Advanced Modelling and Simulation Techniques for Robots: CloPeMa

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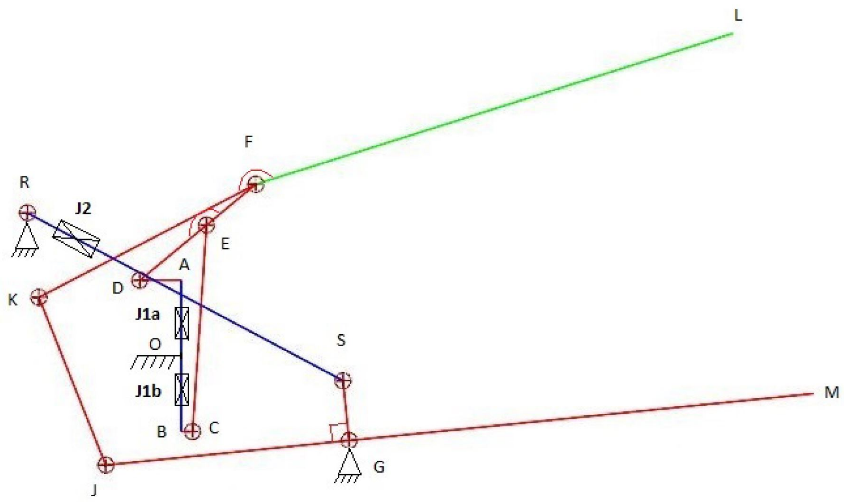


The CloPeMa mechanism

1. Details of the Mechanism

Given: d=4, r=2, n=6

- *Sub-mechanism 1 (sub1): OADF-OBCE*
  Two coupled prismatic joints J1a and J1b are connected to the origin with the axis along y-axis and have the same displacement joint parameter d. CE is connected with DEF at joint E.
  - Active joints: J1a; J1b

- *Sub-mechanism 2 (sub2): RSGJKFL*
  The rigid body (SGJM) has SG perpendicular to JM. Joint R and joint G are fixed in the frame.
  $G = (44.6;, -22.5)$
  $R = (-40.9, 38)$
  $\widehat{KFL} = (n + 12)/18$
  - Active joint: J2

Link	Symbol	Dimension	Link	Symbol	Dimension
OA	$d + l_1$	$d + 20$	GJ	l_7	65
OB	$d + l_1$	$d + 20$	JK	l_8	48
AD	l_3	11	KF	l_9	65
BC	l_2	3	FL	l_{10}	133
DE	l_4	23	GM	l_{11}	124
EF	l_6	17	RS	$r + l_r$	$r + 95$
CE	l_5	55	SG	l_s	16

Values for the mechanism

2. ***Position Analysis***

Aim: Find the position of the tips of gripper fingers (points L;M)

- *As DE and CE have fixed length, point E is calculated using distance formula and taking the Positive solution.*

```
eq_E_DE = sqrt((D(1)-Ex)^2 + (D(2)-Ey)^2) == 23;  % length of DE
eq_E_CE = sqrt((C(1)-Ex)^2 + (C(2)-Ey)^2) == 55;  % length of CE
```

$E = (11.0912, 30.4016)$

- *Since DEF is one Rigid Body, Calculating F using the unit direction vector along EF.*

```
EF_unit_vec = (E-D)/23;
F = E + EF_unit_vec*17;
```

$F = (27.4194, 35.1332)$

- *Again as SR and SG are of constant length. Taking the solution with positive x and negative y*

```
eq_S_SR = sqrt((R(1)-Sx)^2 + (R(2)-Sy)^2) == r+95; % length of RS
eq_S_SG = sqrt((G(1)-Sx)^2 + (G(2)-Sy)^2) == 16;   % length of SG
```

$S = (45.2827, -6.5146)$

- *Taking hypotenuse SJ and constant SG.*

```
eq_J_SJ = sqrt((S(1)-Jx)^2 + (S(2)-Jy)^2) == sqrt(65^2+16^2); % length of SJ
eq_J_GJ = sqrt((G(1)-Jx)^2 + (G(2)-Jy)^2) == 65;                % length of GJ
```

$S = (-20.3408, -19.7266)$

- *JGM is one rigid body.*

```
GJ_unit_vec = (G-J)/65;
M = G + GJ_unit_vec*124;
```

$M = (168.4871, -27.7907)$

- *FK and JK are constant lengths.*

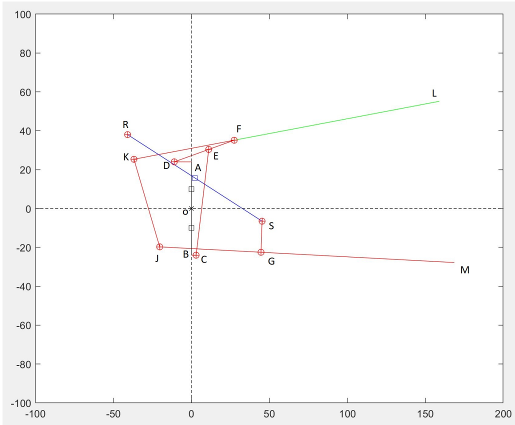
```
eq_K_FK = sqrt((F(1)-Kx)^2 + (F(2)-Ky)^2) == 65; % length of FK
eq_K_JK = sqrt((J(1)-Kx)^2 + (J(2)-Ky)^2) == 48; % length of JK
```

$K = (-36.8399, 25.3486)$

- *Calculating Point F.*

```
% KFL = (n+12)*pi/18; n = 6
% KFL = pi
KF_unit_vec = (F - K)/65;
L = F + 133*KF_unit_vec;
```

$L = (158.903955.1540)$



Plot in Matlab for the calculated position above

3. Instantaneous Center of Rotation

Aim: Find the Instantaneous Center(IC) of links DF and KL on each sub-mechanism

- *In sub-mechanism 1 as bar DEF is one rigid body, the IC of DEF is same as IC of DE. Next we can think of link AB, as OB being fixed and OA moving upwards with $2*d$ displacement. Therefore, D has velocity in Y axis (upwards) with AD(paralle to X-axis) as the perpendicular and E to have only rotation about C, which implies EC is perpendicular to velocity of E. Hence, the IC is the intersection of the two perpendiculars, AD and CE.*
  - $ic_{DF} = (10.1389, 24.0000)$
- *For sub-mechanism 2, if we consider Joint J1 to be blocked, the F point is Fixed. Since triangle-EDC cannot has sides of fixed length, therefore if the angle EDA or BCE does not change, the point F remains fixed. Therefore, submechanism 2 can b reduced to a 4-bar mechanism with G and F as fixed points. Thus, IC of KF is F, as KF rotates about F. Again, because KFL is one rigid body, IC of KL is F as well.*
  - $ic_{KL} = F$

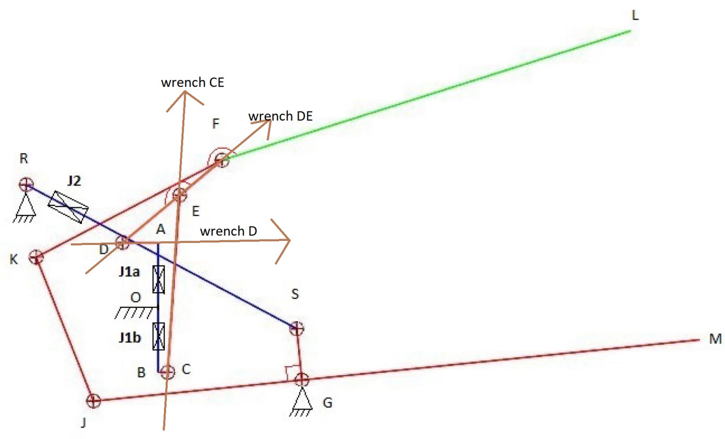
4. Velocity Analysis

Aim: Find the velocity of points in each sub-mechanism

- *Sub 1: Input:* $\dot{d}$ *Output: Velocity of point F* $(v(F))$
- *Sub 2: Input:* $\dot{d}$ *and* $\dot{r}$ *Output: Velocity of point L* $(v(L))$

4.1. Part OADF-OBCE

Writing Input-Output equations using the constraint wrenches as shown.



Wrenches along CE,DE and D

For Leg OADE:

$$\xi_{DF} = \tau_{1a} * \dot{d} + \rho_D * \dot{\theta}_D \tag{1}$$

$$\varphi_{DE} * \xi_{DF} = \varphi_{DE} * \tau_{1a} * \dot{d} \tag{2}$$

$$\varphi_D * \xi_{DF} = 0 \tag{3}$$

For Leg OBC:

$$\xi_{DF} = \tau_{1b} * \dot{d} + \rho_C * \theta_C + \dot{\rho}_E * \dot{\theta}_E \tag{4}$$

$$\varphi_{CE} * \xi_{DF} = \varphi_{CE} * \tau_{1b} * \dot{d} \tag{5}$$

Using Equation 2,3 and 5

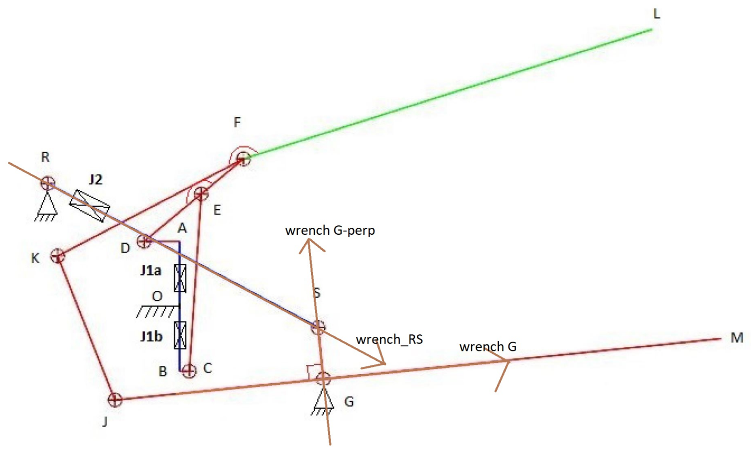
$$\begin{bmatrix} \varphi_{DE}^{\mathrm{T}} \\ \varphi_{CE}^{\mathrm{T}} \\ \varphi_{D}^{\mathrm{T}} \end{bmatrix} \xi_{DF} = \begin{bmatrix} \varphi_{DE} \cdot \tau_{1a} & 0 & 0 \\ 0 & \varphi_{CE} \cdot \tau_{1b} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{d} \\ \dot{d} \\ 0 \end{bmatrix} \tag{6}$$

Thus the velocity of Point F is given by $\overrightarrow{v_F^O} = \overrightarrow{v_F^O} + \overrightarrow{\omega_F} \times \overrightarrow{r_F^O}$

4.2. Part RSGJKF

For the sub-mechanism 2 the analysis is divided into two parts. Part one to calculate the twist of SG and second part is to use this twist and find velocity of L.

4.2.1. RSG



Wrenches along RS,G and G perp

For RS:

$$\xi_{SG} = \tau_2 * \dot{r} + \rho_R * \theta_R + \dot{\rho}_S * \dot{\theta}_S \tag{7}$$

$$\varphi_{RS} * \xi_{SG} = \varphi_{RS} * \tau_2 * \dot{r} \tag{8}$$

For G:

$$\xi_{SG} = \rho_G * \dot{\theta}_G \tag{9}$$

$$\varphi_G * \xi_{SG} = 0 \tag{10}$$

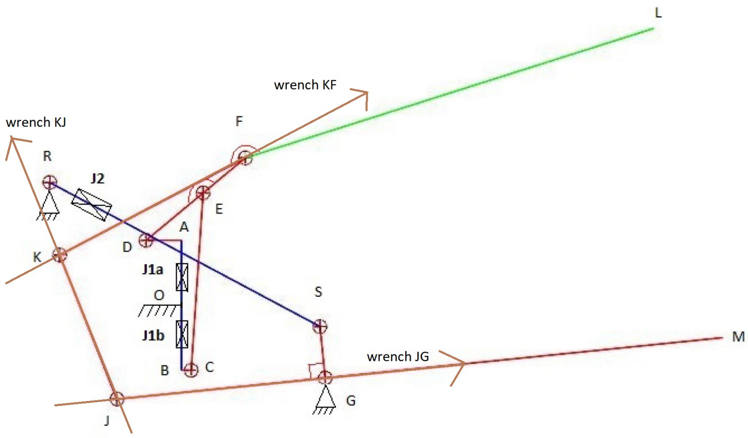
$$\varphi_{G_{per}} * \xi_{SG} = 0 \tag{11}$$

Using equation 8,10,11

$$\begin{bmatrix} \varphi_{RS}^{\mathrm{T}} \\ \varphi_{G}^{\mathrm{T}} \\ \varphi_{G_{per}}^{\mathrm{T}} \end{bmatrix} \xi_{SG} = \begin{bmatrix} \varphi_{RS} \cdot \tau_2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{d} \\ 0 \\ 0 \end{bmatrix} \tag{12}$$

4.2.2. GJKF

If we consider G to be actuated, then GJKF reduces to 4-bar mechanism with G as actuated Joint.



Wrenches along KJ,KF and JG

For GJ:

$$\xi_{KJ} = \rho_G * \dot{\theta_G} + \rho_J * \dot{\theta_J} \tag{13}$$

$$\varphi_{KJ} * \xi_{KJ} = \varphi_{KJ} * \rho_G * \dot{\theta_G} \tag{14}$$

$$\varphi_{JG} * \xi_{KJ} = 0 \tag{15}$$

For G:

$$\xi_{KJ} = \rho_F * \dot{\theta_F} + \rho_K * \dot{\theta_K} \tag{16}$$

$$\varphi_{KF} * \xi_{KJ} = 0 \tag{17}$$

Using equation 14,15 and 17

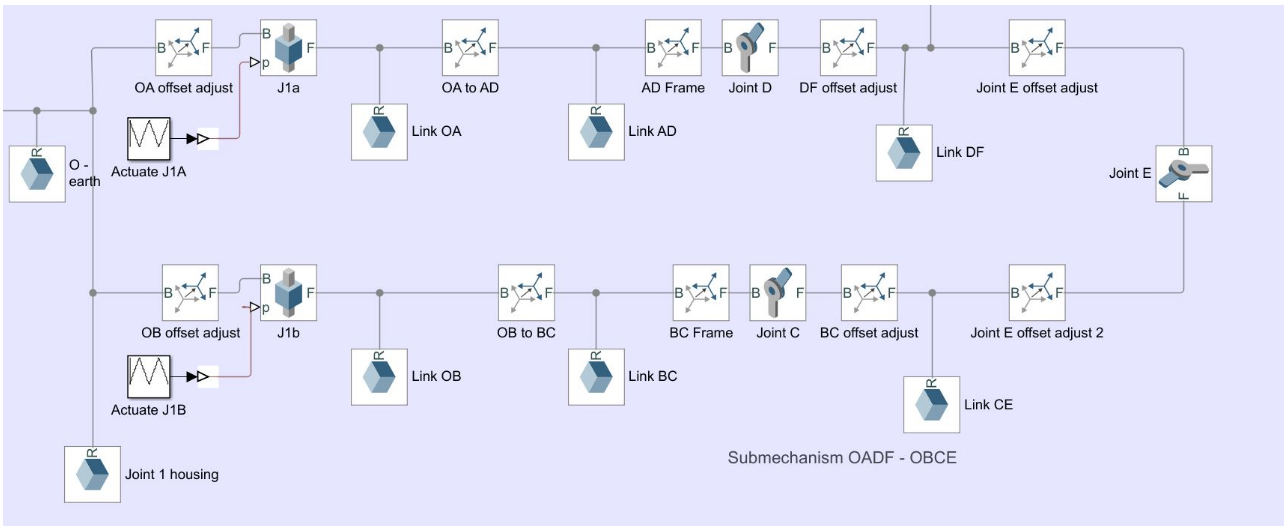
$$\begin{bmatrix} \varphi_{KJ}^{\mathrm{T}} \\ \varphi_{JG}^{\mathrm{T}} \\ \varphi_{KF}^{\mathrm{T}} \end{bmatrix} \xi_{KJ} = \begin{bmatrix} \varphi_{KJ} \cdot \rho_G & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{\theta_G} \\ 0 \\ 0 \end{bmatrix} \tag{18}$$

Thus the velocity of Point L is given by $\overrightarrow{v_L^O} = \overrightarrow{v_K^O} + \overrightarrow{\omega_F} \times \overrightarrow{r_L^O}$

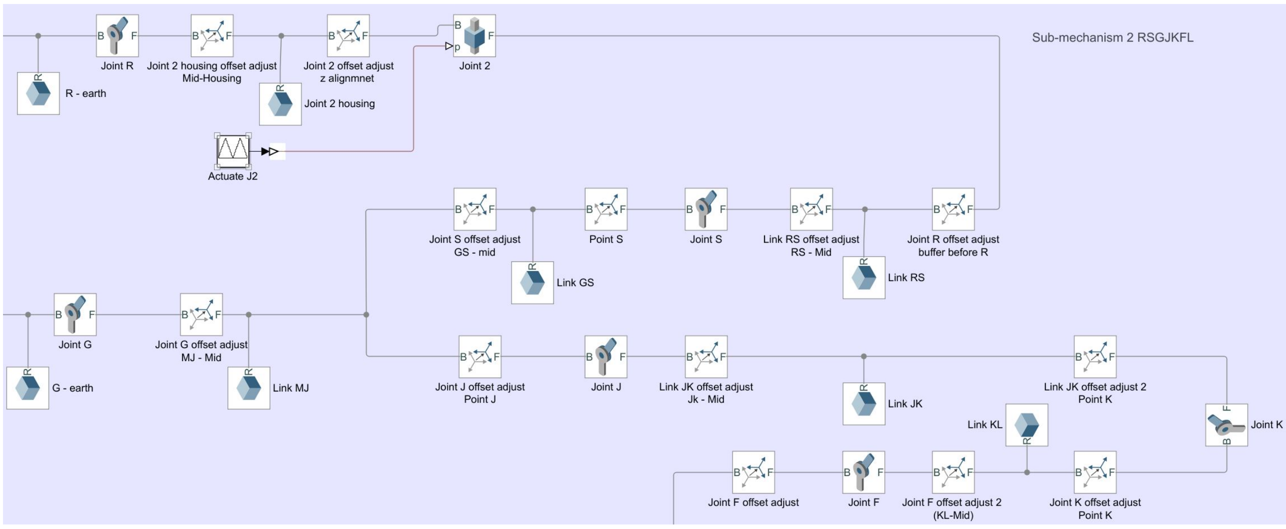
$$velocityF = \begin{bmatrix} 1.0533 * vd \\ -2.6349 * vd \\ -0.094613 * vd \end{bmatrix} \tag{19}$$

$$velocityL = \begin{bmatrix} 0.17052 * vR + 5.2183 * vd \\ -4.8466 * vR - 15.034 * vd \\ -0.018329 * vR \end{bmatrix} \tag{20}$$

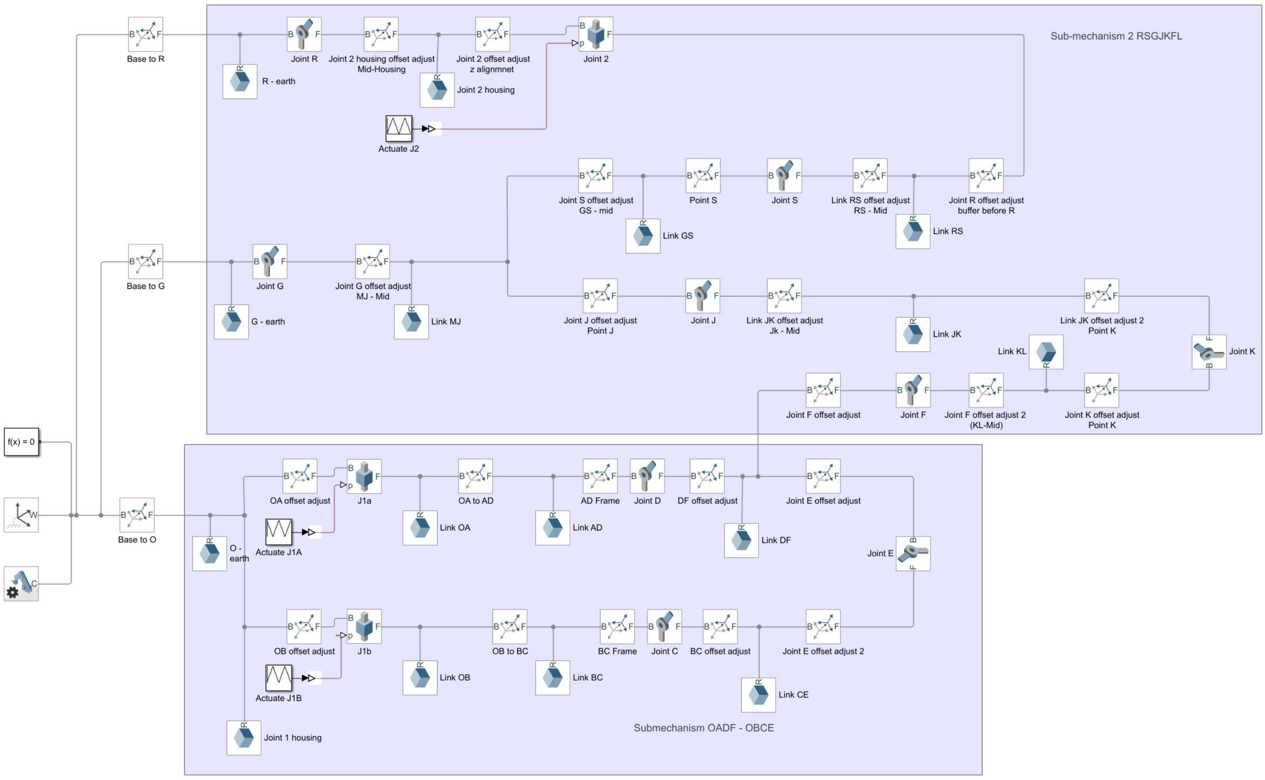
5. *Modeling with Simscape Multibody*



Layout for sub-mechanism 1



Layout for sub-mechanism 2



Combined Layout

Please find the link for Gifs of the simulation on Github astha736/AMSTR-CloPeMa/.