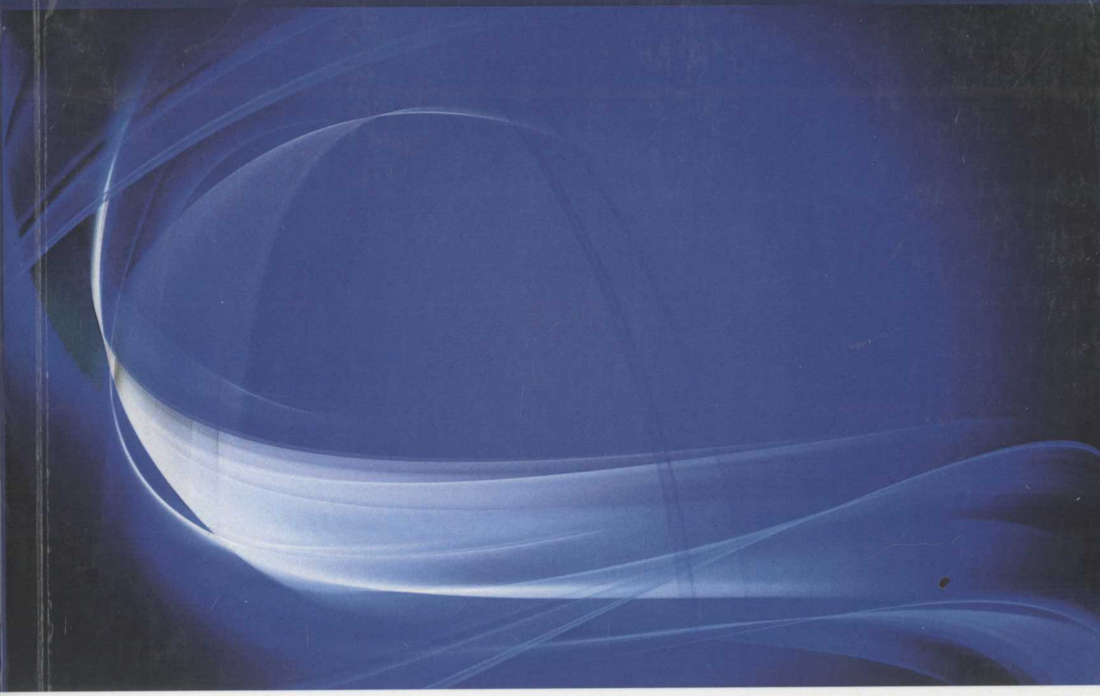

Erdinc Sahin Conkur

PATH PLANNING AND OBSTACLE AVOIDANCE FOR REDUNDANT MANIPULATORS

REAL TIME ALGORITHMS

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NOTATION

${}^{R}\mathbf{T}_{H}$	General transformation matrix from the base of the robot to the end-effector
${}^{n-1}\mathbf{A}_{n}$	Transformation matrix from the frame *n*-1 to *n*
$\mathbf{Trans}\,(p_x, p_y, p_z)$	Translation matrix
$\mathbf{Rot}\,(x,\theta)$	Transformation matrix for the pure rotation about *x*
$\mathbf{Rot}\,(y,\theta)$	Transformation matrix for the pure rotation about *y*
$\mathbf{Rot}\,(z,\theta)$	Transformation matrix for the pure rotation about *z*
$\mathbf{RPY}(\phi,\theta,\Psi)$	Roll-pitch-yaw transformation
s_1, s_2, s_3, s_4	$\sin(\theta_1), \sin(\theta_2), \sin(\theta_3), \sin(\theta_4)$
$c_1\ c_2, c_3, c_4$	$\cos(\theta_1), \cos(\theta_2), \cos(\theta_3), \cos(\theta_4)$
$\mathbf{r}$	Position and orientation matrix of the end-effector
$\dot{\mathbf{r}}$	Linear velocity matrix
$\boldsymbol{\theta}, \dot{\theta}, \boldsymbol{\Delta\theta}$	Joint variables, angular velocity and angular change to the joint variables
ω	Angular velocity matrix, acceleration constant
d_x, d_y, d_z	Cartesian co-ordinates of the end-effector
$\alpha_x, \alpha_y, \alpha_z$	Orientation values of the end-effector
$\mathbf{f}(\theta)$	Function establishing the relationship between joint variables and the position and orientation of the end-effector
$\mathbf{J}, \mathbf{J}(\boldsymbol{\theta})$	Jacobian matrix
$\mathbf{H}$	Jacobian matrix of the augmented matrix
$\mathbf{J}_i$	Jacobian matrix of the *i*th manipulator variable
$\mathbf{J}_{o1}, \mathbf{J}_{o2}$	Jacobian matrices with respect to assigned velocity vector for the first and second obstacles
$\mathbf{J}^{-1}, \mathbf{J}^{\#}, \mathbf{J}^{T}$	Inverse, generalised inverse and transpose of the Jacobian matrix
$\mathbf{J}^{*}$	Singularity robust pseudoinverse
$(\mathbf{p}_{0n} - \mathbf{p}_{0i})$	Position vector of *n*th frame
$\mathbf{k}_{z_i}$	Unit vectors of each frame with respect to the base frame
n	Integer value, surface normal at the boundary and number of the control points

m	Dimension space of the end-effector
t	Task space dimension and parameter of the line equation
$\mathbf{W}, \mathbf{W}_1, \mathbf{W}_2$	Symmetric and positive definite weighting matrices
$\boldsymbol{\alpha}$	Damping factor and the direction of the current point in the potential field
$\mathbf{I}$	Unite matrix
$\mathbf{z}$	Arbitrary vector
$\nabla h(\theta)$	Gradient of the function $h(\theta)$
k	Scalar coefficient, integer value and iteration number
$H_i(\theta)$	Specific definition of the vector **z**
$D_{\min_{i,j}}$	Distance between the *i*th manipulator section and the *j*th obstacle
D_{stop}	Measure for the thickness of the links and the window
$\hat{\mathbf{K}}_o$, $\hat{\alpha}_{o1}$, $\hat{\alpha}_{o2}$, α_1, α_2, α_{n1}, α_{n2}	Weighting constants and functions
$\mathbf{r}_1, \mathbf{r}_2$	First and second manipulator variables
$p(\theta)$	Manipulability measure given as a potential function
$\mathbf{U}_{\mathbf{x}_d}$	Goal presented by an attractive pole
$\mathbf{x}$	Set of parameters describing the end-effector co-ordinates and orientation
$\mathbf{U}_o(\mathbf{x})$	Obstacles are presented by repulsive surfaces
η	Constant gain
ρ_0	Limit distance of the potential field
ρ	Shortest distance to the obstacle
ϕ, Φ	Harmonic function
$\nabla^2\phi$	Laplacian of ϕ
Ω, $\partial\Omega$	Domain, boundary of Ω
$\partial\Gamma$	Closed boundary of an arbitrary region $\Gamma \subset \Omega$
dS	Area element on ($\partial\Gamma$)
$\phi(x)$, $f(x)$	Potential functions representing Dirichlet boundary conditions
$g(x)$	Potential functions representing Neumann boundary conditions
ϕ_d	Solution using the Dirichlet conditions
ϕ_n	Solution using the Neumann condition

h	Grid spacing
T	Virtual torque
a, b, c, d, u, v	Coefficients in line and ellipse equations
$p(x_p, y_p), e(x_e, y_e)$	Start and end point of the link
$s(x_s, y_s), k(x_k, y_k), m(x_m, y_m), n(x_n, y_n)$	Intersections points
pk, **ps, pe**	Vectors establishing intersection between links and margin circles
hm, hn	Vectors by which it can be decided where the link is to be moved
$\Delta\theta_k$	kth link of the manipulator which is moved a fixed amount $\Delta\theta$
Δs_n	Maximum displacement of the end point of the nth link
l_t	Straight line from the start point of kth link to the end point of
nth l_m	length of each line drawn from each u_k value to the link
$\Delta\theta_n$	nth link angular displacement backwards
l_{link}, $l_{\max}$	Link length and physically possible maximum link length
I	Index value
$f_{b_{x-1}}, f_{b_{x+1}}, f_{b_{y-1}}, f_{b_{y+1}}$	Field values at b_x-1, b_x+1, b_y-1, b_y+1 for the point $b(b_x,b_y)$
u	Parameter of B-spline curve segment equation
$\mathbf{p}_i(u)$	B-spline curve segment equation for i curve segment
$\mathbf{U}_k$	Matrix of parameter u for B-spline curve segment equation
$\mathbf{M}_k$	Matrix of coefficients for B-spline curve segment equation
$\mathbf{P}_k$	Matrix of control points for B-spline curve segment equation
d_{min}	Minimum distance from a given point to a curve segment
$\mathbf{p}^u$	Tangent vector at a given point **p**
$b(b_x,b_y)$	Point at the end of each link used to specify the minimum distance
$\mathbf{l}_i(t)$	ith link vector
u_i	ith point on the curve segment
l_m	Minimum distance from the point $b(b_x,b_y)$ on the link
$c(c_x,c_y), d(d_x,d_y)$	Points on the curve segment used to specify the minimum distance
u_c, u_d	Parameter values between the points $c(c_x,c_y)$ and $d(d_x,d_y)$
u_k	kth parameter value on the curve segment
l_n	Distance between the proximal end of the link and the end of
each	line on the curve
θ_{lim}	Limit value on the already-determined angular change

s, $|\mathbf{ki}|$, $|\mathbf{ai}|$, $|\mathbf{ah}|$, $|\mathbf{jh}|$, $|\mathbf{si}|$ — Vector magnitudes used to determine the most appropriate line segment

$d(d_x, d_y)$ — Point on the curve specifying the direction of angular change

u_δ — Parameter value added to existing value while initialising the links

CONTENTS

FIGURES