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Tesi Doctoral

FINE-MOTION PLANNING FOR ROBOTIC ASSEMBLY UNDER MODELLING AND SENSING UNCERTAINTIES

Jan Rosell Gratacòs

Director: Prof. Luis Basañez Villaluenga

Institut d'Organització i Control de Sistemes Industrials

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A la Mireia

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Contents

List of Symbols

$\mathcal{C}$-space	Configuration space
$\mathcal{C}'$-space	Parametrized translational configuration space
$\mathcal{C}_{free}$	Subset of the $\mathcal{C}$-space corresponding to non-contact configurations that satisfy all the geometric constraints of the task
$\mathcal{C}_{contact}$	Subset of the $\mathcal{C}$-space corresponding to the contact configurations
$\{W\}$	Reference frame attached to the workspace
$\{T\}$	Reference frame attached the manipulated object
ϕ	Orientation of $\{T\}$ with respect to $\{W\}$
ψ_T	Orientation with respect to $\{T\}$ of the normal to the contact edge
ψ_W	Orientation with respect to $\{W\}$ of the normal to the contact edge
R_ϕ^S	Set of contact orientations of a contact situation involving a set S of basic contacts
$\mathcal{F}_i$	$\mathcal{C}$-face
$f_i'(\phi_o)$	$\mathcal{C}'$-segment
$\mathcal{F}_i'$	$\mathcal{C}'$-face
$\mathcal{E}_{ij}$	$\mathcal{C}$-edge
$\mathcal{E}_{ij}'$	$\mathcal{C}'$-edge
$\mathcal{L}_{ij}'(\phi)$	Supporting curve of $\mathcal{E}_{ij}'$
$\mathcal{V}_{ijk}$	$\mathcal{C}$-vertex
$\mathcal{V}_{ijk}'$	$\mathcal{C}'$-vertex
$\mathbf{F}_i$	Subset of $\mathcal{F}_i$ that satisfies all the constraints
$\mathbf{E}_{ij}$	Subset of $\mathcal{E}_{ij}$ that satisfies all the constraints
$\mathbf{V}_{ijk}$	$\mathcal{C}$-vertex that satisfies all the constraints
$\vec{n}$	Direction normal to $\mathcal{F}_i$ at the contact configuration
$\vec{t}_r$	Direction of pure rotation about the contact point
$\vec{t}_p$	Direction perpendicular to $\vec{t}_r$ and $\vec{n}$
$\vec{t}_s$	Direction of pure sliding
$\vec{t}_q$	Direction perpendicular to $\vec{t}_s$ and $\vec{n}$
Π_t	Tangent plane
Π_f	Friction plane
Π_r	Rotation plane
$\vec{e}^{\,-}$, $\vec{e}^{\,+}$	Edges of the generalized friction cone
μ	Coefficient of friction
π_t'	Line composed of the dual points of the forces that belong to Π_t
π_f'	Line composed of the dual points of the forces that belong to Π_f
π_r'	Line composed of the dual points of the forces that belong to Π_r
T_p'	Dual representation of the direction $\vec{t}_p$
N'	Dual representation of the direction $\vec{n}$
T_r'	Dual representation of the direction $\vec{t}_r$
(x_o, y_o, ϕ_o)	Observed configuration of the robot
ϵ_t	Manufacturing tolerances
ϵ_s	Imprecision in the positioning of the static objects
ϵ_m	Imprecision in the positioning of the object in the robot gripper
ϵ_{ϕ_r}	Imprecision in the orientation of the robot
ϵ_{p_r}	Imprecision in the position of the robot

$[\phi_{o_m}, \phi_{o_M}]$	Range of possible actual orientations of the manipulated object due to ϵ_{ϕ_r}
ϵ_v	Uncertainty in the position of the the contact vertex due to the imprecision in the positioning of the objects
ϵ_{t_v}	Uncertainty in the position of the the contact vertex due to the manufacturing tolerances
ϵ_e	Uncertainty in the position of the vertices of the contact edge due to the imprecision in the positioning of the objects
ϵ_{t_e}	Uncertainty in the position of the vertices of the contact edge due to the manufacturing tolerances
e	Contact edge
V	Contact vertex
β	Deviation in the orientation of e
$\mathbf{C}(x, y, r)$	Circle of radius r centered on (x, y)
$\mathbf{R}(e, V_a, \beta)$	Region where the vertex V_a of e lies for a given deviation β
$\mathbf{E}(\beta)$	Region that contain all the possible realizations of e
$\mathbf{L}_r(\beta)$, $\mathbf{L}_{V_a}(\beta)$ and $\mathbf{L}_{V_b}(\beta)$	Partition of $\mathbf{E}(\beta)$
$\mathbf{L}(\beta)$	Geometric figure obtained from $\mathbf{L}_{V_a}(\beta)$ and $\mathbf{L}_{V_b}(\beta)$
α_m and α_M	Deviations in the orientations of the adjacent edges to the contact vertex
$\mathbf{V}(\alpha_m, \alpha_M)$	Region where the contact vertex lies
ϕ_o^i	Orientation that satisfies that the basic contact i takes place iff it can take place at ϕ_o^i
Δ_ϕ^i	Orientation gap between ϕ_o^i and the nominal contact orientations of contact i
$\mathbf{U}^i(\alpha, \beta)$	Contact Position Region for contact i and deviations α and β
ϕ_t^i	Orientation used to test the contact condition; $\phi_t^i = \phi_o^i + \Delta_\phi^i$
P_o	Center of $\mathbf{U}^i(\alpha, \beta)$
$Box(\mathbf{U}^i(\alpha, \beta))$	Bounding box of $\mathbf{U}^i(\alpha, \beta)$
r and d	Sides of $Box(\mathbf{U}^i(\alpha, \beta))$
D_{rm}, D_{rM}, D_{dm}, D_{dM}	Distances from the origin of $\{W\}$ to the sides of $Box(\mathbf{U}^i(\alpha, \beta))$
$\mathbf{U}^i(\Delta_\phi^i)$	Contact Position Domain
$Box(\mathbf{U}^i(\Delta_\phi^i))$	Bounding box of $\mathbf{U}^i(\Delta_\phi^i)$
β_m, β_M	Minimum and maximum possible values of β for a given Δ_ϕ^i
S	Set of basic contacts
C_S	Nominal contact situation involving the basic contacts of S
ϕ_o^S	Orientation that satisfies that C_S takes place iff it can take place at ϕ_o^S
D	Set of dependent sources of uncertainty affecting the basic contacts of S
I	Set of independent sources of uncertainty affecting the basic contacts of S
ϵ_D	Sum of the maximum deviations in the contact position due to D
ϵ_I	Sum of the maximum deviations in the contact position due to I
$\Delta_\phi^{S_i}$	Orientation gap between ϕ_o^S and the nominal contact orientations of contact $i \in S$
$\Delta_{\phi_I}^{S_i}$	Deviation in orientation due to the independent sources of uncertainty that affect contact i
$\Delta_{\phi_D}^S$	Deviation in orientation due to the dependent sources of uncertainty that affect all the contacts of S

$\|\Delta_{\phi_D}^{S_i}\|_{max}$	Maximum absolute value of the deviation in orientation of contact $i \in S$ due to the dependent sources of uncertainty
$\|\Delta_{\phi_I}^{S_i}\|_{max}$	Maximum absolute value of the deviation in orientation of contact $i \in S$ due to the independent sources of uncertainty
$\mathbf{U}_I^{S_i}(x, y, \Delta_{\phi_I}^{S_i})$	Contact Position Domain built considering $D = \emptyset$ and $I \neq \emptyset$, and located with respect to (x, y)
$\phi_t^{S_i}$	Orientation used to test the contact condition; $\phi_t^{S_i} = \phi_o^S + \Delta_\phi^{S_i}$
$P_S(\phi)$	Nominal contact position of C_S for an orientation ϕ
$\mathbf{U}_D^{S_i}(\Delta_{\phi_D}^S)$	Contact Position Domain built considering $D \neq \emptyset$ and $I = \emptyset$
ϕ_t^S	Orientation used to test the contact condition; $\phi_t^S = \phi_o^S + \Delta_{\phi_D}^S$
$\mathbf{U}_D^S(\Delta_{\phi_D}^S)$	Intersection of the Contact Position Domains $\mathbf{U}_D^{S_i}(\Delta_{\phi_D}^S)$ for all the contacts of S.
(x_t, y_t)	Point of $\mathbf{U}_D^S(\Delta_{\phi_D}^S)$
$\mathbf{G}_S$	Generalized Force Domain
$\mathbf{G}'_S$	Dual representation of $\mathbf{G}_S$
l_v	Segment that approximates $\mathbf{G}_i$
$\mathbf{W}$	Region where the lines of forces of $\mathbf{G}_i$ lie
$\mathbf{W}_0$	Region $\mathbf{W}$ computed when $\mu = 0$
$\mathcal{H}(P_1, ..., P_n)$	Convex hull defined by the points $P_1, ..., P_n$
s	Sub-set of S with $\inf(n-1, 3)$ basic contacts
$\vec{g}_o$	Measured generalized reaction force
$\mathbf{H}'_S$	Dual region associated to the basic contacts of S
$N(c)$	Number of all the possible contact situations of the assembly task
$C(c)$	Set of contact situations that a given configuration c is compatible with
$F_\mathcal{A}$	Finite set of configurations of a $\mathcal{C}$-arc
n_i and n_g	Initial and goal nodes of a path in a graph.