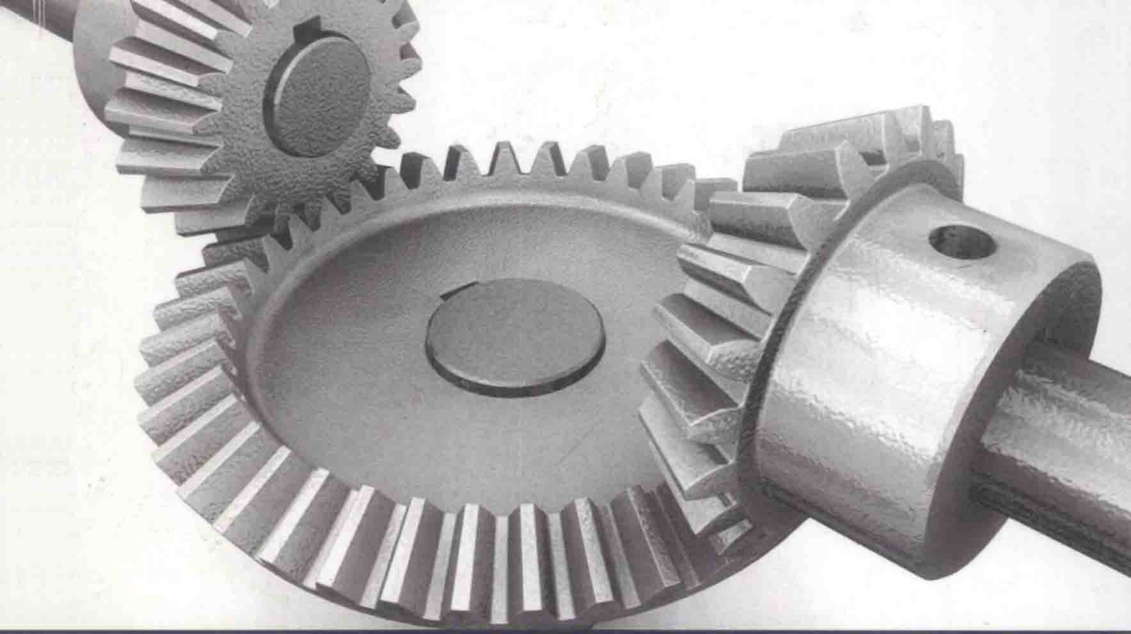

Azfar Khalid

Robotic Manipulator Design and construction

Design and synthesis of parallel robotic manipulators

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NOMENCLATURE

A	-	Pole Area
A_{cap}	-	Area of spherical cap
A_i	-	Upper platform joint position
a_{ix}	-	Upper platform joint co-ordinates in x direction
a_{iy}	-	Upper platform joint co-ordinates in y direction
a_{iz}	-	Upper platform joint co-ordinates in z direction
b	-	Mobility number
B_i	-	Lower platform joint position
b_{ix}	-	Lower platform joint co-ordinates in x direction
b_{iy}	-	Lower platform joint co-ordinates in y direction
b_{iz}	-	Lower platform joint co-ordinates in z direction
b_{max}	-	Maximum expansion of actuator b_i
b_{min}	-	Minimum expansion of actuator b_i
B_r	-	Residual Flux density
B_t	-	Tool tip location
$C(J)$	-	Condition number of Jacobian matrix
$C(J)_{dext}$	-	Maximum condition number value for dexterous workspace boundary
$C(J)_{max}$	-	Maximum condition number value
$C(J)_{total}$	-	Maximum condition number value for total workspace boundary
C_1	-	Condition number based on norm 1
C_2	-	Condition number based on norm 2
C_{det}	-	Manipulability index
C_{fro}	-	Frobenius norm is denoted by C_{fro}
C_{inf}	-	Condition number based on norm infinity
c_{nk}	-	Error amount
d_{fixed}	-	Actuator fixed length
d_i	-	Actuator length
d_{ij}	-	Coefficient in n linear equations in β_j
d_{max}	-	Maximum expansion of actuator d_i
d_{min}	-	Minimum expansion of actuator d_i
F	-	Vector of force and moment
f	-	Vector of force
$F(x)$	-	Target system
F_A	-	Applied force
$F_{applied}$	-	Force applied on the end-effector
F_B	-	Magnetic holding force
F_{Bt}	-	Tangential component of magnetic holding force
f_{dof}	-	DOF of i^{th} joint
F_{fric}	-	Frictional force
f_i	-	Linear actuator force (Only defined for chapter 8 and 10)
F_M	-	Frictional force between ball and magnet
F_{MN}	-	Normal reaction to the forces exerted from the upper ring and the ball
f_p	-	Passive DOF
F_{piezo}	-	Output force provided by piezo actuator
F_R	-	Frictional force due to the upper ring
F_{RN}	-	Normal reaction of frictional force F_R
F_{sol}	-	Solenoid force
F_x	-	x-component of the manipulator output force
F_y	-	y-component of the manipulator output force
F_z	-	z-component of the manipulator output force
g	-	Number of joints
$G(x)$	-	Start system
h	-	Initial height of the manipulator
h_c	-	Spherical cap height
$H(x,t)$	-	Homotopy function
h_{geom}	-	Manipulator height from the pre-selected actuator geometry
$h_{isotropic}$	-	Manipulator height calculated from isotropic conditions
I	-	Identity matrix
J	-	Overall Jacobian

$J_{m,n}$	-	Jacobian matrix of size $m \times n$
J_q	-	Jacobian of actuators
J_x	-	Jacobian matrix for end-effector location
J_θ	-	Jacobian of twists
K	-	Stiffness matrix
$k(J)$	-	Condition number
k_d	-	Stiffness of linear actuator
k_i	-	Stiffness of individual limb
$k_{i,j}$	-	Dimensionless constant
k_{sp}	-	Rotational stiffness of joint
k_x	-	x-component of manipulator stiffness
k_y	-	y-component of manipulator stiffness
k_z	-	z-component of manipulator stiffness
k_θ	-	θ-component of manipulator stiffness
k_ψ	-	ψ-component of manipulator stiffness
k_ϕ	-	ϕ-component of manipulator stiffness
l_i	-	Constant limb length
L_m	-	Magnet length
M	-	Mobility or Degree of freedom
m	-	Number of rows in Jacobian
mg	-	Weight of the inner ball
n_c	-	Number of connectors
n	-	Number of columns in Jacobian
n_e	-	Vector of moment
n_{slices}	-	Number of slices in z height
O	-	Lower platform centre
P	-	Upper platform centre
P_o	-	Tightening force of the upper ring
Pi_{Actual}	-	Actual joint location
Pi_{ideal}	-	Ideal joint location
q	-	Vector for actuators
R	-	Transformation rotation matrix
r	-	Radius of spherical cap
R_b	-	Ball radius
$r(J)$	-	Rank of the Jacobian matrix
r_b	-	Radius of base platform
r_i	-	Ball radius (Only defined for chapter 10)
r_{ix}	-	x co-ordinate of the vector position of the upper joint w.r.t. GCS
r_{iy}	-	y co-ordinate of the vector position of the upper joint w.r.t. GCS
r_{iz}	-	z co-ordinate of the vector position of the upper joint w.r.t. GCS
R_L	-	Pre-defined limits of rotations
r_p	-	Upper platform radius
$R_{u(\psi)}$	-	Transformation rotation matrix for ψ direction
$R_{v(\theta)}$	-	Transformation rotation matrix for θ direction
$R_{w(\phi)}$	-	Transformation rotation matrix for ϕ direction
S	-	$m \times n$ diagonal matrix consisting of the square roots of the eigenvalues of JJ^T arranged in descending order.
s_{bi}	-	Unit vector in the direction b_i
s_i	-	Unit vector in the direction d_i
s_{ix}	-	Projection in x for unit vector in the direction d_i
s_{iy}	-	Projection in y for unit vector in the direction d_i
s_{iz}	-	Projection in z for unit vector in the direction d_i
s_{li}	-	Unit vector in the direction l_i
S_p	-	Twist of the moving platform
S_r	-	Reciprocal screw
t	-	Continuation parameter
T	-	Applied torque
T_{error}	-	transformation matrix including the pose errors for the moving platform with respect to the fixed platform
T_j	-	Pre-selected random points making the plane
T_L	-	Pre-defined limits of translations
u	-	Upper platform translation in x direction
U	-	$m \times m$ orthogonal matrix consisting of the eigenvectors of JJ^T

U_p	-	Local upper platform co-ordinates w.r.t. point P
u_x	-	Upper platform projection of u-axis w.r.t. global x-axis
u_y	-	Upper platform projection of u-axis w.r.t. global y-axis
u_z	-	Upper platform projection of u-axis w.r.t. global z-axis
v	-	Upper platform translation in y direction
V	-	$n \times n$ orthogonal matrix consisting of the eigenvectors of $J^T J$.
v_p	-	Velocity vector of point 'P'
v_x	-	Upper platform projection of v-axis w.r.t. global x-axis
v_y	-	Upper platform projection of v-axis w.r.t. global y-axis
v_z	-	Upper platform projection of v-axis w.r.t. global z-axis
w	-	Upper platform translation in z direction
W	-	Weight of the ball
w_A	-	Angular velocity of upper platform
w_i	-	Angular velocity of i^{th} limb
w_p	-	Angular velocity of the moving platform
w_x	-	Upper platform projection of w-axis w.r.t. global x-axis
w_y	-	Upper platform projection of w-axis w.r.t. global y-axis
w_z	-	Upper platform projection of w-axis w.r.t. global z-axis
x	-	x direction
X	-	End-effector location and orientation vector
y	-	y direction
Y	-	An example vector
z	-	z direction
z_{end}	-	End of z height of the manipulator workspace
z_{start}	-	Start of z height of the manipulator workspace
α	-	Second limb placement angle with respect to the first limb
β	-	Third limb placement angle with respect to the first limb
β_j	-	Number of groups of variables
Γ	-	Random complex constant
γ_i	-	Base inclination angle with respect to ground
δ	-	Linear actuator travel range
δL_i	-	Change in actuator length
δp	-	Change in kinematic parameters
Δq	-	Small change in the vector of actuators
δq	-	Virtual displacement associated with actuators
ΔX	-	Small change in position and orientation vector of the end-effector
δX	-	Virtual displacement associated with the end-effector
ε	-	Angular increment
ε_i	-	General variable for α and β
ζ	-	Inclination of legs over the base platform
θ	-	Angular rotation about v axis
θ_d	-	Actuator inclination over base
θ_c	-	Angular range in spherical cap
θ_{sp}	-	Ball rotation angle
λ_{max}	-	Largest eigenvalue of Jacobian matrix
λ_{min}	-	Smallest eigenvalue of Jacobian matrix
τ	-	Vector of actuated joint torque
ψ	-	Angular rotation about u axis
ϕ	-	Angular rotation about w axis
$[T]_L^U$	-	Upper platform transformation w.r.t. Lower platform
x	-	Velocity vector for end-effector location and orientation
$\dot{q}$	-	Velocity vector of actuators
$\dot{b}_i$	-	Velocity vector of actuators
$\dot{\theta}_{j,i}$	-	Magnitude of the twist of the *jth* joint of the *ith* limb
$\hat{S}_{j,i}$	-	Unit screw associated with the *jth* joint of the *ith* limb
$\lVert . \rVert$	-	Matrix norm
μ	-	Coefficient of friction
μ_M	-	Coefficient of friction between magnet and the ball
μ_R	-	Coefficient of friction between upper ring and the ball

LIST OF ABBREVIATIONS

D.C.	-	Duty Cycle of the solenoid
DOF	-	Degree of Freedom
EDM	-	Electro-discharge machining
GCS	-	Global co-ordinate system
GK	-	Grubler Kutzbach equation
LCS	-	Lower co-ordinate system
PKM	-	Parallel Kinematic machine
PRPS	-	Prismatic-Revolute-Prismatic-Spherical
PRS	-	Prismatic-Revolute-Spherical
PSPS	-	Prismatic-Spherical-Prismatic-Spherical
PSS	-	Prismatic-Spherical-Spherical
RP	-	Rapid prototype
RPS	-	Revolute-Prismatic-Spherical
SPS	-	Spherical-Prismatic-Spherical
SVD	-	Singular Value Decomposition
UCS	-	Upper co-ordinate system
UPU	-	Universal-Prismatic-Universal
UPS	-	Universal-Prismatic-Spherical

DEDICATION

Dedicated to my wife, Tayyaba