Dynamics Analysis for a 3-RPS[1] Parallel Manipulator Wearable Thimble

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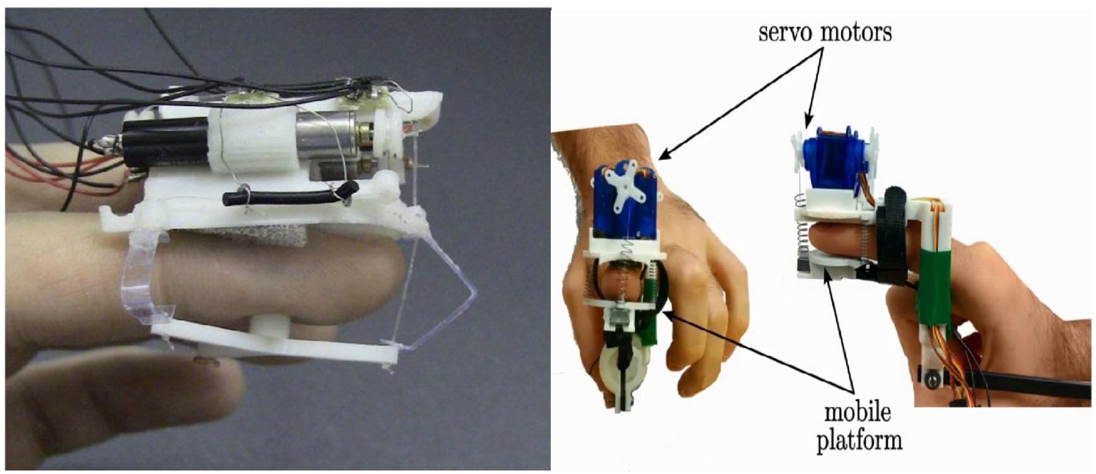


[1]

1. 3RPS stands for 3 revolute, prismatic, spherical joints

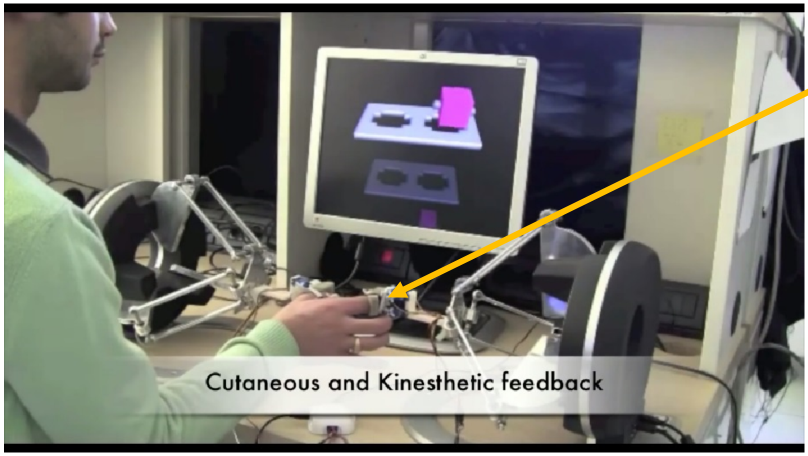
Overview:

1. *Introduction of 3RPS parallel Manipulator robot*
2. *Degrees of Freedom(DOF), links, joints*
3. *Kinematics and dynamics analysis of 3RPS parallel manipulator robot*
4. *Dynamics analysis by experimental work by Matlab*
5. *Conclusions and Future Research Directions*
6. *References*

1. Introduction of 3RPS parallel Manipulator robot

We are interested 3RPS Parallel Manipulator robot due to:

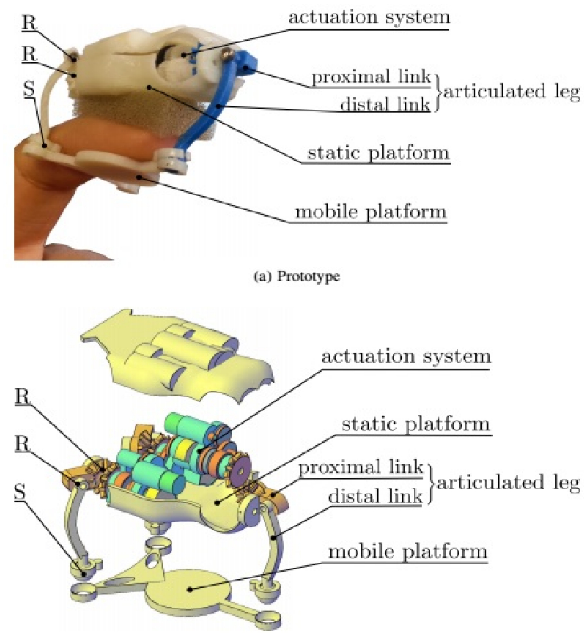
- *Generally in robotics we specify a manipulator as a device that we use to manipulate materials without direct contact*
- *Dealing with radioative or bio hazardous materials , teleoperation , virtual environment*



[2]

3RPS Parallel manipulator for cutaneous feedback in virtual environment

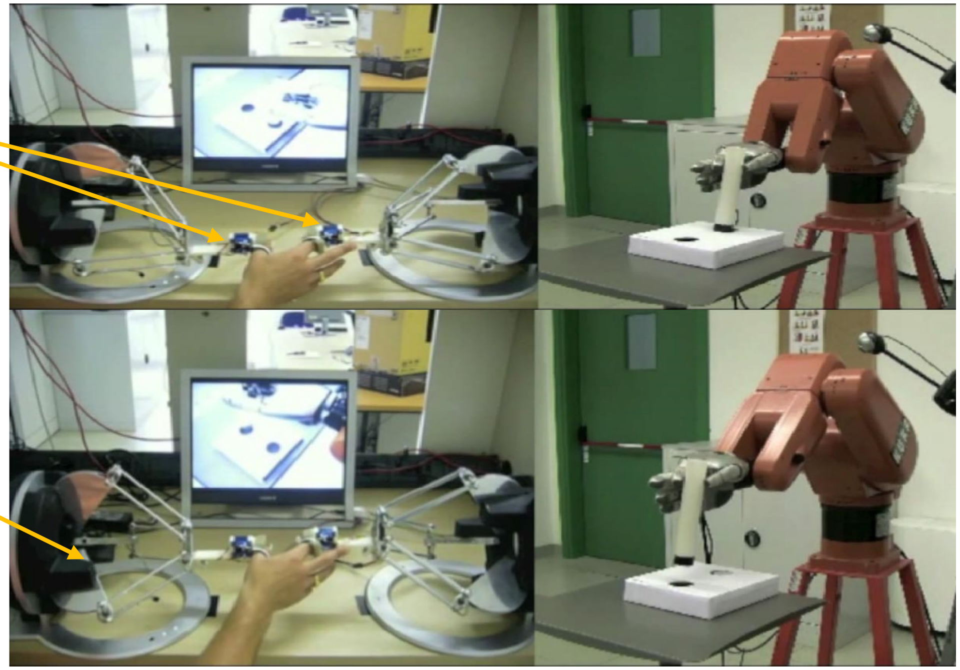
- *We feel by our fingertip pulp what happens in other real environment with high level of transparency without considerable time delay*
- *Robotically assisted surgery ,in space and astronauts*
- *In industrial environments manipulator is a lift assist device for too heavy, too hot, too large lift maneuver*
- Flexible design



[1]

3RPS Parallel Manipulator for cutaneous feedback in grasping objects and lifting

Spherical Parallel Manipulator for grasping objects and lifting



[2]

- *limited weight for the moving parts, move at a high speed*
- *high operational precision ,high positional accuracy of measuring forces and torques over the joints*

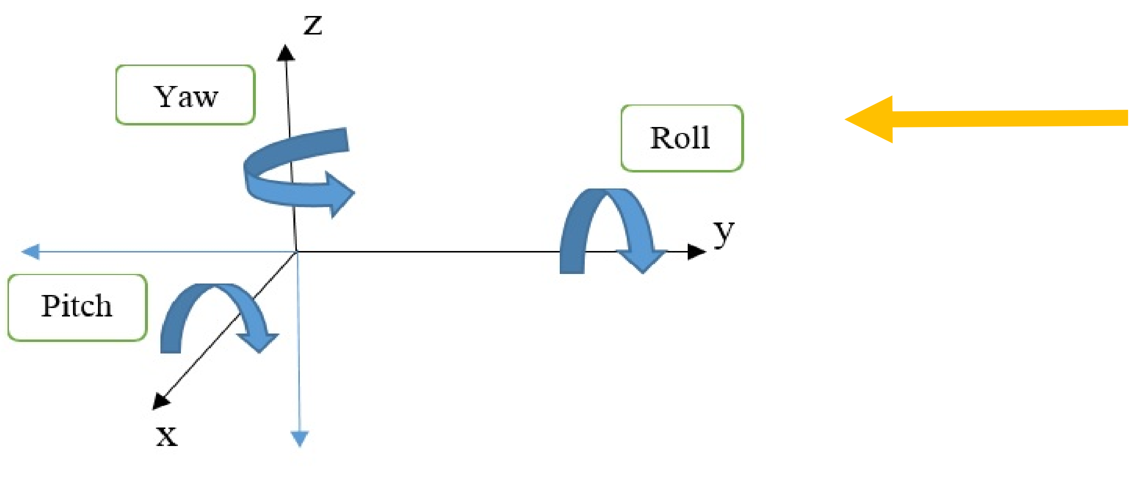
Videos:

https://www.youtube.com/watch?v=Jv88MB6tRTM

https://www.youtube.com/watch?v=mQ8AYmNUBFo

2. Degrees of Freedom(DOF), links, joints

Robots are described by their degrees of freedom and their spatial motion limitations



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Normally Six DOF:
forward/back(+y,-y),
up/down(+z,-z),
left/right(+x,-x)
pitch, yaw, roll

$$F = \lambda\,(n - j - 1) + \sum_{i=1}^{j} f_i$$

F : *Overall degrees of freedom of a mechanism*

f_i : *Degrees of relative motion by joint i*

j : *Number of joints in a mechanism*

n : *number of links in a mechanism, including the fixed link.*

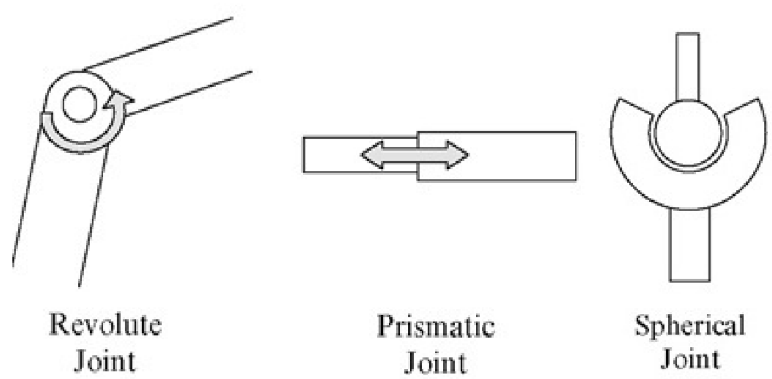
λ : *degrees of freedom of each link in the space in which a mechanism is intended to function.*

Revolute joint (R), Prismatic joint (P) Spherical joint (S)

Revolute joint (R) *Provides single axis rotation such as door hinges. DOF(1)*

Prismatic joint (P) *provides a linear sliding movement between two bodies, and is often called a slider. DOF (1)*

Spherical joint (S) *is a constraint element that allows the relative rotation of two bodies, It is sometimes referred to as a ball joint. DOF (3)*



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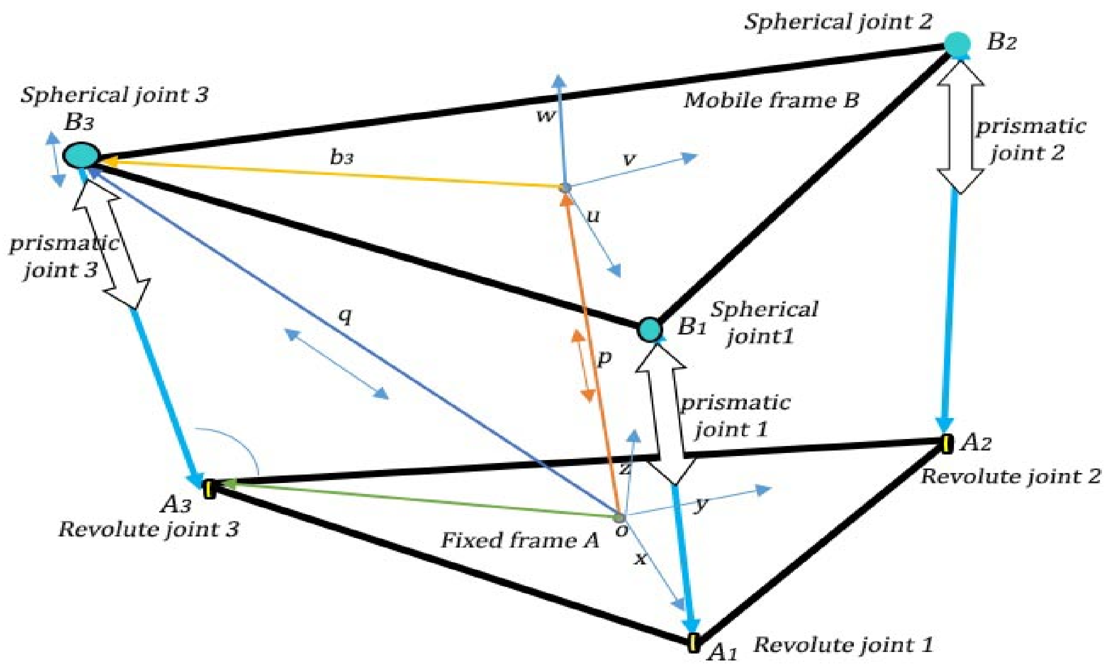
3RPS parallel manipulator DOF

$F = \lambda(n - j - 1) + \sum_i f_i = 6(8 - 9 - 1) + (3 + 3 + 9) = 3$ ***We assumed*** $\lambda = 6$



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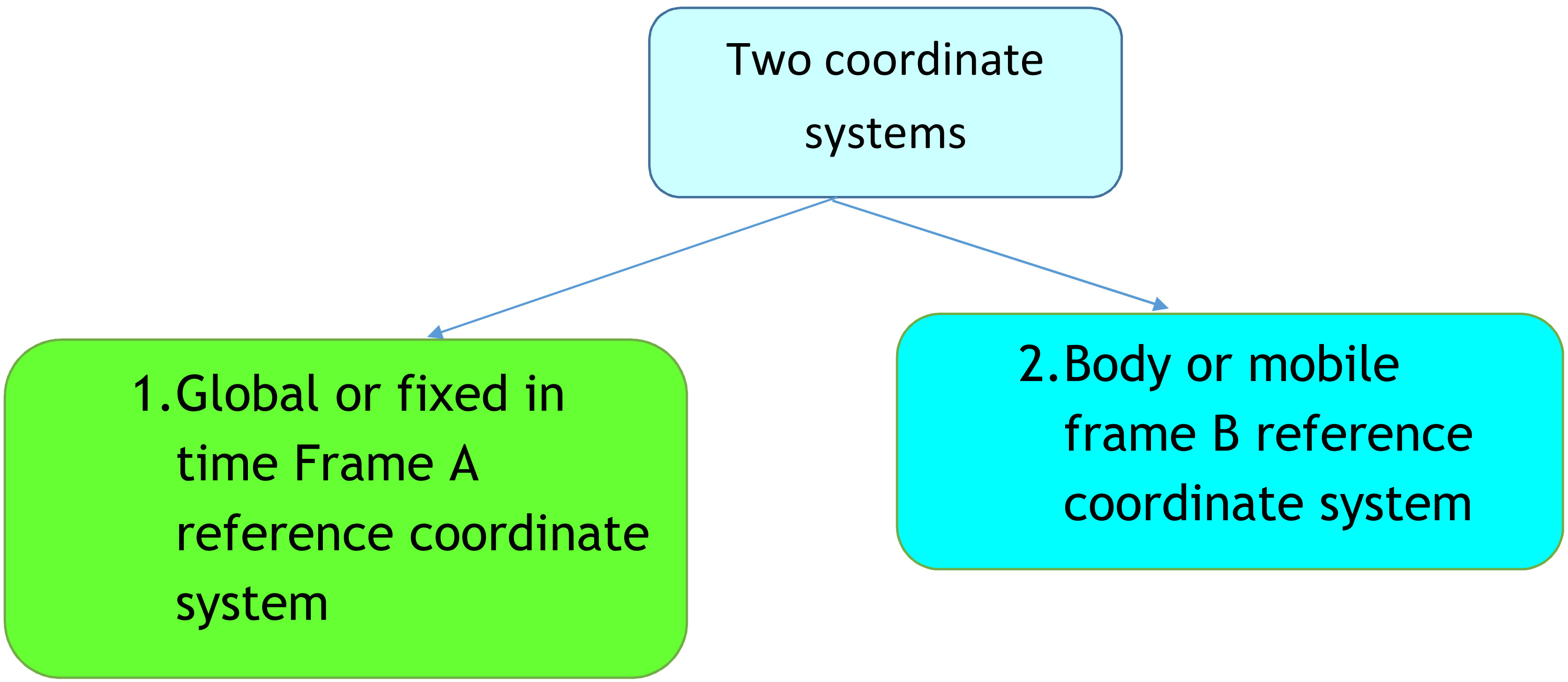
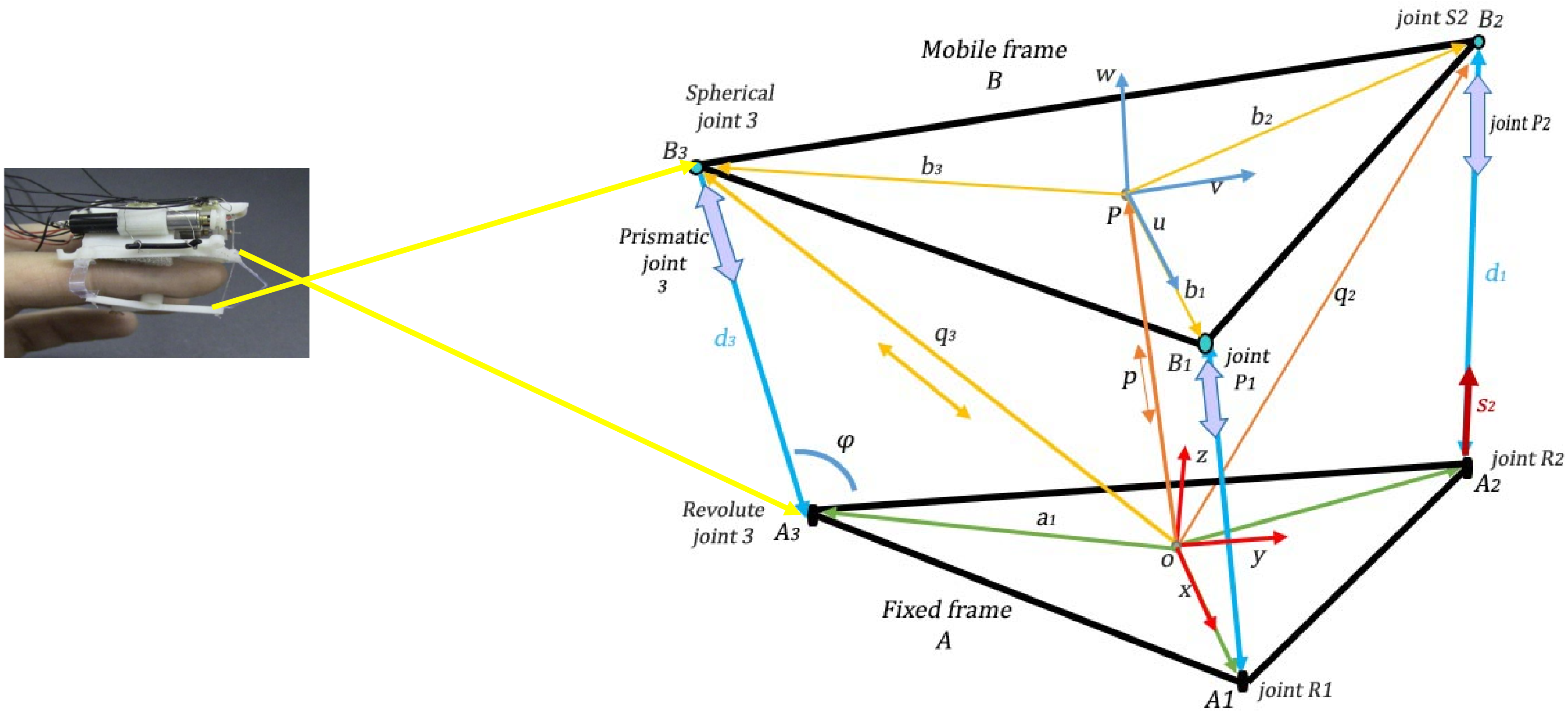
3. *Kinematics and dynamics analysis of 3RPS parallel manipulator robot*

In order to describe the motion and displacement and rotations of 3RPS parallel manipulator we need two coordinate system



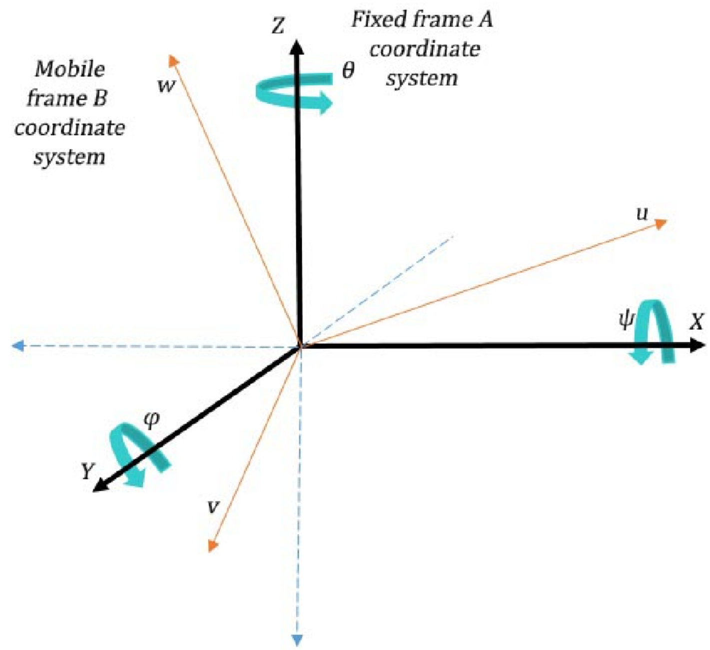


$$\boldsymbol{q}_i = \boldsymbol{p} + {}^{B}\boldsymbol{b}_i \qquad \text{for } i=1,2,3$$

In terms of rotation ${}^{A}R_{B}\boldsymbol{b}_i$ *is update position of points* ${}^{B}\boldsymbol{b}_i$ *with respect to fixed frame*

$$\boldsymbol{q}_i = \boldsymbol{p} + {}^{A}R_{B}\boldsymbol{b}_i$$

$^{A}R_{B}$ *Transformation matrix derived from Euler's Angles (Ψ,θ,φ) theorem states that three successive rotations about the coordinate axes of fixed frame are used to describe the orientation of a mobile frame*



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$$^{A}R_{B} = R(z,\theta)R(y,\varphi)R(x,\psi) = \begin{bmatrix} c\theta c\phi + s\psi s\theta s\phi & -c\theta s\phi + s\psi s\theta c\phi & c\psi s\theta \\ c\psi s\phi & c\psi c\varphi & -s\psi \\ -s\theta c\phi + s\psi c\theta s\phi & s\theta s\phi + s\psi c\theta c\phi & c\psi c\theta \end{bmatrix}$$

The three vectors of limb length can be expressed as

$$d_1 = [-c\varphi \;\; 0 \;\; -s\varphi\,]^T$$
$$d_2 = \left[c\,\varphi\,/2 \;\; -\sqrt{3}\,c\,\varphi\,/2 \;\; -s\varphi\,\right]^T$$
$$d_3 = \left[c\varphi\,/2 \;\; \sqrt{3}\,c\varphi\,/2 \;\; -s\varphi\,\right]^T$$

As we know:

$$a_1 = [a \;\; 0 \;\; 0]^T$$

$$a_2 = \left[-a/2 \;\; \sqrt{3}\;a/2 \quad 0\right]^T$$

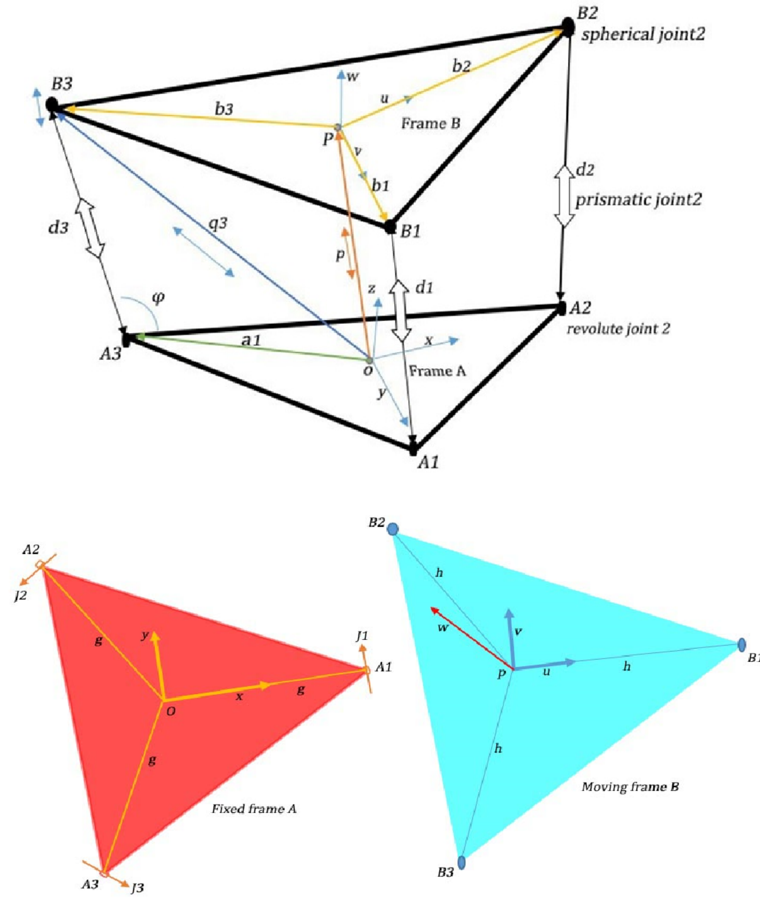
$$a_3 = \left[-a/2 \;\; -\sqrt{3}\;a/2 \quad 0\right]^T$$

And

$$b_1 = [h\,,0\,,0]^T$$

$$b_2 = \left[-\tfrac{1}{2}h\,,\tfrac{\sqrt{3}}{2}h\,,0\right]^T$$

$$b_3 = \left[-\tfrac{1}{2}h\,,-\tfrac{\sqrt{3}}{2}h\,,0\right]^T$$



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Differentiating Eq. ($\boldsymbol{q}_i = \boldsymbol{p} + {}^{A}R_{B}\,{}^{B}\boldsymbol{b}_i$), with respect to time yields a velocity vector-loop equation as follow:

$$s_i . v_p + (b_i \times s_i) . \omega_p = \dot{d}_i s_i . d_i \qquad \text{for } \; i = 1,2,3$$

- s_i *is a unit vector pointing along* $\overline{A_i B_i}$
- ✓ υ_p *is the three dimensional linear velocity of the moving frame B,*
- ✓ ω_p *is the angular velocity of the moving platform*

By assuming $\dot{X}_P$ *be vector of mobile frame B velocity:*

$$\dot{X}_P = \left[v_p \, w_p\right]^T$$

Since DOF is 3, the vector for velocity of actuator joints can be written as $\dot{d} = \dot{q} = \dot{d}_i = \left[\dot{d}_1 \, \dot{d}_2 \, \dot{d}_3\right]^T$

We write equation $s_i.v_p + (b_i \times s_i).\omega_p = \dot{d}_i s_i.d_i$ as

$$J_x \dot{X}_P = J_q \dot{d}$$

$$J_x = \begin{bmatrix} s_1^T & (b_1 \times s_1)^T \\ s_2^T & (b_2 \times s_2)^T \\ s_3^T & (b_3 \times s_3)^T \end{bmatrix}_{3\times 6}$$

$$J_q = \begin{bmatrix} s_1.d_1 & 0 & 0 \\ 0 & s_2.d_2 & 0 \\ 0 & 0 & s_3.d_3 \end{bmatrix}_{3\times 3}$$

$$\dot{q} = J\dot{X}_P$$

Where

$$J = J_q^{-1} J_x$$

J is Jacobian matrix

By having jacobian we can simply acquire the force over autuator joints

$$F_q = J F_x$$

- ✓ F_x *the force applied to the hand or slave robot finger*
- ✓ F_q *the forces and torques over actuator joints of 3RPS Parallel manipulator*

Summary:

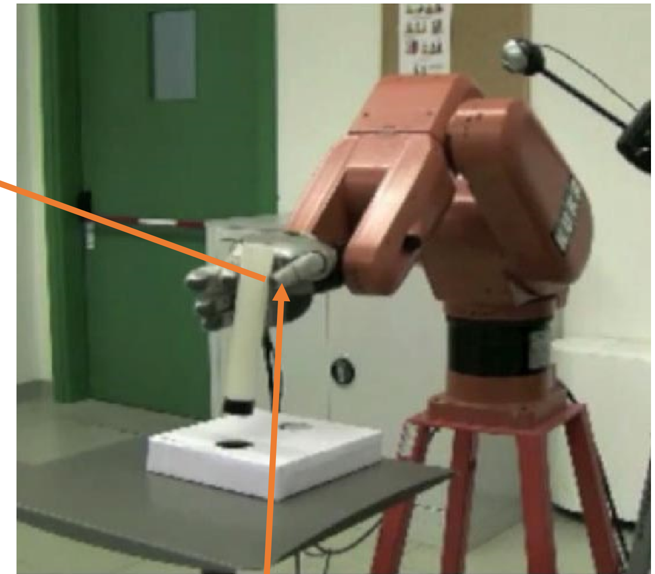
We receive from slave robot fingertip sensors:

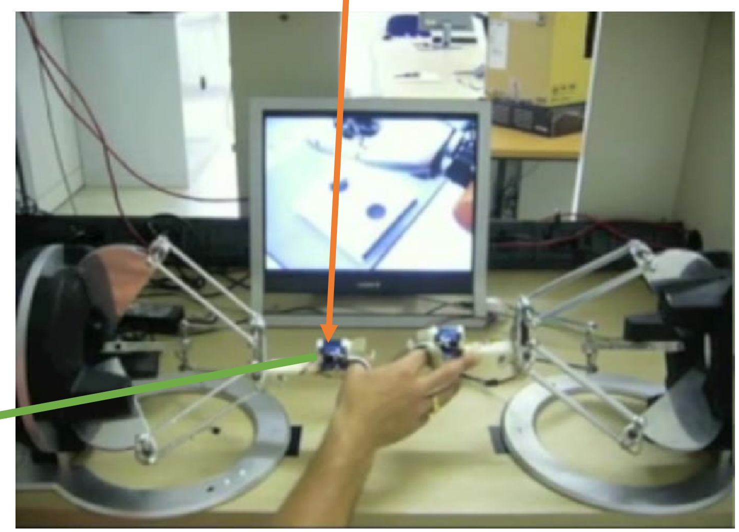
- ✓ *Euler angles* Ψ, θ, φ
- ✓ v_p , ω_p
- ✓ F_x

We compute in 3RPS parallel manipulator:

- ✓ $\dot{q}$
- ✓ Fq

By 3RPS parallel manipulator we get cutaneous feedback and feel in our fingertip surface pulp what happens in slave robot fingertip surface during lifting object in another place





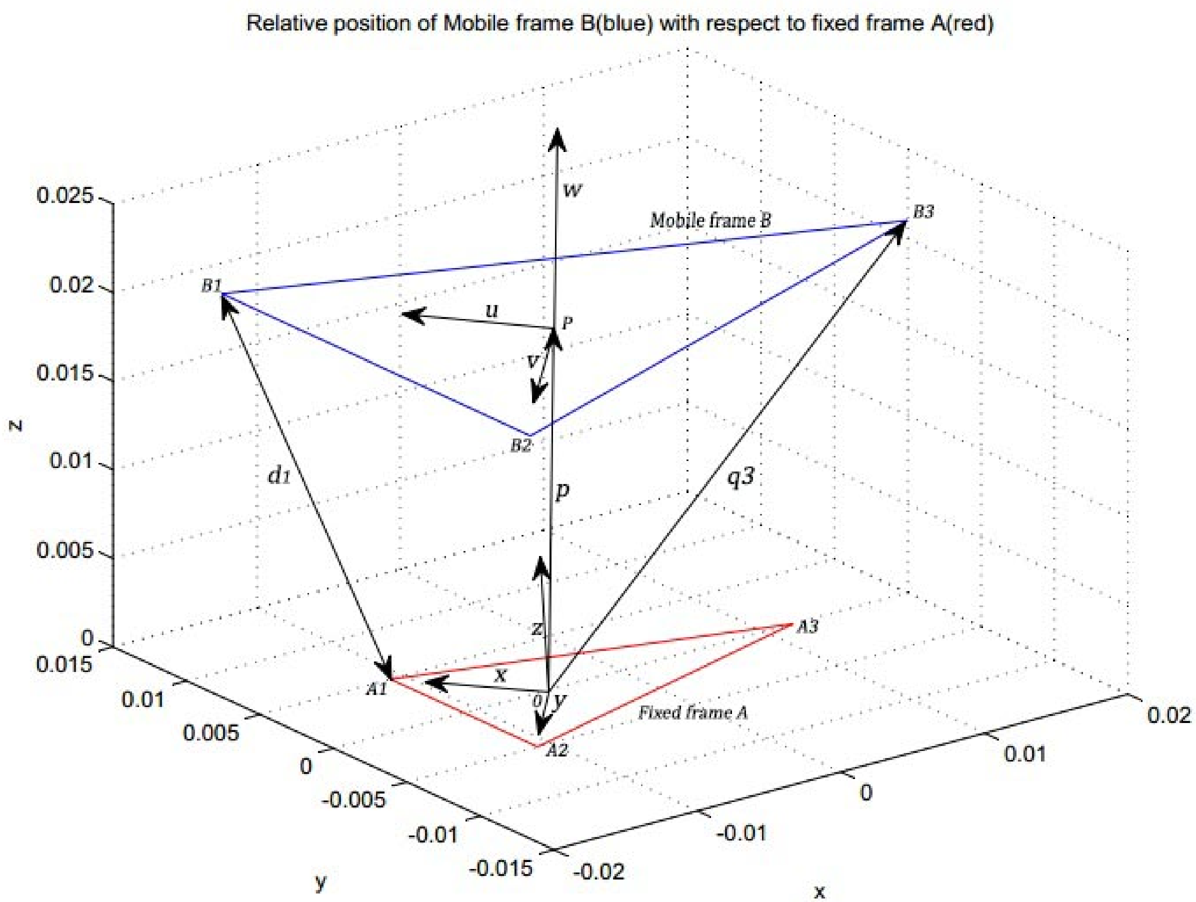
4. Dynamics analysis by experimental work by Matlab

Exp1:

a1,a2,a3	b1,b2,b3	Ψ,θ,φ	$p = [p_x p_y p_z]$	transformation matrix ^AR_B	$q_1, q_2, q_3 = \overline{OB_i}$	$\dot{X}_P = [v_p\, w_p]^T$
a1 = 0.0120 0 0 a2 = -0.0109 -0.0050 0 a3 = -0.0109 0.0050 0	b1 = 0.0200 0 0 b2 = -0.0170 -0.0105 0 b3 = -0.0170 0.0105 0	psi = 0 theta = 0 phi = 0	p = 0 0 0.0210	R = 1 0 0 0 1 0 0 0 1	q1 = 0.0200 0 0.0210 q2 = -0.0170 -0.0105 0.0210 q3 = -0.0170 0.0105 0.0210	x_dot = 1.0e-03 * 0 0 1.0000 0 0 0

$d = [d_1\, d_2 d_3]$	Jacob =
d = -1.0000 1.0000 1.0000 0 -1.7321 1.7321 0 0 0	0.3560 0 0.9345 0 -0.0112 0 -0.2711 -0.2439 0.9312 -0.0047 0.0102 0.0013 -0.2711 0.2439 0.9312 0.0047 0.0102 -0.0013

Velocity over the joints $\dot{X}_P$=J$\dot{q}$, $\dot{q}$ Matrix 3×1	F_x	$F_q = JF_x$
q_dot = 1.0e-03 * 0.2441 0.2441 0.2441	Fx = 0 0 1 0 0 0	Fq = 0.9345 0.9312 0.9312


Relative position of Mobile frame B(blue) with respect to fixed frame A(red)
0.025
0.02
0.015
0.01
0.005
0
z
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
y
-0.02
-0.01
0
0.01
0.02
x
w
Mobile frame B
B1
B2
B3
u
P
v
d1
p
q3
z
x
y
0
A1
A2
A3
Fixed frame A

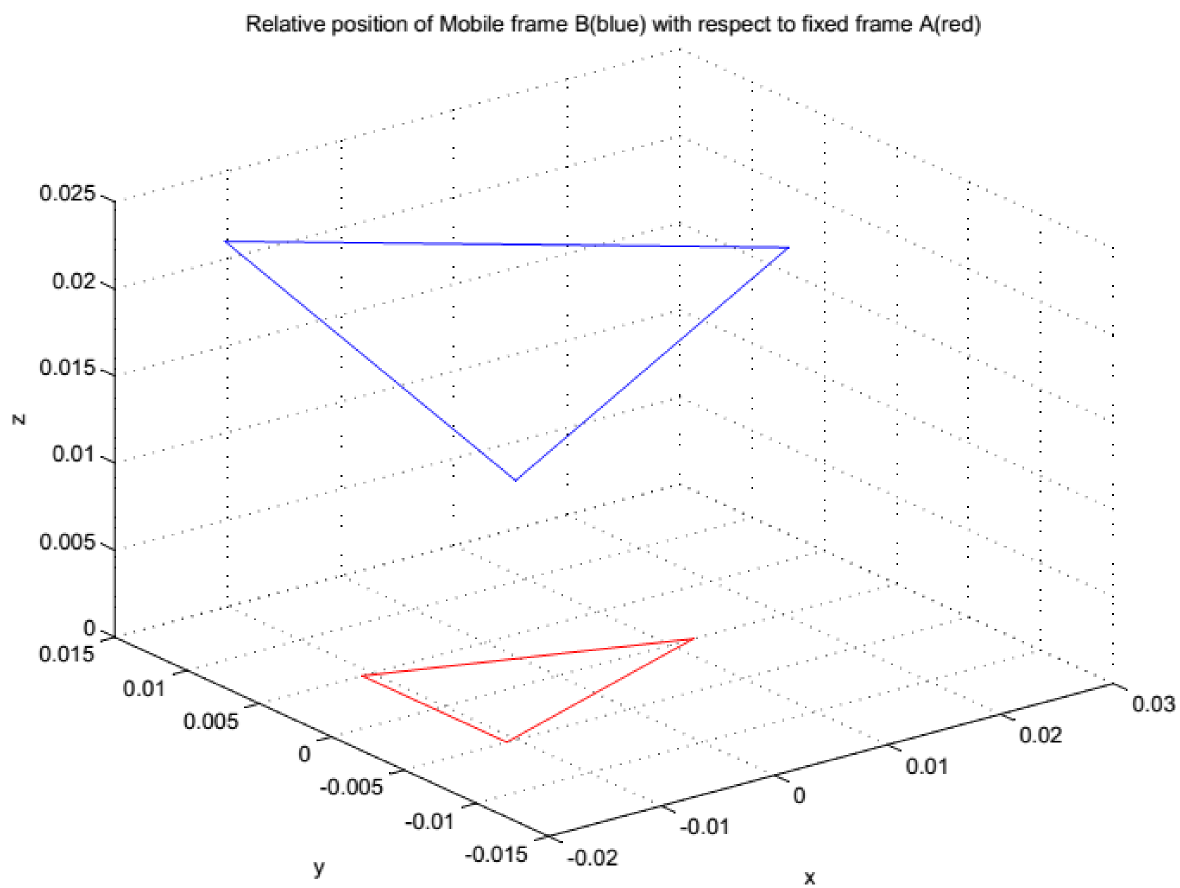
[2]

Exp 2:

a1,a2,a3	b1,b2,b3	Ψ,θ,φ	$p = [p_x p_y p_z]$	transformation matrix $^{A}R_{B}$	$q_1, q_2, q_3 = \overline{OB_i}$	$\dot{X}_P = [v_p\ w_p]^T$
a1 = 0.0120 0 0 a2 = -0.0109 -0.0050 0 a3 = -0.0109 0.0050 0	b1 = 0.0200 0 0 b2 = -0.0170 -0.0105 0 b3 = -0.0170 0.0105 0	psi = 0.2932 theta = 0 phi = 0	p = 0.0004 0 0.0210	R = 1.0000 0 0 0 0.9573 -0.2890 0 0.2890 0.9573	q1 = 0.0204 0 0.0210 q2 = -0.0166 -0.0101 0.0180 q3 = -0.0166 0.0101 0.0240	x_dot = 1.0e-03 * 0 0 1.0000 0 0 0

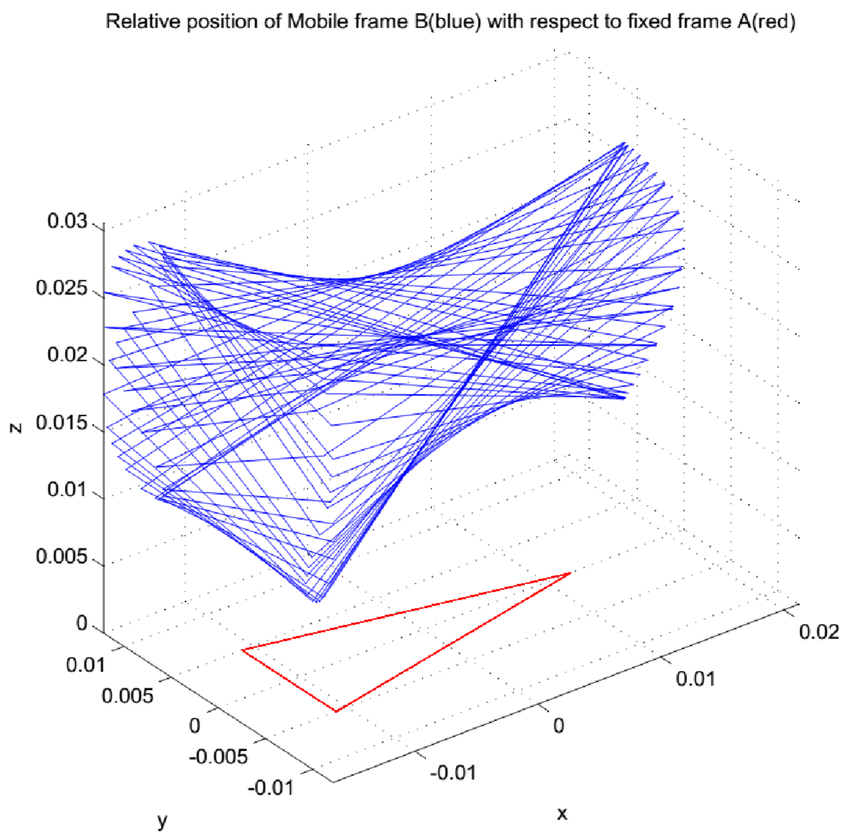
$d = [d_1\ d_2 d_3]$	
d = -1.0000 1.0000 1.0000 0 -1.7321 1.7321 0 0 0	Jacob = 0.3724 0 0.9281 0 -0.0111 0 -0.2915 -0.2589 0.9209 -0.0046 0.0100 0.0014 -0.2256 0.2004 0.9534 0.0048 0.0104 -0.0011

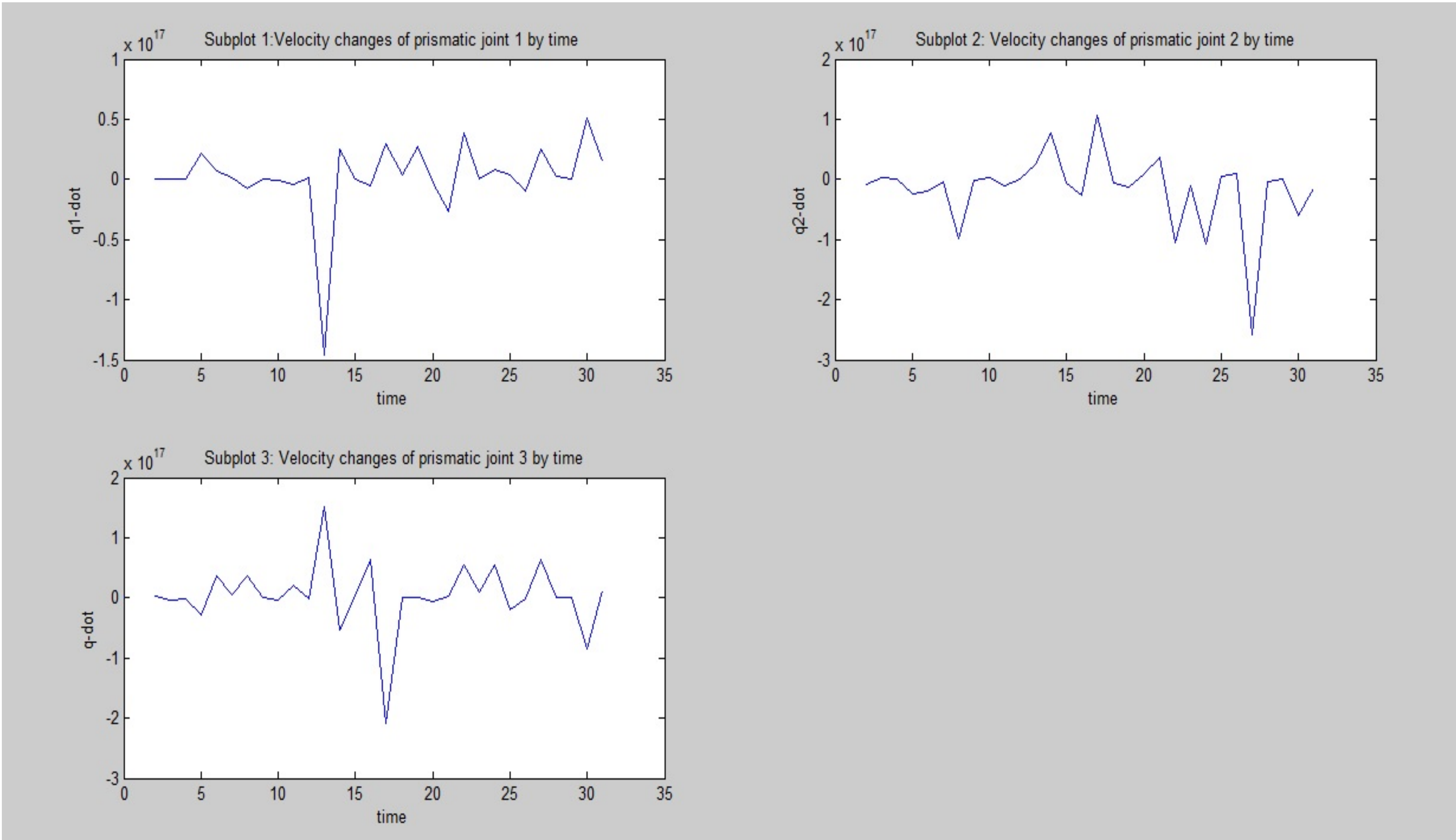
Velocity over the joints $\dot{X}_P$=J$\dot{q}$, $\dot{q}$ Matrix 3 × 1	F_x	$F_q = JF_x$
q_dot = 1.0e+13 * -0.0735 3.0247 -2.2518	Fx = 0 0 1 0 0 0	Fq = 0.9281 0.9209 0.9534


Relative position of Mobile frame B(blue) with respect to fixed frame A(red)
z
0.025
0.02
0.015
0.01
0.005
0
y
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
x
-0.02
-0.01
0
0.01
0.02
0.03

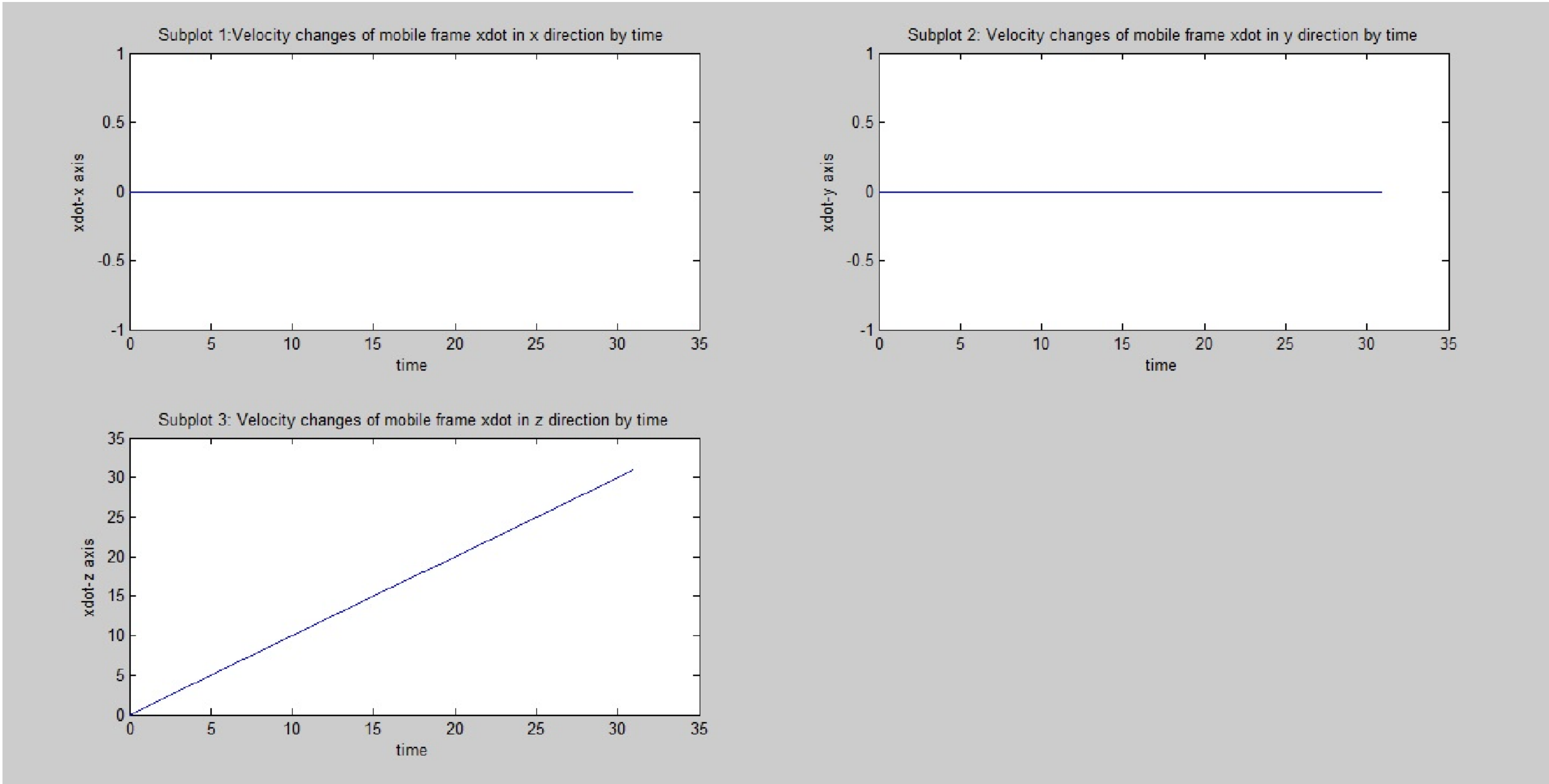
Exp3:

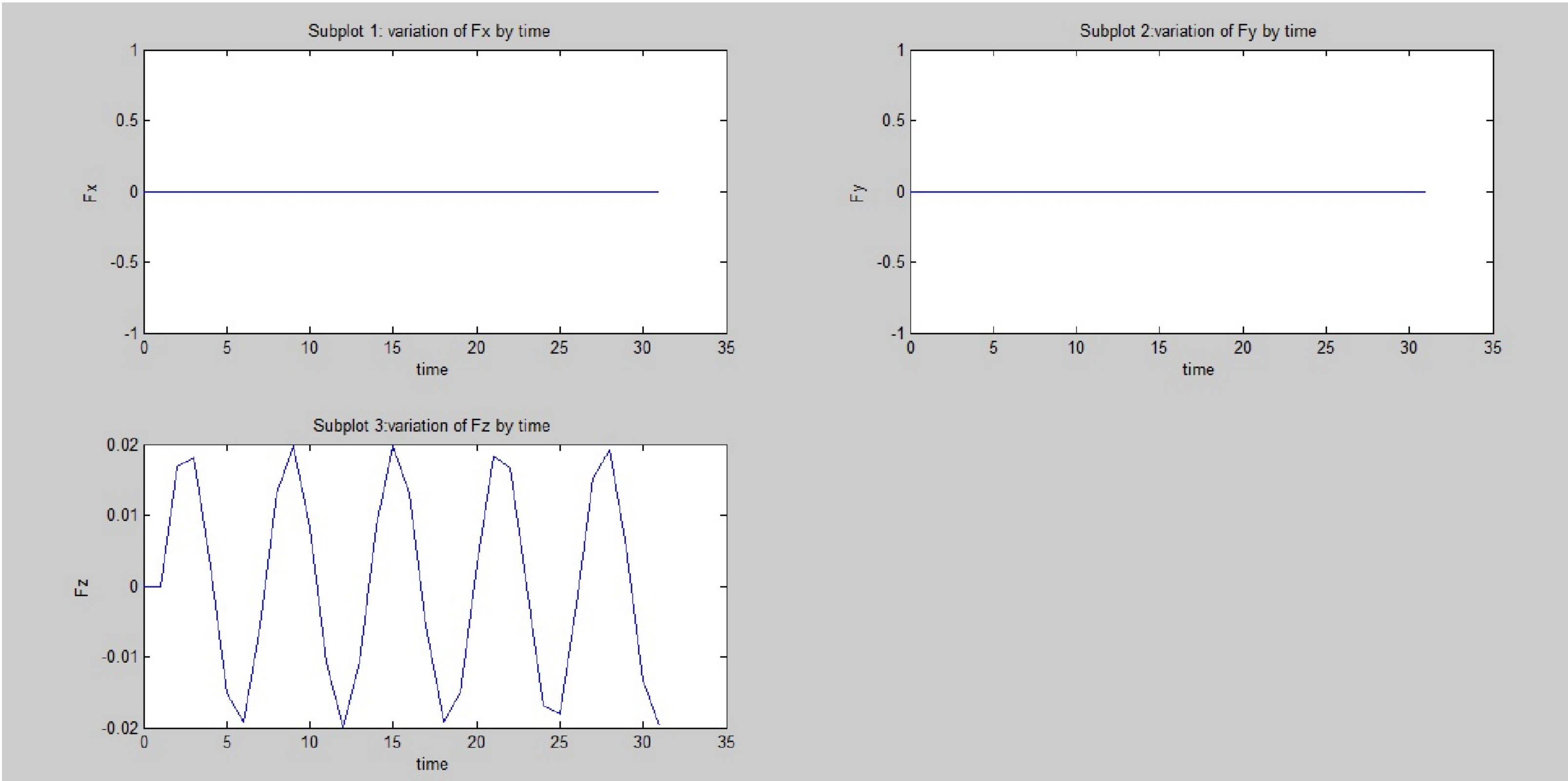
ψ=0.5*sin(α)
θ=0.5*cos(α)
α=[0..30]
$\dot{X}$ is [0 0 v 0 0 0].
v=[0..30]

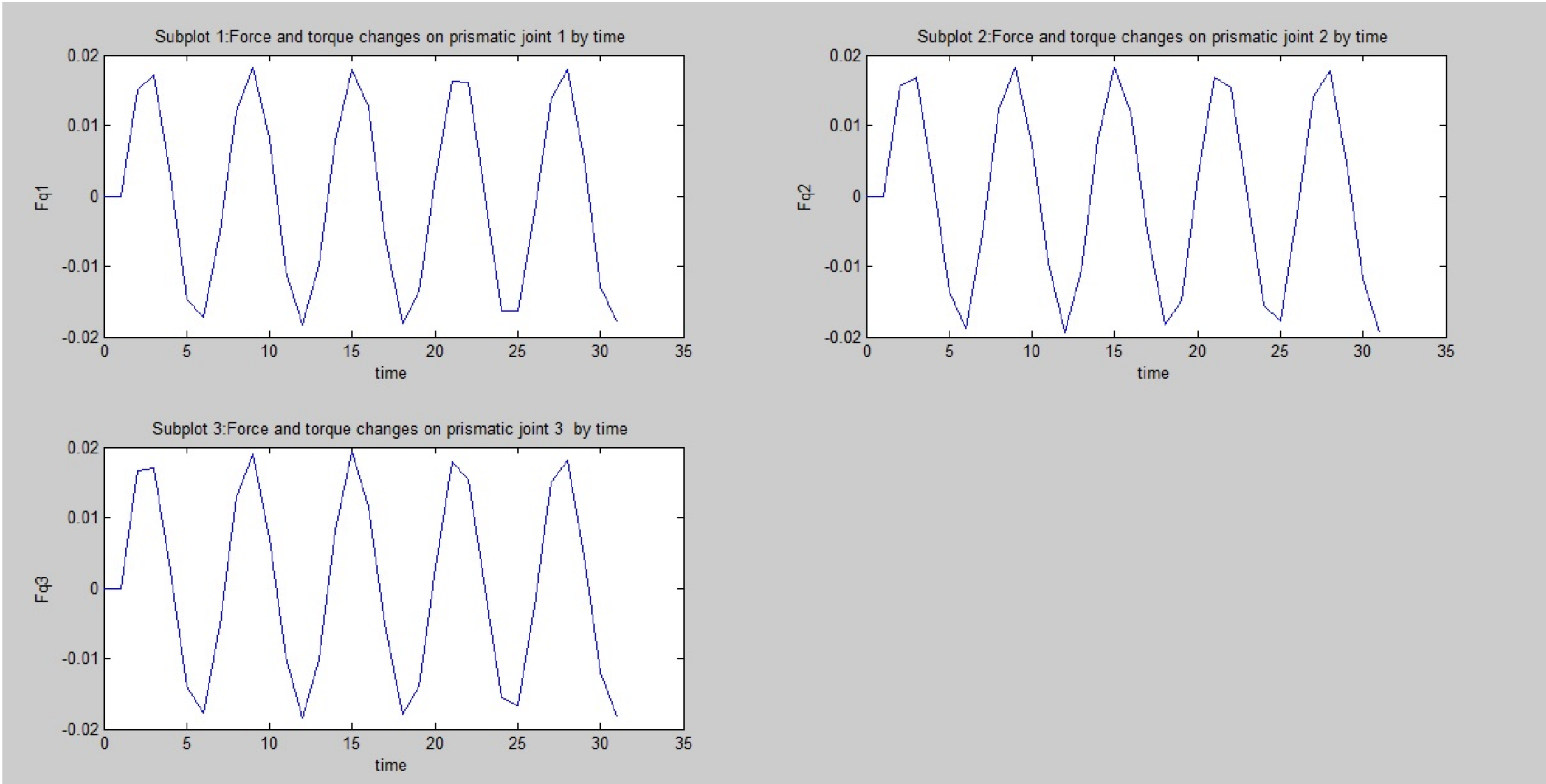



Subplot 1:Velocity changes of prismatic joint 1 by time
x 10^17
q1-dot
time
Subplot 2: Velocity changes of prismatic joint 2 by time
x 10^17
q2-dot
time
Subplot 3: Velocity changes of prismatic joint 3 by time
x 10^17
q-dot
time

[2]


Subplot 1:Velocity changes of mobile frame xdot in x direction by time
xdot-x axis
time
Subplot 2: Velocity changes of mobile frame xdot in y direction by time
xdot-y axis
time
Subplot 3: Velocity changes of mobile frame xdot in z direction by time
xdot-z axis
time


Subplot 1: variation of Fx by time
Fx
time
Subplot 2:variation of Fy by time
Fy
time
Subplot 3:variation of Fz by time
Fz
time



Subplot 1:Force and torque changes on prismatic joint 1 by time
Fq1
time
0.02
0.01
0
-0.01
-0.02
0
5
10
15
20
25
30
35
Subplot 2:Force and torque changes on prismatic joint 2 by time
Fq2
time
Subplot 3:Force and torque changes on prismatic joint 3 by time
Fq3
time

5. Conclusions and Future Research Directions

- ✓ We described completely the kinematics of 3RPS parallel manipulator
- ✓ We tried to present perfect mathematic model
- ✓ Computing forces, torques over the actuator joints in order to achieve high level control while grasping
- ✓ We explained the concept of Jacobian matrix
- ✓ This effort can also be applied to other parallel mechanisms with different DOF.

6. References

[1] F. Chinello, M. Malvezzi1, C. Pacchierotti, and D. Prattichizzo “Design and development of a 3RRS wearable fingertip cutaneous device”.

[2] M. Moeini, Undefended Mcs thesis “Dynamics Analysis for a 3-PRS Spatial Parallel Manipulator-Wearable Haptic Thimble (2016)”.

[3] F. Chinello “Tactile feedback as a sensorysubtraction technique in haptics forneedle insertion (2010)”.

[4] What-When-How,In Depth Tutorials and Information,Kinematics (Advanced Methods in Computer Graphics) Part 1

Thank You