Modelarea robotului paralel PARAMIS

Studiu de caz

Implementarea robotilor paraleli in aplicatii medicale

Cluj-Napoca 2014

Cuprins

- Stadiul actual al cercetarilor in domeniul chirurgiei robotizate
- Necesitatea si justificare temei
- Stabilirea caietului de sarcini cu prezentarea avantajelor si dezavantajelor structurilor seriale si paralele
- Definirea si modelul geometric al unei structuri paralele noi pentru chirurgia minim invaziva – PARAMIS
- Modelul cinematic al robotului pentru chirurgie PARAMIS. Analiza singularitatilor si a spatiului de lucru.
- Proiectarea constructiva a robotului PARAMIS si realizarea unui model de comanda utilizand pachetul software MATLAB - SIMULINK
- Modelul experimental al robotului PARAMIS

Stadiul actual al cercetarilor in domeniul chirurgiei robotizate

Conceptul CMIAR

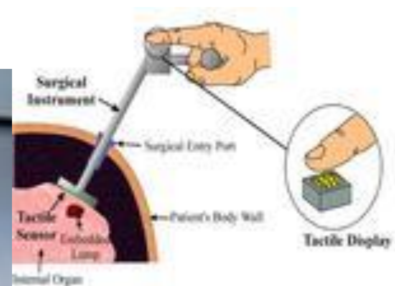
Cu aproximativ 20 de ani in urma, evolutia din tehnica face posibila introducerea unei noi tehnici de interventie chirurgicala: chirurgia minim invaziva.

In ultima parte a anilor 90, s-a concretizat o alta etapa evolutiva in dezvoltarea tehnicilor chirurgicale prin introducerea sistemelor robotizate in chirurgie. Aceste inovatii au creat conditiile necesare pentru solutii minim invazive intr-un spectru larg de proceduri chirurgicale complexe in cele mai variate specialitati (toracica, abdominala, neurologica, ortopedica, etc.).

Principiul CMIAR

Cativa metri

15 000 Km



Modul tactil

Master

Slave

Om versus robot in CMI

Chirurgi	Roboti
Puncte forte Coordonare buna mana-ochi Dexteritate mare (la o scala a omului) Flexibil si adaptabil Poate integra si prelucra informatii complexe Poate folosi informatiile calitative O bună judecata Usor de informat	**Puncte forte** O precizie geometrica mare Stabil si imperturbabil Poate fi conceput pentru o varietate mare de functii Poate fi sterilizat Rezistent la radiatii si infecţii Poate folosi diferiti senzori (chimici, fizici, acustici etc.) în control
Limitari Dexteritate limitata in afara scalei naturale Predispus la oboseala si tremur Limitare a preciziei geometrice Limitare in a folosi informatiile calitative Necesitatea unui camp de operatie mare Posibilitate limitata de sterilizare Vulnerabil la radiatii si infectii	**Limitari** Judecată slaba Dexteritate si coordonare mana-ochi limitate Limitat unor proceduri relative simple Pret ridicat Tot timpul in pas de a fi depasit din punct de vedere tehnologic Greu de construit si de reparat

AESOP

Bratul robotic AESOP (Automated Endoscopic System for Optimal Positioning)

Robotul chirurgical da Vinci ®

Necesitatea si justificarea temei abordate

Avantajele CMIAR

- Distrugerea ţesuturilor sănătoase este minimă;
- Durata de spitalizare, în majoritatea cazurilor este sub 24 de ore;
- Impactul psihologic al procedurii asupra pacientului este scăzut semnificativ;
- Datorită sistemului robotic precizia intervenţiei este sub o sutime de milimetru;
- Riscul unor tăieturi greşite (secţionare de vase, atingerea unor nervi etc.) este minim;
- Riscul infecţiilor intraoperatorii este minim;
- Se pot realiza interventii imposibile pe cale clasica.

Dezavantajele CMIAR

- Campul vizual al chirurgului este limitat;
- Ergonomia sistemului este scazuta si impune un numar mare de ore de pregatire;
- Chirurgul nu simte tesuturile (nu are feedback tactil);
- Spatiul ocupat in sala de operatie este mare;
- Numarul mic de solutii disponibile si prohibitive ca si costuri si dificil de utilizat;
- Costurile unui astfel de sistem si a unei interventii sunt foarte ridicate.

Necesitatea dezvoltarii de noi structuri robotizate in CMI

Se poate concluziona că sistemele robotizate aduc beneficii mari în sălile de operaţie, însă acestea sunt încă la început, iar reacţiile chirurgilor evidenţiază:

- **eficacitatea sistemelor existente;**
- **nevoia dezvoltării unor sisteme mai accesibile din punct de vedere economic;**
- **integrarea pe scară largă a sistemelor robotizate în sălile de operaţii;**
- **încurajarea cercetărilor în domeniu pentru găsirea unor noi concepte care să elimine limitările şi dezavantajele sistemelor existente.**

Stabilirea caietului de sarcini cu prezentarea avantajelor si dezavantajelor structurilor seriale si paralele

Sinergia ingineri - chirurgi

Dezvoltare

Cerinta

Idee

Chirurgi

Ingineri

Concepte

Inovatie

Cooperare

Integrare

Cercetare

Interdisciplinaritate

Solutie optima

Cerintele unui sistem pentru CMI

- ✓Precizie ridicata;
- ✓Spatiu de lucru mic;
- ✓Control eficient al vitezei si fortei in spatiul de lucru;
- ✓Feedback tactil;
- ✓Sisteme de siguranta;
- ✓Imun la interferentele magnetice;
- ✓Evitarea singularitatilor;
- ✓Inerţie redusa;
- ✓Sterilizare usoara;
- ✓Dimensiuni compacte si greutate redusa;
- ✓Brate compacte.

Prioritizarea cerintelor tehnice

Group:	Top Level ITEMS								Output											Completed:	☐

AHP Group Matrix 1

9	9,00	an orde...	+	1,50	somew...	⅐	0,14	demon...
8	8,00	absolut...	○	1,00	Equall...	⅛	0,13	absolu...
7	7,00	demon...	-	0,67	somew...	⅑	0,11	an ord...
6	6,00	demon...	½	0,50	half as...			
5	5,00	essenti...	⅓	0,33	clearly ...			
4	4,00	essenti...	¼	0,25	essenti...			
3	3,00	conside...	⅕	0,20	essenti...			
2	2,00	twice a...	⅙	0,17	demon...			

Input		1 Precizie ridicata	2 Spatiu de lucru mic	3 Control eficient al vitez...	4 Feedback tactil	5 Sisteme de siguranta	6 Imun la interferentele ...	7 Evitarea singularitatilor	8 Inertie redusa	9 Sterilizare usoara	10 Dimensiuni compacte...	11 Brate compacte	Importance in group
	1 Precizie ridicata		+	+	○	○	○	○	+	2	2	+	11,7%
	2 Spatiu de lucru mic			○	-	○	○	-	-	○	+	○	8,0%
	3 Control eficient al vitezei si fortei in toate punctele ...				○	○	○	○	○	○	-	○	8,4%
	4 Feedback tactil					○	○	○	+	2	2	+	11,3%
	5 Sisteme de siguranta						○	○	+	+	+	○	10,0%
	6 Imun la interferentele magnetice							○	○	○	+	○	9,3%
	7 Evitarea singularitatilor								○	+	+	+	10,3%
	8 Inertie redusa									○	○	○	8,3%
	9 Sterilizare usoara										○	-	7,1%
	10 Dimensiuni compacte si greutate redusa											○	7,2%
	11 Brate compacte												8,3%

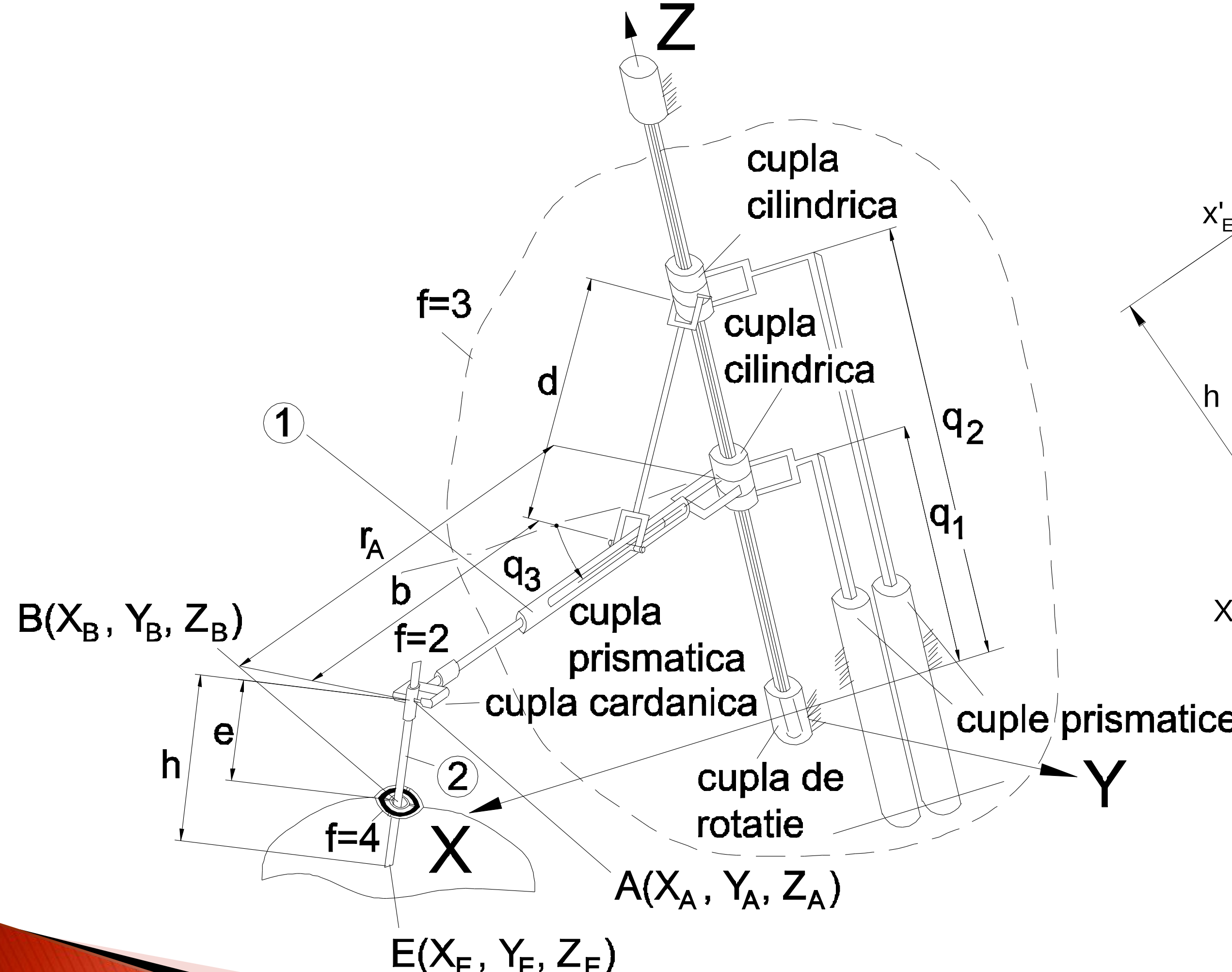
Alegerea structurii optime

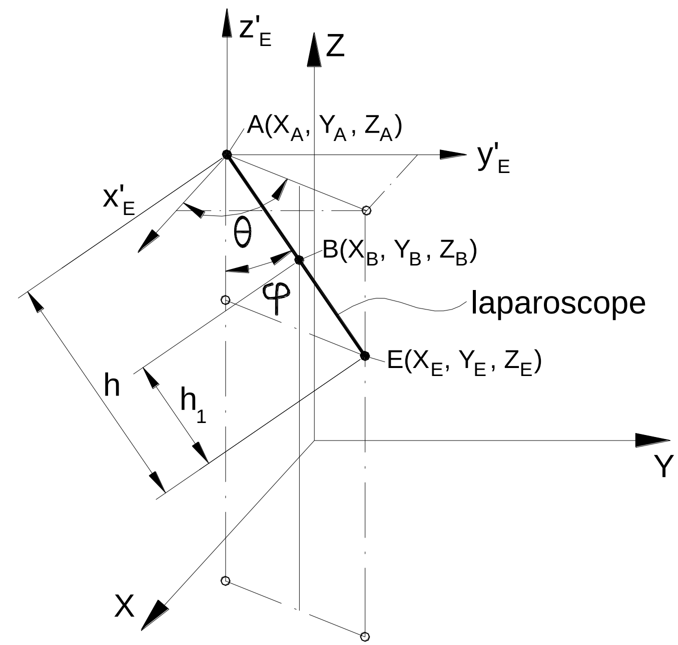
Caracteristicile structurilor paralele şi seriale			
Tendinta	**Caracteristica**	**Robot Serial**	**Robot Paralel**
↗	Precizie	Medie - mica	Foarte mare
↗	Repetabilitate	Medie - mare	Foarte mare
↘	Raport masa proprie / masa manipulată	Foarte mare	Mic
↗	Spaţiu de lucru	Mare	Mic
↗	Rigiditate	Mică	Mare
↗	Viteze, acceleratii	Medii	Foarte mari
↘	Mase în miacare	Mari	Mici

Structura mecanica / Cerinte	1 Structura seriala	2 Structura paralela	Importanta
1 Precizie ridicata	○	++	16,6%
2 Spatiu de lucru mic	○	+	6,1%
3 Control eficient al vitezei si fortei in toate punctele...	○	○	7,1%
4 Feedback tactil	○	○	15,6%
5 Sisteme de siguranta	○	○	11,6%
6 Imun la interferentele magnetice	○	○	9,7%
7 Evitarea singularitatilor	○	-	12,7%
8 Inertie redusa	○	++	6,9%
9 Sterilizare usoara	○	○	3,3%
10 Dimensiuni compacte si greutate redusa	○	+	3,6%
11 Brate compacte	○	○	6,8%
Efecte pozitive		4	
Efecte negative		1	
Efecte neutre	11	6	
Efect net		3	
Prioritizare pozitiva		26,7%	
Prioritizare negativa		-4,2%	
Efect net		22,5%	

Definirea si modelul geometric al unei structuri paralele inovative pentru chirurgia minim invaziva – PARAMIS

Schema cinematica a structurii paralele PARAMIS





Modelul geometric

Modelul geometric invers

Date

X_E, Y_E, Z_E

Necunoscute

$q_i,\ i = 1,2,3$

$X_E, Y_E, Z_E \rightarrow q_i,\ i = 1,2,3$

Modelul geometric direct

Date

$q_i,\ i = 1,2,3$

Necunoscute

X_E, Y_E, Z_E

$q_i,\ i = 1,2,3 \rightarrow X_E, Y_E, Z_E$

Modelul geometric direct

Date: $q_1\ ,\ q_2\ ,\ q_3 \quad b\ ,\ d\ ,\ h\ ;\ X_B\ ,\ Y_B,\ Z_B$

Solutie analitica!

$$r_A = b + \sqrt{d^2 - (q_2 - q_1)^2}$$

$$X_A = r_A \cos q_3\ ,\ Y_A = r_A \sin q_3\ ,\ Z_A = q_1$$

Doua cazuri:

$X_A \neq X_B\ ,\ Y_A \neq Y_B$

$$e = \sqrt{(X_B - X_A)^2 + (Y_B - Y_A)^2 + (Z_B - Z_A)^2}$$

$$\varphi = a\tan 2\left(\sqrt{1 - \left(\frac{Z_A - Z_B}{e}\right)^2},\ \frac{Z_A - Z_B}{e}\right)$$

$$\theta = a\tan 2(Y_B - Y_A,\ X_B - X_A)$$

$$\begin{cases} X_E = X_A + h \cdot \sin\varphi\cos\theta \\ Y_E = Y_A + h \cdot \sin\varphi\sin\theta \\ Z_E = Z_A - h \cdot \cos\varphi \end{cases}$$

$X_A = X_B\ ,\ Y_A = Y_B$

$$\begin{cases} X_E = X_B\ ,\ Y_E = Y_B \\ Z_E = Z_A - h \end{cases}$$

Modelul geometric invers

Date: $X_E\ ,\ Y_E\ ,\ Z_E \qquad b\ ,\ d\ ,\ h\ ,\ X_B\ ,\ Y_B\ ,\ Z_B$

Solutie analitica!

$$h_1 = \sqrt{(X_B - X_E)^2 + (Y_B - Y_E)^2 + (Z_B - Z_E)^2}$$

$$\varphi = a\tan 2\left(\sqrt{1-\left(\frac{Z_B - Z_E}{h_1}\right)^2},\quad \frac{Z_B - Z_E}{h_1}\right) \qquad \theta = a\tan 2(Y_E - Y_B,\ X_E - X_B)$$

Doua cazuri:

$X_E \neq X_B\ ,\ Y_E \neq Y_B$

$$\begin{cases} X_A = X_E - h\cdot\sin\varphi\cos\theta \\ Y_A = Y_E - h\cdot\sin\varphi\sin\theta \\ Z_A = Z_E + h\cdot\cos\varphi \end{cases}$$

$X_E = X_B\ ,\ Y_E = Y_B$

$$\begin{cases} X_A = X_E \\ Y_A = Y_E \\ Z_A = Z_E + h \end{cases}$$

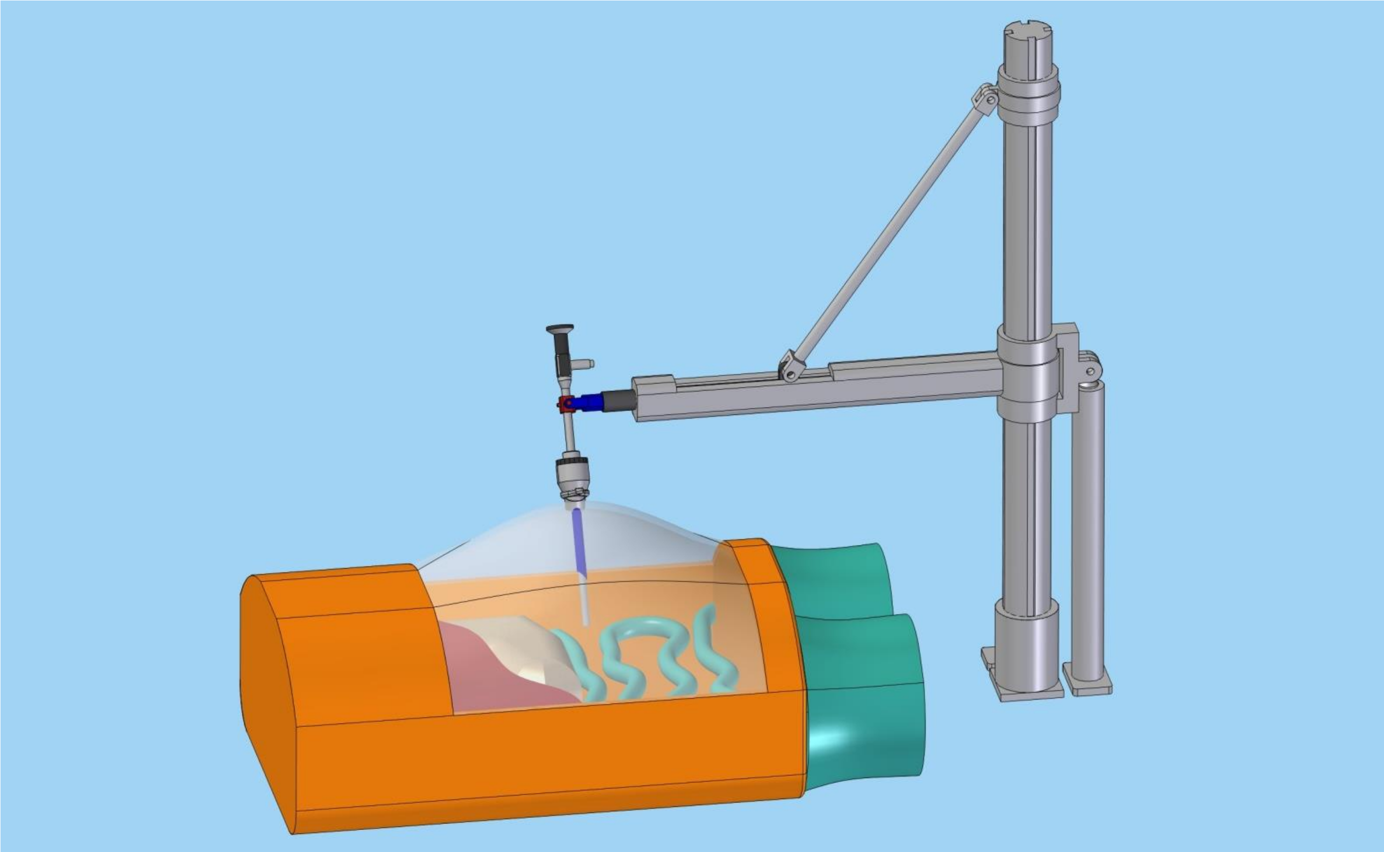
$$r_A = \sqrt{X_A^2 + Y_A^2}$$

$$q_1 = Z_A$$

$$q_2 = q_1 + \sqrt{d^2 - (r_A - b)^2}$$

$$q_3 = a\tan 2(Y_A\ ,\ X_A)$$

Modelul cinematic virtual



Robotul paralel PARAMIS – model cinematic CAD

Validarea modelului geometric

Date de intrare

q_1=535.28 mm

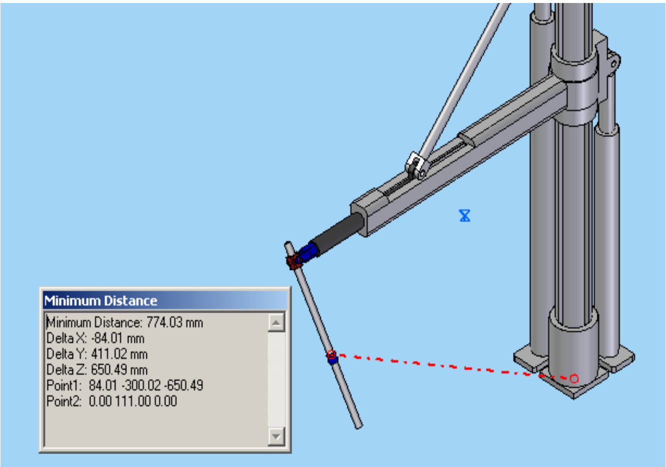
q_2=864.39 mm

q3=0°

h=270 mm

D=545.356 mm

Delta X: -84.01 mm
Delta Y: 411.02 mm
Delta Z: 650.49 mm



Date calculate

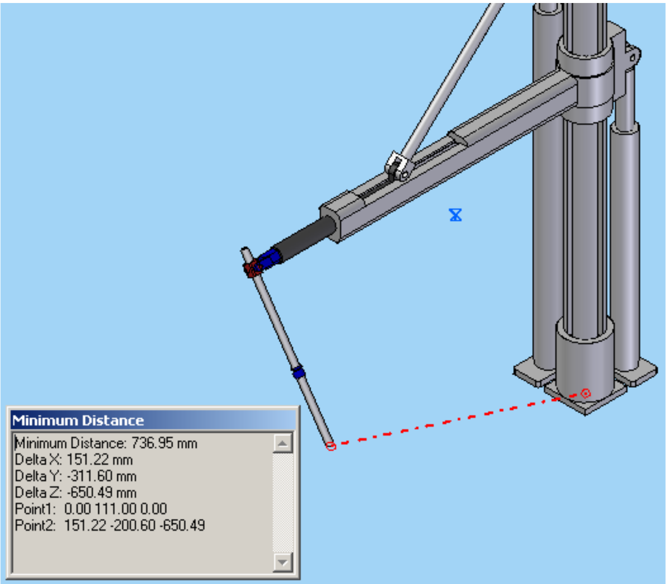
X_E=650.488 mm

Y_E=151.224 mm

Z_E=311.603 mm

Date masurate

Delta X: 151.22 mm
Delta Y: -311.60 mm
Delta Z: -650.49 mm



Modelul cinematic al robotului paralel pentru chirurgie PARAMIS. Analiza singularitatilor si a spatiului de lucru

Modelul cinematic. Generalitati

$$\begin{cases} f_1(X_E, q_1, q_2, q_3) \equiv X_E + h \cdot \dfrac{X_B - X_E}{h_1} - \left[b + \sqrt{d^2 - (q_2 - q_1)^2} \right] \cdot \cos q_3 = 0 \\ f_2(Y_E, q_1, q_2, q_3) \equiv Y_E + h \cdot \dfrac{Y_B - Y_E}{h_1} - \left[b + \sqrt{d^2 - (q_2 - q_1)^2} \right] \cdot \sin q_3 = 0 \\ f_3(Z_E, q_1) \equiv Z_E + h \cdot \dfrac{Z_B - Z_E}{h_1} - q_1 = 0 \end{cases}$$

$$X_E = \left[b + \sqrt{d^2 - (q_2 - q_1)^2} \right] \cdot \cos q_3 - h \cdot \frac{X_B - X_E}{h_1}$$

$$Y_E = \left[b + \sqrt{d^2 - (q_2 - q_1)^2} \right] \cdot \sin q_3 - h \cdot \frac{Y_B - Y_E}{h_1}$$

$$Z_E = q_1 - h \cdot \frac{Z_B - Z_E}{h_1}$$

Modelul cinematic. Generalitati

$$A \cdot \dot{X} + B \cdot \dot{q} = 0$$

$$A = \begin{bmatrix} \frac{\partial f_1}{\partial X_E} & \frac{\partial f_1}{\partial Y_E} & \frac{\partial f_1}{\partial Z_E} \\ \frac{\partial f_2}{\partial X_E} & \frac{\partial f_2}{\partial Y_E} & \frac{\partial f_2}{\partial Z_E} \\ \frac{\partial f_3}{\partial X_E} & \frac{\partial f_3}{\partial Y_E} & \frac{\partial f_3}{\partial Z_E} \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{\partial f_1}{\partial q_1} & \frac{\partial f_1}{\partial q_2} & \frac{\partial f_1}{\partial q_3} \\ \frac{\partial f_2}{\partial q_1} & \frac{\partial f_2}{\partial q_2} & \frac{\partial f_2}{\partial q_3} \\ \frac{\partial f_3}{\partial q_1} & \frac{\partial f_3}{\partial q_2} & \frac{\partial f_3}{\partial q_3} \end{bmatrix}$$

Modelul cinematic. Generalitati

$$A \cdot \ddot{X} + \dot{A} \cdot \dot{X} + B \cdot \ddot{q} + \dot{B} \cdot \dot{q} = 0$$

$$\dot{A} = \begin{bmatrix} \frac{d}{dt}\left(\frac{\partial f_1}{\partial X_E}\right) & \frac{d}{dt}\left(\frac{\partial f_1}{\partial Y_E}\right) & \frac{d}{dt}\left(\frac{\partial f_1}{\partial Z_E}\right) \\ \frac{d}{dt}\left(\frac{\partial f_2}{\partial X_E}\right) & \frac{d}{dt}\left(\frac{\partial f_2}{\partial Y_E}\right) & \frac{d}{dt}\left(\frac{\partial f_2}{\partial Z_E}\right) \\ \frac{d}{dt}\left(\frac{\partial f_3}{\partial X_E}\right) & \frac{d}{dt}\left(\frac{\partial f_3}{\partial Y_E}\right) & \frac{d}{dt}\left(\frac{\partial f_3}{\partial Z_E}\right) \end{bmatrix}$$

$$\dot{B} = \begin{bmatrix} \frac{d}{dt}\left(\frac{\partial f_1}{\partial q_1}\right) & \frac{d}{dt}\left(\frac{\partial f_1}{\partial q_2}\right) & \frac{d}{dt}\left(\frac{\partial f_1}{\partial q_3}\right) \\ \frac{d}{dt}\left(\frac{\partial f_2}{\partial q_1}\right) & \frac{d}{dt}\left(\frac{\partial f_2}{\partial q_2}\right) & \frac{d}{dt}\left(\frac{\partial f_2}{\partial q_3}\right) \\ \frac{d}{dt}\left(\frac{\partial f_3}{\partial q_1}\right) & \frac{d}{dt}\left(\frac{\partial f_3}{\partial q_2}\right) & \frac{d}{dt}\left(\frac{\partial f_3}{\partial q_3}\right) \end{bmatrix}$$

Modelul cinematic direct pentru viteze

$$\dot{X} = -A^{-1} \cdot B \cdot \dot{q}$$

$$B = \begin{bmatrix} \frac{q_1 - q_2}{\sqrt{d^2 - (q_2 - q_1)^2}} \cdot \cos q_3 & \frac{q_2 - q_1}{\sqrt{d^2 - (q_2 - q_1)^2}} \cdot \cos q_3 & \left[b + \sqrt{d^2 - (q_2 - q_1)^2} \right] \cdot \sin q_3 \\ \frac{q_1 - q_2}{\sqrt{d^2 - (q_2 - q_1)^2}} \cdot \sin q_3 & \frac{q_2 - q_1}{\sqrt{d^2 - (q_2 - q_1)^2}} \cdot \sin q_3 & -\left[b + \sqrt{d^2 - (q_2 - q_1)^2} \right] \cdot \cos q_3 \\ -1 & 0 & 0 \end{bmatrix}$$

$$A^{-1} = \frac{1}{\left(1 - \frac{h}{h_1}\right)^2} \cdot Ma = \frac{h_1}{(h_1 - h)} \cdot$$

$$\cdot \begin{bmatrix} 1 - \frac{h}{h_1^3}(X_B - X_E)^2 & -\frac{h}{h_1^3} \cdot (Y_B - Y_E) \cdot (X_B - X_E) & -\frac{h}{h_1^3} \cdot (Z_B - Z_E) \cdot (X_B - X_E) \\ -\frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Y_B - Y_E) & 1 - \frac{h}{h_1^3} \cdot (Y_B - Y_E)^2 & -\frac{h}{h_1^3} \cdot (Z_B - Z_E) \cdot (Y_B - Y_E) \\ -\frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Z_B - Z_E) & -\frac{h}{h_1^3} \cdot (Y_B - Y_E) \cdot (Z_B - Z_E) & 1 - \frac{h}{h_1^3} \cdot (Z_B - Z_E)^2 \end{bmatrix}$$

Modelul cinematic direct pentru viteze

$$\dot{X}_E = \frac{h_1}{(h-h_1)} \cdot \left(1 - \frac{h}{h_1^3} \cdot (X_B - X_E)^2\right) \cdot \left(\frac{(\dot{q}_2 - \dot{q}_1)}{AA} \cdot \cos q_3 + C \cdot \dot{q}_3 \cdot \sin q_3\right) + \frac{h_1}{h-h_1} \cdot \frac{(\dot{q}_2 - \dot{q}_1)}{AA} \cdot \frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Y_B - Y_E) \cdot \sin q_3 +$$
$$\frac{h_1}{h-h_1} \cdot \frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Z_B - Z_E) \cdot \dot{q}_1 + \frac{h_1}{h-h_1} \cdot \frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Y_B - Y_E) \cdot C \cdot \dot{q}_3 \cdot \cos q_3$$

$$\dot{Y}_E = \frac{h_1}{(h-h_1)} \cdot \left(1 - \frac{h}{h_1^3} \cdot (Y_B - Y_E)^2\right) \cdot \left(\frac{(\dot{q}_2 - \dot{q}_1)}{AA} \cdot \sin q_3 + C \cdot \dot{q}_3 \cdot \sin q_3\right) + \frac{h_1}{h-h_1} \cdot \frac{(\dot{q}_2 - \dot{q}_1)}{AA} \cdot \frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Y_B - Y_E) \cdot \sin q_3 +$$
$$\frac{h_1}{h-h_1} \cdot \frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Z_B - Z_E) \cdot \dot{q}_1 + \frac{h_1}{h-h_1} \cdot \frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Y_B - Y_E) \cdot C \cdot \dot{q}_3 \cdot \cos q_3$$

$$\dot{Z}_E = \frac{h_1}{(h-h_1)} \cdot (X_B - X_E) \cdot (Z_B - Z_E) \cdot \left(\frac{(\dot{q}_2 - \dot{q}_1)}{AA} \cdot \cos q_3 - C \cdot \dot{q}_3 \cdot \sin q_3\right) + \frac{h_1}{h-h_1} \cdot \frac{h}{h_1^3} \cdot (Y_B - Y_E) \cdot (Z_B - Z_E) \cdot \left(\frac{(\dot{q}_2 - \dot{q}_1)}{AA} \cdot \sin q_3 + C \cdot \dot{q}_3 \cdot \cos q_3\right) +$$
$$+ \frac{h_1}{h-h_1} \cdot \dot{q}_1 \cdot \left(1 - \frac{h}{h_1^3} \cdot (Z_B - Z_E)^2\right)$$

Solutie analitica!

Modelul cinematic invers pentru viteze

$$\dot{q} = -B^{-1} \cdot A \cdot \dot{X}$$

$$B^{-1} = \frac{1}{\frac{q_2 - q_1}{\sqrt{d^2 - (q_2 - q_1)^2}} \cdot \left[b + \sqrt{d^2 - (q_2 - q_1)^2} \right]} \cdot Mb =$$

$$= \begin{bmatrix} 0 & 0 & -1 \\ \frac{\sqrt{d^2 - (q_2 - q_1)^2}}{q_2 - q_1} \cdot \cos q_3 & \frac{\sqrt{d^2 - (q_2 - q_1)^2}}{q_2 - q_1} \cdot \sin q_3 & -1 \\ \frac{1}{b + \sqrt{d^2 - (q_2 - q_1)^2}} \cdot \sin q_3 & -\frac{1}{b + \sqrt{d^2 - (q_2 - q_1)^2}} \cdot \cos q_3 & 0 \end{bmatrix}$$

$$A = \begin{bmatrix} 1 - \frac{h}{h_1} + \frac{h \cdot (X_B - X_E)^2}{h_1^3} & \frac{h \cdot (X_B - X_E) \cdot (Y_B - Y_E)}{h_1^3} & \frac{h \cdot (X_B - X_E) \cdot (Z_B - Z_E)}{h_1^3} \\ \frac{h \cdot (Y_B - Y_E) \cdot (X_B - X_E)}{h_1^3} & 1 - \frac{h}{h_1} + \frac{h \cdot (Y_B - Y_E)^2}{h_1^3} & \frac{h \cdot (Y_B - Y_E) \cdot (Z_B - Z_E)}{h_1^3} \\ \frac{h \cdot (Z_B - Y_E) \cdot (Z_B - X_E)}{h_1^3} & \frac{h \cdot (Z_B - Y_E) \cdot (Y_B - Y_E)}{h_1^3} & 1 - \frac{h}{h_1} + \frac{h \cdot (Z_B - Z_E)^2}{h_1^3} \end{bmatrix}$$

Modelul cinematic invers pentru viteze

$$\dot{q}_1 = \dot{Z}_E - \dot{Z}_E \cdot \frac{h}{h_1} + \frac{h}{h_1^3} \cdot (Z_B - Z_E) \cdot \left[\dot{X}_E (X_B - X_E) + \dot{Y}_E (Y_B - Y_E) + \dot{Z}_E (Z_B - Z_E)\right]$$

$$\dot{q}_2 = \dot{q}_1 - AA \cdot E \cdot [(X_B - X_E) \cdot \cos q_3 + (Y_B - Y_E) \cdot \sin q_3] - \left(1 - \frac{h}{h_1}\right) \cdot AA \cdot \left(\dot{X}_E \cdot \cos q_3 + \dot{Y}_E \cdot \sin q_3\right)$$

$$\dot{q}_3 = \frac{1}{C} \cdot E \cdot [(Y_B - Y_E) \cdot \cos q_3 - (X_B - X_E) \cdot \sin q_3] + \left(1 - \frac{h}{h_1}\right) \cdot \frac{1}{C} \left(\dot{Y}_E \cdot \cos q_3 - \dot{X}_E \cdot \sin q_3\right)$$

Solutie analitica!

Modelul cinematic direct pentru acceleratii

$$\ddot{X} = -A^{-1} \cdot \left(\dot{A} \cdot \dot{X} + B \cdot \ddot{q} + \dot{B} \cdot \dot{q}\right)$$

$$\ddot{X}_E = (-1) \cdot \left(\frac{h_1}{h_1 - h}\right) \cdot \left[\left(1 - \frac{h}{h_1^3} \cdot (X_B - X_E)^2\right) \cdot (DAX_{11} + BBDQ_{11} + DBQ_{11}) - \frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Y_B - Y_E) \cdot (DAX_{21} + BBDQ_{21} + DBQ_{21}) - \right.$$

$$\left. - \frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Z_B - Z_E) \cdot (DAX_{31} + BBDQ_{31} + DBQ_{31})\right]$$

$$\ddot{Y}_E = (-1) \cdot \left(\frac{h_1}{h_1 - h}\right) \cdot \left[-\frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Y_B - Y_E) \cdot (DAX_{11} + BBDQ_{11} + DBQ_{11}) + \left(1 - \frac{h}{h_1^3} \cdot (Y_B - Y_E)^2\right) \cdot (DAX_{21} + BBDQ_{21} + DBQ_{21}) - \right.$$

$$\left. - \frac{h}{h_1^3} \cdot (Y_B - Y_E) \cdot (Z_B - Z_E) \cdot (DAX_{31} + BBDQ_{31} + DBQ_{31})\right]$$

$$\ddot{Z}_E = (-1) \cdot \left(\frac{h_1}{h_1 - h}\right) \cdot \left[-\frac{h}{h_1^3} \cdot (X_B - X_E) \cdot (Z_B - Z_E) \cdot (DAX_{11} + BBDQ_{11} + DBQ_{11}) - \frac{h}{h_1^3} \cdot (Y_B - Y_E) \cdot (Z_B - Z_E) \cdot (DAX_{21} + BBDQ_{21} + DBQ_{21}) - \right.$$

$$\left. - + \left(1 - \frac{h}{h_1^3} \cdot (Z_B - Z_E)^2\right) \cdot (DAX_{31} + BBDQ_{31} + DBQ_{31})\right]$$

Solutie analitica!

Modelul cinematic invers pentru acceleratii

$$\ddot{q} = -B^{-1} \cdot \left(\dot{A} \cdot \dot{X} + A \cdot \ddot{X} + \dot{B} \cdot \dot{q} \right)$$

$$\ddot{q}_1 = DDAX_{31} + DAX_{31} + BDQ_{31}$$

$$\ddot{q}_2 = (-1) \cdot \left[A \cdot \left(DDAX_{11} + DAX_{11} + BDQ_{11} \right) \cdot \cos q_3 + + A \cdot \left(DDAX_{21} + DAX_{21} + BDQ_{21} \right) - \left(DDAX_{31} + DAX_{31} + BDQ_{31} \right) \cdot \sin q_3 \right]$$

$$\ddot{q}_3 = (-1) \cdot \left[\left(DDAX_{11} + DAX_{11} + BDQ_{11} \right) \cdot \frac{\sin q_3}{C} - \left(DDAX_{21} + DAX_{21} + BDQ_{21} \right) \cdot \frac{\cos q_3}{C} \right]$$

Solutie analitica!

Analiza singularitatilor

$$A \cdot \dot{X} + B \cdot \dot{q} = 0$$

Tipul 1. $\det(B) = 0$

$$\det(B) = \frac{q_2 - q_1}{\sqrt{d^2 - (q_2 - q_1)^2}} \cdot \left[b + \sqrt{d^2 - (q_2 - q_1)^2} \right]$$

$$q_1 = q_2$$

$$d^2 = (q_2 - q_1)^2 \equiv d = q_2 - q_1$$

$$b + \sqrt{d^2 - (q_2 - q_1)^2} = 0$$

Tipul 2. $\det(A) = 0$

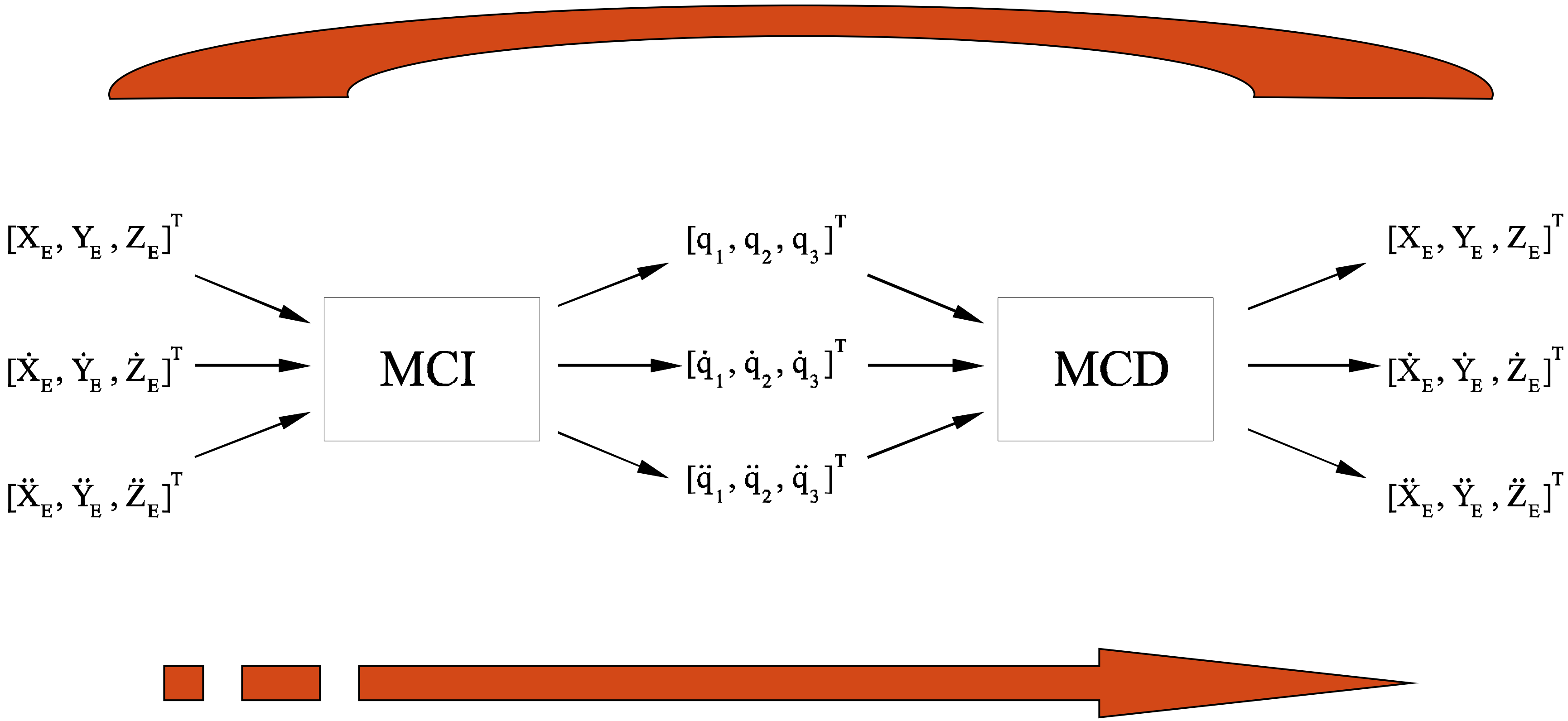
$$\det(A) = \left(1 - \frac{h}{h_1}\right)^2$$

$$h = h_1$$

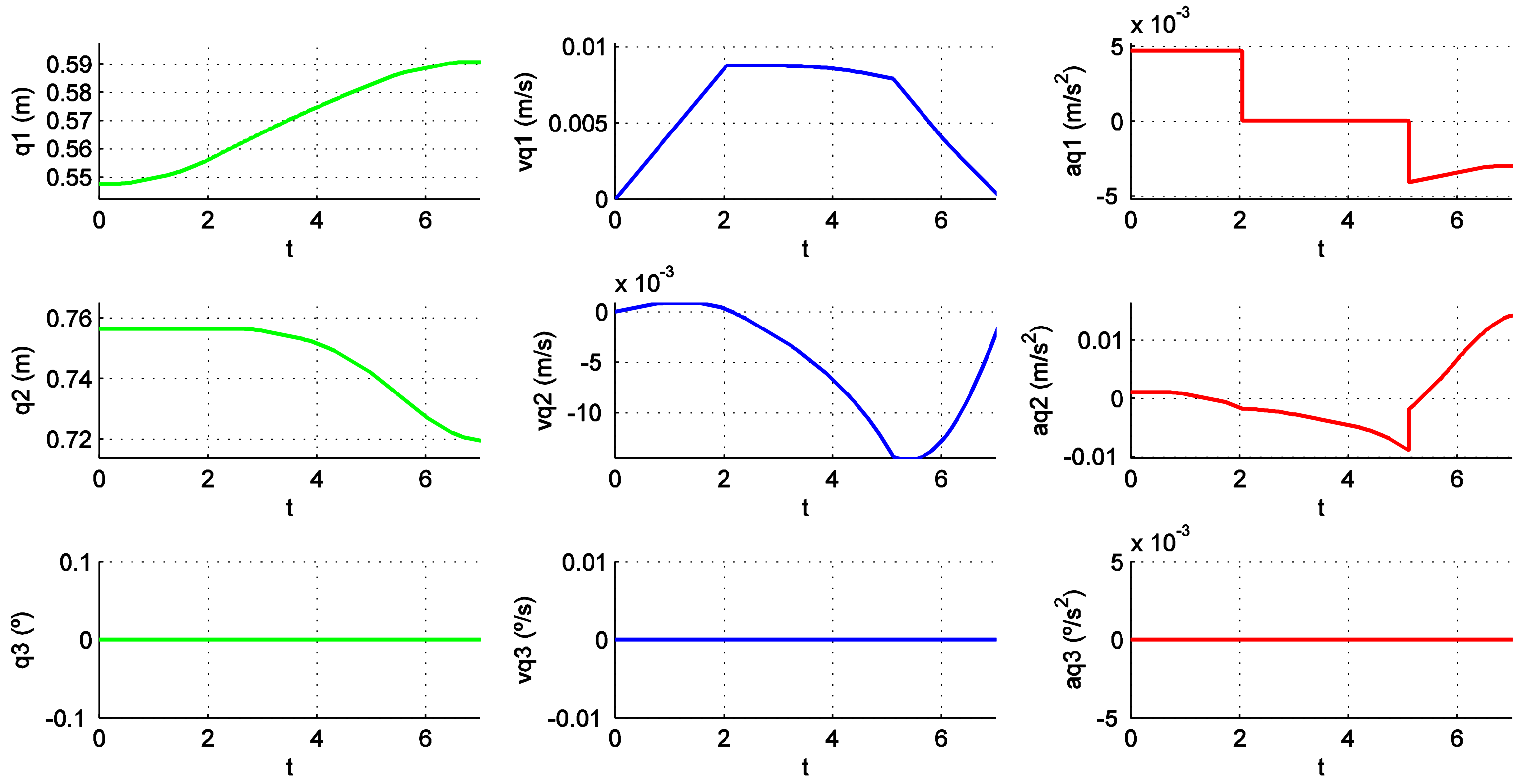
Tipul 3. $\det(A) = 0$ si $\det(B) = 0$

Nu exista puncte de singulatitate!

Validarea modelului matematic



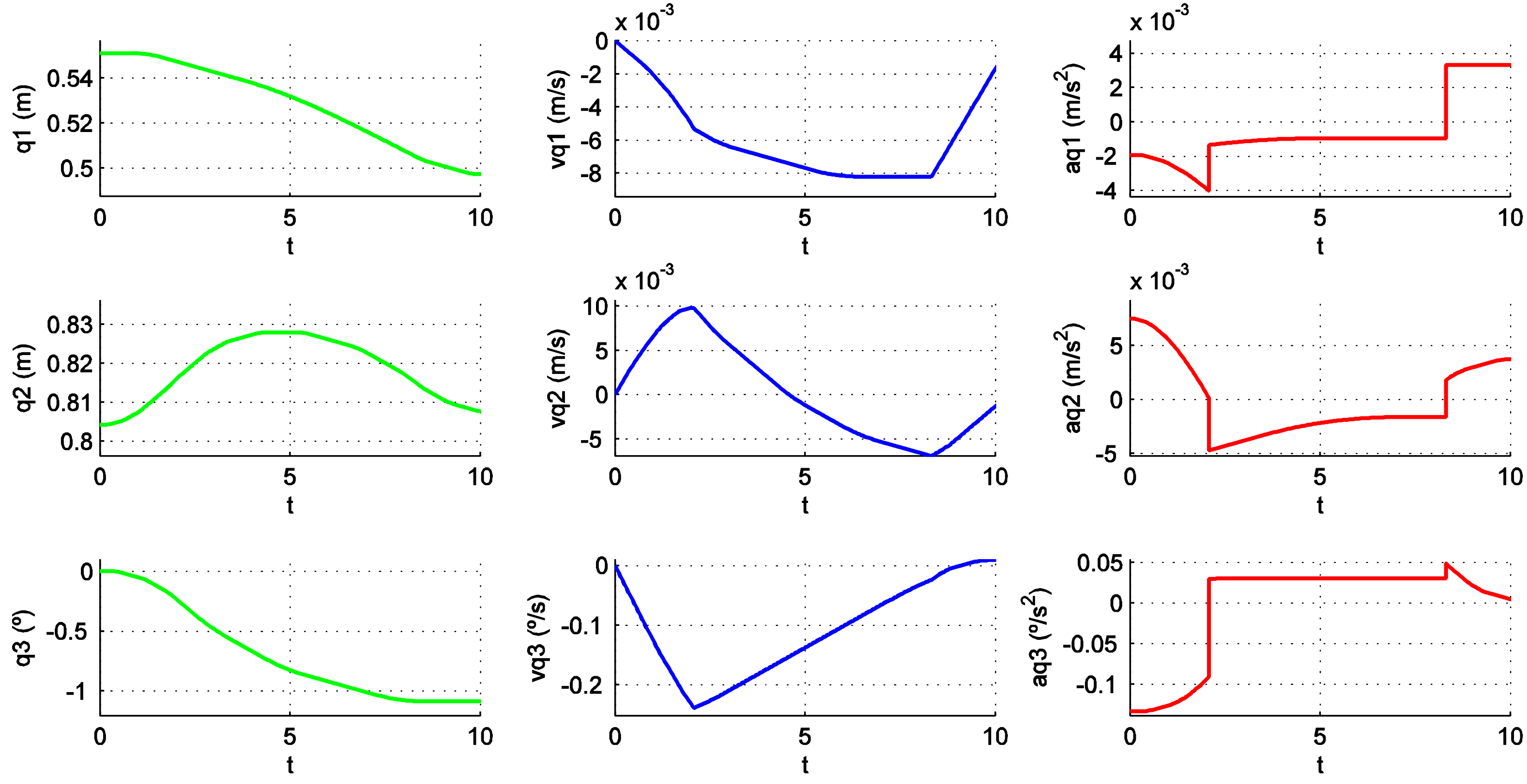
Traiectorii de miscare



Traiectorie paralelă cu axa Z cu laparoscopul aflat în poziţie oarecare

$$X_{E_i} = X_{E_f} = 0.660\,m, , Y_{E_i} = Y_{E_f} = 0\,m, Z_{E_i} = 0.281\,m, Z_{E_f} = 0.331\,m$$

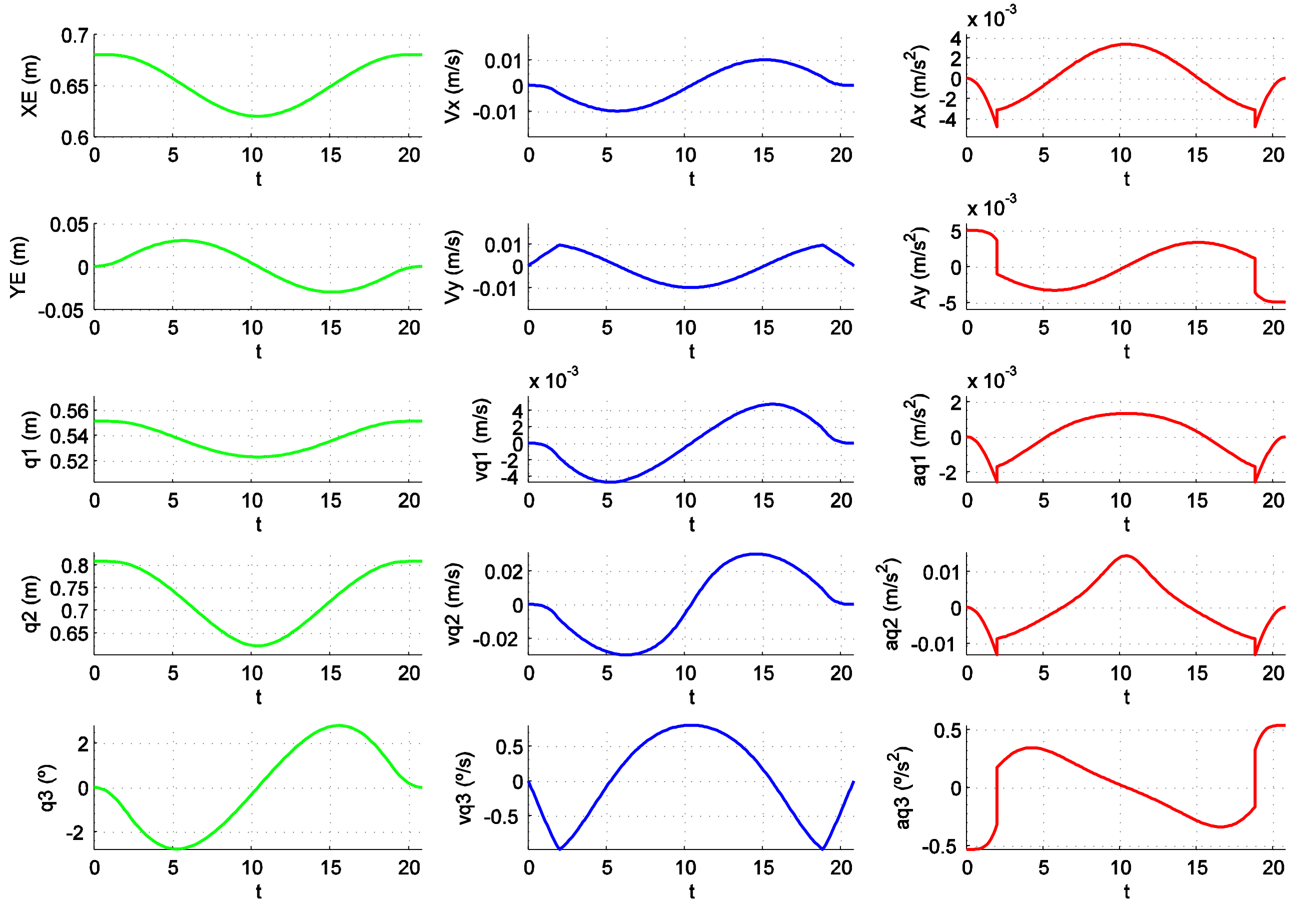
Traiectorii de miscare



Deplasarea robotului, pe o traiectorie liniară între două puncte în spaţiul de lucru

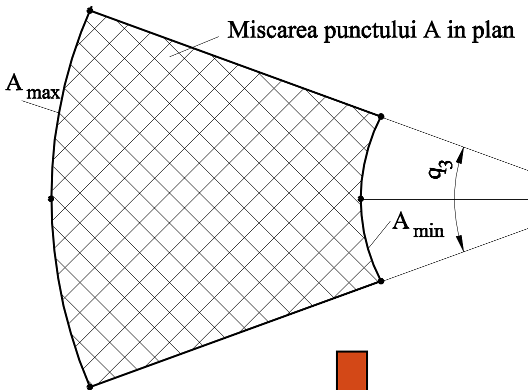
$$X_{E_i} = 0.679\, m, X_{Ef} = 0.750\, m, Y_{E_i} = 0\, m, Y_{E_f} = 0.020\, m, Z_{E_i} = 0.281\, m, Z_{E_f} = 0.250\, m$$

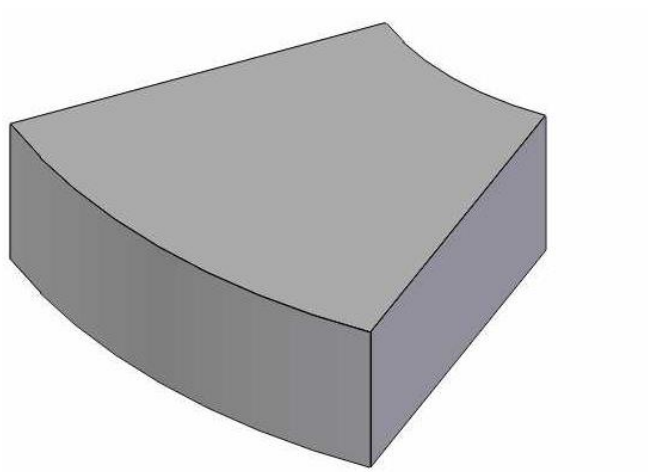
Traiectorii de miscare

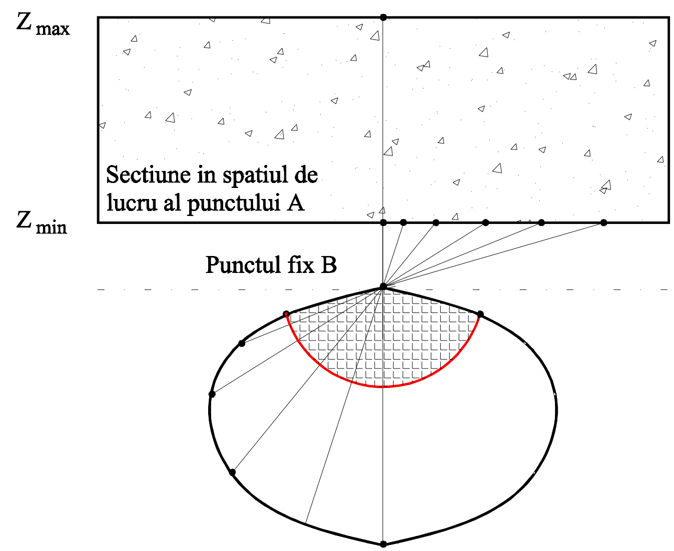


Traiectorie circulară cu parametrii de mişcare R=0.03 m, v=0.01 m/s a = 0.005 m/s^2

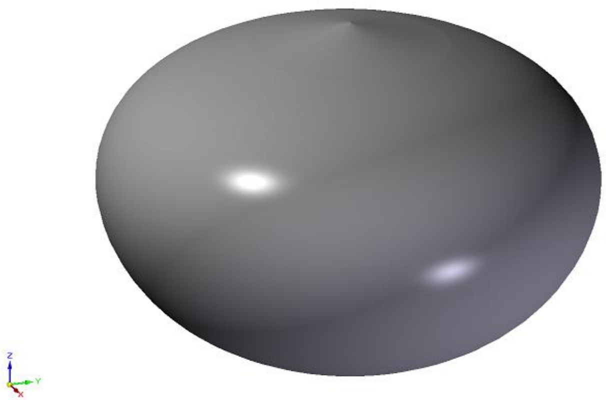
Determinarea geometrica a spatiului de lucru



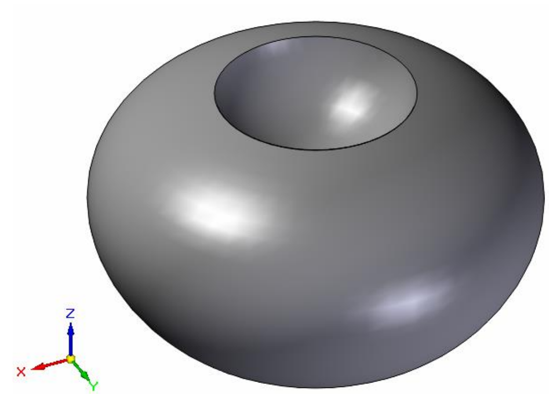




Determinarea geometrica a spatiului de lucru

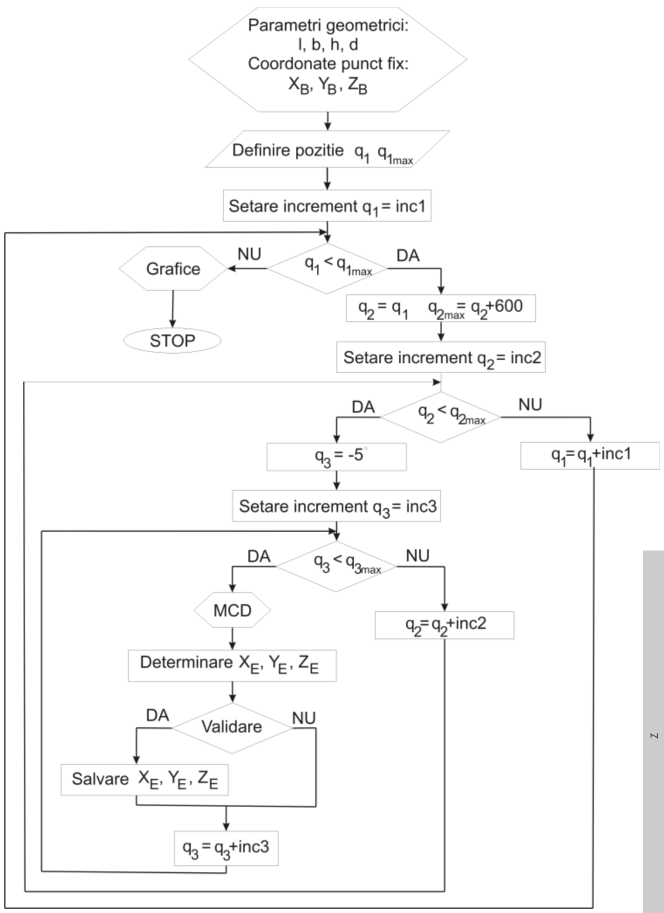


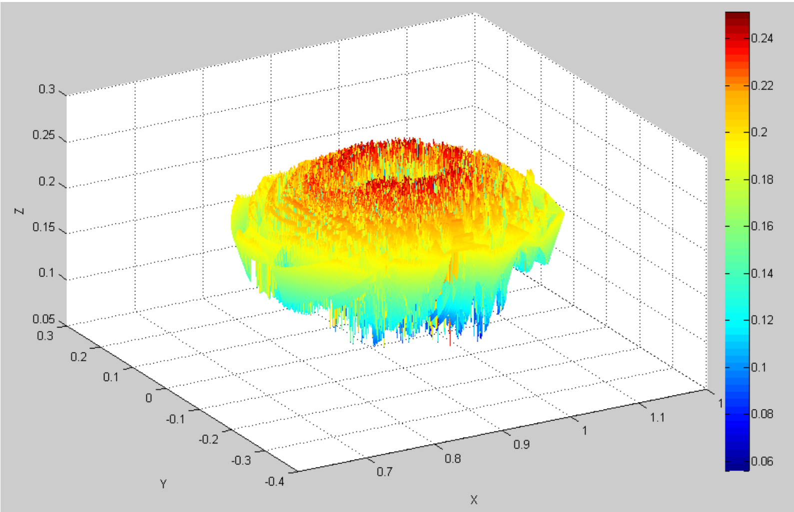
Spaţiul de lucru
efectiv al punctului E

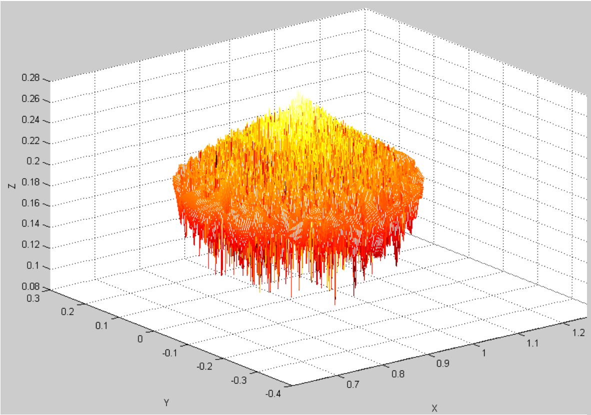


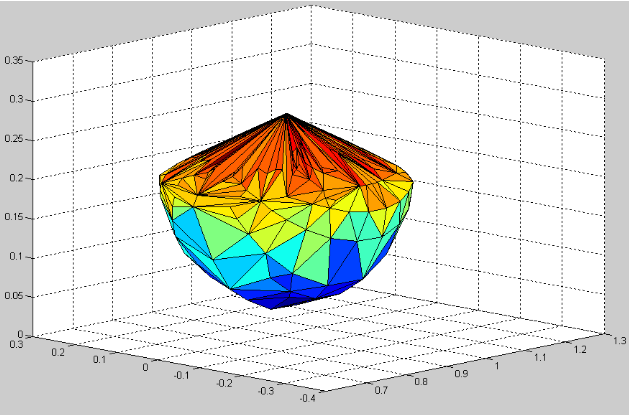
Spaţiul de lucru cu
vizibilitate al punctului E

Determinarea analitica a spatiului de lucru



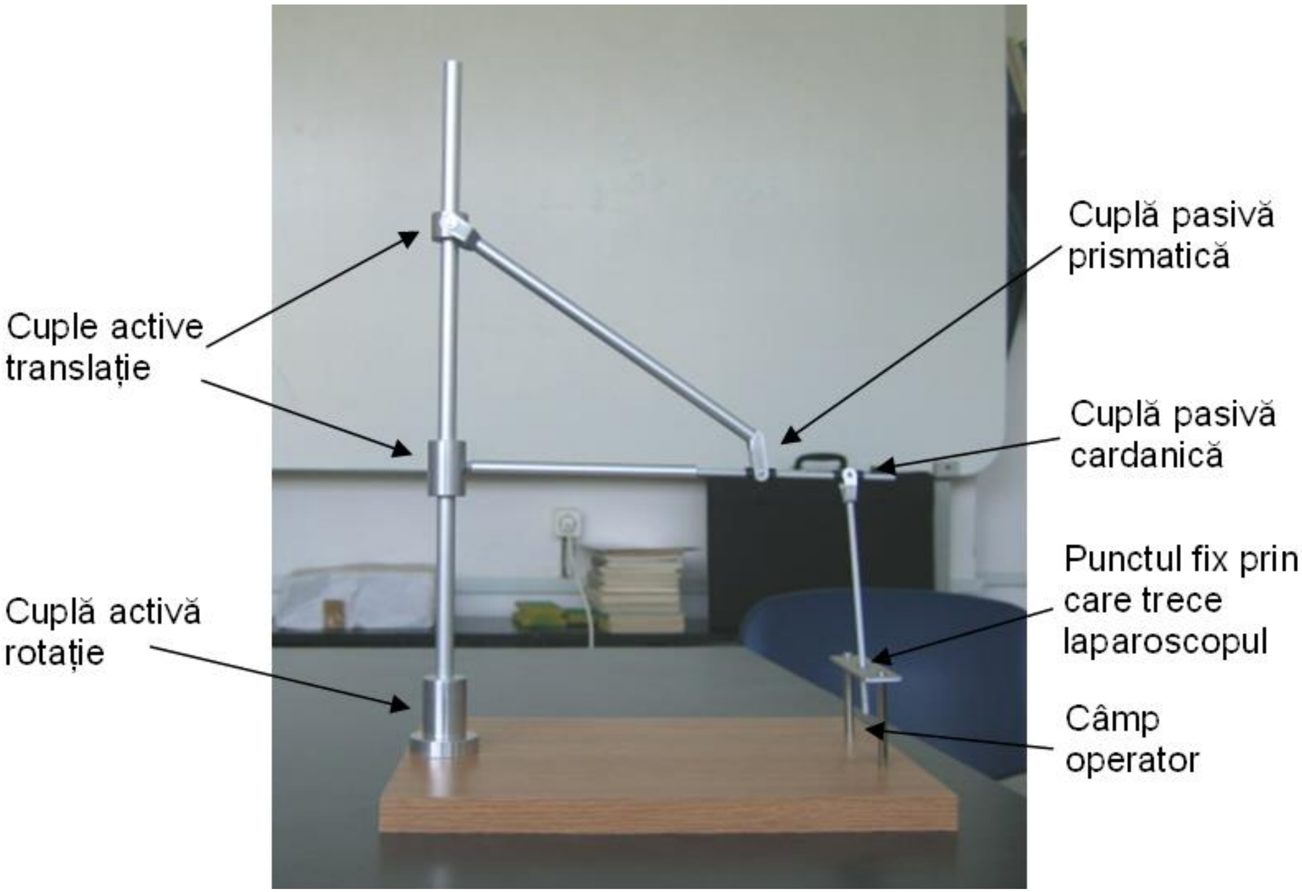




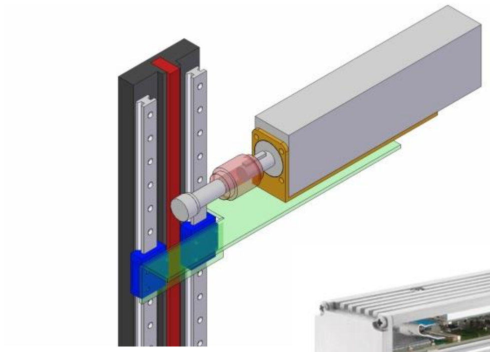


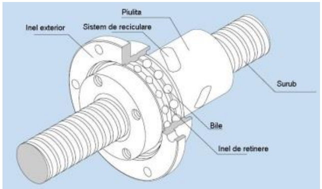
Proiectarea constructiva a robotului paralel PARAMIS si realizarea unui model de comanda utilizand pachetul software MATLAB - SIMULINK

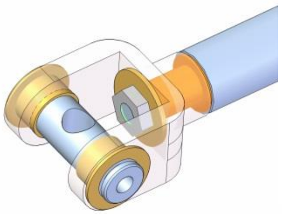
Macheta functionala

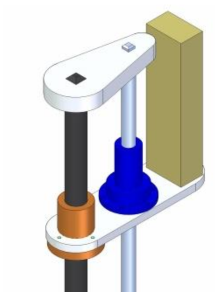


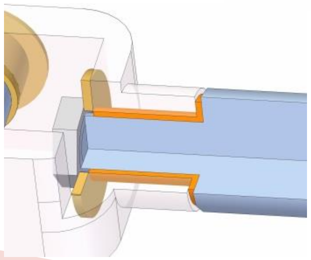
Realizarea modelului experimental

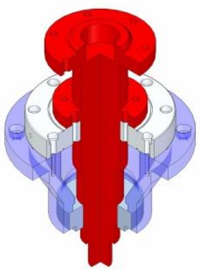


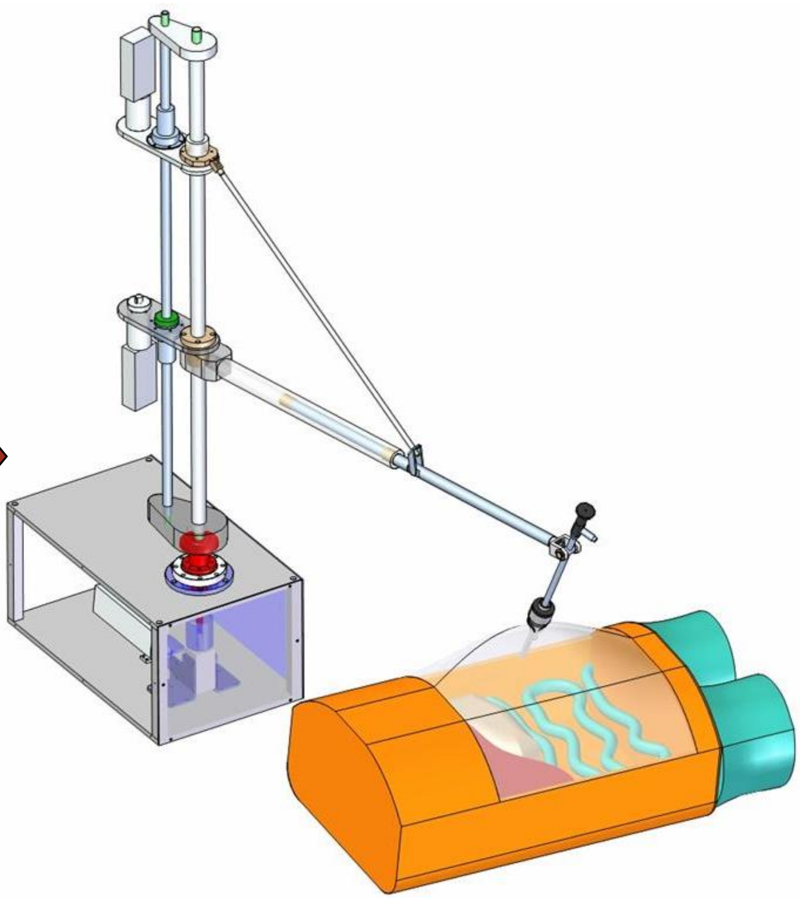




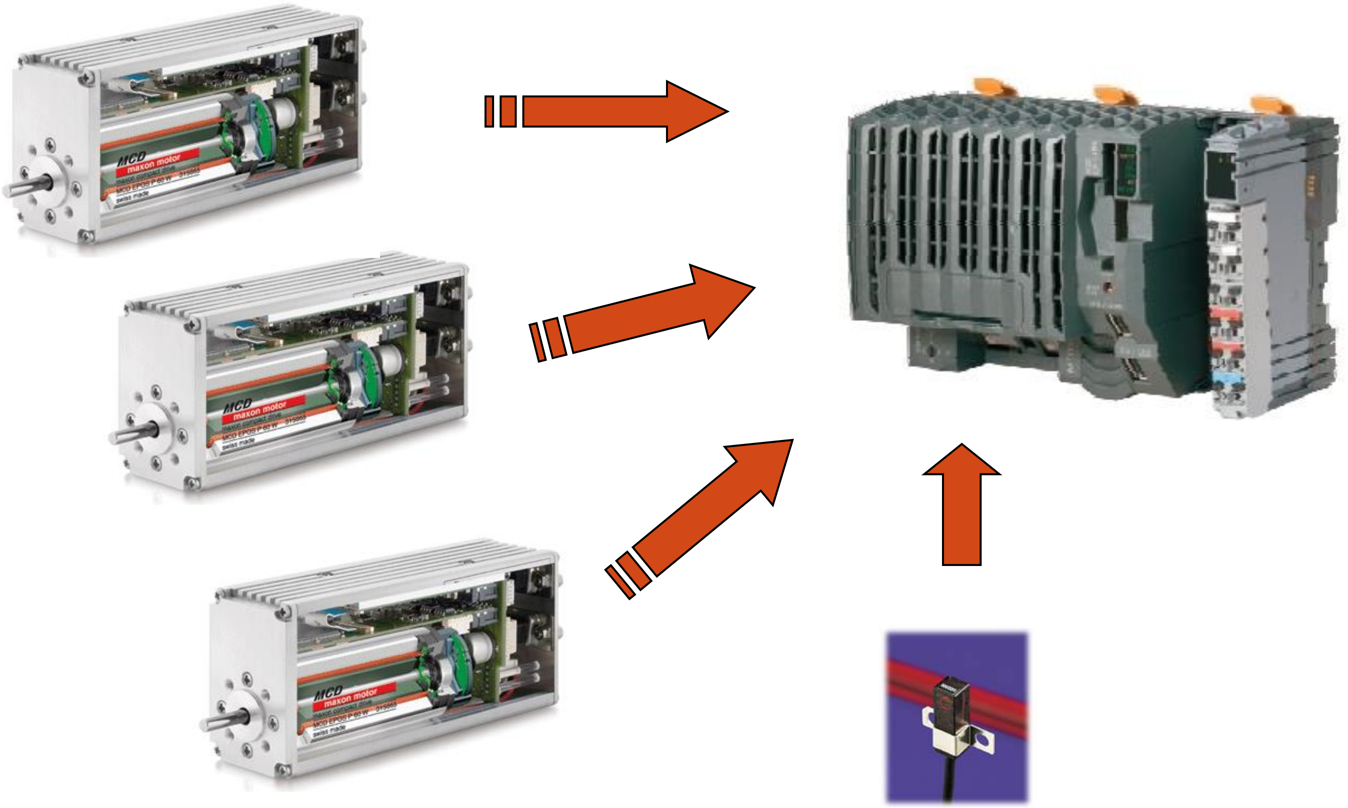




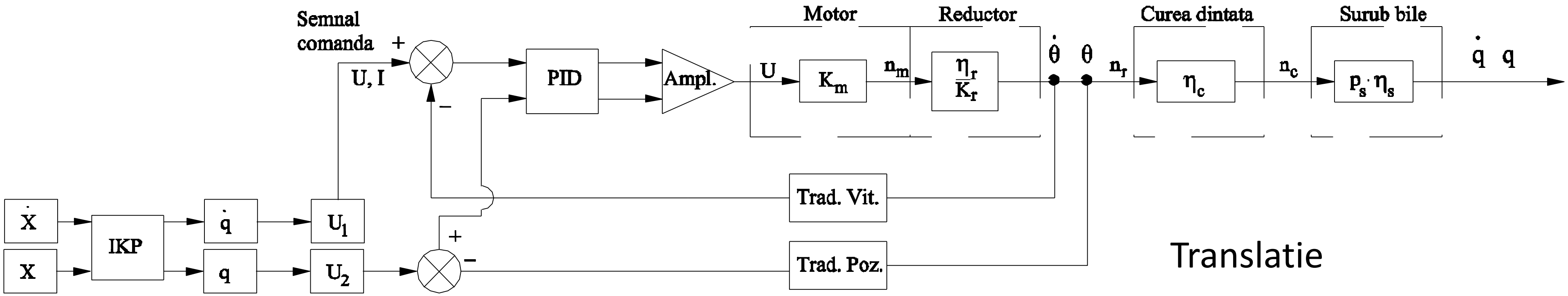


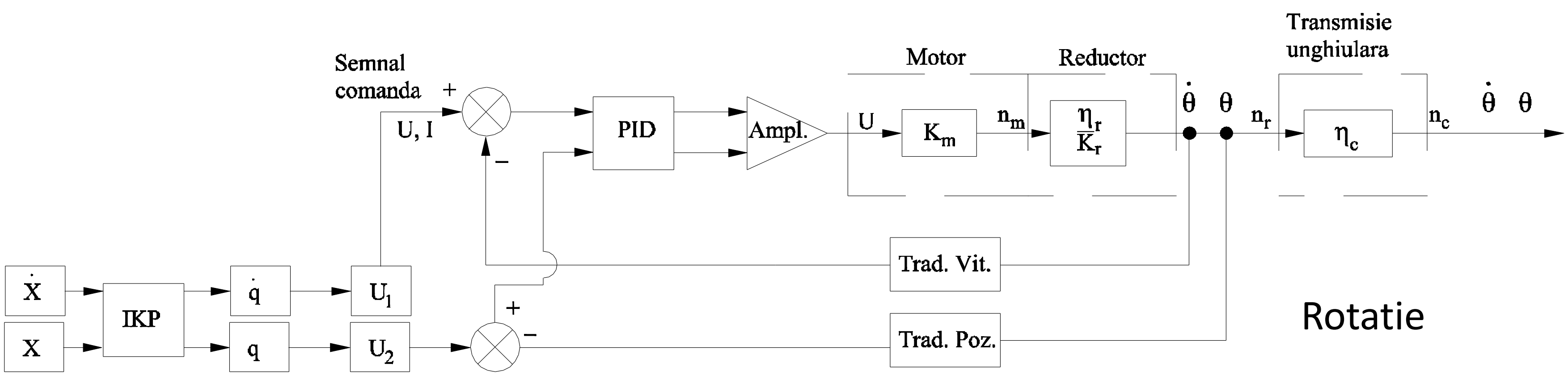


Sistemul de actionare



Schemele de actionare a motoarelor robotului PARAMIS





Configurarea regulatoarelor PID

Motorul pentru cupla motoare q_1

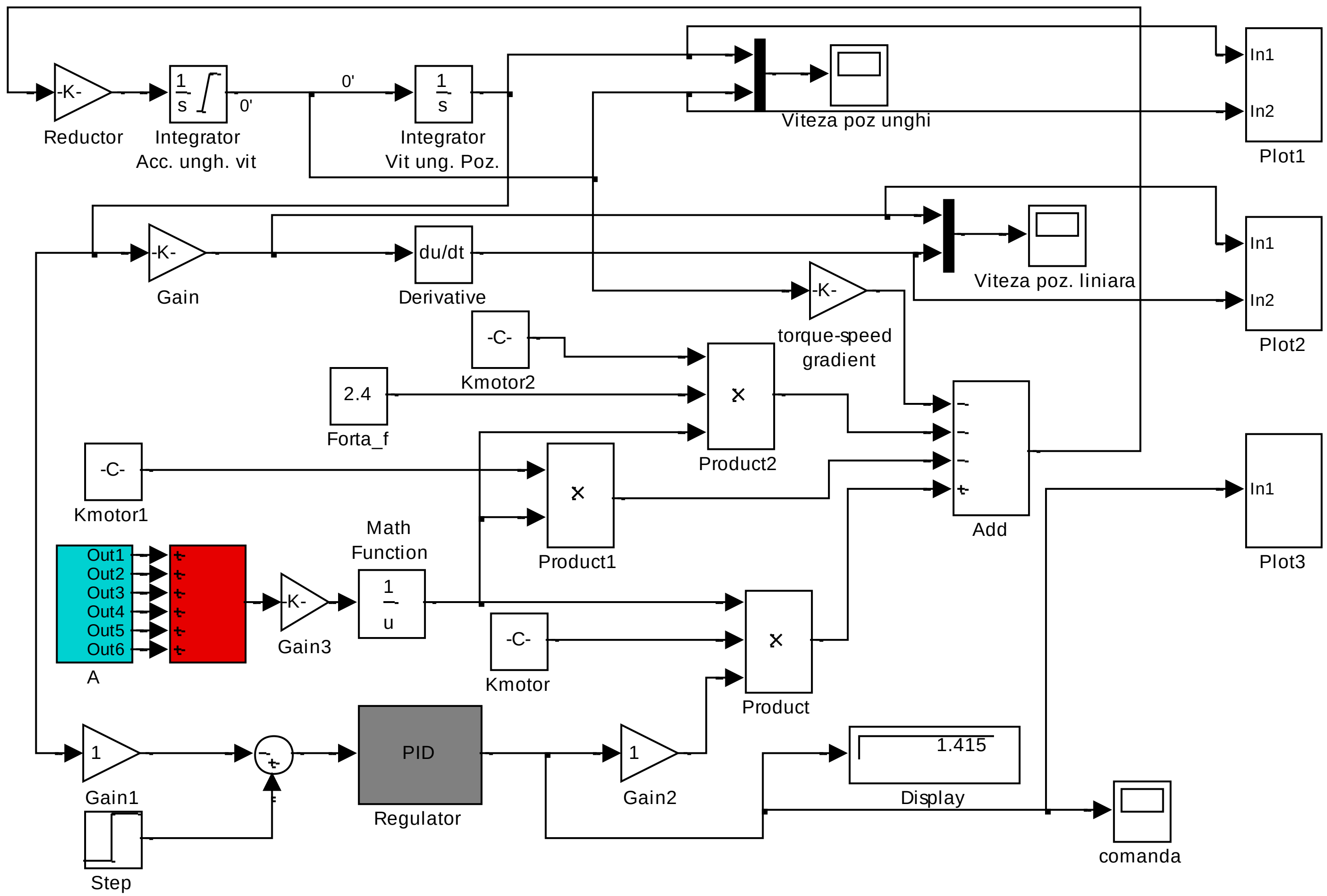
$$J_{RED\_mot} \cdot \ddot{\theta} + \left[J_{roti} + J_{curea} + \left(\frac{m \cdot P}{2\pi} \right)^2 \cdot 10^{-6} + J_{Piulita\_surub} \right] \cdot \ddot{\theta} + M_{1\_surub} +$$

$$+ F_{f\_col} \cdot \frac{\dot{x}}{\dot{\theta}} = K_{motor} \cdot I$$

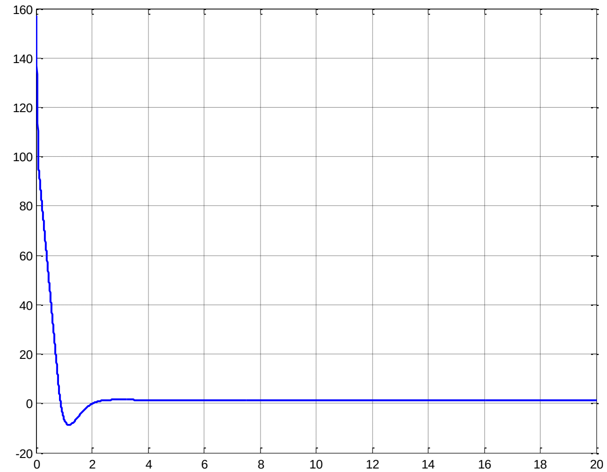
$$A = J_{RED\_mot} + J_{roti} + J_{curea} + \left(\frac{m \cdot P}{2\pi} \right)^2 \cdot 10^{-6} + J_{Piulita\_surub}$$

$$\ddot{\theta} = \frac{K_{motor}}{A} \cdot I - \frac{M_1}{A} - \frac{\dot{x}}{\dot{\theta}} \cdot \frac{1}{A}$$

Blocul de comanda al motorului q_1



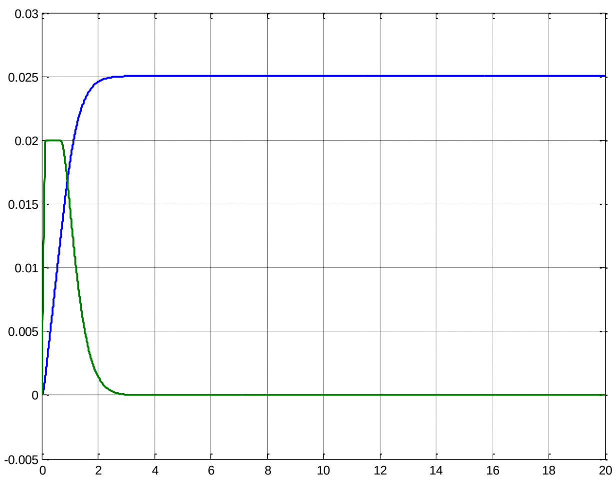
Configurare PID motor q_1



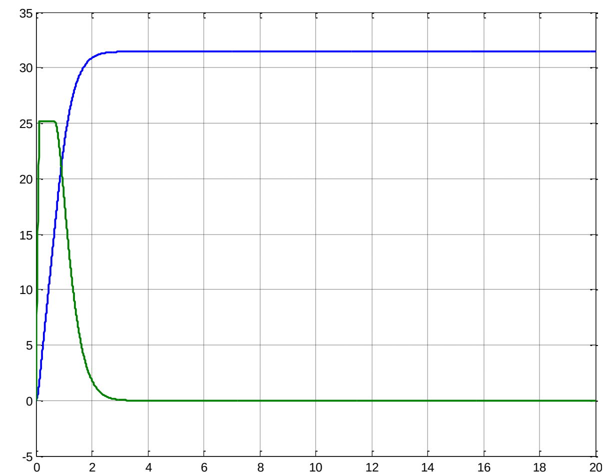
Semnal comanda

Deplasare liniara

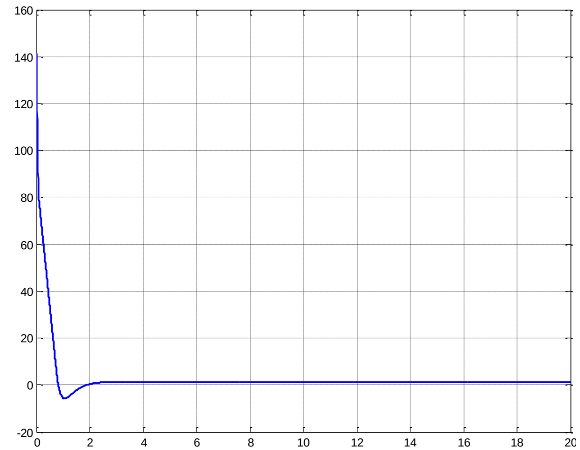
Variatie unghiulara



P- 4, I-0.065, D-2.2

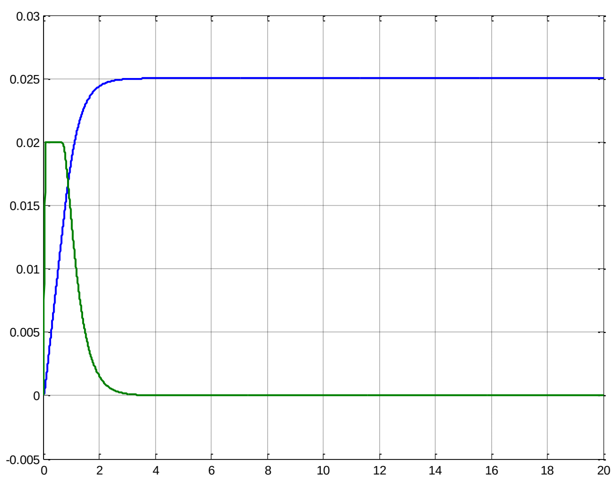


Configurare PID motor q_2



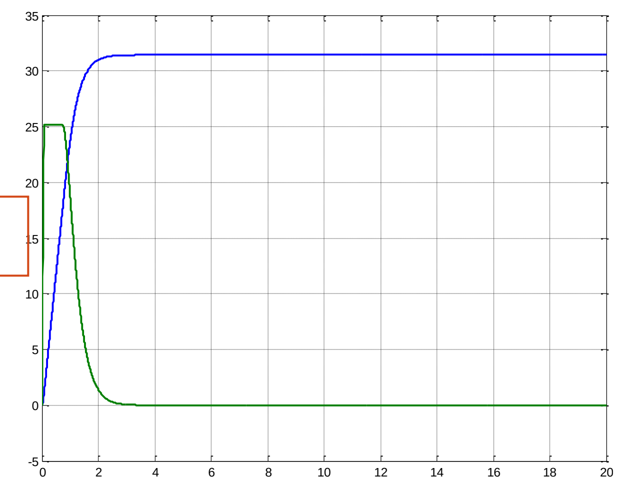
Semnal comanda

Deplasare liniara



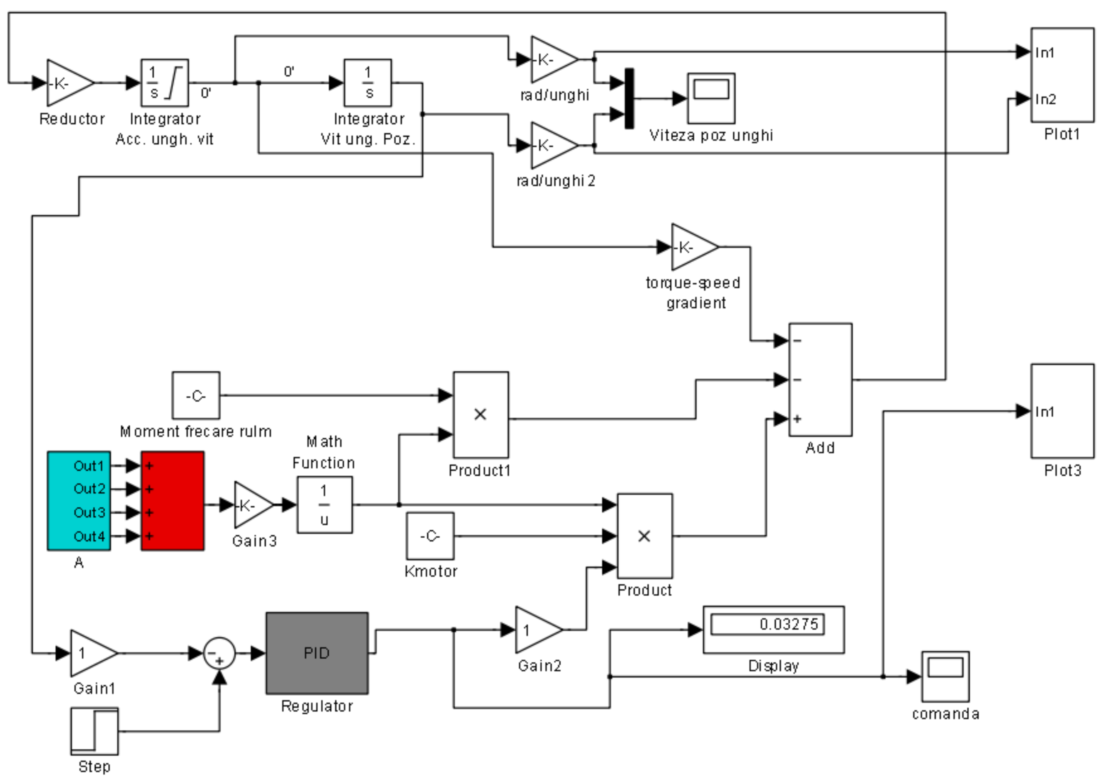
P- 4.5, I-0.065, D-2.2

Variatie unghiulara

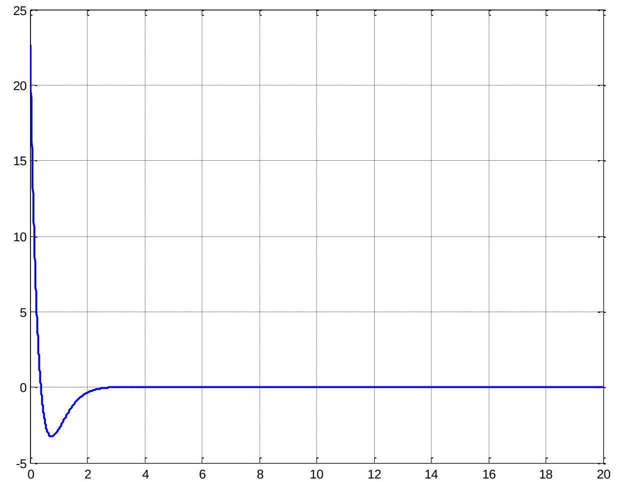


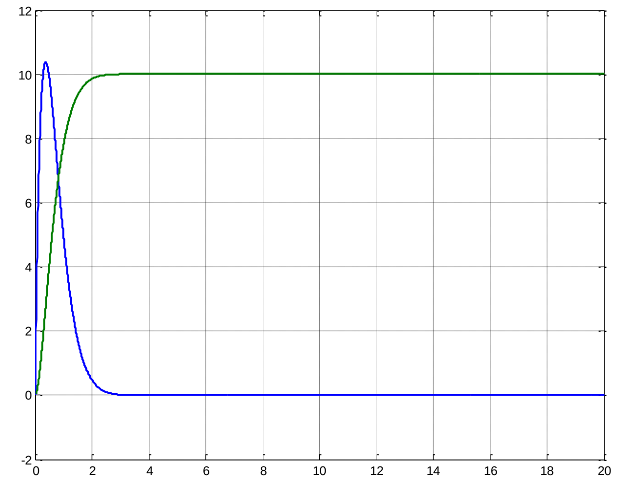
Blocul si ecuatia de comanda ale motorului q_3

$$\ddot{\theta} = \frac{K_{motor}}{A} \cdot I - \frac{M_{fr}}{A}$$



Configurare PID motor q_3

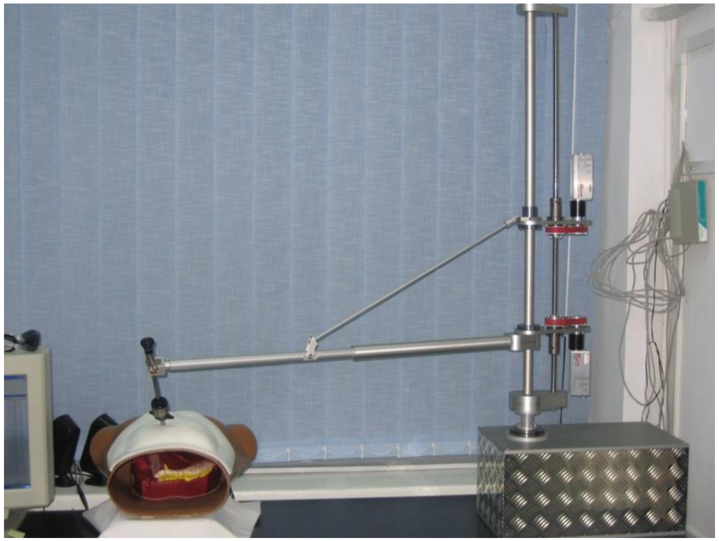


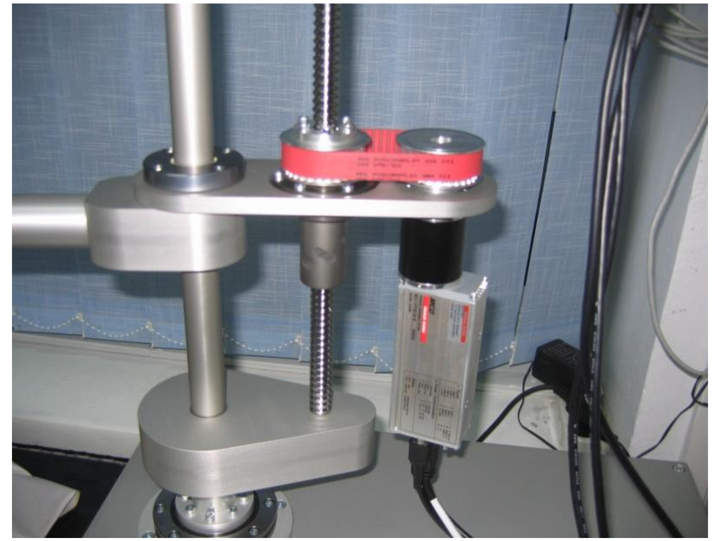


P- 130, I-0.4, D-90

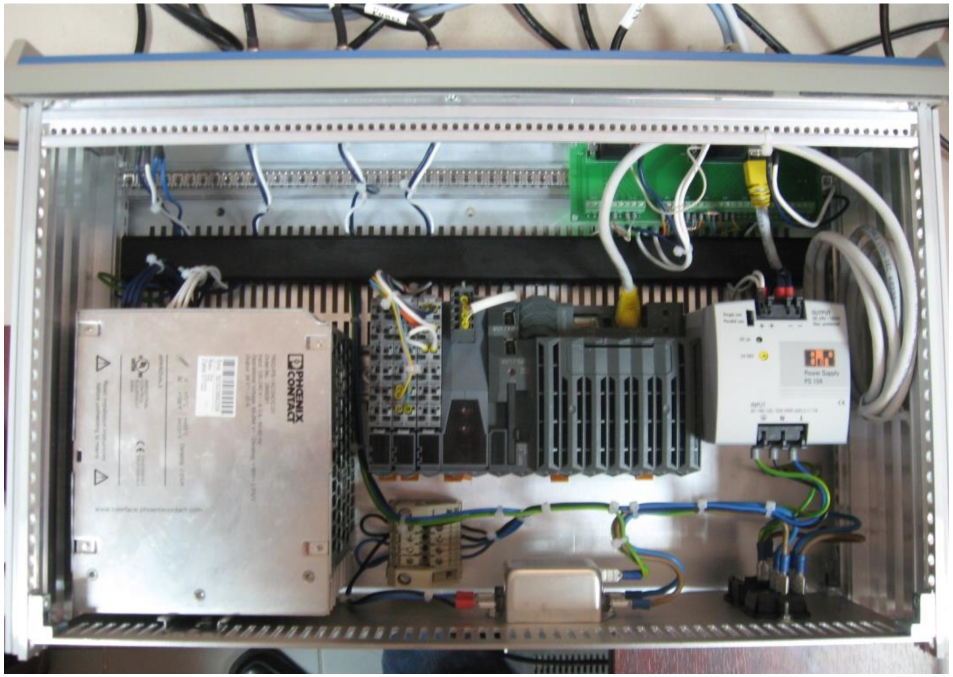
Modelul experimental al robotului PARAMIS

Structura mecanica a robotului PARAMIS

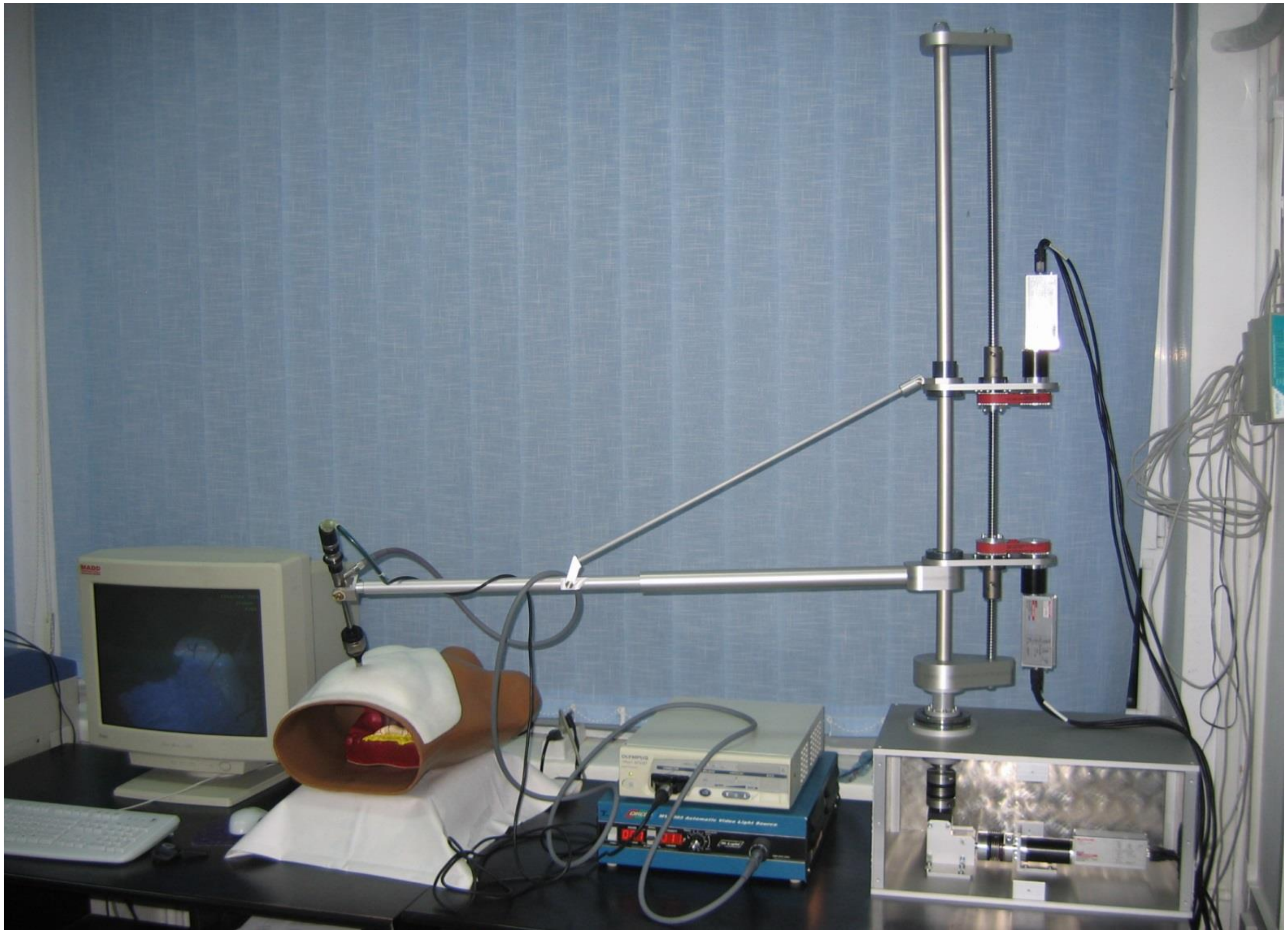




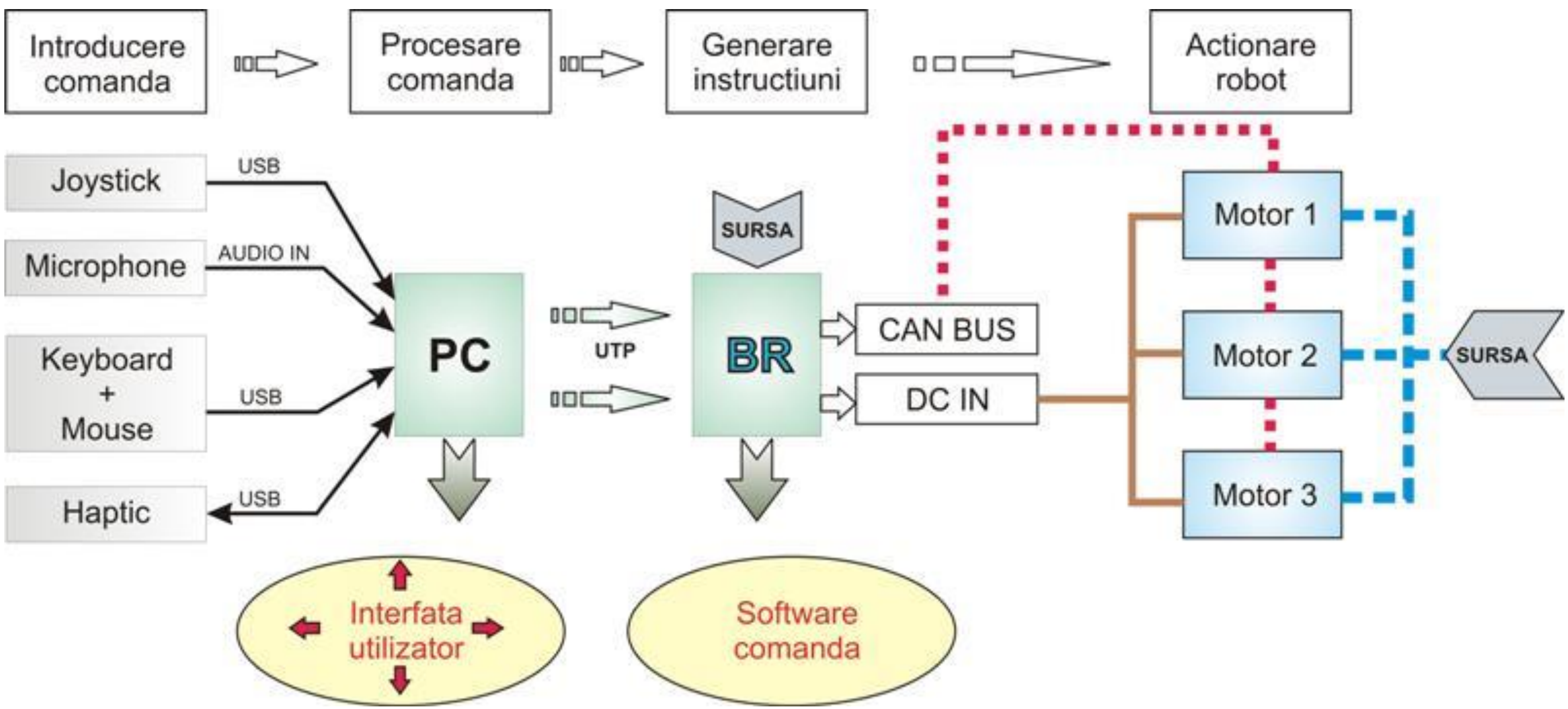
Panoul electric si de comanda al robotului PARAMIS



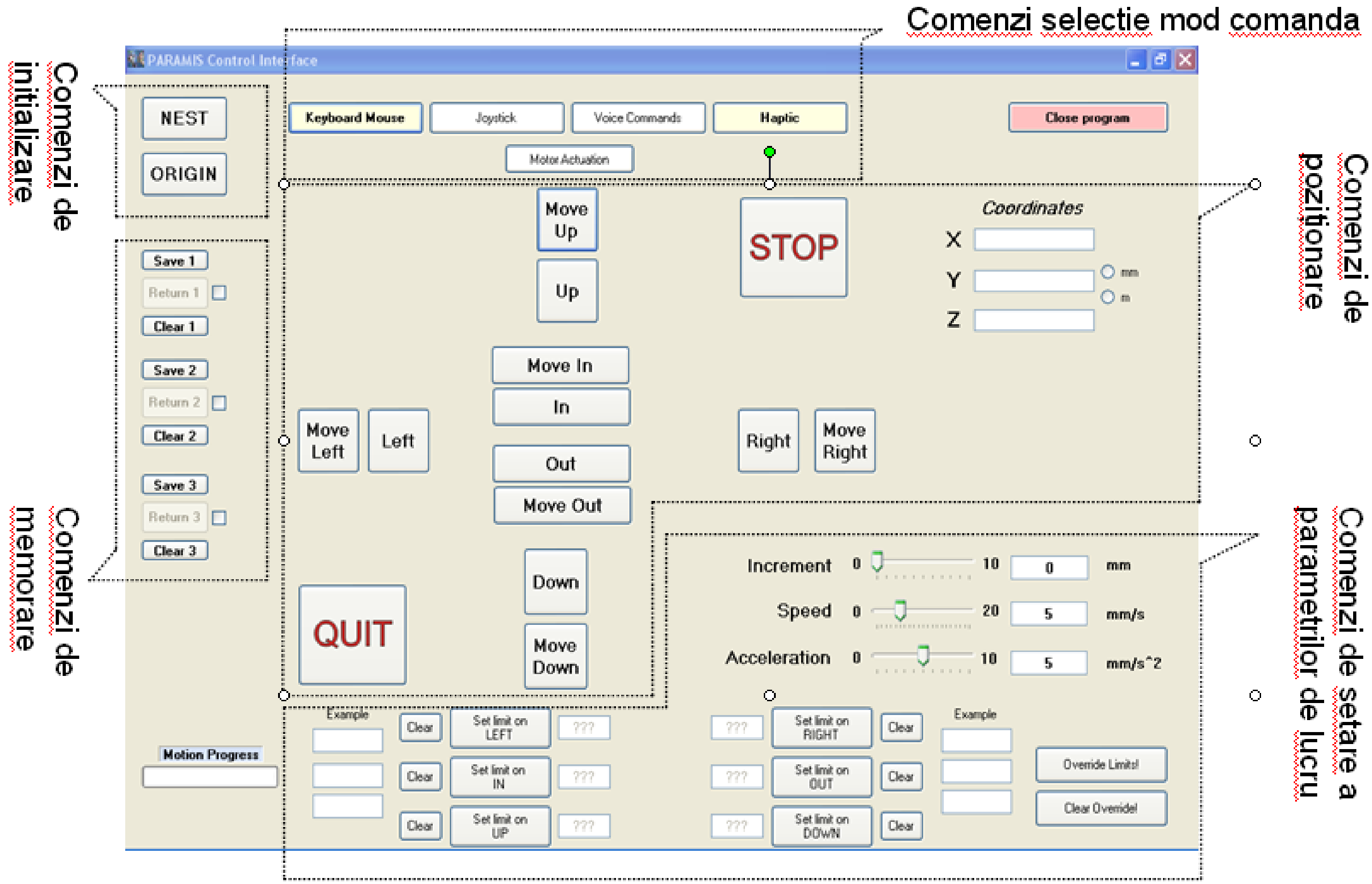
Modelul experimental al robotului PARAMIS



Schema de actionare a robotului PARAMIS



Comenzile definite ale robotului PARAMIS



Intrebari