Nomenclature

List of Greek and Roman Symbols

A	System matrix
b	Input matrix
c	Output matrix
x	State vector
y	Output state vector
s	Sliding surface
$\mathbf{c}^T$	Sliding surface matrix
$[.]^T$	Transpose of $[.]$
$[\hat{..}]$	Estimation of $[..]$
$\|\|[.]\|\|_2$	Norm-2 of $[.]$
$\|\|[.]\|\|_1$	Norm-1 of $[.]$
$\|\|[.]\|\|_\infty$	Norm-∞ of $[.]$
θ	Position of load angle (deg)
$\dot{\theta}$	Velocity of load angle (deg/sec)
α	Tip deflection of the FLM (deg)

$\dot{\alpha}$	Rate of tip deflection of the FLM (deg/sec)
D	Displacement at the tip of the flexible link (m)
L	Length of the link (m)
M	Mass of link (Kg)
f_c	Natural frequency (Hz)
J_l	Moment of inertia of link ($Kg\ m^2$)
J_{eq}	Equivalent moment of inertia of the hub ($Kg\ m^2$)
V_m	DC input voltage (V)
I_m	Input current (A)
L_m	Motor armature inductance (H)
R_m	Motor armature resistance (Ohm)
E_{emf}	Equivalent back emf (V)
θ_m	Motor shaft position (deg)
K_m	Motor back emf constant (V s/deg)
J_m	Motor Inertia $(kg\ m^2)$
T_m	Motor Torque (Nm)
T_l	Load Torque (Nm)
η_g	Gearbox efficiency
K_g	Total gear ratio
B_{eq}	Viscous damping coefficient
η_m	Motor efficiency
K_t	Motor torque constant (Nm/A)

K_s	Total stiffness of model (Nm/deg)
J_h	Inertia of hub (kgm^2)
J_p	Inertia of payload (kgm^2)
M_p	Mass of payload (kg), and are the and
M_{Li}	Mass the end of link i (kg)
J_{Li}	Moment of inertia at the end of link i(kgm^2)
ω_{ij}	j^{th} natural angular frequency of the i^{th} link
T_h	KE due to hub
T_l	KE due to the link
T_p	KE due to payload
T	Total KE of the flexible link system
U	Total PE of the flexible link system
ω_m	Angular speed of the rotor shaft (rad/s)
u	control input
$\mathbf{x}_{sh}$	State vector of the first link of TLFM
$\mathbf{x}_{el}$	State vector of the second link of TLFM
y_{sh}	Output of the first link of TLFM
y_{el}	Output of the second link of TLFM
$\mathbf{A}_T$	Joint rotation matrix through angle θ
$\mathbf{E}_i$	Rotation matrix characterizing end-point of the flexible link.
$\delta_i(t)$	Time varying coordinate of the i^{th} link
$\phi_i(x_i)$	Spatial coordinates of the i^{th} link

$\mathbf{p}_i(x_i)$	Position vector describing point on i^{th} flexible link w.r.t. inertial frame
$\mathbf{r_i}$	Position vector for joint i from the inertial frame
$\boldsymbol{q}$	Matrix of generalized coordinates
$\boldsymbol{q}_r$	Matrix of rigid variables $\boldsymbol{\theta}$
$\boldsymbol{q}_f$	Matrix of flexible variables $\boldsymbol{\delta}$
τ_i	Actuated torque of the i^{th} link
$\theta_i, \dot{\theta}_i$	Joint angle and velocity of the i^{th} joint
$\delta_{ij}, \dot{\delta_{ij}}$	Modal displacement and velocity of the i^{th} link
B	A positive definite symmetric inertia matrix
$\mathbf{h}$	Vectors containing Coriolis and centrifugal forces
K	Diagonal stiffness matrix
D	Damping matrix
K_m, K_M	Constants parameterizing the uncertainty of a system
k, q	Controller parameters of SMC
sgn	Denotes signum Function
V	Lyapunov function
$\Gamma(.)$	Gamma function
J	Integration operator
D_t^α	Fractional derivative of α^{th} order
K_p, K_i, K_d	Proportional, integral and derivative constants of PID controller
e	Error between reference and actual signals
$E_\alpha(t)$	Mittag-Leffler function

T_s	Settling time(sec)
T_d	Delay time(sec)
T_r	Rise time(sec)
d	Lumped uncertainty and disturbance of the system